Public Health and Environmental Safety of Reclaimed Wastewater Reuse

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ABSTRACT

The ever-increasing needs for additional domestic water supplies coupled with the inability to develop additional surface water resources is causing water supply authorities to start to develop alternative water supply sources. Expanded use of reclaimed domestic wastewaters for irrigation of vegetation and for groundwater recharge is occurring. Domestic wastewaters, including those that have been "reclaimed" to various degrees, contain a wide variety of unregulated chemical constituents and may contain, depending on the degree of treatment, pathogenic organisms that can represent significant threats to both surface water and groundwater quality. This paper presents a review of issues on the potential public health and environmental impact of residual chemical constituents and pathogenic organisms in "reclaimed" wastewaters. Particular attention is given to the potential public health and water quality significance of unregulated organic chemicals, enteroviruses and cyst-forming protozoans in reclaimed domestic wastewaters.

INTRODUCTION

With increasing attention being given to the reclamation of domestic wastewaters as a water supply source, increased attention is also being given to the public health and environmental safety of the use of reclaimed domestic wastewaters for various purposes. Reclaimed wastewater proponents claim that such use is "safe," while on the other hand reclaimed wastewater project opponents claim that reclaimed wastewaters are not necessarily safe, and residual pollutants are a significant threat to public health and the environment. Critical review of this issue shows that there is a variety of degrees of treatment of reclaimed wastewaters that are allowed under current regulatory approaches in California and elsewhere that significantly impact the safety of a reclaimed domestic wastewater for reuse.

There are two public health aspects of reclaimed wastewater that are of concern. One of these is the potential for waterborne enteric diseases to be acquired by those who consume or come in contact with reclaimed wastewaters and/or their residuals. The other is the potential for adverse public health and environmental effects associated with residual unregulated chemicals in the reclaimed wastewater.

PROTECTION FROM WATERBORNE PATHOGENS

Recently, the National Research Council (NRC 1994) has released a committee report entitled, "Groundwater Recharge Using Waters of Impaired Quality." This release states in a discussion of public health issues,

"While a vast body of knowledge exists about relatively uncontaminated, conventional source waters, there is still some uncertainty about the risks associated with impaired sources, principally related to the presence of synthetic organic chemicals, disinfection by-products, and some pathogenic organisms."

* * *

"The information available from on-site and laboratory studies do not indicate that the health risks from recovered water are greater than those from existing water supplies or that the concentrations of chemicals or microorganisms are likely to be higher than those established in drinking water standards set by the Environmental Protection Agency (EPA). There are uncertainties, however, such as limited chemical and toxicological characterizations of source waters, the absence of water quality standards for some of the chemicals, and the uncertain environmental fates of chemicals and microorganisms in the recharge system."

While such statements will likely be used by those who support current approaches to reclaimed wastewater reuse asserting that such use represents no greater threat than those currently associated with domestic water supplies, caution should be exercised in accepting such claims as a basis for concluding that residual chemical contaminants and pathogenic organisms in reclaimed domestic wastewaters do not represent significant threats to public health and the environment. It is important to point out that the NRC's statement applies to those situations where high degrees of wastewater treatment are occurring through both post-secondary treatment prior to recharge and in which there is appreciable in-aquifer "treatment" before reuse. There are many situations, however, where reclaimed domestic wastewaters are reused without the degree of enhanced and natural treatment that is associated with the examples provided by the NRC.

The NRC's highly qualified statement about the safety of reuse of reclaimed wastewaters that have been recharged into an aquifer system after extensive treatment should not be applied to many reclaimed wastewater reuse projects. While the NRC raises a number of significant concerns about "safety" of reclaimed wastewater reuse under the conditions considered, there are many situations in which reclaimed wastewater reuse as it is being practiced today would represent a significantly greater hazard to public health and the environment than those considered by the NRC. These issues are discussed below.

Safety of Domestic Water Supplies

There are aspects of the NRC statement that need to be understood to properly evaluate the safety of use of reclaimed wastewaters. First, the NRC statement quoted above to the effect that highly treated, recovered reclaimed wastewaters do not represent threats to public health greater than those associated with domestic water supplies does not address the fundamental issue of

how safe are today's domestic water supplies after conventional water treatment. The Milwaukee treated domestic water supply *Cryptosporidium* outbreak of the spring of 1993 has brought to national attention what has been known since the 1940's with regard to the safety of treated domestic water supplies with respect to the approach that is used to judge this safety. It has been known since that time that the coliform standard that has been used to judge the safety of a domestic water supply delivered to the consumers is not a reliable standard for protection from several types of human intestinal diseases.

The coliform organisms resemble in typical domestic water supply treatment such as disinfection by chlorine, the behavior of typhoid and similar bacteria. These organisms are readily killed by chlorine and other conventionally used water supply disinfectants. However, in addition to concern about bacterial waterborne pathogens there is also concern about enteroviruses and cyst-forming protozoans such as *Cryptosporidium* and *Giardia*. These organisms are now widely recognized as common contaminants of many surface water supplies and can be present in large numbers in domestic wastewaters. Further, they are being found in treated domestic water supplies.

Okun (1994) reviewed the regulatory gaps that exist today in protecting water supplies from *Cryptosporidium*. Southern (1994) reviewed the information currently available on *Cryptosporidium* as a cause of water supply waterborne disease. Lee and Jones-Lee (1993a) have presented a comprehensive review of domestic water supply waterborne disease issues. Moore, *et al.* (1994) have presented a comprehensive review of waterborne disease in the US. Further, Yates (1994) has summarized the information available on waterborne pathogens that are of concern to golfers who play on courses that have been irrigated by reclaimed wastewaters.

The NRC statement that the use of reclaimed, highly treated, recharged domestic wastewaters represents no greater threat than current domestic water supplies should be examined in the context of the fact that domestic water supplies today are not necessarily treated adequately even though treatment standards are met to protect public health and the environment from waterborne diseases and, as discussed below, non-conventional contaminants. A water supply such as Milwaukee's met all existing standards yet caused over 400,000 people to get sick and approximately 100 people to die associated with a *Cryptosporidium* outbreak. Further, because of the large number of unregulated chemicals present in many domestic water supplies, it should never be assumed that just because a treated water meets current drinking water standards (MCL's) that the water is "safe" from hazardous chemicals.

At about annually there have been Milwaukee-type waterborne epidemic disease outbreaks. In February 1987, an estimated 13,000 people became ill from drinking a treated domestic water supply that contained *Cryptosporidium* in Carrollton, Georgia. Similarly, 15,000 people are estimated to have become ill due to *Cryptosporidium* in domestic water supplies in Jackson County, Oregon in 1992. According to Southern (1994), in 1989 55,000 people became ill from the exposure to *Cryptosporidium* in the domestic water supply for Oxfordshire, Scotland.

In addition to the epidemic outbreaks of this type, there is also the endemic domestic water supply waterborne pathogen problem. Lee and Jones-Lee (1993a) have reviewed the information available on this topic and report that the Centers for Disease Control (CDC) report that there are

an estimated 940,000 cases of domestic water supply waterborne disease that occur in the US each year with an estimated 900 deaths associated with this disease. This disease is attributable to enteroviruses and cyst-forming protozoans. It is now widely recognized that the regulatory approaches that have been used in the past and are in effect today for protection of domestic water supplies are not adequate to protect people who use these supplies from occasional epidemic outbreaks of waterborne disease and frequent endemic occurrence of waterborne disease.

The American Water Works Association Executive Committee (AWWA 1995) has recently approved a *Cryptosporidium* "white paper" which discusses various activities that water utilities can undertake to minimize public exposure to *Cryptosporidium* in treated drinking water. This committee states as one of these activities, *"Educating sensitive populations to the fact that public drinking water supplies, even when they meet or exceed all state and federal standards, are not sterile drinking water supplies... ."* The AWWA "white paper" suggests that the "sensitive populations" should consider routine "boiling of water" to reduce the risk of *Cryptosporidium* infection. This is to take place even though the water supply meets current sanitary water quality standards.

According to the CDC, the especially sensitive populations are young children, the elderly and those with immune deficiencies. This is the group that experience significant serious illness, including death, from *Cryptosporidium* infections. Many individuals become ill from *Cryptosporidium* exposure. The illness is typically manifested in diarrhea and/or vomiting which may be sufficiently severe to significantly hamper an individual's ability to perform work or other activities. It therefore may be concluded that while many water utilities have claimed that many domestic water supplies are "safe," the facts are that such safety does not mean that people are not becoming debilitated or even dying from exposure to *Cryptosporidium* that passes through conventional domestic water treatment.

This illness and death is not manifested in a *Cryptosporidium* epidemic, but is part of the widespread endemic public health problem associated with inadequate treatment of domestic water supplies to control *Cryptosporidium* and enteroviruses. As discussed by Lee and Jones-Lee (1993a), this situation is not just now being discovered; it has been known since the mid-1980's.

It may be concluded that little consolation should be given to the NRC statement that certain types of reclaimed wastewater reuse associated with some recharge projects are as safe as typical domestic water supplies today. The facts are that the typical domestic water supply today is not necessarily safe, with respect to pathogenic organisms that can cause illness and death, and represents what most individuals would consider to be highly hazardous conditions for those who consume the water relative to the hazards - risks that are commonly accepted as appropriate for today's society from regulated chemical contaminants in domestic water supplies.

In considering the appropriateness of a particular reclaimed wastewater reuse project, attention must be given to the degree of treatment that is actually practiced. NRC used for the purposes of comparison in discussing the safety of water supply reclaimed wastewater reuse situations examples where there is extensive treatment of the wastewater before recharge. Further, there are significant safeguards in terms of aquifer characteristics and travel time within the aquifer which

would be expected to provide the opportunity for removal and death of any residual waterborne pathogens in the recharged reclaimed wastewaters. However, as discussed by Lee and Jones-Lee (1993b), the current regulatory requirements in California and elsewhere governing reclaimed domestic wastewater recharged to a domestic aquifer have markedly different treatment requirements depending on the situation. Some of these situations would not provide the degree of protection that NRC assumed in its conclusions about the safety of reclaimed wastewater recharged to an aquifer.

Use of Reclaimed Wastewaters for Shrubbery Irrigation

Another major use of reclaimed domestic wastewaters is the irrigation of ornamental shrubbery. Such practices reduce the demand for high quality waters that can be used for domestic water supply. Often such uses reduce the magnitude of the need for reclaimed wastewater recharge to an aquifer as a result of reducing the demand for groundwater in the area. The NRC statement on the safety of highly treated reclaimed recovered domestic wastewaters applies only to certain types of reclaimed wastewater groundwater recharge projects. It does not necessarily apply to the safety of many other reclaimed wastewater reuse projects such as for shrubbery irrigation, golf course watering, etc., where the degrees of treatment assumed in the NRC statement do not occur before use.

There is increasing attention being given to the use of reclaimed wastewaters for golf course irrigation. In 1993, the US Golf Association and several other golf course organizations sponsored a golf course wastewater symposium (USGA 1994). The proceedings of this symposium have been published: *Wastewater Reuse for Golf Course Irrigation.* A review of this publication shows that, with few exceptions, the authors of the chapters proclaim that the use of reclaimed wastewaters on golf courses is "safe" for public health. The basis for such "safety" is a US EPA published report (US EPA 1992) entitled, "Guidelines for Water Reuse." This "Guidelines" was prepared by a consultant and evolved out of a US EPA and US Agency for International Development (US AID) committee effort. The "Guidelines," however, do not represent US EPA or US AID standards for reclaimed wastewater reuse. The report states in the introduction, *"Water reclamation and nonpotable reuse only require conventional water and wastewater treatment technology that is widely practiced and readily available in countries throughout the world."* This report does not adequately address many of the key issues of concern associated with unregulated chemical constituents and waterborne enteroviruses and cyst-forming protozoans that are present in domestic wastewaters that are not removed by conventional domestic wastewater treatment.

The report was developed pre-Milwaukee *Cryptosporidium* epidemic and pre-urban stormwater runoff control programs that are being implemented for cities - areas with populations greater than 100,000. Both of these situations are significantly changing views on the "safety" of using secondarily treated domestic wastewaters for many nonpotable uses, such as irrigation of golf courses and runoff from reclaimed wastewater irrigated areas, where individuals can be exposed to an increased health risk due to inadequate treatment of reclaimed domestic wastewaters.

Recently, Crook *et al*. (1994) have published the results of a Water Environment Research Foundation (WERF) research project devoted to review of various issues associated with

domestic wastewater reuse. Lee and Jones-Lee (1995) have conducted a review of aspects of this report and have concluded that it does not adequately address the public health and environmental problems associated with some domestic wastewater reuse projects. In particular, the report fails to properly address the potential public health problems associated with domestic wastewater reuse for ornamental shrubbery and golf course irrigation where disinfection to remove enteroviruses and cyst-forming protozoans is not practiced. Also, this report fails to consider the potential environmental and public health problems associated with stormwater runoff from areas that have received repeated applications of partially disinfected and treated reclaimed wastewaters.

One of the significant problems that many of the evaluations of the "safety" of reclaimed wastewater reuse is that proponents of only secondarily treated reclaimed wastewaters assert that epidemiological studies of populations that have been exposed to such wastewaters have failed to show significant increased incidence of disease. However, a review of the ability of epidemiological study techniques to detect small increases in the incidence of enteric diseases shows that such approaches are not reliable for this purpose. Further, many of the enteric diseases of greatest concern associated with enteroviruses and cyst-forming protozoans, such as *Cryptosporidium*, do not result in reportable disease incidence. For many individuals, the problem associated with these organisms is intestinal upset leading to diarrhea, vomiting, etc. In most cases, the problem is not sufficiently severe to contact a physician. The infected individuals may lose a day or so of work or operate at lower levels of productivity because of the disease.

The primary areas of concern with respect to disease associated with enteroviruses and many of the cyst-forming protozoans is death among young children, elderly and individuals with immune deficiencies. Further, it is becoming increasingly recognized that secondary infections among family members is common where the individual who originally was exposed to the disease organism transmits it to his/her family members and others with whom he/she has contact.

As a result of the Milwaukee epidemic it is becoming clear that the disease caused by *Cryptosporidium* has been grossly under-reported. In the past year there have been a number of papers published in the *Journal of the American Medical Association* which show that *Cryptosporidium*-caused disease is fairly common. For example, McAnulty *et al.* (1994) has reported on a community-wide outbreak of cryptosporidiosis associated with swimming at a community wave pool. A *JAMA* Centers for Disease Control and Prevention statement (CDC 1994) reported on *Cryptosporidium* infections associated with swimming pools in Dane County, Wisconsin. A CDC editorial note in this report states, *"Person-to-person, waterborne, and zoonotic transmission of* Cryptosporidium *has been well documented."* It also indicates that the cryptosporidiosis associated with the use of swimming pools has been under-recognized.

Millard *et al.* (1994) have reported on a cryptosporidiosis outbreak associated with the consumption of apple cider where a substantial number of people at a county fair became ill. They also reported a secondary household transmission rate of 15%. It was only a few years ago that cryptosporidiosis was not generally considered a major threat to public health. Certainly today any properly conducted domestic wastewater reuse project must include a detailed evaluation and monitoring for public exposure to *Cryptosporidium* and the enteroviruses.

Another significant problem with assessing what is meant by the "safety" of partially treated reused domestic wastewater where some members of the public are exposed to the residues of the pathogenic organisms present in the reused wastewaters, is that those who are characterizing these waters as "safe" often use unstated definitions of safety which are significantly different from those that are typically used today in managing hazardous chemicals in drinking waters. The US, through its regulation of Priority Pollutants in domestic water supplies, is regulating certain potentially hazardous chemicals, such as the chlorinated solvents VOC's and benzene, at cancer risks of one additional cancer in a million people who are exposed to the water over their lifetime. If exposure to pathogenic organisms, such as enteroviruses and cyst-forming protozoans were regulated to the same degree of risk as many of the VOC's, many of the uses of partially treated domestic wastewaters would not be allowed.

Basically, different standards are being used in the regulation of chemicals that are known to cause tumors in rodents at high concentrations and are therefore suspected human carcinogens and the standards that are applied to the pathogenic organisms which cause real illness in people. Haas *et al.* (1993) has reported that the US population lifetime risk of death from exposure to waterborne viruses is as high as 1 in 20. The waterborne pathogen risk is far greater than all the chemical constituents, which are the primary thrust of regulatory programs today, combined. While there are many who feel that the chemical constituents are being over-regulated compared to their real risks and the risks that the public typically accepts in its everyday activities, the pathogenic organisms associated with domestic wastewaters and present in domestic water supplies are significantly under-regulated at this time. This inconsistency in regulatory approach and safety is beginning to be rectified where the hazards of waterborne pathogens that cause illness in people are beginning to be more appropriately addressed by regulatory agencies.

Generally, groundwaters have been used for domestic water supplies without disinfection since they were considered to be "safe." However, the US EPA as part of its Groundwater Disinfection Rule is now considering requiring all groundwater-based water supplies to be disinfected unless it can be demonstrated that there is little likelihood of pathogenic organisms being present in the groundwater due to "natural disinfection." It would certainly be appropriate to require far greater disinfection of domestic wastewaters that are used in reclaimed wastewater reuse projects, such as for shrubbery irrigation, to significantly reduce the public health hazard associated with the project.

From a superficial review of the USGA conference proceedings and from the US EPA "Guidelines," and the recent WERF review, it might be concluded that there is little need to be concerned about public contact with areas, including golf courses, that have been irrigated with reclaimed wastewaters. However, a review of the degree of treatment of reclaimed wastewaters that can be used for golf course and shrubbery irrigation in California shows that the California Department of Health Services (DHS) will allow the use of essentially secondarily-treated domestic wastewaters for irrigation of golf courses provided that the golfers are not present during the time of the irrigation. They are not, however, restricted from entering the irrigated parts of the golf course within a short time after irrigation.

Lee and Jones-Lee (1994a) have discussed the inadequacies of currently allowed and proposed DHS treatment standards for public health protection associated with reclaimed wastewater

reuse. While current reclaimed domestic wastewater irrigation practices allowed in California and elsewhere will not likely lead to epidemic outbreaks of waterborne disease where large numbers of people become ill at one time, such practices can readily lead to an increase of the endemic waterborne disease problem that exists where individuals who are exposed to the residues associated with the reclaimed wastewater use acquire an increased risk of enteric pathogen disease. This could also be of importance not only to this individual but also to members of the exposed person's family or others with whom he/she has contact through secondary infections.

Protozoan cysts can persist in the environment for long periods of time and would therefore be expected to be present in areas that have received reclaimed domestic wastewater that has not been treated to adequately remove the cysts. While it is often claimed that enteroviruses die off fairly quickly, Abad, *et al.* (1994) have recently reported on the survival of enteric viruses on various types of surfaces. They found that while there is some initial die-off, typically in the order of one to two logs, many of the remaining enteroviruses persist with little die-off for over 60 days, i.e. the duration of their studies.

It may therefore be concluded that the repeated irrigation of an area with reclaimed wastewater in which there has only been partial removal of enteroviruses and protozoan cysts can lead to increased public health risk to those who use an area, such as a golf course, irrigated park or other area. Further, large numbers of these organisms can be present in stormwater runoff from the reclaimed wastewater irrigated areas. It would certainly be appropriate for those golf courses that use only partially treated domestic wastewaters for course irrigation to post a notice informing those who use the course that they are exposed to an increased risk of enteric pathogenic disease due to reclaimed wastewater irrigation of the course.

Runoff From Reclaimed Wastewater Irrigated Areas

One of the issues that needs to be considered in evaluating the potential source of waterborne pathogen indicator organisms in stormwater runoff from areas that have been irrigated with inadequately treated reclaimed wastewaters, such as highway right-of-way shrubbery, is the potential for this runoff to contain pathogenic organisms derived from the repeated application of reclaimed wastewaters. One of the uses of partially treated reclaimed wastewaters today is the irrigation of shrubbery along highways. Some of the reclaimed wastewaters that are used for this purpose are treated little beyond secondary treatment, and therefore these reclaimed wastewaters would be expected to contain enteroviruses and pathogenic protozoan cysts.

In some instances the irrigated shrubbery along the highways is on a sloped area which drains to the highway. This means that whenever it rains, the residues from the irrigation waters that have accumulated on the vegetation and the soil will be transported to the highway and become highway runoff-derived materials. There are situations, however, where the reverse is true, i.e. the irrigated vegetative areas slope away from the highway. While typically at the point where the wastewaters are applied there is limited opportunity for public contact with the residual organisms from the reclaimed wastewaters, with the next storm runoff event from the area many of the enteroviruses and the protozoan cysts that were present in the reclaimed wastewaters used

for irrigation are transported in the stormwater runoff to watercourses where they could be a threat to public health.

In the Los Angeles area there is considerable concern about the presence of waterborne pathogens in the nearshore - beach waters of Santa Monica Bay as they are derived from storm sewer runoff. The increased use of inadequately treated reclaimed wastewaters for irrigation for maintenance of vegetation during dry periods will lead to increased nearshore pollution of Santa Monica Bay with pathogens which, in turn, will result in an increased public health threat to those who recreate in the nearshore waters of Santa Monica Bay or, for that matter, other waterbodies which receive runoff from inadequately treated reclaimed domestic wastewaters.

It therefore must be concluded that even such widely accepted practices as watering of highway vegetation with reclaimed wastewaters as it is now currently practiced is not without potentially significant public health concerns due to the residual pathogens that are present in the reclaimed wastewaters supplied to the irrigated areas.

Monitoring of Residual Pathogens in Reclaimed Wastewater Irrigated Areas

The presence of human pathogens in the form of enteroviruses and protozoan cysts in stormwater runoff from some reclaimed wastewater irrigated areas would not necessarily reliably be indicated by monitoring for coliform organisms. The fecal coliforms would be expected to have significantly different persistence than the enteroviruses and protozoan cysts. Monitoring for enteroviruses and protozoan cysts is necessary to ensure that the use of reclaimed wastewaters for irrigation purposes does not result in a significant public health problem arising from stormwater runoff from the irrigated areas as well as to those who use the irrigated areas for recreation or other purposes.

The runoff from these irrigated areas also could be a significant source of chemical constituents that could be adverse to aquatic and terrestrial wildlife. The terrestrial life could be exposed through direct contact in the irrigated areas, and the aquatic life exposure would occur through runoff from these areas associated with stormwater runoff events.

While in the past there has been limited concern about waterborne pathogens in runoff from reclaimed wastewater irrigated areas, in the future this concern is likely to change significantly as a result of the US EPA's requirements that water utilities, stormwater management agencies, and others control activities in their watersheds that could be adverse to water quality. Increased emphasis on managing waterborne pathogens will result in direct monitoring of pathogens rather than relying on monitoring fecal coliforms as indicators of waterborne pathogens. As noted elsewhere in this paper, fecal coliforms are not reliable indicators for enteroviruses and cyst-forming protozoans.

There is considerable concern today for the potential of enteroviruses in inadequately treated domestic wastewaters that are recharged to an aquifer to lead to waterborne disease associated with the use of that water for domestic water supply purposes. NRC (1994) stated, *"There are significant uncertainties associated with the transport and fate of viruses in recharged aquifers. These uncertainties make it difficult to determine the levels of risk of any infectious agents still*

contained in the disinfected wastewater." Powelson and Gerba (1994) point out that pathogenic enteric viruses from domestic wastewater ponds, septic tank wastewater disposal systems and other sources have been found to be the cause of human disease. Considerable additional research at a wide variety of locations is needed to understand and manage the threat that pathogenic enteric viruses present in partially treated domestic wastewaters represent to groundwater quality.

PROTECTION FROM CHEMICAL CONSTITUENTS

Reclaimed domestic wastewaters contain a wide variety of chemical constituents that are normally classified as conventional and non-conventional pollutants and Priority Pollutants that represent threats to public health and the environment. These constituents range from increased total salts through heavy metals, regulated organics and, most importantly, non-regulated organics. As discussed by Lee and Jones-Lee (1994b), over 95% of the organic matter present in reclaimed wastewaters is unidentified and of unknown characteristics.

Typically, as a water is used by a city for domestic water supply purposes, the total dissolved solids (salts) increase by several hundred milligrams per liter. If the water supply is hard water with total hardness above about 150 to 200 mg/L as $CaCO_3$, then the increase in salts from the water supply through the wastewaters can be even greater due to the use of ion exchange softening. This increase in salts is primarily due to an increase in sodium and chloride. While both of these constituents are normally considered to be relatively innocuous at moderate concentrations, at elevated concentrations they both can be significantly detrimental to the use of a water for domestic water supply purposes as well as for irrigation. This, in turn, can adversely impact the use of a reclaimed domestic wastewater.

Lee and Jones-Lee (1994b,c) have discussed the potential significance of increased TDS in reclaimed wastewaters that are used to recharge aquifers. They point out that increased TDS leads to greater corrosion and scale formation in the recovered recharged reclaimed wastewater which, in turn, shortens the useful life of distribution systems, plumbing, household fixtures and clothing, increases the costs of the heating of hot water due to scale formation on heat transfer surfaces and for some individuals who are sensitive to sodium, represents a public health threat through increased risk of heart disease.

In the spring of 1994, the California Regional Water Quality Control Board for the San Diego Region as well as the State Water Resources Control Board adopted a modified Basin Plan Objective for total dissolved solids for several areas near San Diego based on the premise that continuing to maintain a TDS standard for groundwaters in the area would inhibit reclaimed wastewater recharge. The Regional and State Board staff with the approval of their respective Boards stated that there were no adverse impacts associated with the increase in TDS from 500 to 750 mg/L and that this increase represented a significant increase in cost to groundwater recharge projects. However, as Lee and Jones-Lee (1994c) point out, this increase in cost is on the order of a few cents/person/day who cause the increase in the TDS through the use of the water for domestic water supply purposes where the waste salts added to the water by the communities increase TDS. Further, the increased costs associated with reverse osmosis (RO)

removal of salts from the reclaimed wastewater must be considered in light of the increased cost to the users of the reclaimed wastewater for domestic water supply purposes.

Lee and Jones-Lee (1994c) also discuss the potentially significant advantages of treating the reclaimed wastewater for TDS removal using RO as a result of the concomitant removal of the non-conventional pollutants and thereby reducing the public health and environmental risk associated with the large number of unregulated chemicals that are present in reclaimed domestic wastewaters. The RO treatment of domestic wastewaters before recharge provides an additional advantage of placing less reliance on soil aquifer treatment (SAT) to remove chemical and pathogenic constituents, thereby reducing the potential for the aquifer to become a future "Superfund" site due to the accumulation of residual chemical contaminants in the aquifer.

DEGREE OF TREATMENT OF RECLAIMED WASTEWATERS

Those who promote reclaimed wastewater reuse typically fail to discuss, as part of the promotion efforts, that there are a wide variety of allowable degrees of treatment of domestic wastewaters which enable it to be called "reclaimed" wastewater. As discussed by Lee and Jones-Lee (1994a), at this time the state of California DHS which regulates reclaimed wastewater treatment and use does not require high degrees of treatment for all types of reuse. There are situations, such as in the Santa Ana River, where enhanced groundwater recharge is practiced through the construction of small earthen dams that enable the low-flow waters in the river which are essentially secondarily-treated domestic wastewaters to be recharged to the aquifer. While some recharge will naturally occur through the riverbed, the construction of the earthen dams in the riverbed enhances recharge. This enhanced recharge, however, is not regulated by DHS. On the other hand, if the recharge of these same wastewaters were to occur in off-channel basins, they would be regulated to some extent. It is situations such as this that point to a need for a more comprehensive approach for more adequately regulating domestic wastewater reclamation projects to ensure that all such projects provide high degrees of public health and environmental protection.

For the past several years DHS has been in the process of developing revised reclaimed wastewater recharge regulations. While preliminary drafts of proposed regulations have been available for several years, the final version of these regulations has not yet been submitted for public review and comment as part of DHS rulemaking. The proposed rules are directed primarily to addressing increased public health protection from reclaimed wastewaters that are directly injected (pumped) into an aquifer as well as for those situations where domestic wastewaters are allowed to gravity recharge in basins. The proposed regulations, however, do not address enhanced recharge of wastewaters through the construction of low head dams in streambeds that are constructed specifically for enhanced recharge of wastewaters.

The proposed DHS regulations do not necessarily result in a recharged groundwater that can be considered "safe" for domestic consumption. As with most public health regulatory policies, there is always a compromise between increasing the cost of public health protection, i.e. for reclaimed wastewaters the degree of treatment necessary to increase the public health protection associated with residual pathogens and chemical constituents in the treated wastewaters, and the cost of such treatment. There are well-organized lobbying efforts such as the WateReuse

Association of California as well as by some water and wastewater utilities that oppose any strengthening of public health protection associated with reclaimed wastewater reuse because of the increased cost associated with the additional treatment that would be required to achieve the additional public health and environmental protection. Some members of these organizations claim that if greater public health protection is mandated that this would be a significant impediment to domestic wastewater reuse. Such an approach is extremely short-sighted and can readily be strongly contrary to appropriate reclaimed wastewater reuse.

At this time, direct injection-pumping of reclaimed wastewaters into the aquifer requires additional treatment of the wastewaters that removes pathogenic organisms and reduces the total organic carbon content of the injected wastewaters. The TOC reduction is directed toward removing some of the public health threat associated with the unregulated chemicals (non-conventional pollutants) in reclaimed wastewaters. Lee and Jones-Lee (1993a) discuss the inappropriateness of assuming as is now done by DHS that TOC or DOC are necessarily appropriate surrogates for potentially hazardous, unidentified, uncharacterized, non-conventional pollutants in reclaimed wastewaters. The reduction in TOC that would be required for directly injected reclaimed wastewaters may fall far short of the necessary reduction in concentrations of some unknown hazardous chemical that could readily be present in the reclaimed wastewater.

Fujita *et al.* (1994) have been conducting studies designed to characterize the dissolved organic carbon present in an advanced treated effluent from the Orange County, California Water Factory 21. This highly treated reclaimed domestic wastewater is directly injected into an aquifer as a sea water intrusion barrier. This domestic wastewater effluent is treated by granular activated carbon beds and/or reverse osmosis. The DOC after treatment is 0.8 mg/L. They found substantial quantities of unidentified, unquantified organics present in this highly treated reclaimed wastewater that were transported in the groundwater system. They were able to identify a number of chemicals such as EDTA, NTA and alkylphenol ethoxylates.

At this time, there are still substantial quantities of organic materials that are present in highly treated reclaimed domestic wastewaters that are transported in groundwater systems that could represent significant threats to public health. Certainly the situation with respect to potential public health and environmental problems associated with less treated reclaimed wastewaters will be greater than the reclaimed wastewaters produced by Water Factory 21 which practices near the ultimate in wastewater treatment.

PERSPECTIVE ON COSTS OF RECLAIMED WASTEWATER TREATMENT

Typically, proponents of a reclaimed wastewater reuse project will present the costs of the project in terms of so many millions of dollars for initial construction of the facilities. With high degrees of treatment beyond secondary treatment, the costs of such facilities can be substantial. However, if these costs are put in a proper perspective in which they are examined in terms of the cost/person/day for the population served, either for those who contribute wastewaters to the facility or those who would benefit because of reclaimed wastewater reuse in terms of not having to provide an equivalent amount of domestic water supply for that purpose, and when the operating costs over the expected life of the project are considered, typically wastewater reuse

projects, even with very high degrees of reclaimed wastewater treatment, will cost the public who benefit from such an approach a few cents/person/day.

As discussed by Lee and Jones-Lee (1994d), it is very important to present the costs of various water supply and wastewater projects in terms that the public can understand. When these costs are expressed in cents/person/day, the public has a much better opportunity to understand what it means to them in terms of the use of their daily disposable income than to inform them that the cost of the project will be so many millions of dollars.

It is also important to present the cost of reclaimed wastewater compared to alternative sources of domestic water supply should such sources be available. In many parts of California and other parts of the country, alternative sources of water supply are becoming extremely difficult to develop. Where they are available, the costs can easily range up to $500/acre foot. The attitude that sometimes prevails today of trying to make the domestic wastewater reuse project as inexpensive as possible at the potential expense of project users' and future generations' health and welfare is short-sighted and highly inappropriate. It is far more appropriate to take the ultra-protective approach of treating the wastewaters to remove to the maximum extent readily achievable, residual pathogenic organisms and non-conventional pollutants. This is the technically valid, cost-effective approach for developing and operating domestic reclaimed wastewater reuse projects.

It is also important to consider in these costs the potential for long-term problems associated with the reuse project that could be attributable to inadequately treated wastewaters in addition to the public health costs of associated illness and death which are largely unquantifiable but can be substantial to society. These include the costs discussed by Lee and Jones-Lee (1994b) of relying on the aquifer to remove residual constituents through SAT, rather than through an engineered and managed treatment works. What might save the people of a region a cent to a couple of cents/person/day by recharge or use of domestic wastewaters that are only little treated beyond secondary treatment, could result in very high costs to future generations who have to pay Superfund clean-up costs associated with an improperly designed and operated reclaimed wastewater reuse project.

RECOMMENDED APPROACH FOR DOMESTIC WASTEWATER REUSE

Lee and Jones-Lee (1993b, 1994b) have pointed out that of the 60,000 chemicals that are in commerce today, only about 100 to 200 are regulated. Each year new chemicals are found in water supplies that are hazardous to public health that have been in the water supply for many years. Further, it was not until the Milwaukee *Cryptosporidium* epidemic of 1993 that it has become known that this organism is present in many raw waters and in some treated domestic water supplies.

The overall approach that should be used in developing a domestic wastewater reuse project is where there are questions about environmental issues to err on the side of public health and environmental protection rather than on a potentially cheaper-than- real-cost project. The maximum treatment of the domestic wastewater technically feasible should be used. Even with such treatment as activated carbon beds and RO, extensive comprehensive environmental

monitoring programs should be conducted for the purpose of not only monitoring the operations, but also specifically searching for incipient problems.

Lee and Jones-Lee (1994b) have discussed an approach for more reliably evaluating potential problems associated with proposed domestic wastewater reuse projects than is typically used today. They suggest that those responsible for developing such projects should be required to conduct a detailed site-specific analysis of how the proposed project could potentially fail to protect public health and the environment. The typical pro-project CEQA EIR or NEPA EIS falls far short of reliably informing the public and decision makers about the potential environmental impacts of proposed projects. Instead of presenting a pro-project approach on behalf of the applicant, the EIR/EIS should use plausible worst-case failure scenario evaluations.

A reliable detailed evaluation should be made where for each potential area of public health and environmental concern, an assessment should be made of the reliability of the monitoring program that is being used to detect failure before widespread failure occurs. Further, an estimate of the impact on public health and the environment should be made at the time that the failure would be expected to be detected.

This plausible worst-case failure scenario approach should include an estimate of the cost of remediation of any damage, as well as any liabilities that might develop through litigation arising from the failure. Also a discussion of who will provide the necessary funds to address these issues, if problems do develop at any time in the future, should be presented. Those responsible for developing the project should be required to develop a dedicated trust fund to cover all plausible worst-case failure scenario liabilities.

In most situations, it is no longer possible to rely on regulatory agencies to reliably monitor and enforce regulatory requirements. With the support of regulatory agencies significantly decreasing, it is imperative that additional protection of public health and the environment be developed through other approaches. It is recommended that reclaimed wastewater reuse project sponsors be required to provide sufficient funds for third-party independent monitoring of the project on behalf of the public. This third-party monitoring should be designed to supplement the regulatory agency's responsibilities where the results of the third party's activities would be reported directly to the public who could be adversely impacted by failure of the reclaimed wastewater reuse project to provide for public health and environmental protection.

CONCLUSION

Insufficient attention has been given to the potential public health problems associated with inadequately treated domestic wastewaters that are used in reclaimed wastewater projects. The residual enteroviruses and cyst-forming protozoans present in domestic wastewaters that are used in wastewater reclamation projects represent significant threats to cause disease in individuals who are associated with the wastewater residues. Further, the uncharacterized residual organics present in domestic wastewaters that are used in wastewater reuse projects, including groundwater recharge and ornamental shrubbery irrigation, represent significant threats to surface and groundwater quality that should receive greater attention. It is important to not let the zeal for inexpensive domestic wastewater reuse overcome high degrees of public health and

domestic water supply protection from the residual pathogenic organisms and chemical constituents present in reclaimed domestic wastewaters.

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