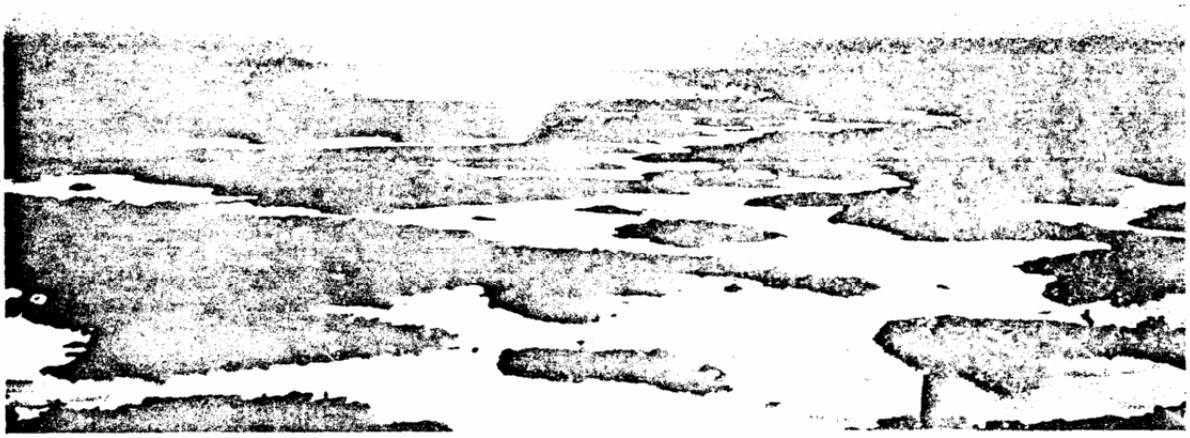
WASHINGTON TECHNICAL INSTITUTE
WASHINGTON, D. C. 20008

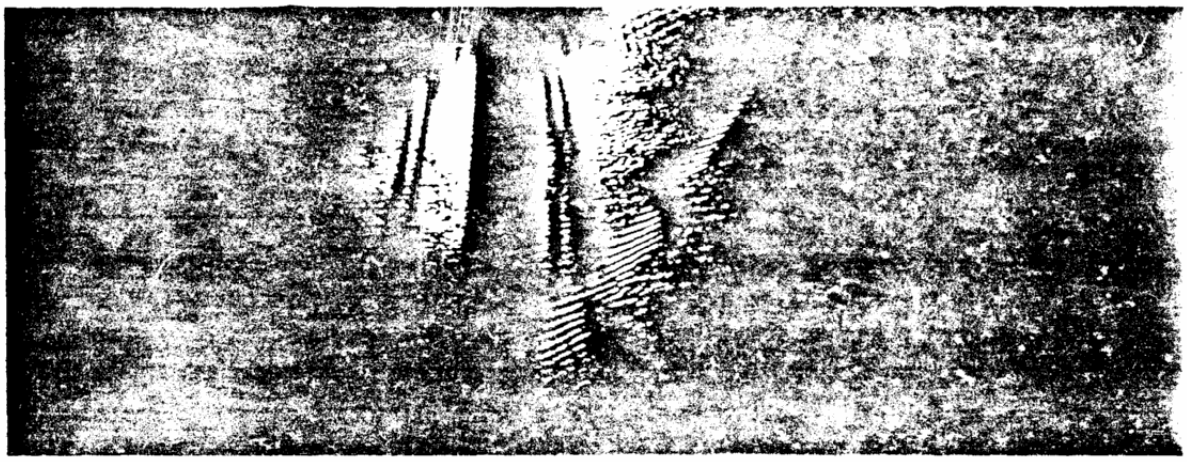
PROJECT REPORT NO.

AN ASSESSMENT OF THE USE OF POTOMAC ESTUARY WATERS AND AWT EFFLUENTS FOR EMERGENCY WATER SUPPLY

GEORGE K. YOUNG
RALPH C. PALANGI



WATER RESOURCES RESEARCH CENTER



AN ASSESSMENT OF THE USE OF POTOMAC ESTUARY WATERS AND AWT EFFLUENTS FOR EMERGENCY WATER SUPPLY

By

George K. Young and Ralph C. Palange [1/]

October 1973

Water Resources Research Center
Washington Technical Institute
Washington, DC 20008

FOREWORD

The project covered by this report was funded in its entirety by the Department of Environmental Services of the District of Columbia. The work was carried out under the direction of the Water Resources Research Center, Washington Technical Institute, Washington, D.C.

The Literature survey and the final report were accomplished by the staff of Meta Systems Inc, 6434 Brandon Avenue, Springfield, Virginia under contract to the Water Resources Research Center.

ABSTRACT

The Washington, D.C. area is experiencing resistance from public and private sectors to the continued development of upland dams to supply future metropolitan water needs. A result of this resistance is a heightened interest in the exploration of alternatives, one of which is direct or indirect reuse including the use of the Potomac estuary.

Previous studies are very cautious and guarded about direct reuse for domestic consumption. However, these studies give the impression of endorsement of reuse for domestic consumption, conditional upon additional research to insure safety and reliability. A study commissioned by the Corps of Engineers recommends a substantial experimental pilot plant to test operating measures and safeguards for indirect reuse of the Potomac estuary.

The purpose of this report is to study and evaluate the reuse of treated wastewater and of estuarine waters for domestic consumption. It is found that professional and lay opinion would generally weigh against direct reuse of wastewaters regardless of the adequacy of measurement and treatment practices. Furthermore, only one significant instance of direct reuse is discussed in the literature. Indirect reuse, such as pumping raw waters from the Potomac estuary, is practiced elsewhere and appears to be feasible for Washington.

The contrast between what constitutes direct or indirect reuse is clear in some cases, but not very distinct in others. Nevertheless, although the definition of indirect reuse is very vague, it apparently is not as onerous as direct reuse and it is officially tolerable and at least marginally acceptable from a public health standpoint. This is a matter of necessity in the U.S. as indirect reuse is basically an existing condition in many densely populated regions.

The report presents guidelines for establishing criteria for safeguards in reusing estuary waters. Until viral and bacterial measurement techniques are improved, physical-chemical monitoring is suggested to use for decisions concerning operating criteria. Such criteria would include: free chlorination, turbidity control, ammonia monitoring, pH adjustment, and high energy mixing at the point of chlorination followed by high contact time. Other specific concerns are addressed such as acute and chronic toxicity, storm water overflows, and public relations.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

General

The purpose of this report is to study and evaluate the reuse of treated wastewater and of estuarine waters for domestic consumption, with particular reference to Washington, D.C. It is found that professional and lay opinion would generally weigh against direct reuse of wastewaters regardless of the adequacy of measurement and treatment practices. Furthermore, only one significant instance of direct reuse is discussed in the literature. Indirect reuse, such as pumping raw waters from the Potomac estuary, is practiced elsewhere and appears to be feasible for Washington. Although the emphasis herein concerns domestic water use, it should be noted that the maintenance of adequate pressure in the distribution system for fire fighting is a major consideration for emergency use of the Potomac estuary.

This report focuses upon:

1. The extent of and experience with reuse.
2. Federal, state and other requirements for domestic use of wastewater.
3. Identification of hazards and the associated risks.
4. Identification of operating precautions and procedures to use in the processing of reused waters.

A literature review was conducted beginning with abstracts obtained from the Water Resources Scientific Information Center, Office of Water Resources Research. These were reviewed to obtain data from selected primary references. Bibliographies from the primary sources led to additional data. Study of this body of data and first-hand interviews (27)'with water works officials were used to develop the information presented in this report.

Broad studies oriented to the reuse of effluents for varied purposes, including domestic consumption, have been conducted on behalf of the National

---

Citations in parentheses are listed in the last section of this report, Selected References.

Water Commission (8,24), the Office of Water Resources Research (2) and the World Health Organization (34), WHO. These studies have extensive bibliographies. The existence of such overview studies indicates the national and international concern and interest associated with reuse. The WHO report, in particular, develops the health-related issues and clearly focuses upon the problem. A special Potomac estuary study (10) conducted for the Corps of Engineers discusses engineering and economic feasibility of indirect reuse for the Washington, D.C. area.

The overview studies are very cautious and guarded about direct reuse for domestic consumption. However, these studies give the impression of endorsement of reuse for domestic consumption, conditional upon ad additional research to insure safety and reliability. The Potomac study commissioned by the Corps of Engineers recommends a substantial experimental pilot plant to test operating measures and safeguards for indirect (estuary) reuse.

Policy Statements and Public Wants

Published professional and non-professional opinion is summarized by the following points:

l. American Water Works Association, AWWA (1)

> " . . . The Association is of the opinion .: . . that current scientific knowledge and technology in the field of wastewater treatment are not sufficiently advanced to permit direct use of treated wastewaters as a source of public water supply. . .

2. National Water Commission (24)

> " . . . Direct reuse of water for human consumption should be deferred until it is demonstrated that virological and other possible contamination does not present a significant health hazard."

3. Environmental Protection Agency, EPA (18)

> " . . . EPA does not currently support the direct interconnection of wastewater reclamation plants with municipal water treatment plants. . . . [11]

4. California Department of Public Health (7)

The Department does not permit direct use of reclaimed water for domestic purposes and its position is summarized by: "The benefits of such an operation in light of the existing state of knowledge would in no way justify the risk."

5. WHO Committee of Experts (34)

WHO is concerned, but not as negative about the direct domestic use of reclaimed waters as are the U.S. agencies. This probably reflects their international constituency and the fact that water shortages in other countries may be severe enough to partially overcome public health priorities. Also, as a group, the U.S. members appear to be much more cautious than their counterparts from other countries. The WHO Experts state: "By grading and reusing effluents to low-grade purposes, it will usually be possible to effect such water savings that potable water may be obtained from existing natural sources. If this proves impossible, present day technology is adequate if proper conditions prevail, to treat most municipal waste-waters to a degree that will render them safe for drinking and other domestic uses, but careful management, the application of appropriate treatment processes, and a rigorous programs of sophisticated surveillance, monitoring and testing are absolutely essential if the public health is to be protected. "

6. Public Attitudinal Survey (3,4)

A statistically defensible set of interview results indicate that the majority of the public is not yet ready for directly using reclaimed wastewater for drinking water, food preparation,-atop in restaurants, cooking in the home and the preparation of canned vegetables. However, the public is poorly informed in general concerning such matters.

The term direct reuse appears frequently in the above statements. According to WHO (34), the definitions for direct and indirect reuse are:

"DIRECT REUSE - the planned and deliberate use of treated wastewater for some beneficial purpose . .

INDIRECT REUSE - indirect reuse of wastewater occurs when water already used one or more times for domestic or industrial purposes is discharged into fresh surface or underground waters and used again in its diluted form."

It would appear that the contrast between definitions is clear in some cases, but not very distinct in others. Nevertheless, although caution is normally expressed concerning indirect reuse, it apparently is not as onerous as direct reuse and it is officially tolerable and at least marginally acceptable from a public health standpoint. This is a matter of necessity in the U.S. as indirect reuse is basically an existing condition in many densely populated regions.

Note that the WHO Committee of Experts refers to municipal wastewaters as being within the limits of technology as a potable water source and excludes mention of industrial wastewaters. This is no accident as the presence of industrial wastes raises many possibilities for toxic constituents; this uncertain situation is difficult to manage from a water treatment standpoint. Thus, great caution is advisable relative to the effects of industrial wastes. This is also true for municipal waste, but the supposition is that domestic waste composition being more or less predictable and known, can be coped with.

Further note that the National Water Commission specifically mentions viruses as a major item of concern; this theme repeats itself many times in studies concerning reuse.

Interviews

How do these public policy statements fit in with the current individual concerns of water works officials? Interviews (27) were conducted with officials from New York City, Philadelphia, Fairfax County, Virginia, Denver, California State Department of Health, San Francisco and Marin and North Marin County Water Districts in California. These officials confirmed the AWWA position against direct reuse; the prevailing attitude is strong opposition. Relative to indirect reuse, the foremost issues appeared to be concern over viruses in water supplies and a very keen appreciation for public attitudes. Heavy metals also were mentioned as an item of concern as were reliability and safeguards. It is of note that the western areas have either administrative or legal sanctions against reuse and their officials seem more wary about indirect reuse than do their eastern counterparts.

The information derived from each interview is summarized as follows:

1. New York City.

During a drought emergency period, March 1966 to January 1967, the City supplemented its raw water with Hudson River water. This emergency water was diluted at least 4 to 1, subject to partial treatment involving alum nosing at the intake with flocculation and settling in a raw water storage reservoir and heavily chlorinated. The opinion was offered that direct reuse of treated wastes is still a long way off and the principal problems are viruses, trace elements and the unreliability of waste treatment.

2. Philadelphia.

There is no immediate need to consider direct reuse of wastewaters for domestic purposes. Should direct reuse be contemplated, necessary precautions would include:

a. breakpoint chlorination at the water supply intake,
b. treatment to provide low turbidity, nitrates and total dissolved solids,
c. virus inactivation with consideration given to ozone treatment, and
d. provision for reliability and completeness of water treatment processes.

3. Fairfax County, Virginia.

There is no known local direct reuse of treated wastes. Standards for use of such waters do not exist and when developed, should include microbiology, total dissolved solids, chlorides, trace organics and other materials. Public reaction is a major concern when considering reuse. Initially, only emergencies should stimulate direct reuse and the water should not be used for drinking but rather be restricted to watering golf courses, industrial cooling and the like. The question of viruses is of concern and laboratory procedures for viral measurement are needed.

4. Denver.

More research needs to be done on viruses, organic Chemicals, detergent and heavy metals as discharged in treated effluents. Denver anticipates future use of treated wastewaters, however the current position is that it is not possible or advisable to accept treated effluents directly into the distribution system. Looking toward the future, the City is involved with a 5 gpm pilot plant having an effluent goal of industrial grade waters. Plans are underway to pro vide a 1 to 10 mgd reclamation plant for industrial users and hopefully bring the reclaimed waters to ' potable grade use after five years; additional planning is directed toward dual distribution systems for new service extensions.

Under existing state laws, water cannot be reused in the basin of origin. However, under a later special statute any waters transmitted from the western slope to the eastern slope areas may be reused once.

5. California State Department of Health.

It is believed that at the present time it is not possible to set criteria for domestic reuse, in view of the current status of our technology. Research is required, particularly with regard to viruses. California has a. great deal of direct reuse of treated wastes, but none for domestic purposes. Two facilities have indirect reuse for domestic water supply; both involve groundwater reservoirs and their recharge. One is the Whittier Narrows Plant, Los Angeles County, which discharges 50 to 100 mgd to a groundwater basin and this discharge constitutes 5 to 10% of well plumage for water supply. The other is in Orange County where treated effluent is being injected into the ground to control salt-water intrusion; an unknown quantity of the injected water may reach drinking water wells. If treated wastewater is to be directly used, the following advice applies:

a. the system must be foolproof and reliable (backup units, good power supply, high quality operations and alarm systems),

b. concern should be shown for infectious disease and toxicity effects (heavy metals),

c. the system should provide heavy doses of chlorine with high residuals and long contact time.

6. San Francisco.

The public is not ready for direct reuse; opposition would be high and imaginary ills, aches and pains could prevail. Where renovated water is to be used for domestic purposes, the supply should be divided. That used for human consumption should receive full water supply treatment and preferably be mixed with treated water from other sources. If at all possible, renovated waste waters should not be used for human consumption.

7. North Marin and Marin County, California.

Both mention a need for more information on long-term effects and risks of trace elements (independent and synergistic) and on public attitudes. North Marin County recommends use of treated wastes for golf courses, green spaces around industrial parks and on highway and freeway green areas. Marin County takes the position that direct reuse and indirect reuse are 10 to 15 years away. Several precautionary items are listed:

a. cross connection control,

b. provision of sophisticated laboratory techniques,

c. standby equipment measures,

d. larger treated wastewater, storage reservoirs, and

e. need for public relations.

Major Issues

From the standpoint of assessing reuse for the Washington, D.C. water supply, the following ground rules are established:

1. For either direct or indirect reuse, current technology can produce a product which will satisfy finished water specifications given in existing drinking water standards (34). However, informed judgment (27) and public opinion (particularly in the U.S.) (3,4), suggests the rejection of direct reuse for Washington. In the long run, this may change. To consider immediate needs, the orientation of this report is short-run and is directed to the indirect reuse of Potomac estuary water.

2. The incremental addition of total dissolved solids added as a result of a reuse cycle is predictable and the solids buildup can be limited to defined upper bounds by blending fresh water from upland or other sources (12).

3. Reuse for Washington, D.C. implies using the existing distribution system. Previous studies discuss the desirability of separating reused waters and servicing classes of users which have lower public health requirements than drinking water users (34) - such as certain industries like steel. Because of the limited industry in the metropolitan Washington, D.C. region and the substantial investment requirement for dual distribution facilities, separation does not appear to be practical for this area.

4. Drinking water standards are based on the premise that the raw water source is relatively uncontaminated, preferably from a protected watershed, which is an inherent and unstated limitation of the standards (15,17). Certainly, the standards were not framed for processed wastewaters, although it is common practice to apply them to water indirectly receiving some contamination which implies the indirect reuse condition. However, raw water guidelines or numerical limits do not exist for polluted raw waters even though these may be relatively pure because of waste treatment or natural processes and dilution. Public health considerations should dominate the analysis of reuse because knowledgeable professionals are well aware of the limitations of the drinking water standards.

Given the above conditions, the following major issues remain to be addressed in consideration of reuse for the Washington, D.C. water supply:

1. *DISINFECTION.* If reuse is to be safe, the water must be known to be disinfected. Domestic wastewaters are known (5) to contain enteric viruses and these agents should be removed. The virus issue is paramount in the minds of public health workers.

2. *TOXICITY.* The drinking water standards require the Carbon Chloroform Extract (CCE) to be less than 0.2 mg/1 and specify a number of limits for heavy metals. Even with a low CCE, and particularly when the CCE is obtained from reused waters, the possibility exists of long-term chronic toxicity and allergic effects; the same holds true for heavy metals in trace amounts.

3. *RELIABILITY.* Professional thinking is that water treatment unit processes constitute a much more reliable and predictable set of processes than waste treatment unit processes. By directly coupling the two together, the combined process chain assumes the reliability of the least reliable link.

4. *INDIRECT REUSE.* Basically, indirect reuse puts nature in the process chain between water and wastewater treatment. The effects of natural processes and dilution over a sufficiently long time of travel make the water quality of the water treatment plant more predictable, averages out quality fluctuations, tends to kill off biological agents, and adds flexibility to the management of the combined system.

5. *PUBLIC ATTITUDES.* People must be willing to use and reuse water. Indirect reuse, given a proper emphasis upon public relations, appears to be acceptable.

The remainder of this report reviews case studies, addresses major issues and presents operating precautions which may be desirable to implement in an indirect reuse application for Washington, D.C.

II. PREVIOUS EXPERIENCE

Overview

There are two cases of direct reuse documented in the literature: Chanute, Kansas (20,34) and Windhoek, Africa (25,31,34). The Chanute reuse situation was in response to a midwest drought whereas in Windhoek, direct reuse was carefully planned and implemented. No illness has been attributed to either case.

Data which serve to support a case for reuse derive from the South Tahoe (6,34) experience where well-documented, advanced waste treatment methods are employed and the Santee reclamation project (19,34). Both projects produce water which meets numerical finished water specifications of drinking water standards and the water is apparently free of bacterial and viral contamination.

Indirect reuse of the Potomac estuary (1o) for emergency or even on a regular basis would constitute a situation very similar to that already in existence in Philadelphia, Pennsylvania. In Philadelphia, wastewater is discharged to the Delaware estuary downstream from the water supply intakes.

In addition to the above cases, it is common knowledge that there are numerous instances in the United States where a city uses raw water which contains diluted wastes. The difficulty of evaluating such incidents of indirect reuse lies in an inability to define what constitutes acceptable dilution or travel time between the point of discharge and the point of 'water intake.

The use and reuse of the Ohio River water from Pittsburgh to the Mississippi River offers a good example of indirect reuse; the Rhine River basin is very similar to the Ohio in this respect. Closer at hand, the Fairfax County, Virginia Water Authority draws water from the Occoquan Reservoir which receives treated wastes from upstream sources.

Brief highlights of the Chanute, Windhoek, Tahoe, Santee and Philadelphia situations are presented below.

Chanute, Kansas

During a drought in the mid-1950's, Chanute, Kansas recycled treated sewage for a period of five months. The sewage reuse system was an emergency

operation which employed a closed cycle between the sewage treatment plant, a stabilization pond and the water treatment and distribution facility. The system could not be called advanced waste treatment as the term is used today. The cycle time of the water through this temporary emergency system was approximately twenty days. The performance of this system can be summarized as follows: during the five-month emergency period, bacteriological quality was always maintained at adequate levels and in conformance with drinking water standards. Chemical quality violated the standards. No adverse effects on the health of the population of Chanute were reported.

Enteric virus agents were identified in sewage treatment plant samples with methods available at that time, but none were detected in the treated water. The water at Chanute was reused approximately eight to fifteen times. Although there were no noted ill effects (as regards public health), the water developed a yellow color and had an unpleasant taste and odor. It is unlikely that people drank it, as bottled or imported water was obtainable.

From a practical standpoint, the Chanute case is of historic interest only and marks the first well-documented situation where direct reuse occurred.

Windhoek, South Africa

A shortage of water in Windhoek, which is situated in a very arid region with scarce surface waters, left no reasonable economic alternative to direct reuse. This case, the planned reuse of treated effluent on a continuing basis, is unique. Separate waste disposal is provided for industrial wastes. A combined water treatment-waste treatment system handles l mg/d of domestic -sewage and mixes it with conventionally treated waters in a proportion of 1, to 3 and pipes the mixture into the water distribution system.

Treatment consists of primary settling, trickling filtration, secondary settling and detention in a series of nine maturation ponds for a period of fourteen days. The pond effluent flows by gravity to processing which consists of floccuation/flotation, foam fractionation, settling, rapid sand filtration, activated carbon adsorption and breakpoint chlorination. The floc-cuation/flotation step is designed to remove algae introduced during the detention in the maturation ponds.

Viral studies gave the results shown in Table 1 below. No enteric viruses were detectable after advanced waste treatment. It is noteworthy that breakpoint chlorination was conducted to a free chlorine residual of 0.2 to 0.6 mg/l, with two to three hour contact.

From a Washington, D,C. perspective, the fourteen-day holding ponds placed between treatment processes makes the overall cycle akin to indirect reuse. The breakpoint chlorination also conforms to current thinking relative to viral inactivation.

TABLE 1: Virus Content of 24-hour Composite Samples, Detected by Concentration at Windhoek, South Africa (25).

			Enterovirus Per Liter	
	TCID*$_{50}$	PFU*	TCID*$_{50}$	PFU*
Raw sewage	6450	240	234	240
Humus tank effluent	1152	30	88	30
Maturation pond effluent	60	NVD*	NVD*	NVD*
Post chlorinated effluent	NVD*	NVD*	NVD*	NVD*

* $TCID_{50}$ = Expected tissue culture infective dose; PFU = plaque forming units; NVD = no virus detected.

South Tahoe, California

The capability of advanced modern processes to produce a very high quality effluent that can be used in a*man-made lake for boating, swimming, fishing and irrigation has been demonstrated by the treatment system at Lake Tahoe, California. At Lake Tahoe the wastewater is treated by the activated sludge process followed by the addition of .lime and by recarbonation to recover the carbonate (which is reburned to lime). The water is then filtered, subjected to activated carbon adsorption and chlorinated. Basically, the Tahoe plant is a good secondary sewage treatment system followed by an efficient water purification plant followed by activated carbon adsorption. On the face of it, then, this process should remove virus based on the experience of numerous existing water works which receive raw water containing raw, primary, or secondary treated sewage. Actually, it does more than this because the. sewage treatment portions of the plant are designed and the plant is operated with the specific aim of producing a safe water from wastewater. The addition of provisions for adsorption of organics on carbon is another plus factor.

The plant produces water of high clarity, which enhances chlorination efficiency and implies that virus cannot escape chlorine contact by being encapsulated in particulate matter as particulates are removed completely.

If the reclaimed water was intended for potable use, double chlorination with several hours or even days of intermediate contact would provide even further assurance of virus removal. Also at Tahoe, the pH of the water is lowered to about 7.0 prior to chlorination to improve disinfection efficiency.

Viral removal data are given in Table 2 below. As with the Windhoek plant, the final effluent is free of measurable viruses. Apparently, from a disinfection standpoint, the South Tahoe effluent is potable even though domestic reuse is not done.

TABLE 2: Virus Recoveries, in Plaque Forming Units, at South Tahoe, California Plant (6).

1969 Date		Primary Effluent	Secondary Effluent	Carbon Column Effluent	Final Effluent
May	29	3	0	1	0
June	5	-	-	0	0
June	12	-	-	0	0
Aug.	20	3	18	NRD*	0
Aug.	27	-	-	NRD*	0
Sept.	11	-	-	0	0
Sept.	18	179	14	9	0
Sept.	25	NRD*	430	0	0
Oct.	2	207	320	0	0

* NRD = No reliable data.

The key feature of the South Tahoe operation is very high quality research oriented operations; high caliber people have been involved. Given these operating conditions, direct recycle apparently is operational. In this case, the link between wastewater and water treatment is direct with no provision for detention in ponds or groundwater systems.

Santee, California

The use of treated wastewaters for filling lakes to be used for contact sports is relatively new. Lakes fed by treated wastewater at Santee, California

are in existence. At this location the municipal wastewater is treated by the activated sludge process, fed into a lagoon, chlorinated and spread onto a natural bed of sand and gravel, where it passes through several hundred feet of horizontal filtering. The water then flows into man-made lakes which are used for boating and fishing. The water has been found to be bacteriologically safe and free of enteric viruses. No deleterious effects on the health of the users have been detected.

The Santee operations have been going on for ten years and epidemiological studies have not shown greater disease incidence from contact sports in the lakes. Whereas the Windhoek has fourteen-day maturation ponds as a natural barrier, the Santee situation has several hundred feet of sand and gravel to filter through. Thus, a natural barrier is imposed between the waste effluent and its use in the lake.

Philadelphia, Pennsylvania

A situation bearing close resemblance to the Washington, D.C. region would be Philadelphia. A major water intake is located on the. Delaware estuary about six miles upstream of the major sewage treatment plant discharge. The average withdrawal at the water intake is about 220 MGD and the average waste discharge to the estuary is about 180 MGD. Tidal mixing can transport diluted waste effluent upstream to the water intakes depending upon the amount of fresh water flow to the estuary.

Table 3 shows several of the more significant comparisons between Washington and Philadelphia; the data represents current conditions. There are differences, of course, but the similarities are sufficient to indicate that Philadelphia has been operating, for years, a similar system to that which is being considered for emergency use for Washington. The distance between waste discharge and water withdrawal on the Delaware is almost half what it would be on the Potomac. As with the Windhoek practice, Philadelphia uses breakpoint chlorination and stresses free chlorine residuals.

The breakpoint chlorination (approximate dose = 16 mg/1) is performed on the estuary intake water, after its point of withdrawal, on its way to the 176 MG storage pond. Effluent from the pond enters the water treatment plant and has free chlorine residual of 1 to 2 mg/l. Post chlorination is used on the finished water, which has a free chlorine residual of 1 mg/l as it enters the distribution system. For many years, Philadelphia sewage received only primary treatment; currently the treatment of sewage is being upgraded to a secondary level.

TABLE 3: Comparison of Water Supply Conditions, Washington, D.C. and Philadelphia, Pennsylvania

ITEM	WASHINGTON	PHILADELPHIA	NOTES
Estuary	Potomac	Delaware	Heavy shipping in Delaware - near Philadelphia
Minimum Day/Average Daily River Flow	540/9248	1240/11930	Potomac River at Point of Rocks (1895-1960) Delaware River at Trenton (1912-1960)
Tidal Range	3.1 feet	6 feet	More mixing at Philadelphia.
Water Treatment Plant Withdrawal	200 MGD	220 MGD	Washington - Washington Aqueduct Philadelphia - Torresdale W.T.P.
Raw Water Storage	50 MG	176 MG	Washington - Dalecarlia Reservoir Philadelphia - near Torresdale Intake
Sewage Treatment Plant Discharge	300 MGD	180 MGD	Washington - Blue Plains S.T.P. Philadelphia - North East S.T.P.
Distance Between Intake and Discharge	11 miles	6 miles	For Washington the distance is from Blue Plains to Chain Bridge
Estuary Volume Between Intake and Discharge	9600 MG	15500 MG	Less volume at Washington

III. REVIEW OF ISSUES

This section of the report elaborates upon the major issues of disinfection, toxicity, reliability, indirect reuse and public attitudes. The orientation is from a Washington, D.C. perspective and assumes indirect reuse is at least a reasonable possibility for this area. Direct reuse is assumed to be a dead issue in the near future based on current policy, although the issues discussed below are relevant to both direct and indirect reuse.

Disinfection

If the raw waters are of sufficient quality, subject only to indirect reuse, and chemical treatment provides for sufficient chlorine residuals with low turbidities, they are judged safe to drink. After the fact monitoring of coliform organisms provides feedback to the judgment. The above logic is indirect because there is a time lag in the measurement of coliforms and these organisms themselves are not the disease agents.

Can the same logic apply to raw waters having greater degrees of indirect reuse or even directly used wastewaters? The answer is strongly dependent upon uncertainty associated. with viral contamination.

The following points relative to viruses and disinfection are known:

1. Viruses can be inactivated by conventional chlorination, but they are much more resistant than bacteria (5,13,23). However, the same physical laws and processes apparently govern. It takes free chlorine residual and long contact periods to inactivate viruses. Table 4 gives relative germicidal effects.

2. Problems in connection with attempts to chlorinate to high free chlorine residual are associated with ammonia and organic-nitrogen; breakpoint chlorination is required and it takes about 8.5 mg/l of available chlorine to produce a breakpoint with 1 mg/l of ammonia nitrogen (23).

TABLE 4: Relative Germicidal Effects of Disinfecting Materials (23)

Germicide	Enteric Bacteria	Amoebic Cysts	Viruses	Bacterial Spores
03	0.001	1.0	0.10	0.20
HOC1 as $C1_2$	0.02	10.	to 0.40	10.
OC1 as Cl_2	2.	10.	>20.	> 103
NH_2Cl as Cl_2	5.	20.	102	4 x 102
Free C1, pH 7.5	0.04	20.	0.8	20.
Free C1, pH 8	0.1	50.	2.	50.

NOTE: Numbers represent the concentration of the germicide in mg/1 required to kill or inactivate 99% of the listed type of organism within ten minutes at 5°C. The figures are derived from data in the literature, but some personal judgment is involved in setting the numbers given. Most values are probably accurate within a factor of two: a few are good only to order of magnitude.

3. Aerobic detention for two to three weeks prior to chemical treatment will oxidize ammonia to nitrate, and pathogenic viruses and bacteria will decrease in number (23). This is a case for indirect reuse where dilution waters are and remain aerobic.

4. Measurement problems for viruses (9,22) make the conventional disinfection assumptions difficult but not impossible to check. The overall problem is reduced to the unavailability of a reliable and standard methodology to sample, recover, concentrate and isolate viruses occurring in low concentration levels in waters. Viral and coliform methods have the same attribute of a time lag between sampling and completed test which makes immediate rejection of processed waters impossible. In addition, the viruses are cultured in living cells (for example: monkey kidney cells),

one of a number of facts which makes virus measurement techniques sensitive, operational only under highly skilled supervision and expensive. Research is underway to find simple, inexpensive methods (11, 14,16,28,30,32,33).

5. Production of very low turbidity waters is assumed to improve disinfection (6). There are two important reasons: (i) particles upon which bacteria and viruses could reside or agglomerate are almost missing in low turbidity waters, (ii) particles which could be partially composed of organic-nitrogen materials, which inhibit free chlorine residuals, are nearly absent. Table 5 shows water quality and turbidities in the Potomac River at Little Falls and in the estuary. From a turbidity standpoint, the estuary provides settling and yields less turbid, higher quality raw waters than upstream fresh water.

6. Under proper pH conditions (23), the breakpoint chlorination process can proceed with a high ratio of free chlorine as one of the available chlorine species. Combined with vigorous mixing (6), this condition can be exploited for viral inactivation.

The above knowledge should aid in establishing criteria on safeguards today for using and reusing waters. Until viral and bacterial measurement techniques are improved, it will be necessary to employ physical-chemical monitoring to use for decisions concerning operating criteria. Such criteria should include: free chlorination, turbidity control, ammonia monitoring, pH adjustment, and high energy mixing at the point of chlorination followed by high contact time. Specific recommendations are given in the section on operating precautions.

Toxicity

An epidemiological point of view exists (29) which shows concern for the complex chemicals found in agricultural and industrial usage. Following this viewpoint, one should consider the trace amounts of heavy metals and organic chemicals which would constitute even an acceptable level of CCE. The perspective is akin to the practices of the Food and Drug Administration (FDA) approach relative to food additives and new drug regulations.

TABLE 5: Existing Potomac River Water Quality (10)*

Parameter	Present Raw Water Quality Dalecarlia, D.C.	Present Range** In Estuary
Chlorides (mg/1)	8 - 14	50
Total Dissolved Solids (mg/1)	120 - 260	-
Turbidity (JTU)	45	2 - 30
Ammonia (mg/1-N)	--	0.1 - 3.0
$NO_2 + NO_3$ (mg/1-N)	0.6 - 2.5	0 - 0.5
Algae (No/ml)	1,000 - 10,000	1,000 - 20,000

* Data for present loads and with no flow reversal in the estuary.

** General Generally for the Potomac estuary at Chain Bridge and downstream for about seven miles.

The FDA approach would revolve around a batch concept. Batches of treated water would be held and tested to determine their safety; large holding reservoirs would be required. As batches are certified safe, they would be released to the distribution system. This approach has practical limitations in an urban setting such as Washington, D.C. where finished water storage facilities are limited and land costs are high thus making the development of such facilities very expensive. It appears to be more practical to certify the processes which produce the finished waters rather than certify the finished waters themselves; the reason being the time delays associated with testing.

Two possible approaches (29) to the toxicological evaluation of renovated wastewater treatment processes have been proposed and could have application to Washington, D.C.

1. Establish maximum allowable concentrations or limits for each of the potentially hazardous chemicals that may be found in renovated water; an example of this is that the USSR (29) recognizes some 300 chemicals in their drinking water standards. Then monitor the finished waters over a trial period of operations and, certify the processes.

2. Conduct, for particular situations, long-term animal feeding experiments (26) using both the finished water and chemical concentrates extracted from the finished water. Such experiments would involve more than one species of experimental animal. Three groups would be established. One control group would consume water from a separate source. The other two would use treated Potomac estuary water and would consume either the finished product or chemical concentrates extracted from the finished product. The objective would be to observe any adverse physiological differences between the control and the other two groups. In the absence of adverse effects during the trial operations, the processes would be certified.

Either of these two approaches would provide a rational means to implement reuse. Additional supporting studies can be envisioned which would identify-segments of the population which are exposed now to indirect or un intentional reuse. Comparison of the health of these segments of the population with others who use more pristine waters may provide further information relative to reuse.

Given the fact that current knowledge does not support either the establishment of hundreds of maximum allowable concentrations or their routine

measurement, the second approach appears more operational. Therefore, the following steps, which consider the epidemiological point of view, appear to be feasible for the indirect reuse situation facing Washington, D.C. should estuary waters be treated for consumption:

1. Conduct intensive animal feeding studies using pilot plant finished waters to determine potential toxicities, or the absence thereof; and certify the pilot processes; this would be done prior to the introduction of treated estuary waters; not the distribution system.

2. Provide rigid control over the industrial wastes placed into sewers; the objective being to keep industrial chemicals out of the estuary. The permit program provided under P.L. 92-500 should facilitate such control.

3. Maintain routine animal feeding studies on water delivered to the distribution system to provide feedback to the decision process.

The results of these measures could also be coordinated with public relations activities.

Reliability and Indirect Reuse

There is major concern that the unreliability of waste treatment processes would be the weak link in a water reuse operation. Similar concerns over water treatment reliability are not as apparent.

Waste treatment is not always reliable. EPA data support this contention. A survey of 1500 waste treatment plant operating difficulties over a period July 1, 1962 through December 31, 1964 revealed the following data (21):

Problem	Percentage of Plants (%)
Operational	7.8
Mechanical	24.5
Structural	7.8
Odor Complaints	18.7
Sewage Bypass	37.8

What about water treatment? Judging from quality of finished waters as reported in an EPA survey (18); water treatment reliability is also questionable. Thirty-six per cent of 2600 individual tap-water samples, geographic ally distributed across the U.S., contained one or more constituents exceeding

the drinking water standards (Washington, D.C. was not included in the 36%). It appears that a case can be made that both wastewater and water treatment plants are not as reliable as one might suppose just on the basis of informed opinion.

Apparently, water treatment reliability I equated with the fact that most raw waters come from sources having more or less uniform chemical and biological properties. Given this consistent input, water treatment be comes a matter of steady state operation; that is, input fluctuations are minimal, and the output is of predictable quality.

Waste treatment, on the other hand, has highly variable inputs and this produces highly variable finished effluents. This variability contributes to operating difficulties.

Coupling the two together introduces the undesirable variability associated with treated sewage. However, if natural processes intervene to a sufficient degree, the variability is reduced or removed. This would be the case in Washington, D.C. should estuarine waters be withdrawn for water treatment. Furthermore, pilot plant studies should lead to operations which can cope with variability. The Lake Tahoe waste management has demonstrated that reliability is possible; in other words, it seems whatever variability remains in estuarine raw water can be handled given sufficient management care and incentives.

It is apparent that indirect reuse is occasioned by dilution, detention, mixing and natural chemical-physical processes which tend to buffer out variability. This is a major technical reason that indirect reuse is desirable. Translated into concrete terms, the estuary at Washington would provide all these mechanisms to a fairly large degree.

However, Washington has a source of variability associated with storm water overflows. Rainfall, of sufficient magnitude and duration, causes the combined sewer system to overflow to the estuary; untreated sewage is thus intermittently introduced into the buffering system. Under these conditions, the estuary has a shock loading and withdrawals for water treatment should be evaluated and possibly discontinued until natural processes buffer out and reduce the associated biological and chemical effects. Overflow monitoring should be a major part of any system designed to supply estuary waters.

The approximate amount of detention afforded by the Potomac estuary in the vicinity of Washington, D.C. can be computed under some simplifying assumptions:

1. Waste discharge of 450 MGD.

2. Estuary volume of approximately 9600 MG between
   Blue Plains and Chain Bridge.

3. No fresh water inflow.

4. No tidal mixing.

Under these very conservative conditions, division of Item 2 by Item 1 indicates that three weeks of detention would be available if 450 MGD was discharged as treated sewage into the estuary and 450 MGD of raw water was withdrawn at Chain Bridge. Of course, tidal mixing will flush materials both ways, up and downstream, there normally will be fresh water inflow, and 450 MGD is a very high volume of waste (approximately the 1980 water demand for the entire metropolitan region).

To sum up, considerable detention exists in the estuary. Such detention should insure buffering of waste variability and the exposure of the wastes to natural processes over long periods of time. Table 5 shows that existing turbidities in the estuary are low - a fact that partially demonstrates the effect of one natural process, settling. It happens that water treatment of estuarine wastes could proceed on fairly uniform raw water conditions. Of course, the effect of storm water flows and overflows would tend to disrupt the uniformity on a temporary basis and would have to be considered in the design of operating criteria.

Public Attitudes

Even assuming that a strong technical case can be made for the indirect reuse of Potomac estuary water, public reaction could have an adverse effect on the project. Recall the controversy surrounding the issue of the fluoridation of public water supplies, which illustrates how decisions having strong technical support can be questioned by an uninformed public.

California polls (3,4) indicate that the public is not yet ready for direct reuse. Indirect reuse is another question which may be controversial depending upon the amount of publicity and how the issue is presented to the public. Many eastern areas already are involved with indirect reuse and the public awareness or concern over this fact apparently is minimal. Most of the existing cases are associated with limited options; choice in the matter does not exist.

In Washington, D.C. there are options. The element of choice of water supply provides a fruitful area for controversy and discussion. Should indirect reuse be undertaken, it would amount to a deliberate choice.

Under such conditions, one could well pay heed to recommendations of the California investigators. They stress the need for comprehensible information

for the public. Their results indicate a need for increased communication with the public regarding the aspects of reclaimed water and regarding new water supply sources.

Public information and education should emphasize the adequacy of technology. Psychological rejection of reclaimed water because of its source may be dealt with by stressing the safety of reclaimed water, its clarity, freedom from undesirable additives and absence of unpleasant taste and odor. A pilot plant for Washington, D.C. could be strongly coordinated with public relations efforts to inform the public. Toxicologic studies, including animal feeding experiments, associated with such a plant could furnish sufficiently strong proof of safety in order to gain public acceptance.

In short, regardless of the technologic, safety, engineering and economic justifications, the public must be considered. Concrete demonstrations of adequacy and desirability would probably be necessary, as well as communication of basic facts and options in an understandable format.

IV. OPERATING PRECAUTIONS

The assumption is that upland water will be withdrawn and mixed with water drawn from below the fall line in the estuary. Both sources will be mixed prior to introduction to the Dalecarlia raw water storage reservoir.

It has been recommended that a period of trial operations using a pilot plant be used (10). This seems to be a good approach and could be strongly tied to a public relations effort. This would involve the same withdrawal
scheme as the full-scale operation, but would require special piping which segregates the pilot processes from the conventionally treated water. The finished water from trial operations would be returned to the Potomac River.

Operating precautions for the reuse of estuary waters, which may have future applicability for direct reuse, would be tested during trial operations and could include the following measures:

1. For the estuary waters, prior to mixing, the provision of facilities for:

   a. PH adjustment to 7.5,

   b.breakpoint chlorination,

   c. energetic mixing,

   d. detention sufficient to complete the breakpoint reaction and have 10 to 30 minutes of chlorine contact with a free residual of at least 1 mg/l, and

   e. standby chlorination facilities.

2. Estuary water dilution with upland water in a predetermined ratio (New York City was required to use at least a 4 to 1 dilution in their emergency use of the Hudson River in 1966). The dilution should be accomplished in such a way that total dissolved solids do not undergo excessive buildup.

3. Short-term (control) monitoring to provide the basis for temporary suspension of use of estuary waters. Measurement and factors should include:

   a. ammonia, turbidity and chlorine levels at appropriate points,

b. abnormal operations of the Blue Plains Sewage Treatment Plant, or

c. storm water overflows.

4. For the water mixture composed of the Potomac estuary and upland waters, facilities (which already exist in Washington, D.C.) should be provided for:

a. the production of very high clarity water (turbidity measurement of 0.1 JTU),

b. post chlorination to a free chlorine residual, and

c. standby post chlorination.

5. Long-term (certification) monitoring, for which the results are determined long after the water is produced, should be done to certify that the processes are safe and provide delayed feedback to public health decisions. Such time lagged monitoring would include:

a. biological assessments to include bacteria and viruses on a large volume measurement basis,

b. trace organic assays,

c. trace heavy metals assays, and

d. animal feeding experiments on finished waters and on concentrates derived from finished waters.

6. Administration of a program for inventory and control of non-domestic wastes which reach the Blue Plains Sewage Treatment Plant (or reach the estuary in any other way) to be aware of and control their chemical composition including heavy metals and other toxicants.

7. Administration of a public relations program to inform the public, measure their attitudes and utilize this information in making decisions relative to the eventual extent of the use of estuarine waters.

V. SUMMARY CONCLUSIONS AND RECOMMENDATIONS

A literature review was conducted for the purpose of assembling information to assess direct and indirect reuse of wastewaters for water supply. The assessment was focused upon the Washington, D.C. situation and the results were formatted for use of regional decision makers. In addition, first-hand interviews with water works professionals were conducted to strengthen the assessment.

The Washington, D.C. area is experiencing resistance from public and private sectors to the continued development of upland dams to supply future metropolitan water needs. A result of this resistance is a heightened interest in the exploration of alternatives, one of which is direct or indirect reuse including the use of the Potomac estuary. Direct reuse would involve treatment of wastes and their direct introduction into the water distribution system. Whereas, indirect reuse, for the Washington, D.C. region, would involve treatment of Potomac estuary waters which receive treated wastes from the City. These wastes would undergo dilution and experience natural purification as they reside in the estuary adjacent to downtown; therefore, estuary use would be indirect.

There has been extensive discussion of reuse by groups who influence national policy. Drinking water standards, as currently framed, do not address the use of contaminated raw waters. Criteria for raw water quality, finished water quality, treatment and acceptance of such waters are lacking. Public officials follow uniform thinking about direct reuse: at this point in time it is unacceptable although the definitions of acceptable situations and conditions are extremely vague.

The Washington, D.C. officials are seriously considering the use of Potomac estuary water, particularly on an emergency basis. This report assesses previous experience with reuse, governmental requirements for domestic use of treated wastewaters, the associated hazards and risks, and identifies a set of possible operating measures to employ should estuary waters be developed as a supply source. The assessment should aid in the evaluation of the situation and identify where we can go from here in solution efforts with respect to our metropolitan water resources.

The conclusions of this report are:

1. There exists very limited experience with direct reuse to aid in decisions. Indirect reuse, however, is an accomplished fact. Many examples of indirect reuse exist throughout the United States.

2. The technology exists to implement direct reuse to produce finished waters having constituent levels within the limits stated in drinking water standards.

3. Public policy and private opinion is strongly against direct reuse as an acceptable alternative at this time.

4. Chlorine disinfection of sewage contaminated waters is feasible provided proper pH levels are maintained, ammonia is reduced to low levels, high contact times and free residuals are maintained, and very low turbidities result. Biologic agents including viruses can be inactivated.

5. Trace organic and metallic constituents are a major item of concern and uncertainty; such materials may have toxic or chronic long-term effects the extent of which, by and large, is unknown at this time.

6. Animal feeding experiments, along the lines used to assess the safety of drugs, can be used to certify water produced from contaminated sources. Such experiments can address the acute and chronic toxicity effects that may be caused by the trace organics and metals; they also can serve as a check on disinfection effectiveness.

7. Inventory and control of industrial discharges can be used to manage the introduction of trace organics and metals into the, water supply.

8. A definition of what constitutes acceptable indirect reuse does not exist. This is true in spite of the fact that public policy and professional opinion condones indirect reuse, although reluctantly. Thus, professional judgment must be used to decide upon the degrees of dilution, travel time, and natural processes which are acceptable on a case-by-case basis. Clearly, a rational definition is needed.

9. Criteria for what constitutes acceptable constituent levels for acutely or chronically toxic substances in finished waters derived from sewage or diluted sewage do not exist. In large measure, the absence of such criteria leads to the arguments that wastewater be minimized as a ratio of raw water and direct reuse is not acceptable. Animal feeding experiments can serve as a stopgap measure until such criteria are developed.

10. The use of the Potomac estuary for drinking water supply appears to be feasible at this time provided the operating criteria as suggested in this report are followed. The criteria are given in general outline which must be refined into concrete measures that include: breakpoint chlorination, dilution of estuary with upland waters, physical-chemical monitoring of ammonia, turbidity and chlorine, monitoring for sewage treatment operations at the Blue Plains Plant as well as for storm water overflows, monitoring for bacteria, viruses, trace organics and heavy metals, and the use of animal feeding experiments.

11. Public relations are an important aspect of reuse and should be deliberately planned and pursued before and during reuse efforts.

The above conclusions should be reviewed with the knowledge that an experimental pilot plant is being planned to treat Potomac estuary waters. The existence of the plant will permit the technology to be tested and operating criteria to be refined. The recommendations of this report are:

1. The proposed operating precautions should be used as a starting point to develop fail-safe procedures using the experience gained through the pilot plant. As a major part of this development, animal feeding experiments should be designed and tested in order to cope with the possible toxic effects associated with trace organics and metals.

2. An up-to-date, accurate inventory of industrial wastes should be developed. Possible industrial discharge restrictions should be considered to limit the introduction into the estuary of trace organic and metallic compounds.

3. An epidemiological study of another area involved with reuse should be conducted. Such a study would contrast population attributes of an area having reuse with an area using pristine waters to seek to quantify any adverse physiological effects.

4. A thorough investigation, involving discussions with responsible officials, should be conducted within the following regions:

a. Selected U.S. locations such as Philadelphia and the Ohio River basin - to determine the practices used and the extent of reuse,

b. Windhoek, South Africa - to assess their experience with direct reuse, and

c. U.S.S.R. - to evaluate the constituent limits imposed on their drinking water standards and assess whether or not they could be used as a basis of criteria for finished waters. (The U.S.S.R. currently specifies some 300 constituent limits in their standards.)

5. The hydrodynamic and biologic attributes of the Potomac estuary should be determined. If the estuary is to be part of the system, its responses to various stresses should be quantified. The idea is that the estuary itself is a water treatment process and as such its performance characteristics should be known. Dye studies, in situational measurements, and mathematical models should be considered in the quantification of estuary performance as a component of the overall water cycle system.

6. A public relations program should be structured. Its objectives should be clear and it should exploit the pilot plant experiences.

7. Research should be started to develop criteria for constituent limits for finished waters derived from wastewater-contaminated sources. Indirect reuse should be defined in a rigorous technical fashion such that acceptability determinations are part of a rational process. This is a long-term recommendation the implementation of which may best be sponsored by Federal agencies.

SELECTED REFERENCES

1. American Water Works Association, "Use of Reclaimed Wastewaters as a Public Water Supply Source," AWWA Journal, Yearbook 1971.

2. Banks, Harvey 0., A. J. Inerfield, C. G. Wolfe, D. L. Tucker and P. G. Harris, "Economic and Institutional Analysis of Wastewater Reclamation and Reuse Projects," NTIS, PB-206-522, 1971.

3. Bruvold, William H., "Public Attitudes Toward Reuse of Reclaimed Water," Contribution No. 137, University of California Water Resources Center, August 1972.

4. and Paul C. Ward, "Using Reclaimed Wastewater - Public Opinion," Journal Water Pollution Control Federation, Vol. 44 No. 9, September 1972.

5. Chambers, Cecil W., "Chlorination for Control of Bacteria and Viruses In Treatment Plant Effluents," Presented at the 41st Annuol Meeting of the Central States Water Pollution Control Association, Saint Paul, Minnesota, June 1968.

6. Culp, Russell L., Jerry C. Wilson and David R. Evans, "Advanced Wastewater Treatment as Practiced at South Tahoe," Water Pollution Control Research Series, Project 17010 ELQ, GPO, August 1971.

7. Foster, Herbert B. and William F. Jopling, "Rationale of Standards for Use of Reclaimed Water," Journal Sanitary Engineering Division ASCE, June 1969.

8. Gavis, Jerome, "Wastewater Reuse," Report NWC-EES-71-003 to the National Water Commission, July 1971.

9. Hill, William F., Jr., Elmer W. Akin and William H. Benton, "Detection of Viruses in Water: A Review of Methods and Application," Water Research, Vol. 5, 1971.

10. Hydro science, Inc., "The Potomac Estuary as a Supplemental Source of Water Supply," Prepared for N.E.W.S. Water Supply Study, North Atlantic Division, Department of the Army, January 1971.

11. Klein, E., J. K. Smith, F. Morton and B. H. Sweet, "Concentration of us From Water by Osmotic Ultra filtration -- II Mass Transport," Water Research, Vol. 5, 1971.

12. Linstedt, K. 0., E. R. Bennett and S. W. Work, "Quality Considerations in Successive Water Use," Journal Water Pollution Control Federation, Vol. 43, No. 8, August 1971.

13. Liu, 0. C. and F. McGowan, "Effect of Chlorination on Human Enteric Viruses in Partially Treated Water from the Potomac River Estuary," A Study Report for the U.S. Army Engineers, North Atlantic Division, July 1971.

14. D. A. Brashear, H. R. Seraichekas, J. A. Barnick and T. G. Metcalf, "Virus in Water - A Preliminary Study on a Flow-Through Gauze Sampler for Recovering Virus from Waters," Advances in Applied Microbiology, March 1971.

15. Long, W. N. and F. A. Bell, Jr., "Health Factors and Reused Waters," AWWA Journal, April 1972.

16. Lund, Ebba and C. E. Hedstrom, "A Study on Sampling and Isolation Methods for the Detection of Virus in Sewage," Water Research, Vol. 3, 1969.

17. McDermott, J. H., "Federal Drinking Water Standards Past, Present and Future," EED Journal ASCE, August 1973.

18. "Federal Research in Potable Water Technology - part of a discussion," AWWA Journal, October 1972.

19. Merrell, J. C., Jr. and P. C. Ward, "Virus Control at the Santee, California Project," AWWA Journal, February 1968.

20. Metzler, D. F., et al, "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas," AWWA Journal, 1958.

21. Michel, R. L., A. L. Pelmoter and R. C. Palange, "Operation and Maintenance of Municipal Waste Treatment Plants," Journal Water Pollution Control Federation, March 1969.

22. Moore, Marion L., Peter P. Ludovici and Wayburn S. Jeter, "Quantitative Methods for the Concentration of Viruses in Wastewater," Journal Water Pollution Control Federation, Vol. 42, No. 2, February 1970.

23. Morris, J. Carrell, "Disinfection of Water Supplies," Proceedings of Joint Symposium, The Society for Water Treatment and Examination and The Water Research Association, University of Reading, England. January 1970.

24. National Water Commission, "Water Policies for the Future," Final Report to the President and to the Congress of the United States, June 1973.

25. Nupen, Ethel M., "Virus Studies on the Windhoek Waste-Water Reclamation Plant (South-West Africa)," Water Research,Vol. 4, 1970.

26. Ottoboni, Alice and Arnold E. Greenberg, "Toxicological Aspects of Wastewater Reclamation -- A Preliminary Report," Journal Water Pollution Control Federation, Vol. 42, No. 4, April 1970.

27. Palange, Ralph C., Unpublished Memorandums, July 1973.

28. Scarpino, Pasquale V., Gerald Berg, Shih Lu Chang, Daniel Dahling and Merrilee Lucas, "A Comparative Study of the Inactivation of Viruses in Water by Chlorine," Water Research, Vol. 6, No. 8, August 1972.

29. Shuval, Hillel I. and Nachman Gruener, "Health Considerations in Renovating Wastewater For Domestic Use," Environmental Science and Technology, July 1973.

30. Sorber, Charles A., Bernard P. Sagik and Joseph F. Malina,'Jr., "Monitoring of Low-Level Virus in Natural Water," Advances In Applied Microbiology, 1971.

31. Stander, G. J. and J. W. Funke, "Direct Cycle Water Reuse Provides Drinking Water Supply in South Africa," Water and Wastes Engineering, May 1969.

32. Sweet, B. H., J. S. McHale, K. J. Hardy and E. Klein, "Concentration of Virus from Water by Electro-Osmosis and Force-Flow Electrophoresis," Gulf South Research Institute, Marcel Dekker, Inc., 1971.

33., Janiece S. McHale, K. J. Hardy, F. Morton, J. K. Smith and E. Klein, "Concentration of Virus from Water by Osmotic Ultra filtration -- I Biological Aspects," Water Research, Vol. 5, 1971.

34. World Health Organization. Technical Report Series No. 517, "Reuse of Effluents: Methods of Wastewater Treatment and Health Safeguards," Report of a WHO Meeting of Experts, Geneva, Switzerland, 1973.