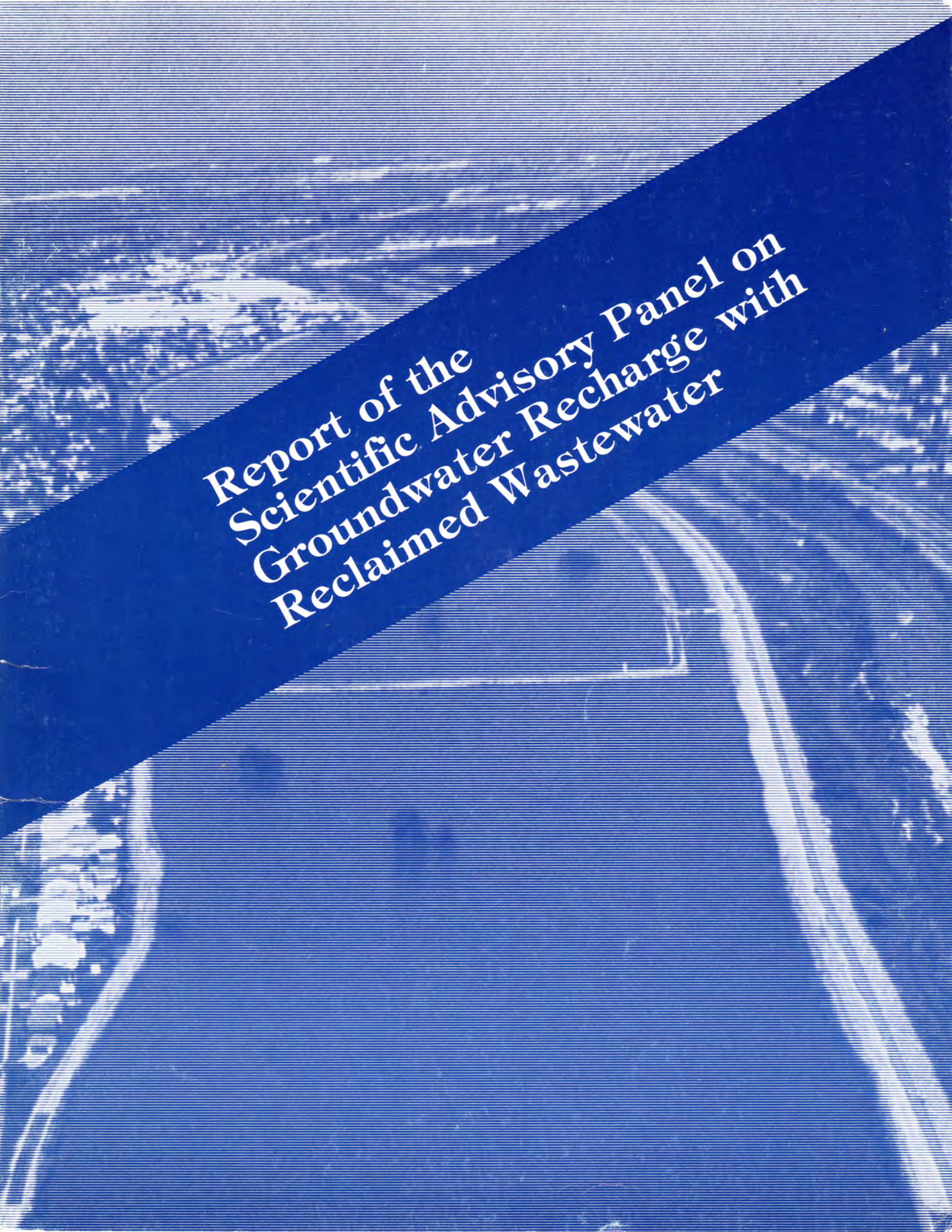
Report of the
Scientific Advisory Panel on
Groundwater Recharge with
Reclaimed Wastewater



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Report of the Scientific Advisory Panel on Groundwater Recharge with Reclaimed Wastewater

November 1987

Prepared for

State of California

State Water Resources Control Board
Department of Water Resources
Department of Health Services

August 1987

614-Q Avenida Sevilla
Laguna Hills, CA 92653

State of California
State Water Resources Control Board
Department of Water Resources
Department of Health Services

Gentlemen:

Transmitted herewith is the Report of the Scientific Advisory Panel on Groundwater Recharge with Reclaimed Wastewater. This report is in compliance with the basic charge from the State of California to: define health significance of using reclaimed water for groundwater to augment domestic water supply, evaluate the benefits and risks associated with groundwater recharge with reclaimed water, and provide detailed background information needed for establishment of statewide criteria for groundwater recharge with reclaimed water.

The panelists wish to thank The Interagency Water Reclamation Coordinating Committee, which included Dr. Takashi Asano, Dr. James Crook and Mr. Roger Lindholm, for the opportunity to review the **Health Effects Study Report** and all the other pertinent literature provided. They have been most generous with their time and resources during our deliberations.

Personally, I have enjoyed working with the Committee and the Panel. It was an enriching experience for all of us. I sincerely hope our efforts will be of assistance to the State of California in making future decisions about groundwater recharge with reclaimed wastewater.

Respectfully submitted,

Gordon G. Robeck

Gordon G. Robeck, Chairman
Scientific Advisory Panel
on Groundwater Recharge

TABLE OF CONTENTS

FOREWORD

The State of California recognized the need for careful consideration of planned use of reclaimed wastewater for groundwater recharge many years ago and convened a Consulting Panel in 1975 to review the available information and identify the research needed for the establishment of criteria for such recharge.

Since then, six water supply and wastewater authorities in Orange and Los Angeles Counties organized the OLAC Water Reuse Study, which was guided by the recommendations of the Consulting Panel. Their report entitled **Health Effects Study** was published in March 1984. It includes extensive results from epidemiological, toxicological, chemical and microbiological studies in the OLAC area.

In June 1986, the State of California Interagency Water Reclamation Coordinating Committee appointed a Scientific Advisory Panel to review the current information on health, technology and monitoring aspects of recharging groundwater with reclaimed wastewater; and then to present in a written report their opinions and advice about the risks and benefits associated with such a practice.

The members of the Scientific Advisory Panel are:

Mr. Gordon G. Robeck,	Chairman Water Consultant Laguna Hills, CA
Dr. Kenneth P. Cantor,	Environmental Epidemiology Branch National Cancer Institute Bethesda, MD
Dr. Russell F. Christman,	Department of Environmental Sciences and Engineering University of North Carolina Chapel Hill, NC
Dr. Robert C. Cooper,	Department of Biomedical and Environmental Health Sciences University of California- Berkeley, CA
Dr. Joseph A. Cotruvo,	Office of Drinking Water U.S. Environmental Protection Agency Washington, DC
Dr. John Doull,	Department of Pharmacology, Toxicology and Therapeutics University of Kansas Medical Center Kansas City, KS
Dr. Perry L. McCarty,	Department of Civil Engineering Stanford University Stanford, CA
Dr. Daniel A. Okun,	Department of Environmental Sciences and Engineering University of North Carolina Chapel Hill, NC (Emeritus)
Dr. Talbot Page,	Center for Environmental Studies Brown University Providence, RI
Dr. David K. Todd,	Department of Civil Engineering University of California Berkeley, CA (Emeritus)

The Scientific Advisory Panel was conducted under the coordination of the State of California Interagency Water Reclamation Coordinating Committee whose membership included:

Dr. Takashi Asano,	Chairman of the Committee State Water Resources Control Board
Dr. James Crook,	Department of Health Services
Mr. Roger Lindholm,	Department of Water Resources

In addition the following persons represented the sponsoring agencies:

State Water Resources Control Board

Mr. James Easton
Mr. Kurt L. Wassermann
Mr. Richard A. Mills

Department of Water Resources

Mr. Arthur Gooch
Mr. John R. Fielden

Department of Health Services

Mr. Peter A. Rogers

View of the Second Scientific Advisory Panel Meeting in San Diego, California on December 2 and 3, 1986.

State of California Scientific Advisory Panel on Ground Water Recharge

(Front Row: Left to Right) J. Crook, G. Robeck, T. Asano, K. Cantor, J. Doull, D. Todd, P. McCarty, R. Lindholm, and T. Page. (Back Row: Left to Right) K. Wassermann, P. Rogers, J. Cotruvo, A. Gooch, R. Christman, R. Cooper, and D. Okun.

SUMMARY

The State of California recognizes the need for overall evaluation of the planned groundwater recharge with reclaimed municipal wastewater, especially as it relates to safety. They and several local groups therefore have sponsored extensive health effects research recommended by a Consulting Panel in 1975. The **Health Effects Study** report resulting from that research was published in 1984.

In 1986 the California Interagency Water Reclamation Coordinating Committee (representing the State Water Resources Control Board, Department of Water Resources and the Department of Health Services) established a Scientific Advisory Panel on Groundwater Recharge to review this report and other pertinent information so they could achieve the following objectives: (1) define the health significance of using reclaimed water for groundwater recharge to augment domestic water supply; (2) evaluate the benefits and risks associated with groundwater recharge with reclaimed water; and (3) provide detailed background information needed for the establishment of statewide criteria for groundwater recharge with reclaimed water.

After its review of the **Health Effects Study** report and subsequent discussions, the Panel concluded that it was comfortable with continuation of the current Whittier Narrows groundwater replenishment project and with the safety of the product water. It felt that the risks, if any, were small and probably not dissimilar from those that could be hypothesized for commonly used surface waters.

The Panel also suggested certain types of analyses and decision mechanisms that could be applied to future reclaimed wastewater projects, which would potentially further reduce some of the uncertainties or at least articulate those uncertainties more systematically to facilitate decision making.

Evaluation of Health Effects Study

The Panel found the research described in the **Health Effects Study** to have been thorough and well-conducted with state-of-the-art methodology. The data collectively established that groundwater in the study sites is presently contaminated with a variety of organic compounds of industrial, and perhaps treatment, origin. The overall result of the extensive organic analytical effort was that compounds representing approximately 10 per cent of the total organic carbon present were identified. The data do not permit an unambiguous judgment regarding whether or not the organic compounds present and of greatest health concern were identified.

Most of the toxicity data presented in the **Health Effects Study** were obtained with the Ames Salmonella Microsome Mutagen Assay which detects mutagenicity in bacterial cells as surrogate for possible carcinogenicity. The mammalian cell transformation assay was included in the program to provide an assay that is more directly related to carcinogenicity, but there were some problems in using this assay with water samples and thus transformation assay data are limited and serve primarily to support the results of the Ames mutagenicity assay data.

The major question concerning the data does not involve the data itself, but rather the issue of whether genotoxicity assay data are adequate, in the absence of other toxicologic information, to serve as a basis for risk assessment. Whether these kinds of data are sufficiently robust to establish good credibility for the subsequent conclusions regarding the safety of the various water sources and treatment processes needs to be carefully studied, because the traditional basis for evaluating safety is the two-year oncogenicity protocol in rodents. Unfortunately, there is no clear consensus as to how such studies could or should be carried out with water samples or with water concentrates, however, such protocols are being designed.

Although the ecologic and household interview studies show no significant differences in any of the health outcomes measured between persons living in areas exposed to recharged water and non-exposed areas, circumstances in the Los Angeles Basin cause the results to be marginal or inconclusive with cancer as an end point. This is because if any risk existed, it would be very small. Also, the latency or induction period for most human cancers that have been linked to chemical agents is a minimum of about 15 years, and may be much longer. In one recent study, bladder cancer risk related to exposure to chlorinated surface waters appears to increase after 40 or 50 years of exposure. Most people in this study were exposed under 15 years. Also, human migration in and out of the study area resulted in less than half the study population to residing at the current address for more than 10 years.

Evaluation of the Safety of Reclaimed Waters

All waters are subject to contamination by a variety of substances that would fall within four basic groups: inorganic chemicals, radionuclides, microbial and organic chemicals. The state-of-the-art science and technology have demonstrated capability to identify, evaluate and control inorganic chemicals and radionuclides to an acceptable degree. Quality standards have been established for most of these substances of interest. There also is good consensus that available technology is capable of reliably eliminating human pathogens from reclaimed water.

Most of the questions remain in the organic chemical group because of their potential large number and low concentration that defy comprehensive analyses, and unresolved human risk potential during a lifetime of exposure. It could well be that the disinfection technology that is used could be the greatest single contributor to the risk from residual organic chemicals in the product water.

Technologies are available to reduce the aggregate concentrations of organics to well below 1 mg/L but only a few per cent of the remaining substances have been identified and quantified. To determine the acceptability of the use of any processed water, a decision mechanism must be designed that will function in the light of the uncertainties that will always remain even after the most intensive scientific investigations are conducted.

The following questions could be used to analyze the options:

1. What is the known chemistry and toxicology of the reclaimed water and how much of the organic material present is uncharacterized?

2. What is the likelihood that hazardous substances will be present in the reclaimed water at harmful levels?

3. How does the composition and quality of the reclaimed water compare to other drinking waters that have been historically acceptable, including the alternative choices?
4. What are the upper bound, lower bound and most probable risks that could be attributed to lifetime consumption of the reclaimed water, as well as the alternatives?
5. What is the marginal effectiveness of alternative treatment processes that could be applied?
6. To what degree do costs influence the treatment alternatives, at the margin, relative to upper bound and most probable risks?
7. What additional costs would be incurred if groundwater quality changes resulting from recharge necessitated in the future the centralized treatment and distribution of extracted groundwater?

In response to the charge regarding guidelines to use when reviewing projects proposing to use reclaimed wastewater for recharge to the groundwater, the Panel has the following suggestions.

Technological Actions Available To Reduce Risk

The quality of wastewaters to be used for recharge can be improved through segregation to reduce industrial and commercial contributions and stormwater runoff. Efficient biological treatment prior to advanced treatment also is effective in improving quality. There are a variety of processes available—chemical coagulation with filtration; air stripping; granular activated carbon adsorption; reverse osmosis membranes; and disinfection—which, collectively, can further clean wastewaters to produce almost any quality of water desired. In addition, with a highly competent management and technical team, with a significantly increased level of analytical monitoring over what is normally used in wastewater treatment, and by controlling flow rates through treatment systems and selecting water of the desired quality prior to recharge, a high degree of reliability can be built into a recharge system. This reliability can be greater than what is commonly achieved when typical surface waters are treated by conventional technologies. However, there are additonal costs involved in each of these measures.

The degree of treatment of wastewater necessary for any recharge site will depend upon the type of application to the soil, the type of soil formation, the depth of the groundwater, the rate of movement, the quality of the groundwater, the dilution available and the residence time to the first point of extraction. Applying the reclaimed water upon spreading basins is the most effective way to use the soil as further treatment before extracting the water for drinking.

Reclaimed water should be disinfected by a potent disinfectant as part of the treatment process prior to injection or spreading for percolation. The disinfection process should not be one that would produce biologically or chemically stable byproducts that may be harmful. Ozonation may be a good candidate or dechlorination shortly after adding chlorine to the final plant effluent may minimize the formation of chlorinated hydrocarbons.

Monitoring of the biological quality of water should be conducted at the point of extraction and disinfection may also be necessary in many cases prior to delivery to consumers.

Prospective health surveillance of populations, at least initially, should be part of any project proposing to use reclaimed wastewater for recharging to the ground.

Analytical studies should emphasize application of biochemical tests of concentrates to determine whether likely harmful substances are present at low levels.

The currently used single chemical and simple *in vitro* toxicological evaluations are not likely to be responsive to the cosmic question of whether the unknown aggregated trace organic substances in reclaimed water would cause any meaningful risk to populations consuming water. This can only be addressed by whole animal tests on mixture concentrates and by retrospective surveillance of population. State-of-the-art toxicology studies in animals provide the only recognized methods for evaluating risk prior to human exposure.

Analytical chemistry investigations and monitoring should be conducted on reclaimed wastewater as well as extracted groundwater to assure that concentrations of key identified substances, such as those in the Drinking Water Standards, are not exceeded and any other biologically-active chemicals are identified.

Finally, the Panel believes the best available quality water in an area should be reserved for drinking water use. Other factors notwithstanding, wastewater should not be used as a source unless it can be demonstrated that natural and engineered treatment can be expected to produce consistently a better quality of drinking water than other alternatives.

Accordingly, before recharge projects are undertaken, other alternatives such as nonpotable reuse, conservation, other nonstructural measures, and modifications to water rights regulations should be thoroughly evaluated.

Additional research with the following goals should allow decisions on recharge to groundwater to be made more precisely.

1. Determine which potent disinfectant produces the least harmful byproducts.
2. Develop a toxicological testing scheme that correlates simple *in vitro* methods with whole animal bioassays so the simple, low-cost test can be used for water quality surveillance.
3. This toxicological scheme should be developed and validated on a relative basis by comparing a variety of concentrates from good to poor quality waters.
4. Identify with more certainty the sources of unidentified health suspect agents and the structures of compounds causing biological test responses in cellular assays.
5. Determine which portion of the total organic carbon and the total halogenated organics should be removed by treatment barriers.

The same goals could well be cited for natural waters. In neither case can an absolute conclusion of zero risk be expected. In either case, given appropriate currently available treatment and quality control, it is expected that a "safe" product water can be achieved.

CHAPTER I

INTRODUCTION

California periodically faces dry-year water deficits. Among the options for providing additional water resources is wastewater reclamation and reuse, a practice being increasingly adopted in California and across the United States.

Reuse can be characterized as potable or nonpotable, or direct or indirect. Direct nonpotable reuse for urban irrigation, cooling, industrial processing and agriculture is already widely practiced, releasing resources of high quality fresh water for potable purposes.

The only potable reuse practiced in the U.S. is indirect, where wastewaters are discharged to the environment and withdrawn downstream from either underground or surface sources. This practice was adopted when the only health threats perceived were attributable to microbiological vectors of infectious disease which would be attenuated during flow underground and in rivers and then easily eliminated by conventional water treatment processes. With the growing appreciation of the health significance of the long-term ingestion of waters containing trace organic chemical contaminants, purposeful indirect reuse, particularly groundwater recharge with reclaimed wastewaters, is being examined more critically.

Because a significant potential for reuse in California is through such recharge of groundwaters, and because of the health risks associated with this practice, the State of California through its State Water Resources Control Board, Department of Water Resources and Department of Health (now Department of Health Services) established in April 1975 a "Consulting Panel on Health Aspects of Wastewater Reclamation for Groundwater Recharge". It was to recommend a program of research that would assist in the establishment of criteria for groundwater recharge to augment public water supplies and the development of programs of reclamation consistent with these criteria.

The Panel Report (June 1976)[1] incorporated a number of conclusions and recommendations. While many of these are still appropriate, significant changes in our knowledge and perceptions have occurred: the standards for trace contaminants in drinking water have become more rigorous and are continually undergoing change; analytical techniques have improved significantly, allowing detection and quantification of previously unidentified contaminants; determinations of the toxicity of contaminants are being improved and even standardized; the passage of time has allowed the latency period for these relatively new contaminants to be more fully evaluated; findings from epidemiological studies are becoming less ambiguous; and, as a result of such new developments, the techniques for risk assessments are being improved. The panel did make, *inter alia,* a recommendation for epidemiological studies of exposed populations.

In June 1978, six water supply and wastewater agencies in Orange and Los Angeles Counties organized the OLAC Water Reuse Study which, among its many other activities promoting nonpotable water reuse, initiated an epidemiological Health Effects Study in November 1978, guided largely by the Consulting Panel's recommendations. The Final Report of this $1.6 million study was published in March 1984.[2]

The State of California Interagency Water Reclamation Coordinating Committee, representing the three agencies that organized the Consulting Panel, established in June 1986 a Scientific Advisory Panel on Groundwater Recharge. This document constitutes the report of the Scientific Advisory Panel.

The objectives of the Panel were to: (1) define the health significance of using reclaimed water for groundwater recharge to augment domestic water supply, (2) evaluate the benefits and risks associated with ground water recharge with reclaimed water; and (3) provide detailed background information needed for the establishment of statewide criteria for groundwater recharge with reclaimed water.

To achieve these objectives, the Panel was asked to:

1. Assess applicability of wastewater treatment processes and operations for producing reclaimed water suitable for groundwater recharge.
2. Evaluate wastewater treatment process reliability and monitoring protocol.
3. Analyze factors influencing water quality conditions at the points of recharge and extraction.
4. Assess water quality change during infiltration-percolation and in movement through the saturated groundwater zone and contribution of these systems to overall treatment system performance and reliability.
5. Provide detailed background information and recommendations needed for the establishment of state-wide criteria and standards for groundwater recharge with reclaimed water.
6. Assess and recommend groundwater quality monitoring protocol that are necessary to protect health when reclaimed water is used to recharge groundwater.

As a basis for its study, the panel undertook an evaluation of the **Health Effects Study,** which is summarized in Chapter III, following the framework for the panel's analysis in Chapter II. Chapter IV constitutes an examination of the health implications of microbiological and trace chemical contaminants, including toxicity and epidemiological assessments. Chapter V reviews the state-of-the-art of water treatment technology appropriate to the treatment of wastewaters prior to recharge and to waters being abstracted from underground after recharge. Chapter VI examines the water quality changes that take place as water flows through both unsaturated and saturated zones underground and the problems that may need to be faced in the event that an aquifer becomes excessively contaminated. Chapter VII presents the measures that are required to assure sound management of a recharge operation, which includes considerations of reliability and, most particularly, programs for monitoring trace chemical contaminants, microorganisms, and toxic properties of waters used for recharge and withdrawn for consumptive use. Also included are proposals for continuing epidemiological assessments of recharge operations. Because so many imponderables remain, Chapter VIII is devoted to the further research necessary while Chapter IX summarizes the conclusions and recommendations of the panel.

Options for Additional Water Resources in California

Theoretically speaking, most community water supplies pose some risk to those who ingest the water over a long period. Where water supplies are drawn from surface waters or aquifers of good quality, and where land use controls are effective in preventing the discharge of pollutants in the watershed or contamination of the aquifers, little treatment is required and the risks are minimal. Where water supplies are drawn from polluted sources, and the safety of the water depends upon treatment technology and high quality management, the risks are greater. The recharge of aquifers with reclaimed wastewater potentially adds to the risk to those withdrawing water for drinking from the aquifers if the hazardous contaminants in the source have not been adequately removed. The risks that result from the discharge of wastewater treatment plant effluents into streams that recharge aquifers are mitigated by distance and time, as volatile organics are released, and natural purification and dilution with fresh water exert their beneficial effects.

Whether the added potential risk of purposeful recharge of wastewaters directly into potable water aquifers is warranted cannot be established without consideration of the availability, cost and risk of other options for providing potable water to the community. Where other options for meeting the potable water needs of a community are not available, the added risks of recharge with reclaimed water may be warranted. However, where other options which pose less health risk are available, or can be developed, then recharge may be inappropriate. Thus criteria for recharge must be reflective of the options available. The Consulting Panel in 1976 had concluded that state agencies should: "Require cost-benefit analysis of alternatives to groundwater recharge projects to illuminate the available options."

Among the options are alternative sources, which are generally adequately evaluated. Not always considered are other structural and nonstructural means for meeting water supply requirements:

a. Increased direct nonpotable reuse becomes increasingly attractive as the marginal costs for new supplies increase, an inevitable consequence of the fact that existing sources were selected because their costs were the lowest then available;

b. Regulations might be adopted leading to greater conservation in water use, including permanent measures that reduce demand;

c. Financial subsidies for water might be eliminated, which would reduce uneconomic water use practices;

d. The appropriation doctrine might be modified to eliminate the "use it or lose it" practices which are wasteful of water and uneconomic.

REFERENCES

1. **Report of the Consulting Panel on Health Aspects of Wastewater Reclamation for Groundwater Recharge,** H. W. Wolf, Chairman, State of California, p. 32 (June 1976).

2. **Health Effects Study,** Final Report, Prepared by Nellor, M.H., Baird, R. B., and Smyth, J.R., County Sanitation Districts of Los Angeles County. (March 1984).

CHAPTER II

FRAMEWORK FOR ANALYSIS

There are three main criteria in risk assessment and risk management. The first is economic efficiency. This criterion, in the context of groundwater recharge, says that risks should be managed to minimize expected costs, where costs include the sum of the risks of the health costs associated with pathogens, trace organics, heavy metals, and other contaminants, and the costs of controlling these risks.

Expected cost minimization implies the following qualitative relationships: Other things equal,

1. An increase in the probability of harm from a contaminant requires a higher level of precautionary control;
2. An increase in the severity of toxicity requires a higher level of precautionary control;
3. An increase in the costs of control means a lower level of control;
4. Where there is more uncertainty, greater emphasis should be put on intermediate and hedging strategies of control;
5. Where there is more irreversibility, greater weight should be put on preservation of options; and
6. Research priorities should be based on the expected value of information to be gained by the alternative research activities.

These implications, which can be derived formally from expected cost minimization, accord with common sense and help explain the appeal of the efficiency criterion. However, other criteria are also important. The second criterion is equity, which has to do with the fair distribution of costs and benefits. For example, due to long periods of transport and long periods of latency, effects of contaminants may be borne 40 or more years after the discharge. As a matter of fairness, policy makers may value a future cancer as heavily as a present one. The third criterion is the protection of important rights. These last two criteria, when defined more explicity by policy makers, provide side conditions or constraints for the expected cost minimization of the first criterion. Taken together, expected cost minimization, subject to constraints, provides a systematic approach to managing risks from groundwater recharge.

To apply the criterion of efficiency and expected cost minimization, two types of judgment are needed. First are judgments about scientific facts and uncertainties. We would like to know what contaminants are present, in what concentrations, with what levels of toxicity; the engineering alternatives of treatment, their effects, reliability and resource trade-offs; and the transport and natural treatment of contaminants in soils. We know a great deal about these things, but what we know is dwarfed by what we do not know.

Second are judgments about value. For practical decisions concerning groundwater recharge some judgment needs to be made about the cost of too much precautionary control relative to the cost of too little; the cost of a false positive in a toxicological study relative to the cost of a false negative; and the amount of social risk aversion to build into the decision process. As a matter of equity and the protection of rights some judgment needs to be made as to whether $1 million spent to save a statistical life is valued the same as $1 million saved in lower resource costs obtained by imposing the loss of a statistical life. In the language of decision theory, judgments about scientific uncertainty are judgments about probability, judgments about value are judgments about utility, and the two are combined symmetrically in an expected utility (or expected cost) calculation.

Role of the Scientific Advisory Panel in Policy Making

The process of risk assesment and risk management is traditionally viewed as an interactive one, with a division of labor between scientists and policy makers. It is the primary role of the scientists to identify and assess the key facts and uncertainties, the resource trade-offs and health implications of various actions, and the predictive accuracy (or validity) of various tests and research activities. It is a primary role of policy makers to assess values.

With this division of labor, the process needs to be interactive. The policy makers must communicate to the scientists the relative costs of false positives and false negatives, and help identify which uncertainties are the most important to resolve for decision purposes. This information is needed by the scientists to guide research choices, design research studies (especially for considerations of statistical power), and provide a framework for the interpretation of results (not all research results are equally important for decision purposes). In turn the scientists must communicate to the policy makers their assessment of the probability of toxicity of various substances at various potencies, the probability of exposure and the predictive accuracy of various tests and research procedures. This type of information helps identify the most important regulatory options.

The process of risk assessment and management is a sequential one. At each step two decisions need be made: what actions to take on the basis of the presently existing information and what new research to be done to acquire better information for the next step. At each step, current assessments about uncertainty and cost need to be passed back and forth between policy makers and scientists. The process is one of feedback: previous decisions both foreclose and preserve future options and previous research results and predictions are calibrated in light of new information.

The above framework can be briefly contrasted with a simpler, and we believe, more naive view of risk assessment and management. In the simpler view, the process is taken to be a two-step process, with science the first step and policy the second. In the first step scientists are told to stick with the facts and be objective. The scientists are told not to consider the policy implications of their deliberations. The scientists are to do their work in a vacuum, isolated from contamination of policy.

A goal of keeping the science pure is commendable. A scientific advisory panel, such as this one, should not attempt to manage the political process and should not make policy judgments under the guise of scientific judgments. But the isolated role of the scientist is neither workable nor desirable. Scientists know that if they come out with a low risk assessment it will tend to lead to a low level of precautionary action, and vice versa, no matter how isolated the scientist is from the later political process, and it is naive to think otherwise.

Further, for a problem such as groundwater recharge where there is a great deal of uncertainty, it would be a mistake for the scientists to stick with the facts and avoid (subjective) judgment. If scientists who possess the most comprehensive basic information attempting to be objective, avoid the subjective process of assessing and interpreting scientific uncertainty, who will make these judgments? For in this area, decisions are inescapably decisions under uncertainty. In 1978 six water supply agencies in Orange and Los Angeles Counties organized the OLAC Water Reuse Study to try and determine the health effects from replenishing the aquifer with reclaimed wastewater. This decision to gather more information was a decision under uncertainty. In 1984, after the Final Report was completed, the state policy makers decided not to change its policy of case-by-case review of large scale groundwater recharge. The decision to maintain that policy was itself a decision, and one under uncertainty.

And now the present Scientific Advisory Panel has been asked to define health significance, evaluate benefits and risks, and provide information for state-wide criteria. Meeting these objectives requires assessing the state-of-the-art of epidemiology and toxicology, treatment processes, and groundwater transport. Providing succinct and focused summaries of the existing science requires subjective judgment on the part of the panel members. And this is as it should be. A scientific advisory panel cannot resolve all the important uncertainties, but it can attempt to assess the existing scientific knowledge and uncertainty in a way which is suitable for decision purposes. This exercise in judgment is taken to be a proper role.

Decisions To Be Made

To focus on the assessment, it is important to know at least roughly what alternatives are up for decision. As understood, the potential for groundwater recharge in the Los Angeles Basin is large, up to about 500,000 acre feet per year. The marginal cost of imported water for groundwater recharge is about $400 per acre foot. As an alternative to imported water, reclaimed water is essentially free because it normally would be discharged to the nearest stream or ocean.

The first question is how much, if any, water should be used for recharge. At one extreme, the decision might be none; at the other, about 500,000 acre feet per year. If there were no pumping, health or environmental cost associated with using reclaimed water for groundwater recharge, the decision for 500,000 acre feet would be very attractive, since it would be associated with about $200 million annual saving compared with the imported water alternative.

If there were health effects, the decision might be to go to the other extreme. For example, if the full use of reclaimed water, even with treatment, would lead to an extra 200 cancers per year, plus additional chronic illnesses and birth defects, a decision for no use of wastewater for groundwater recharge might be the expected cost minimizing one.

The problem, of course, is the uncertainty about the severities and types of risks associated with using reclaimed water for recharge and their relationships to the alternative choices. This case appears to be the middle range of uncertainty. There is not enough information to be sure that the risk is zero or close to it. What information there is suggests that there is a conceptual risk, but it is relatively small. This estimate is soft, which means that it likely to be revised up or down in light of future information.

For comparison, a probability assessment of 0 or 1 is a statement of complete knowledge and certainty. A probability assessment very close to 0 or 1 is a statement of strong evidence and little uncertainty. Such assessments are ones of hard numbers, numbers which are unlikely to be revised much in light of future information.

As noted at the beginning of the chapter, when there is a middle range of uncertainty, hedging strategies are often the expected cost minimizing strategies. The idea of a hedging strategy is to protect against potential worst cases (an everyday example of a hedging strategy is insurance). For the problem of groundwater recharge a worst case could arise if the state policy makers decided to use the maximum capacity of wastewater recharge with very little treatment, believing that there was very little risk, whereas, in fact, there was a substantial risk. At the other extreme, in the sense of a missed opportunity, a worst case could arise if the state decided to use no wastewater, believing the risk substantial, when in fact there was little or no risk. A hedging strategy suggests avoiding both potential worst cases by taking an intermediate rather than an extreme action of complete or no groundwater recharge, and in addition taking an intermediate rather than an extreme amount of treatment (an extreme level of treatment would be either none or "everything.")

The second question is how much treatment, and what types of treatment. At one extreme is no additional treatment, at the other extreme is very advanced treatment. Since the potential saving in resource cost, from using reclaimed water rather than imported water, is on the order of $400 per acre foot, very advanced treatment could be required with still a net saving in resource costs. A hedging strategy suggests (but does not directly imply) avoiding both extremes. Where the expected total costs might be minimized in this broad middle range of treatment options depends on the assessments of health risk and engineering costs of control.

A principal issue, for this second question, is the proper role of chlorination or other forms of disinfection. To address this question the state policy makers need to balance the risks from pathogens with those from organics; the Scientific Advisory Panel will attempt to characterize these risks as well as the existing information allows.

In addressing both questions, it is important to identify, and evaluate, the most important potential irreversibilities. One of particular concern is the long-term contamination of aquifers. This is a principal reason for minimizing the entry of chlorination byproducts and toxic substances. Thus we need to ask if increased contamination of aquifers from chlorination byproducts is more, or less, permanent than the possible contamination from pathogens without chlorination. As part of this assessment, we need to compare the relative severities from the two types of contamination, the tradeoffs in risk achievable by different combination of treatment, and the resource costs of controlling both together.

The third question is what research and monitoring is appropriate. To address this question, from the perspective of economic efficiency, there is a need to ask what information might be gained from different research and monitoring efforts and what difference this information, once obtained, would make to the decision process. This analysis, known as pre-posterior analysis, helps set research priorities and define productive monitoring strategies.

The above three questions are questions of resource commitment. They deal with decisions the state policy makers must make on the allocation of such resources as the construction of treatment plants and monitoring wells, the undertaking of epidemiological studies and record keeping, and the development of new technologies. The Scientific Advisory Panel will take the value judgments of the legislature, the courts, the regulatory agencies and other policy makers as parameters which help define the decision context. Within this context, the Advisory Panel is to contribute to decisions by assessing and interpreting scientific fact and uncertainty. Keeping the questions of resource commitment in mind helps focus the effort.

To illustrate how questions of resource commitment help focus the work, consider two assessments of scientific uncertainty. In one, there is no scientific consensus that there is at least a 99.9 per cent probability that organic chemicals in drinking water increase cancer rates by 0.001 per 100,000 at risk (or more). For the 99.9 per cent confidence, the evidence of a causal link must be overwhelming, a virtual "scientific proof." In the second assessment, there is a scientific consensus that there is at least a 30 per cent probability that organic chemicals in drinking water (in their average concentration) raise cancer rates by 4 (or more) per 100,000 at risk.

In attempting to maximize net expected benefits, the first assessment is nearly worthless. A 0.001 effect may not be worth controlling, in light of the costs of control and the benefits obtained. But if the state policy makers knew there was an effect of 4 per 100,000, this risk might well be worth controlling, and even if the state policy makers knew that the evidence was sufficiently uncertain to lead to a probabilistic weight of evidence of 30 per cent, by a consensus of scientists, there might still be grounds for precautionary controls. The grounds would depend on evaluations of the expected costs and benefits of the alternative controls and would probably be a hedging strategy. Note that the two assessments could arise from the same information base. The point is that the second is typically more useful for decision purposes than the first, which gives an operational meaning to the sometimes vague notion of "proof" of causality.

Part of this effort is directed at the specific decision problem of the Whittier Narrows recharge project of the County Sanitation Districts of Los Angeles County – how much recharge under what conditions of treatment? And part of this effort is directed at the more general policy problem of developing information for establishing statewide criteria for groundwater recharge with reclaimed water, as seen in the subsequent chapters.

CHAPTER III

EVALUATION OF HEALTH EFFECTS STUDY

The Panel was given various pertinent documents to use as a basis for discussion and reference in its deliberations. The Final Report of the **Health Effects Study** by the County Sanitation Districts of Los Angeles, dated March 1984, was a major effort in this regard and it proved to be very helpful in evaluating the health consequences of their water replenishment project at Whittier Narrows. Because of the extent and technical detail of this report, the Panel decided to present an evaluation of it in this chapter. The report's merits and limitations served as a basis for preparing the guidelines requested.

CHEMISTRY AND MICROBIOLOGY REVIEW

1. Inorganic Chemicals

Traditional chemical and physical water quality evaluations (minerals, trace metals, nutrients, pH, color, turbidity) were performed on water samples in each of four study sites. Two of these sites have been used for groundwater recharge with reclaimed water for several years (Montebello Forebay, surface spreading since 1962; and Talbert Gap, injection since 1976), and two are proposed sites of future recharge with reclaimed water by surface spreading (San Fernando Basin and Anaheim Forebay). The Anaheim Forebay has three groundwater replenishment facilities in use, with a design capacity of 300,000 acre-feet per year, primarily from the Santa Ana River. No intentional recharge of reclaimed water is practiced, but some reuse may have occurred from wastewater loading of the Santa Ana River. Thus, for the first two sites, it was possible to evaluate the impact upon groundwater quality of past recharge with reclaimed water, while for the latter two sites, the water quality data constitutes background data for future reclaimed water recharge.

In general, all sampling well-sites showed values within primary drinking water standards, although three of the ten Montebello Forebay wells had samples exceeding secondary standards for turbidity, color, iron, and manganese.

The poorest water quality in the Montebello Forebay site was associated with the storm water samples (high turbidity, color, iron, and lead), and for the San Fernando Basin samples, the poorest was associated with the dry weather runoff samples (high turbidity, color, dissolved solids, and sulfates).

Comparison of the chemical data in the **Health Effects Study** with other "historical data" for the well waters suggests that observed changes in dissolved solids, alkalinity, sulfate, and total hardness are due to changes made in source of replenishment water used in spreading operations in the Montebello Forebay study area. The "historical data" are not presented in the **Health Effects Study** Report, and the reader must assume that these correlations are valid. This is important, as it is the only evidence referred to in the Report which establishes a link between replenishment water quality and groundwater quality. Analysis of the individual chemical data obtained in the **Health Effects Study** does not reveal any correlation between groundwater quality and the quality of the replenishment source. Nitrate concentrations in the Montebello Forebay well samples (approximately 1-4 mg/L N) were higher than concentrations found in either reclaimed water or imported water and could be due to surface fertilizer applications in the Forebay area. A similar explanation might account for the nitrate values in the Anaheim Forebay wells, except that the nitrate was probably imported by upstream wastewater discharges to the Santa Ana River.

2. Virus

Owing to the special health concerns over virus transmission via percolation or injection, a separate effort was made to characterize the virus content of treatment plants (disinfected and non-disinfected effluents) and groundwater in the Montebello and Anaheim Forebay sites. The data suggests that for the four reclamation plants studied, the concentration of viruses in unchlorinated effluent decreases as the degree of treatment increases. No viruses were found in chlorinated tertiary effluents (174 samples) or in the groundwater samples (110 samples).

Summary of Opinions on Inorganics and Viruses

- Water quality characterization studies for inorganics and viruses were done with state-of-the-art procedures.
- Water quality data for groundwater and replenishment source samples are conveniently summarized and appropriately compared with the existing drinking water standards.
- The conclusion that relative impacts of the replenishment sources could not be seen in the groundwater quality data is not persuasive. Temporal trends in mineral quality of the Montebello Forebay ground samples were noted and attributed to a change in replenishment practice. It is perhaps an overly subtle point that reclaimed water quality (one replenishment source) could not be correlated with groundwater quality, because the reported dissolved solids and alkalinity values for reclaimed water are essentially the same as for the Colorado River water. This claim may be true, but the data and presentation are not persuasive.

3. Trace Organics

Total organic carbon (TOC) values and selected purgeable targeted organic (PTO) and non-purgeable targeted organic (NPTO) compound concentrations were measured on all samples. Specific organic analyses were done using gas chromatographic/mass spectrometric (GC/MS) techniques. In addition to the targeted organic analyses, efforts were made to chemically characterize the organic components in those high pressure liquid chromatographic (HPLC) fractions with evidence of mutagenicity.

The results of the general organic characterization revealed that a group of non-targeted industrial organics and metabolic byproducts were at significantly higher concentrations in both reclaimed water and storm water than were all targeted organic compounds. These chemicals were not as concentrated as the targeted organics in the groundwater samples. It would seem, therefore, that this group of phthalates, solvents, and petroleum byproducts might become useful markers (relative to targeted compounds) for detecting future effects of reclaimed water recharge.

It is apparent from inspection of the total organic carbon data and the compound category data that only a small percentage of total carbon was identified as a result of a relatively massive effort to do so. This is not unusual in studies of this type.

The discussion of the results of the PTO analyzed in the **Health Effects Study** Report is generally appropriate, and interpretations are consistent with the data. It is clear that the groundwater in all four study sites presently contains measurable concentrations of halogenated industrial solvents and that this probably reflects past replenishment practice or illegal disposal. The data are consistent with the interpretation that the Talbert Barrier observation wells showed probable influence from injection of reclaimed water (solvents and phthalates). However, the concentration levels of these solvents was relatively low in all groundwater samples, as well as in imported water, storm water, and dry runoff samples. Concentrations of these solvents were somewhat higher in reclaimed water (except Talbert Barrier and Anaheim Forebay reclaimed water effluents), but it is not clear from the data that these can be used to measure any future impacts of reclaimed water replenishment without more certainty regarding the time dependency of the concentration levels. The same is true of the NPTO data in which the possibility exists that phthalate levels could be used to monitor the influence of reclaimed water replenishment. Generally, fewer NPTO's were found, and the data do not clearly suggest that phthalates, chlorinated phenols, s-triazine herbicides, or phenylacetic acid could be used to measure impact on groundwater of reclaimed water replenishment. Conversely, the levels of these compounds in groundwater may reflect contamination from other replenishment sources.

The chemical studies focused on the identification of mutagens and resulted in the chemical identification of four known mutagens in approximately 15 per cent of the samples from the various sources. None of these was found to be in sufficient concentration to account for observed mutagenicity levels of residues from the various sources (which appeared to increase with chlorination). Additional research efforts to characterize the compounds responsible for residue mutagenicity did not result in positive chemical identifications. Although use of chemical derivatization and negative chemical ionization GC/MS techniques resulted in some data, no persuasive trends were observed, other than to indicate the possible presence of organohalides and epoxides.

The report correctly concludes that more study is needed before long-term effects from replenishment can be evaluated. The complete toxic organic data clearly suggest that groundwater in the study areas is susceptible to contamination from potentially worrisome chemical compounds of industrial (and perhaps treatment) origin.

Summary of Opinions on Trace Organics

- The trace organic analyses in the **Health Effects Study** were performed with state-of-the-art techniques, including capillary GC and GC/MS.
- The data may suggest that a group of non-targeted organics (phthalates, solvents, petroleum by-products) may be useful markers (relative to targeted organic concentrations) of future impacts of reclaimed water replenishment by virtue of their greater relative concentration in reclaimed water.
- The targeted organics and non-targeted organics data suggest, but do not clearly establish, that industrial solvents alone could be used to monitor future impacts of replenishment with reclaimed water.
- Certain compound groups (phthalates, chlorinated phenols, s-triazine herbicides, phenylacetic acid) may be useful indicators of impacts from replenishment from other than reclaimed water.
- The data collectively establish that groundwater in the study sites is presently contaminated with a variety of organic compounds of industrial, and perhaps treatment, origin.
- The mutagenicity (histidine reversion assay) of whole sample residues was not accounted for.
- The overall result of the extensive organic analytical effort was that approximately 10 per cent of the total organic carbon was identified.
- The data do not permit an unambiguous judgment regarding whether or not the majority of compounds present and of greatest health concern were identified.

TOXICOLOGY REVIEW

The **Health Effects Study** describes the results of three programs: A survey of specific organics present in groundwater, reclaimed water and various other surface waters from the four study areas; an estimation of the relative toxicity of the identified organics detected in the survey; and a search for mutagenic effects due to non-identified contaminants in the survey samples. A fortified Ames Salmonella Microsome Mutagen Assay and a Mammalian Cell Transformation Assay were used to establish the toxicology data base on the samples.

The lowest mutagenicity values were noted for samples from chlorinated wells and imported water (Colorado River water and State Project water). Storm runoff and dry weather runoff yielded the highest levels of mutagenicity in the percolation source waters. The mutagenicity of the reclaimed water samples was intermediate between the surface runoff and imported water assay values. The limited number of samples from each site and the complexity of the percolation process and aquifer systems precluded a more rigorous statistical analysis of the correlations between the mutagenicity data and the sample sites or the percentage of reclaimed water.

The data from the mammalian cell transformation assays showed that fungal contamination at the contractor laboratory complicated the adaptation of this assay for use with the water residue samples and this limited the number of samples for which cell transformation and mutagenicity bioassay data could be compared. Dose response cytotoxicity measurements on a group of the initial samples suggested that the cell transformation bioassay was less sensitive than the mutagenicity assay. Additional studies are needed to develop the cell transformation bioassay into a reliable and reproducible test system for evaluating the potential carcinogenicity of the various types of water residue samples. However, the mammalian cell transformation bioassay has a major advantage over the Ames mutagenicity bioassay in that it provides a more direct link to carcinogenicity potential.

Additional results were obtained by using GC/MS analysis in combination with the mutagenicity bioassay and reversed-phase separation to identify additional fractions with mutagenic activity and to isolate and identify the specific organics responsible for the effects.

The third and final effort involved the chemical derivatization/negative chemical ionization studies with NTP (4-

nitrothiophenol) and silver nitrate which anticipated that these and similar techniques will be useful in quantifying and characterizing epoxide and organohalide mutagens which are present in the water residue samples.

Summary of Opinions on Toxicology

Most of the data were obtained with the Ames Salmonella Microsome Mutagen Assay, which detects mutagenicity in bacterial cells as surrogate for possible carcinogenicity. The Mammalian Cell Transformation Assay was included in the program to provide an assay that is more directly related to carcinogenicity, but there were some problems in using this assay with water samples and thus the cell transformation assay data presented are limited and serve primarily to support the results of the Ames mutagenicity assay data.

The major question concerning the data does not involve the data itself but rather the issue of whether Ames mutagenicity assay data are adequate in the absence of other toxicologic information to serve as a basis for risk assessment. For many of the samples included in this program, the Ames mutagenicity assay data are the only toxicologic data available for making any predictions on the safety of the water source for its intended uses. Whether these kinds of data are sufficiently robust to establish good credibility for the subsequent conclusions regarding the safety of the various water sources and treatment programs needs to be carefully studied since the traditional basis for evaluating safety is the two-year oncogenicity protocol in rodents. This issue has been considered by previous scientific groups and although there is some consensus that the conventional rodent studies will be needed, there is no clear consensus as to how such studies could or should be carried out with water samples or with water sample residues. Finally, although this chapter correctly points out some of the problems in risk assessment that increase the difficulty of making reliable decisions regarding safety, it does not address the issue of risk communication which is likely to be an important issue in the handling of all aspects of reclaimed water use.

EPIDEMIOLOGY REVIEW

As part of the **Health Effects Study** to evaluate potential impacts of drinking water reuse, a group of evaluations was conducted by the School of Public Health at the University of California, Los Angeles. Two general approaches were taken. Several analyses of routinely collected data determined average annual rates of mortality and morbidity (disease) outcomes in census tracts characterized as having used groundwater with "high" or "low" levels of reclaimed water, and compared them with rates in two control areas in which there had been no residential exposure to reclaimed water. Comparisons were made during three periods, 1969-71, 1972-78, and 1979-80. In a separate telephone interview study, adult females in "high" exposed and control areas were interviewed to detect possible differences in spontaneous abortions and other adverse reproductive outcomes, general health characteristics, annual days of disability, perception of well-being, and other health outcomes.

Exposure Measurement

Accurate estimates of exposure are central to the success of epidemiologic evaluations. Groundwater recharge with reclaimed wastewater started on a small scale in the Montebello Forebay area of Los Angeles County in 1962. The epidemiologic studies compared health outcomes of persons who lived in census tracts with "high," "low" and no exposure to reclaimed water. For the 1969-71 comparisons of mortality and morbidity, "high" areas were defined as census tracts receiving a groundwater which contained more than five per cent reclaimed water in at least one year prior to 1970, and "low" areas as tracts with some—but less than-five per cent reclaimed water. Census tracts in the control areas received no reclaimed water. Areas with "high" exposure probably received much less reclaimed water than many U.S. cities, such as Cincinnati and New Orleans that use river water from major drainage basins with multiple upstream municipal and industrial outfalls. This does not dismiss the issue of health effects that may be associated with reclaimed water for domestic purposes, but it does place an upper bound on the possible magnitude of adverse health impacts that might be experienced.

Study Description of Geographic Comparison Studies

Monitoring of several adverse health outcomes in "high" and "low" exposed census tracts, and two groups of unexposed control census tracts occurred for the periods 1969-71, 1972-78, and 1979-80. The health outcomes included mortality patterns (death from all causes, heart disease, stroke, all cancer, and cancers of the colon, stomach, bladder, and rectum), cancer incidence (total and the four specific cancer sites), infant and neonatal mortality patterns, birth outcome patterns (low birth weight and congenital malformations), and infectious diseases (all potentially related to waterborne agents, and Hepatitis A and shigellosis individually). Both "direct" and "indirect" standardization methods were used. In the 1969-71 and 1979-80 time periods, when accurate denominator census counts were available for the study census tracts, age- and sex- standardized mortality, incidence, or morbidity rates were calculated, using as a standard the Los Angeles County population during 1970 or 1980. In addition, indirectly standardized (by age and sex) ratios were calculated in each of the four study areas (for mortality, incidence, or morbidity), using the appropriate mortality, incidence, or morbidity experience of the Los Angeles County population as the standard. The expected number of adverse birth outcomes in 1969-71 and 1979-80 in each of the four study areas were based in Los Angeles County age-of-mother specific rates, or for infant or neonatal deaths, age-of-mother and birth-weight-specific rates. In the intercensal years 1972-78, accurate age- and sex-specific census enumerations were not available for the study areas, so adjusted or standardized proportionate mortality, incidence, or morbidity ratios were used for each of the mortality or disease outcomes of interest. Since denominator data were available in 1972-78 for births, standardized ratios were used in the evaluation of birth-related outcomes.

The general approach to analysis was a statistical comparison of standardized rates or ratios across the four study areas, with special attention to causes of death or disease conditions that were elevated in "high" and "low" reclaimed water areas, as compared to the control areas. Temporal trends in the various mortality, cancer incidence, or birth-related indices were analyzed by a linear regression method. Analysis of covariance was also used to adjust for time trends in the comparison of the four study areas.

With few exceptions, there were but minor differences between areas. The only noteworthy exceptions were higher standardized mortality ratios (SMRs) (or proportionate mortality ratios, SPMRs) for rectal cancer in reclaimed water census tracts. In the 1969-71 period, the SMR was 1.67 (18 cases) in the "high" area and 1.17 (45 cases) in the "low" reclaimed water area (differences not significantly different). In the 1972-78 period, the SPMR was 1.27 in the "high" area (significant, $p=0.03$), and 0.95 in the "low" exposed area. Comparable elevations were not observed for rectal cancer incidence in the 1972 – 78 time period. In 1979-80, the SMR rectal cancer was 1.52 (10 cases, not significant) in the "high" area, 0.63 in the "low" exposed area (13 cases) and 0.45 (3 cases) in the two control areas. This method of comparing the ratio of observed vs. expected cases of mortality from reclaimed water-used areas and control areas shows in these cases there were no significant differences among the four geographical areas.

Comment on Geographic Comparison Epidemiology Studies

Geographic comparison studies, sometimes called indirect or "ecologic" studies, have been important in etiologic research and public health surveillance. Ecologic studies compare geographical or temporal distribution of disease occurrence in populations with the distribution of exposure to environmental or occupational factors, or sociodemographic characteristics. Higher disease rates in populations with higher exposures or elevated levels of participation in an occupation or industry, are viewed as first indicators of a possible causal association, or in a public health context, as indicators of possible adverse impact of the exposure in question. The ecologic approach was the first method used in investigating associations of drinking water contaminants with cancer in human populations. Several studies found that bladder, colon, and rectal cancers were more frequently observed (after statistically adjusting for population differences) in places served by chlorinated surface sources than ground sources, and raised the possibility of a causal link. Ecologic studies have many advantages in taking a first, quick look at hypothesized but previously unexamined associations between environmental exposures and adverse health impacts. They are relatively inexpensive and rapidly performed because they utilize available morbidity, mortality, and census information originally collected for other purposes. They are useful in demonstrating the feasibility of hypotheses and enabling a rapid assessment of potential threats to the public health.

Ecologic studies also have several weaknesses. They are deficient in that exposure and outcome data describe characteristics of groups, not those of individuals. The diseased persons in a study population may consequently not be the most highly exposed, but this is not ascertainable. Information is frequently not available on important risk factors in the study population, such as cigarette smoking, specific occupational exposures, or dietary practices. If these (unascertained) factors vary geographically, with patterns similar to the environmental exposure of concern, the geographic disease pattern may correlate well with exposure and lead to misleading perceptions of association, in the face of no causal relationship. This is called confounding, and the true, but unascertained risk factor, the confounder or confounding factor.

The timing of exposure to reclaimed water relative to the period of observation of chronic effects is an important consideration in evaluating the study results. Latency or induction period for cancer is the time between first exposure to a carcinogenic agent and the appearance of a tumor. For most human cancers that have been linked to chemical agents, the minimal observed latency period is about 15 years, and may be much longer. Bladder cancer risk related to exposure to chlorination byproducts in disinfected surface waters appears to increase even after 40 or 50 years of exposure. Since a minimum of 15 years between first exposure and disease is required, it is unlikely that examination of cancer mortality rates in 1969-71, 1972-78, or even 1979-80 in Los Angeles would have detected an effect, if present, of exposure to reclaimed water that started in the mid-1960's. This, combined with high in-migration rates in the study areas, severely weakens the sensitivity of the ecologic studies of cancer rates to detect effects of reclaimed water.

In studies of chronic disease, where years or decades may separate exposure and disease, in-migration can result in the weakening of even strong associations. If a significant fraction of the population in a high or low exposure area has migrated into the study area during the disease latency period, an underlying assumption of the ecologic analysis is violated. Under such conditions, disease patterns cannot be reasonably linked to exposure, no matter how well-characterized or intense the exposure may be. In this respect, the studies of chronic disease and reclaimed water in Los Angeles are weak. Migration rates in the Los Angeles census tracts in this study are quite high, suggesting that most of the population had been exposed to drinking water of different quality in places outside the study areas.

The ecologic studies of infectious disease and birth-related outcomes are not weakened by high in-migration rates, because of the brief time span between exposure and effect.

Study Description of the Household Survey

An interview survey of the health status of women residing in 11 census tracts of the "high" reclaimed water area, and 13 tracts in the control area (no reclaimed water), was conducted in 1981. Demographically, the study areas were largely similar, with approximately 60,000 persons residing in each, of whom over 98 per cent were white. The reclaimed water area contained more Hispanics. In control areas, the average socioeconomic status was higher, there was a slightly lower percentage living in rental units, and a slightly higher percentage of professional workers among the employed. Population stability was comparable, with about 60 per cent residing at the same address for at least five years.

Standard methods were used to randomly select women as subjects from the two study areas. Four attempts were made to contact each household before classifying it as a nonrespondent. The participation rate, 71 per cent (using all households as the denominator), was similar in both study areas, and typical for surveys conducted in a large urbanized population. One thousand, two-hundred forty-three (1,243) women in the high reclaimed water area and 1,280 women in the control area were interviewed. Questions were asked on demographic and socioeconomic characteristics, smoking habit, alcohol consumption, occupation, the use and consumption levels of tap and bottled water, and attitudes toward community air and water quality. To evaluate health status of these groups, a series of questions focused on general health, disability days, specific diseases, and reproductive-related conditions or outcomes, such as infertility, menstrual problems, spontaneous and induced abortions, and congenital defects among offspring.

Standard statistical methods were used to analyze data collected in the interview survey, including simple t-tests and chi-square tests for differences between reclaimed water and control area respondents for a number of personal characteristics and health outcomes. In addition, multivariate techniques were applied to detect differences in the two exposure areas of health outcomes or perception of general health status, after adjusting for differences other than water type between the two areas that could influence health. Overall, there were no significant differences in any of the health outcomes measured between women in the exposed and non-exposed areas that could reasonably be ascribed to differences in water quality.

Comment on Household Epidemiology Survey

The study used sound methodologic approaches to detect differences in several measures of health status between the two study areas. Power calculations were not provided in the report (although it is likely they were performed), and the exact levels at which this study would have detected differences in rates of adverse health effects are not explicitly presented.

The generally negative results (that is, no demonstration of effects linked to reclaimed water use) were strengthened by a subset analysis which evaluated health outcomes among women who had lived at their current address for at least five years and reported consuming tap (not bottled) water. If use of reclaimed water had resulted in undesirable health outcomes, this is the group which would have been at highest risk. In this regard, more use could have been made in the multivariate statistical models of the data on level of tap water consumption. The average tap water consumption level in this population was reported to be about 1 liter/day, somewhat lower than other surveys, in which adult females are reported to consume about 1.4 liters/day.

The high level of bottled water use (26.3 per cent) among respondents is noteworthy, especially its more frequent use among women in the reclaimed water area than control area women (28.2 per cent vs 24.4 per cent, statistically significant at $p < 0.05$ level). Additionally, a smaller proportion of women in the reclaimed water area (77.2 per cent) reported consuming tap water than control area women (80.5 per cent, difference not statistically significant). Reasons for these differences are not apparent from this report, except that there were small differences in attitude toward water quality, 61.2 per cent having a "good" attitude in reclaimed water areas, vs 64.0 per cent in control areas (difference not statistically significant).

The number of years of residence at the present address was also of interest. There were small, but statistically significant differences between the areas, with persons in the reclaimed water area having greater residential stability. Of greater importance than the difference between areas, however, is the fact that less than half the study population in both areas had resided at the current address for more than 10 years. Information is not presented as to what proportion of persons with new residences moved from places some distance away from the current residence.

In the interview survey, there apparently was no questioning of the respondent's knowledge of the source of her drinking water, specifically knowledge of reclaimed water use. It is possible that differences between areas in bottled water consumption, for example, are related to perception of water quality deriving from knowledge of the water source.

CHAPTER IV

HEALTH IMPLICATIONS

All waters are subject to contamination by a variety of substances which would fall within four basic groups: inorganic chemicals, radionuclides, microbials and organic chemicals. Natural waters have been subjected to precipitation, evaporation, adsorption, biological, chemical and radiation processes as well as aging which collectively can achieve residual levels of these substances. These are commonly accepted to be without significant harm potential for human consumption—i.e., safe for its intended use, but not necessarily zero risk in the absolute sense.

Because of its proximate origin and history, a recycled wastewater has not had the opportunity to undergo those processes in the same way, thus it is changed and improved by being subject to similar processes under controlled conditions with the intent of also reliably producing a product that is "safe" for lifetime human consumption.

The fundamental question is how to have a sufficient understanding of the quality of the reclaimed water to judge its safety—in the absolute sense as to the presence of known toxic substances at unacceptable levels—and in the relative sense as to its comparability with natural waters of accepted quality.

The technological challenges are: the design and reliable operation of a treatment train that achieves at least the desired quality; the analytical chemistry and microbiology to identify and quantify the undesirable components; and in the predictive and retrospective health evaluation of the consequences of human exposure to those components.

Inorganic Chemicals

The state-of-the-art science and technology have a demonstrated capability to identify, evaluate, and control inorganic chemicals and radionuclides to an acceptable degree. Quality standards have been established for most of these substances of interest.

Microbial Contaminants

Historically, public health agencies have been concerned with the potential for the transmission of infectious disease via the drinking water route. The dissemination of these diseases via groundwater that has been contaminated with wastewater continues to be a concern to public health officials.

The soil mantle has been shown, however, to be effective in the removal of bacteria from percolated water. Movement of bacteria through soil was shown to be restricted by the decay of these microorganisms due to the effects of an environment hostile to their survival and to the sifting and sorptive capacity of the soil through which the contaminated water passed. Travel of these types of disease agents for any significant distance in non-fissured soil is very limited; distance traveled is a function of the effective pore size and adsorption characteristics of the soil.

Investigations into the potential for the waterborne transmission of viral diseases were begun in the early 1950's. The isolation of polio virus from sewage gave impetus to the concern that transmission of this disease via the water route might well occur. The recognition that enteric viruses, such as polio, were more resistant to chlorination than were standard indicator bacteria raised many concerns as to the efficacy of routine monitoring procedures and associated standards. Questions as to the ability of soil systems to remove enteric viruses from applied wastewater were also raised. The ability of soils to remove viruses from percolating water is seen as a function of the adsorptive nature of the soil and the chemistry of the viral surface. Because of the minute size of the viron, mechanical removal is considered to be relatively ineffective. A number of instances have been reported in which small numbers of viruses have been isolated from groundwater affected by a recharge operation. In these instances, the bacteriological quality of the applied water was frequently poor and often coliform bacteria were present in those groundwater samples positive for viruses. There is little if any evidence that infectious viral diseases have been associated with water from properly operated recharge projects in which bacteriological standards have been met. This observation may well be due to the low numbers of viruses present in effectively treated reclaimed water and perhaps to the limited sensitivity of our disease surveillance methods. Because of uncertainties concerning virus movement in groundwater and uncertainties as to the relationship of virus concentration to human disease, it seems prudent to treat water to be reclaimed for groundwater recharge in a manner that best reduces the number of viruses present.

The most effective virus removal process in wastewater reclamation is disinfection, normally using chlorine. The processes prior to disinfection such as activated sludge, filtration, etc., reduce virus levels by two to three orders of magnitude, but to reduce the number to below detectable limits (less than one plaque forming unit per 380 L) requires disinfection. Because of the possible health risk associated with chlorinated byproducts produced by this activity there is some concern as to the desirability of disinfecting reclaimed wastewater with chlorine prior to recharge. However, highly effective non-chlorine disinfection such as by ozone is available, thus obviating this issue.

If chlorine were to be the disinfectant, it can be argued that the water best be disinfected, if at all, upon withdrawal by the user/distributor and thus reduce the concentration of chlorinated chemical that might occur due to pre-recharge chlorination and the associated extended contact time. This approach seems eminently sensible; however, if there are down gradient users such as those with private wells who will not disinfect the withdrawn water, then there is risk that infectious disease may be transmitted. Also, the usefulness of bacteriological monitoring as a measure of water quality may be significantly reduced. The latter may be the case because bacteria are readily removed by flow through porous medium while such may not be the case for viruses. This aspect of pathogen removal in groundwater recharge should be carefully considered. Not to chlorinate protects the exposed population from a suspected health risk (trace chemical residuals) while to chlorinate protects them from a known health risk (microbial pathogens).

Epidemiology

This suspected health risk arises in part from epidemiologic studies that show an increase in cancer risk where consumers used chlorinated water. As mentioned above in Chapter III, several epidemiologic studies found positive associations between the geographic distribution of drinking water supplies that provided chlorinated water from surface sources (vs ground sources) and mortality rates of colon, rectal, and bladder cancer. These studies were followed by several case-control studies that used death records as their primary sources of data, and defined exposure as the water supply serving the address listed on the death certificate. Although there were inconsistencies, findings from these death certificate studies generally supported results from the earlier geographic correlation studies.

Case-control interview studies of newly-diagnosed patients offer a sound methodologic approach for testing these findings in a more precise manner. Case-control interview studies provide the opportunity for careful control of a myriad of potential confounding factors such as smoking habit, occupational exposures, individual medical history, and others; and permit the definition of lifetime exposure. Earlier study designs precluded both of these possibilities.

In a case-control study of colon cancer, from North Carolina, 200 cases diagnosed in 1978-80, and 407 controls who had lived in the state for at least 10 years were interviewed by telephone or completed in a mailed questionnaire. Type of water source (surface/ground) and chlorination status were assessed from a 25-year residential history and by contacting waterworks that supplied water to respondents. Colon cancer risk was associated with home consumption of chlorinated water among those 60 years old and over, but not among younger subjects. Almost all chlorinated water was from surface sources. Relative risks were computed for two exposure duration groups (1-15 years, 16+ years). In all instances, relative risks were higher for those exposed for 16+ years. Relative risks for 16 or more years exposure were 0.8, 0.9, 1.4, 2.2, and 3.4 for 40, 50, 60, 70, and 80-year olds respectively, and the risks for persons 60 or over were statistically significant ($p < 0.05$). A potential problem was the limitation of exposure histories to 25 years duration.

Findings from a large national case-control study of bladder cancer in ten areas of the United States provide the most suggestive evidence to date linking chlorinated surface drinking water with elevated cancer risk. Analyses of bladder cancer risk among white respondents (2,805 cases, 5,258 controls) showed a modest but highly significant increase in risk with tap water consumption level, but not other beverages. The relative risk for the highest vs. lowest quintile was 1.43 (p for trend < 0.0001). This association was apparent in 8 of the 10 study areas. When type and duration of water source were accounted for, the risk gradient with water intake was most pronounced among subjects with at least 40 years at residences served by chlorinated surface water, with no risk gradient among long-term groundwater users. Risk by duration of exposure to chlorinated surface water was also measured. An overall effect of exposure duration was found in women and non-smokers of both sexes, especially those who reported tap water consumption above the population median. Among these non-smokers, the relative risk for 60+ years exposure to chlorinated surface waters was 3.1, relative to non-smokers who had used unchlorinated groundwater. The increase in risk with duration of chlorinated surface water use was highly significant.

Although this study was also subject to methodologic limitations, its findings for elevated bladder cancer risk associated with consumption of chlorinated surface waters are highly suggestive. Among the criteria for judgment for assessing causality from epidemiologic findings are internal and external consistency, dose-response gradients, coherence, high relative risks, and biologic plausibility. The bladder cancer study findings generally meet these criteria except for not showing high relative risks. With minor exception, the results are similar for men and for women, and consistent among geographic areas. Dose-response patterns, both with regard to tap water intake and exposure duration, would be difficult to explain by invoking the action of one or more confounding agents. If the positive findings of the national bladder cancer study were not the result of bias or confounding, they suggest that about 12 per cent of bladder cancer in this study population was caused by elements of chlorinated surface water.

These results suggest that other means of disinfection, which do not produce undesirable byproducts, should be considered as a means to disinfect reclaimed water prior to recharge. Ozone is one possible alternative.

Organic Chemicals

Most of the other questions remain in the organic chemical group. The number of potential substances is virtually infinite. Many of them are generated by the treatment processes, e.g. chlorination. Analytical chemistry is not capable of identifying each of the substances at the parts per trillion levels or less that may occur, and even if it could, the toxicology of those that might be hazardous cannot be and probably never will be precisely characterized at those low levels. Of course, interactions between large and variable numbers of substances cannot be predicted and quantified, especially at the low concentrations involved.

Analysis of Recharge Proposals

Technologies are available to reduce the aggregate concentrations of organics to well below 1 mg/L but only a few per cent of the remaining substances have been identified and quantified. To determine the acceptability of the use of any processed water, a decision mechanism must be designed that will function in the light of the uncertainties that will always remain even after conducting the most intensive scientific investigations.

The following sequence of questions could be used to analyze a recharge project proposal:

- What is the known chemistry and toxicology of the reclaimed water and how much of the organic load is uncharacterized?
- What is the likelihood that hazardous substances will be present in the reclaimed water at harmful levels? (Biological Tests).
- How does the composition and quality of the reclaimed water compare to other drinking waters that have been historically acceptable, including the alternative choices?
- What are the upper bound, lower bound and most probable risks that could be attributed to lifetime consumption of the reclaimed water, as well as the alternatives?
- What is the marginal effectiveness of alternative treatment processes that could be applied?
- To what degree do costs influence the treatment alternatives, at the margin, relative to upper bound and most probable risks?
- What additional costs would be incurred if groundwater quality changes resulting from recharge, necessitated in the future the centralized treatment and distribution of extracted groundwater?

The answers to these questions will vary from site to site, so no one set of answers can be given here. However, the **Health Effects Study** Report is a good example of how one group tried to accumulate the necessary information to determine benefit and risk associated with groundwater recharge with reclaimed water. The results were not all definitive because toxicological and epidemiological methods are still not capable of precisely characterizing all risks from trace organics in drinking water. Nonetheless, there are treatment processes that minimize the contaminants and thus the risk, so there are still options available to evaluate how to proceed with a project. Some of these are discussed in subsequent chapters.

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CHAPTER V

SOURCE CHARACTERISTICS AND TREATMENT OF WASTEWATER FOR GROUNDWATER RECHARGE

Wastewater to be used for recharge of groundwater, either through surface spreading or direct injection, must be treated with sufficient reliability to a quality that will insure to the degree possible that no significant health hazard or aesthetic problems will occur to consumers. This chapter is a discussion of municipal wastewater characteristics and treatment alternatives for reliably achieving a given quality of treated wastewater for recharge.

The average characteristics and variability in quality of municipal wastewater is affected by several factors, important of which are the relative contributions from industrial and commercial establishments and from introduction of stormwater runoff. The treatment processes required to achieve stated quality criteria in turn are greatly affected by the characteristics of the raw water to be treated. In the following, the effect of wastewater quality on treatment needs is briefly discussed.

Wastewater Chemical Quality

Municipal wastewater quality is greatly affected by the contributions from various sources, including domestic, industrial, and commercial wastes, and stormwater runoff. Table V-l represents a summary of wastewater quality following secondary biological treatment from four different municipal districts: Washington, D. C.; Orange County, California; Phoenix, Arizona; and Palo Alto, California. The Palo Alto system treats wastewater representative of a residential/commercial community that also receives wastewater from a major university and from several electronics industries. The concentration of chlorinated solvents here is relatively high. The Orange County wastewater results from a variety of industries as well as municipal and commercial activities. Here, the concentrations of chlorinated solvents is also high, but in addition, there is a higher concentration of petroleum-related chemicals including various aromatic hydrocarbons (benzenes and naphthalenes). Phoenix, Arizona, represents another large municipality with a variety of commercial activities. The wastewater from Washington, D. C., on the other hand, comes largely from residential and governmental-office related activities, and the above noted organic contaminants are relatively low in concentration. It should be noted that the concentrations listed here are for a blended water of biologically treated municipal wastewater and Potomac River water. Thus, the concentration of total organic carbon (TOC) and total organic halogens (TOX) of the wastewater itself would be about double the concentration listed, or similar to that at Phoenix and Palo Alto.

Table V-l also contains a comparison of data from Orange County for two different time periods to illustrate the effects on both of different biological treatment processes and segregation of wastewaters to reduce the industrial contribution. During the second period noted, all wastewaters from Orange County were treated by trickling filter biological treatment, and this water was used as the influent to an advanced wastewater treatment system, Water Factory 21, operated by the Orange County Water District. During the third period indicated, the wastewaters were treated by the activated sludge process following segregation to reduce the industrial contribution in the water sent to Water Factory 21. These changes resulted in a significant reduction in the chemical oxygen demand of the treated wastewater and in the concentrations both of chlorinated and unchlorinated benzenes and naphthalene. However, an increase in the concentration of trihalomethanes occurred, compounds normally resulting from water disinfection.

The quality of the biologically-treated wastewaters listed in Table V-l are similar to that from several secondary wastewater treatment plants in Southern California as surveyed for the **Health Effects Study** and contained in the Final Report dated March 1984[7]. The results are summarized in Table V-2. No more than three samples were taken from each plant, and median or average values are included in the Table. At all plants the wastewater was filtered and disinfected as well as subjected to primary and secondary treatment. The concentrations are similar to those found at other treatment plants as summarized in Table V-l.

At Water Factory 21, a portion of the Orange County wastewater was further processed with a combination of lime treatment, air stripping, breakpoint chlorination, and activated carbon adsorption in preparation for groundwater injection. A portion was also treated by reverse osmosis. As anticipated, better effluent quality was achieved for contaminants when their influent concentration was lower. This means that effort to improve the quality of wastewater to be treated, by whatever means, will be rewarded by better quality of water for recharge from a given treatment system.

The above point is also illustrated by studies at the Blue Plains Experimental Water Treatment Plant in Washington, D.C., where a similar degree of treatment as noted above was provided for biologically-treated municipal wastewater (which included nitrification). The detailed results from the treatment plant also illustrate that the concentrations of the organic constituents noted at Palo Alto and Orange County were much lower in the Blue Plains wastewater, and as a consequence, the quality of the treated water was also greatly improved. Thus, the greater the extent to which industrial wastewaters and stormwaters can be kept from the source of municipal wastewater for recharge, the better will be the quality of recharge water.

Wastewater Infectious Agents

Wastewater treatment processes such as those used by the Los Angeles County Sanitation Districts during the health effects study (biological treatment, filtration and disinfection) for groundwater recharge appeared to be adequate for the removal of infectious agents. As indicated in Table V-2, no viruses were detected in treated wastewater after filtration and disinfection, and none were found in groundwater samples taken down gradient from the recharge area.

The results of the Pomona Virus Study[8] also indicated that the type of treatment processes used prior to recharge (at the time of the **Health Effects Study**) was able to reduce the *in situ* virus level to less than detectable limits. More recently the Castroville study[9] further confirmed the above findings.

Table V-1. Average Concentrations of Selected Contaminants in Municipal Wastewater Following Secondary Biological Treatment (Concentrations in μg/L unless otherwise indicated)

Contaminant	Washington[1] D.C.*	Orange County Water District 2nd[2] Period	Orange County Water District 3rd[3] Period	Phoenix**[4]	Palo[5] Alto
Total Organic Carbon (TOC), mg/l	4.5	30	16	9	11
Total Organic Halides (TOX)	85		131	87	192
Trihalomethanes:					
$CHCl_3$	1.5	1.6	3.5	3.5	13
$CHBrCl_2$	<0.3	0.1	0.5	0.3	0.2
$CHBr_2Cl$	<0.2	0.2	0.7	0.2	0.1
$CHBr_3$		0.1	0.5	0.1	0.0
Total	2.0	2.0	5.2	4.1	13.3
Other Chlorinated Organics:					
1,1,1-Trichloroethane	<0.2	4.7	4.8	1.4	65
Trichloroethylene	<0.1	0.9	1.1	0.4	25
Tetrachloroethylene	<0.8	0.6	3.6	1.7	44
Chlorobenzene		2.5	0.1		0.3
o-Dichlorobenzene	<0.05	2.4	0.7	2.4	2.7
m-Dichlorobenzene	0.08	0.7	0.2	0.4	3.6
p-Dichlorobenzene	<0.11	2.1	1.9	1.8	5.4
1,2,4-Trichlorobenzene	<0.02	0.5	0.3	0.4	11.3
Nonchlorinated Organics:					
Toluene	<0.12				
Ethylbenzene	<0.02	1.4	0.04	0.2	0.03
o-Xylene	<0.04			0.4	
m-Xylene	<0.05		0.01	0.8	0.2
p-Xylene	<0.05		0.05	0.2	0.06
Naphthalene	<0.04	0.6	0.1	0.2	3.3

*After mixing with a 1:1 Potomac River Water and Blue Plains treated effluent.

**Samples taken from spreading basins after secondary treatment.

Table V-2. Concentrations of Selected Contaminants in Southern California Municipal Wastewater Following Secondary Biological Treatment, Filtration, and Disinfection [After Health Effects Study[7]]

Concentrations in μg/L unless otherwise indicated*

Contaminant	San Jose Creek	Whittier Narrows	Pomona	L.A. Glendale
Total Organic Carbon mg/l				
Total Organic Halides				
Trihalomethanes:				
$CHCl_3$	14	5.1	7	5.3
$CHBrCl_2$	0.4	1.4	2.5	5.8
$CHBr_2Cl$	0.2	0.6	1.8	5.6
$CHBr_3$	0.2	0.4	0.9	2.0
Total	15	8	12	19
Other Chlorinated Organics:				
Trichloroethylene	0.2	0.7	0.2	1.0
Tetrachloroethylene	1.0	3.4	3.6	5.2
o-Dichlorobenzene	0.3	2.0	0.4	1.0
p-Dichlorobenzene	2.7	2.1	0.8	2.9
Methylene Chloride	14	46	2.5	5.5
1,2-Dichloroethane	0.2	0.2	0.2	0.6
Carbon Tetrachloride	0.5	0.2	0.2	0.1
DEHP	3.8	3.1	1.2	4.0
Nonchlorinated Organics:				
Toluene	0.2	0.3	0.1	0.3
Benzene	0.6	<0.2	0.1	<0.2
Virus:				
pfu/1000 gal	<2	<2	<2	

* Median of three samples, except Pomona which represents average of two samples.

Here, the virus-removing efficiency of two treatment systems was compared. The influent into both systems was undisinfected secondary (activated sludge) effluent. One system included coagulation, sedimentation, dual-media filtration and chlorination, and was identified as the T22 process. The second system employed direct filtration with a variety of prefilter coagulants added. During the five-year study period, more than 150 liters of reclaimed effluent from each process was examined for the presence of enteric viruses; none were detected. Viruses were routinely present at detectable concentrations in the influent to the two treatment processes.

During the course of the Castroville study a number of virus seeding trials, using poliovirus, were conducted in such a manner that virus removal efficiency of the two processes could be determined. The results of the seeding studies indicated that there was no statistical difference in the virus removal efficiency of either process. In each case the process was, on the average, able to reduce the number of seeded viruses by more than five orders of magnitude. In both instances chlorination was required to reach such virus removal levels. The average seeded virus removal in the filtered, but undisinfected effluent from each process was 98.5 per cent. The major difference between the two treatment processes was the greater variability in the virus removal efficiency of the direct filtration process. Thus, the latter process appeared to be less reliable than the more involved treatment associated with the T22 process. The question of reliability must be addressed when pre-recharge treatment processes are being selected.

Treatment Processes

The minimum level of wastewater treatment used for recharge has normally been primary and secondary treatment followed by disinfection. Data in Table V-I indicate that wastewater following such treatment normally contains measurable concentrations of several organic compounds that are of health concern. In addition, such wastewater normally contains suspended materials that will tend to cause clogging of soil, or of an aquifer when the wastewater is used for recharge. This is less of a problem with surface spreading than with direct injection for two reasons. First, with surface spreading, cleaning of the soil surface is relatively easy through drying of the basin and discing of the surface. Second, the application rate of wastewater per unit surface area is lower by several orders of magnitude with surface spreading than with direct injection. Very low concentrations of suspended solids, on the order of 1 mg/L, can clog an injection well, but should cause no technical problems when using spreading basins. In addition, even low concentrations of dissolved biodegradable organic material remaining in a wastewater in an injection system can result in well clogging due to biological growth near the point of injection. In order for direct injection to be feasible then, a much higher degree of wastewater treatment is needed than with surface spreading. Thus, the treatment required for recharge is dictated by technical needs for operation of the system as well as by public health considerations.

The level of treatment necessary for a specific groundwater recharge site in order to satisfy health and aesthetic requirements will vary with the quality of the wastewater and the physical and hydrological conditions in the soil. Some guidance, however, can be given to indicate the water quality levels that might be achieved by various treatment alternatives. In such an analysis it is well to remember that it is not currently possible to measure the concentration of most of the organic constituents present in treated wastewaters due partly to the complexity of the mixtures present and partly to the analytical limitations of currently available measurement methods. For example, chlorination for disinfection results in the formation of many chlorinated organic species other than trihalomethanes, but just what these compounds are is presently not well known. Thus, the following analysis can by no means be complete. In addition to normal primary and secondary treatment and disinfection, options for advanced wastewater treatment generally include chemical treatment, filtration, aeration, activated carbon adsorption, and demineralization.

Measured quality changes occurred at Water Factory 21 following each of the above levels of treatment. Chemical treatment and filtration are useful for removing particulate materials, pathogens, and heavy metals. Dissolved organic materials are not well removed by these processes. Air stripping is excellent for removal of a wide range of volatile organic compounds that generally represent the majority of the organic priority pollutants remaining in biologically-treated wastewaters. However, little removal is obtained of other dissolved organic materials that constitute the major organic fractions present. Activated carbon treatment, however, is quite effective in removing the non-volatile materials, and so is a complimentary process to air stripping. Finally, use of reverse osmosis (RO) for demineralization can also result in the removal of the majority of dissolved non-volatile organic materials. Using RO treatment, treated water with less than 1 mg/L of dissolved organic carbon can be achieved, and essentially all identifiable trace organic compounds should be absent in detectable concentrations. Water treated in this manner is perhaps of better quality than most polluted surface waters now used as sources of drinking water supply.

Additional treatment of wastewater requires additional costs that must be factored into decisions of the degree of treatment required. The following example values are based on 1980 costs for construction and operation at Water Factory 21 in dollars per acre-foot of treated water: lime treatment, recarbonation, and solids processing, $113; filtration and chlorination, $29; air stripping for ammonia removal, $57; granular activated carbon treatment, $50; and reverse osmosis treatment, $273. The total cost for the extensive treatment would thus be $522 per acre-foot. The air stripping cost is higher than normally would be required for volatile organics removal alone as ammonia stripping requires about ten times more air volume per unit of wastewater treated. Demineralization, while quite effective for removal of both organic and inorganic materials, is relatively costly. Newer membranes should reduce the cost considerably if just organic removal is desired. Thus, these costs may be useful to obtain a general idea of cost range, but should be used with caution.

Groundwater Treatment

Treatment of groundwater that is removed for potable purposes is an option that deserves consideration. Because of the health-risk uncertainties from using reclaimed wastewater, decisions are difficult to make about the degree of treatment necessary so that groundwater recharge will pose no significant health risk to groundwater consumers. However, if an error were made such that treatment prior to recharge were later found to be insufficient to protect human health, then the underground supply need not necessarily be abandoned as a potable water supply. Withdrawn groundwater could be treated prior to use as is commonly done with surface water supplies. Questions of relative cost and equity would then arise.

With surface water supplies, where treatment prior to potable use is accepted practice, treatment is generally given at a central facility, and a distribution network is established for delivery of water to consumers. Since simple disinfection or no treatment is common with groundwater supplies, many consumers have private wells and a distribution system is not needed. However, if groundwater contamination necessitated treatment, then this situation may need to be changed. If more than simple disinfection were required, then it may be more economical and reliable to have a central treatment facility and a distribution system. This could entail a large initial capital expense and higher operational costs. Whether this would be less expensive than a higher degree of treatment prior to recharge is problematical, but should be evaluated prior to reaching a decision on the treatment requirements and desirability of groundwater recharge.

Effects of Disinfection

There is little question that disinfection is essential for controlling infectious agents in reclaimed wastewaters. However, disinfection—especially chlorine—also produces chemicals that have a health risk. The trihalomethanes (THMs) are markers for the byproducts that are formed from the reaction between chlorine and humic substances in water. However, the sum total concentrations of halogenated organics formed during disinfection are much higher than of THMs alone, and their composition and health risks are less well known. Chlorination reduces a known health risk, but may create another health risk, the magnitude of which is poorly understood. There are alternative disinfectants to chlorine, such as ozone and chlorine dioxide, but there are uncertainties associated with their usage too, but they do not produce extensive amounts of stable chlorinated byproducts.

In order to reduce health risks, it thus appears desirable to treat wastewater rigorously prior to disinfection, such as by secondary biological treatment, coagulation, and filtration, and then to use sufficient disinfection to obtain the pathogen kill desired, but without unnecessarily producing stable byproducts. If chlorine is being used, it may then be advantageous to dechlorinate the water to minimize the further production of halogenated organics in the reclaimed water for recharge. Under some circumstances the presence of ammonia in the reclaimed wastewater may also minimize the formation of THMs and other chlorinated hydrocarbons. Another way to further reduce this risk from chlorination byproducts is to use granular activated carbon or reverse osmosis to reduce the total organic carbon (TOC) that reacts with chlorine.

Summary

The quality of wastewaters to be used for recharge can be improved through segregation to reduce industrial and commercial contributions and stormwater runoff. Efficient biological treatment prior to advanced treatment also is effective in improving quality. There are a variety of advanced treatment processes available which collectively can further clean wastewaters to produce almost any quality of water desired. In addition, with a highly competent management and technical team, with a significantly increased level of analytical monitoring over what is normally used in wastewater treatment, and by controlling flow rates through treatment systems and selecting water of the desired quality prior to recharge, a high degree of reliability can be built into a recharge system. However, there are costs involved in each of these measures.

The measures necessary to insure that the overall recharge system is sufficiently reliable and effective to provide the consumer now and in the future with a safe and wholesome groundwater supply will vary with each site and thus only general guidelines have been presented in the chapter.

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CHAPTER VI

RECHARGE METHODS AND SUBSURFACE TREATMENT

When reclaimed water is recharged into the ground, a natural treatment occurs which can significantly improve the water quality. As the water passes through the unsaturated and saturated zones of the aquifer, a series of processes occurs. Among these are filtration, sorption, oxidation/reduction, precipitation, ion exchange, and dilution. The degree of modification depends on the quality of the reclaimed water and local hydrogeologic conditions.

This chapter briefly describes methods for recharging reclaimed water and the natural treatment resulting by water passage underground.

Recharge Methods

Reclaimed water can be recharged into the ground to supplement natural groundwater resources by water spreading methods on the ground surface or by well injection. Placement of the water underground increases the available groundwater for subsequent extraction by wells and reuse for municipal purposes. In addition, recharge provides a convenient local storage site, and minimizes losses by evapotranspiration.

Water spreading facilities are designed and operated to maximize the area and length of time of water contact with the soil. The spreading efficiency of an installation is measured by its recharge rate, which is the velocity of downward water movement over the wetted area. A variety of water spreading methods are available, involving basins, stream channels, ditches and furrows, flooding, irrigation, and pits. Basins are the most widely employed method in California. These are formed by building surrounding dikes and can be adapted to fit local topography and available land. Stream channel methods depend upon low check dams, either temporary or permanent, to distribute reclaimed water released into a stream over the widest possible surface area. Other methods, although used for recharging surface water, are not generally applicable for reclaimed water. Injection through wells is another possibility; however, capital, operation, and maintenance costs are high and also the beneficial treatment provided by percolation through the unsaturated zone is lost. As a consequence, recharge wells are primarily employed where an alternative purpose, such as control of sea water intrusion, is to be achieved, or where land with suitable characteristics is not available.

Geologic Conditions

Recharge of reclaimed water is normally conducted on permeable geologic materials. The underlying aquifer should be unconfined so that water can percolate vertically downward to the water table unhindered by intercepting clay layers. Almost all recharge projects in California are situated on outwash alluvium consisting primarily of sand and gravel with lesser amounts of silt and clay. The water table should be sufficiently far below ground surface so that fluctuations caused by seasonal rainfall and mounding under recharge areas do not raise the water table to within about 10 feet of ground surface. This will permit an unsaturated, aerobic zone to be maintained and thus enhance decomposition.

The ideal soil for percolation of reclaimed water should have the following characteristics:

1. Permit rapid rates of infiltration and transmission of water.
2. Not contain underlying clay layers or other layers that restrict movement of water.
3. Not contain expanding-contracting clays that create cracks which allow the reclaimed water to bypass the percolation medium during infiltration.
4. Contain sufficient clay and TOC content to sorb organic compounds, microorganisms, and heavy metals as well as provide surfaces of which microorganisms decompose organic matter.

Unfortunately, an ideal system rarely exists because rapid infiltration and fine-grained soils tend to be mutually exclusive.

Operating Techniques

Application of reclaimed water to basins is normally done on an intermittent basis of alternate flooding and drying because infiltration rates otherwise decrease with time if aerobic conditions are not maintained. Durations for the cycle depend on water quality, climate, and geology. Field trials are necessary to obtain optimal recharge performance. Recharge rates approximating 300 ft/year can be achieved at some places but frequently they are somewhat less. Algae can clog the bottom of basins, thereby reducing infiltration rates. Also, algae removes carbon dioxide, raises the pH, causes precipitation of calcium carbonate, and hence further aggravates soil clogging. Algal growth can be minimized by reducing the detention time of the water both from the treatment plant to the basins and within the basins. Also, discing of soil following the drying cycle can help alleviate clogging potential.

Chemical Changes

Depending upon the chemistry of the reclaimed water, the local geology, and the quality of the natural groundwater, substantial chemical changes can occur with the subsurface migration of the recharged water. These changes can involve sorption, precipitation, ion exchange, oxidation, reduction, and dilution. Aerobic conditions above the water table produce different reactions than those associated with anaerobic conditions in the saturated zone. In general, some inorganic and organic constituents are reduced with time and distance traveled underground.

Processes such as sorption, biodegradation and ion exchange reduce the rate at which chemicals move in the subsurface environment relative to the rate of movement of water. For example, chloroform may move only one-third to one-fifth as fast as water, chlorobenzene perhaps only one-thirtieth as fast, and strongly-sorbed materials such as DDT and PCB even slower. For this reason, recharged water may be free of many chemicals when it first arrives at a given extraction well, but much later the chemicals may begin to appear. Thus, chemical retardation needs to be evaluated when determining the effectiveness for contaminant removal of a recharge system.

Removal of Microorganisms

Bacteria and larger parasites associated with wastewater are effectively removed after passage through short distances of the soil mantle. The data in Table VI-l are examples of the removal of coliform bacteria from sewage after passage through three feet of a variety of California soil types[1].

Table VI-l Texture and Coliform Count at a Depth of Three Feet for Five California Soils upon which Sewage was Spread**

Soil Type	Effective Size (mm)	Flow Rate (ft./day)	Coliform* MPN/100 ml
Hesperian Sandy Loam	0.0020	0.23	3.6
Columbia Sandy Loam	0.0033	0.18	2.3
Hanford Sandy Loam	0.0074	0.21	23.
Yolo Sandy Loam	0.021	0.23	240.
Oakley Sand	0.020	0.21	2400.

*Influent coliform count ranged from 2.4 million to 11 million per 100 ml.

**Adapted from Orlob, G. and Butler, R., "An Investigation of Sewage Spreading on Five California Soils," Tech. Bull. 12 IER, Series 37-12., SERL, University of California, Berkeley, (1955)

The investigation carried out at Santee, California in the 1960's, where a secondary effluent was infiltrated laterally through 1,500 feet of sand and gravel, resulted in excellent bacterial removal within the first 200 feet[2]. These results were impressive for passage through such coarse media.

The case for the removal of viral infectious agents is not as clear as that for the reduction of bacteria and larger organisms during passage through the soil mantle or through saturated aquifers. For example, in the Santee study, referred to above, viruses were isolated during the 10-month period nine per cent of the time in the percolation bed influent and two per cent of the time in the effluent. Virus isolations have been reported by a number of investigators examining a variety of recharge operations after various distances of migration. These are summarized in Table VI-2.

Thus, the presence of enteric viruses in recharged groundwater has been observed; however, the concentration of viruses has been low and not infrequently bacterial indicators have also been present. In some instances, the wastewater applied was of poor quality. It should be noted that no viruses were recovered from the groundwater associated with the Whittier Narrows site and no infectious disease has ever been associated with water from a well-managed recharge operation.

The ability of soil to remove viruses varies considerably dependent upon a variety of variables, many of which are not well understood. Important factors in this regard are soil type, virus type, saturated or unsaturated flow, flow rate, cation concentration, and the presence of soluble organics. Adsorption of virons to soil particles is considered to be the major way that virus travel in groundwater is curtailed. Because of the complexities of these interactions, it is very difficult to accurately predict the ability of a soil system to remove any of the large variety of enteric viruses that might be present in wastewater. Perhaps the conservative approach would be to base estimates of virus removal on the reported decay rate of viruses in soil and water. Reddy *et al.*[4] report the decay rate of poliovirus in soil flooded with unchlorinated secondary effluent to be 69 days for a 99.9 percent (T99.9) reduction. Berg[5] reported the survival (T99.9) of Poliovirus in river water to range between 13 and 20 days.

Biotransformation of Organic Chemicals

Recent studies have demonstrated the numbers of microorganisms residing in subsurface material are in the order of 10^6 to 10^7 per gram of dry material, both above and below the water table. These organisms can transform many important organic chemicals. The rate of transformation is limited by the availability of organisms, while the extent of transformation is usually limited by some metabolic requirement such as oxygen, pH buffering capacity, or mineral nutrients. Therefore, the degree of biological degradation of a particular organic compound depends upon the geochemical properties of the subsurface environment.

Experimental evidence revealed that halogenated aliphatic hydrocarbons in shallow aerobic aquifers were not biologically degraded, whereas many could be transformed in anaerobic subsurface material. Thus, carbon tetrachloride was transformed to chloroform; similarly, tetrachloroethylene was transformed to trichloroethylene, then to all three dichlorethylenes, and perhaps to vinyl chloride and ultimately to chloride. Thus in the subsurface environment some chemicals may be transformed biologically into others which may or may not be more hazardous than the parent compound.

Guidelines for Reclaimed Water Recharge

The development of generalized criteria for recharging reclaimed water will be difficult to specify because of the many interrelated factors involved under different geologic conditions. Perhaps better would be a statement of guidelines which indicates the variables that need to be considered. Enumeration of these, even if only in a qualitative sense, will focus the attention of recharge system designers on the controlling factors which will be scrutinized by regulatory agencies. It can be presumed that approval of recharge projects will of necessity have to be done on a case-by-case basis.

Excluding the engineered treatment of the reclaimed water, which is discussed in Chapter V, the guidelines should embrace the following topics:

1. Rate of reclaimed water recharge – this involves the degree of dilution by native groundwater and introduces factors such as volume of aquifer storage, rate of groundwater flow, area of application of recharge, and distance to nearest municipal wells.
2. Residence time of reclaimed water underground-this should be sufficiently long so as to assure elimination of pathogens and reduction of some chemicals subject to biodegradation.
3. Subsurface soil and geology – this is needed to ascertain that filtration and adsorptive processes are effective.
4. Method of recharge – this should involve consideration of basins, stream channels, and recharge wells.
5. Unsaturated zone flow – this could involve a requirement for a minimal distance (such as 10 feet or so) between ground surface and the water table in spreading operations both for efficiency of recharge and effectiveness of subsurface treatment.
6. Groundwater quality – this should address the quality of the native water which receives the reclaimed water.

7. Monitoring of subsurface water – this should include regular sampling and analysis of groundwater upstream and downstream of the recharge area together with groundwater containing reclaimed water which is extracted for domestic use to determine if an acceptable steady state is achieved or if, with time, quality deteriorates.

8. Contingency plans – this should specify alternative measures to supply water in the event that groundwater containing reclaimed water is found to be unsafe for human consumption.

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Table VI-2 Isolation of Viruses Beneath Land Treatment Sites[3]*

Site Location	Site Type	Maximum Distance of Virus Migration (m)	
		Depth	Horizontal
St. Petersburg, FL	S	6.0	–
Gainsville, FL	S	3.0	7.
Lubbock, TX	S	30.5	–
Kerrville, TX	S	1.4	–
Muskegon, IL	S	10.0	–
San Angelo, TX	S	27.5	–
East Meadow, NY	R	11.4	3.0
Holbrook, NY	R	6.1	45.7
Sayville, NY	R	2.4	3.
12 Pines, NY	R	6.4	–
North Masapequa, NY	R	9.1	–
Babylon, NY	R	22.8	408.
Ft. Devons, MA	R	28.9	183.
Vineland, NJ	R	16.8	250.
Lake George, NY	R	45.7	400.
Phoenix, AZ	R	18.3	3.
Dan Region, Israel	R	31-67	60-270

R = Rapid infiltration

S = Slow-rate infiltration

* Adapted from: Gerba, C. P. and Goyal, S. M. (1985) "Pathogen Removal From Wastewater During Groundwater Recharge," in Asano, T., Artificial Recharge of Groundwater, Butterworth Publ, Boston.

CHAPTER VII

MANAGEMENT AND RELIABILITY

CHEMICAL MONITORING

The extensive analytical chemistry effort extended in the **Health Effects Study** Final Report establishes the need for careful and time-consuming background studies before the initiation of any groundwater replenishment project using reclaimed water. Careful evaluation must be made of the water quality of all recharge source waters as well as existing groundwater in the recharge area.

The fundamental purpose of a chemical monitoring program is to provide early detection of potential impacts on groundwater quality resulting from the recharge operation. The resulting data should be sufficiently sensitive to permit cessation of recharge in the event that any significant degradation of groundwater quality is observed. Elements of knowledge required include (a) the chemical quality of the existing groundwater, (b) the chemical quality of the recharge water, and (c) the chemical quality of other major sources affecting groundwater quality. Satisfying the latter requirement will be important in the event that health-significant organic materials are found in the groundwater prior to planned recharge with reclaimed water.

Importance of Pre-Recharge Background Studies

It is vitally important that the characteristics of the groundwater regime that will receive the reclaimed water be defined to such a degree that an appropriate number of monitoring wells can be located in order that a statistically valid number of samples can be obtained. Without this degree of care in the background study phase, it is possible that either the extent of any future degradation from reclaimed water or the significance of variation in any chemical parameter will be undeterminable. Owing to the likelihood that the groundwater regime will underlie the jurisdictions of multiple water authorities, this matter will require the dedicated attention of state officials.

Monitoring frequency should be tied to water recharge and migration rates in the aquifer. It would be desirable to build a representative background data base rapidly: monthly, bimonthly, or quarterly monitoring to accomplish this task. Subsequent monitoring frequency should be adjusted so that significant chemical changes or trends can be detected. Quarterly, semi-annual, or even annual monitoring may be sufficient. If a rapid significant increase is noted for a toxic target compound at a particular well, prudence dictates immediate rechecking of that well. Depending upon the outcome of the recheck, the monitoring frequency may need to be adjusted for that well or adjacent wells included in a more detailed examination of the area.

The types of chemical analyses recommended for background studies fall into different categories.

Inorganic Chemicals

A complete inventory of the major mineral constituents and selected physical properties of the reclaimed water and the existing groundwater should be compiled. A recommended list of water quality constituents to be measured is shown in Table VII-1. Many inorganic ingredients have demonstrated health significance as well as standards under the Safe Drinking Water Act. After sufficient experience is obtained with data on inorganic composition, it should be possible to focus routine monitoring efforts on a smaller list of inorganic species (Table VII-2). It is important to include in the routine monitoring program principal inorganic ingredients of the reclaimed water, even if they are not detectable in pre-recharge groundwater samples.

Organic Chemicals

Previous experience suggests that the most time-consuming, expensive, and perhaps important analytical monitoring will be devoted to identification of organic contaminants. Earlier studies of groundwater quality in the L. A. Basin in particular indicate the desirability of characterizing existing groundwater quality and reclaimed water for a limited number of small molecular weight industrial solvents and trihalomethanes (Table VII-3). These organic contaminants have been frequently found in industrial and domestic effluents, and some have known genotoxic effects in mammals and have established drinking water standards. Many of these compounds move through the aquifers at the same, or nearly the same, rate as water. Thus, at a well, they should signal the arrival of source waters contaminated by these common chemicals. Having maintained a representative chemical inventory or data base on source waters is critical to interpretation of monitoring observations at the wells.

Additional organic analytical efforts should be focused on general, rather than specific, measures of chemical residues. These are TOC and TOX. They may be regarded either as surrogate measures of increases in potentially toxic but unknown mixtures or as empirical means for monitoring the efficacy of reclamation (treatment) and recharge (soil percolation) steps for removing organic carbon and halogenated organics from recharge supplies.

Identification of those organic contaminants specifically indicative of the degradation of groundwater by reclaimed water should be the subject of investigation during background studies. A list of those compounds of known health significance should be established from analysis of reclaimed water and known industrial and agricultural operations in tributary areas of the proposed project. In addition, additional data or information regarding leaks from underground storage tanks, other spills, or other major toxic compounds identified in other regional studies should be included. Compounds on this list should be monitored with the same frequency as those in Table VII-3 and the surrogate measures referred to above.

The foregoing addresses routine monitoring of identifiable chemical parameters only. However, because the spectre of unknown health effects from unknown organics is still a significant issue related to drinking water and health, some investigative efforts combining chemical and toxicological methods are justified. The state-of-the-art in these areas and the expense associated with their practice dictate a goal-oriented approach to such work, since the routine collection

Table VII-1. List of Constituents for Water Quality Characterizations

Parameter	Significance	Method
Turbidity	PDWS[a]	Turbidimeter
Color	SDWS[b]	Nessler
pH	Aesthetic	pH Meter
Dissolved Solids	SDWS	Filtration/Evaporation
Total Alkalinity	Aesthetic	Titration
Chloride	SDWS	Mercuric Nitrate
Sulfate	SDWS	Turbidimeter
Nitrate - Nitrogen	PDWS	Cadmium Reduction
Nitrite - Nitrogen	Health	Colorimetric
Ammonia - Nitrogen	Health	Distillation/Titration
Phosphate	Agricultural	Ascorbic Acid
Fluoride	PDWS	Specific Ion Electrode
Cyanide	Health	Distillation
Total Hardness	Health	Titration
Arsenic	PDWS	Atomic Absorption
Barium	PDWS	Atomic Emission
Cadmium	PDWS	Atomic Absorption
Chromium	PDWS	Atomic Absorption
Copper	SDWS	Atomic Absorption
Iron	SDWS	Atomic Absorption
Lead	PDWS	Atomic Absorption
Manganese	SDWS	Atomic Absorption
Mercury	PDWS	Atomic Absorption
Nickel	Health	Atomic Absorption
Selenium	PDWS	Atomic Absorption
Silver	PDWS	Atomic Absorption
Sodium	Health	Atomic Emission
Zinc	SDWS	Atomic Absorption
Total Organic Carbon	Health	TOC Analyzer
Bromide	Health	Colorimetric

[a] PDWS = Primary Drinking Water Standard
[b] SDWS = Secondary Drinking Water Standard

Table VII-2. Suggested List of Inorganics Species

Arsenic
Cadmium
Chromium
Lead
Mercury
Nickel
Nitrate
Nitrite
Selenium
Zinc

Table VII-3. Suggested Minimum List of Volatile Organics

vinyl chloride
dichloromethane
chloroform
bromodichloromethane
chlorodibromomethane
bromoform
tetrachloroethene
trichloroethene
1,1-dichloroethane
1,2-dichloroethane
trans-1,2-dichloroethene
1,1-dichloroethene
1,1,1-trichloroethane
1,1,2-trichloroethane
benzene
toluene
chlorobenzene
o-dichlorobenzene
p-dichlorobenzene

of GC/MS chromatograms or Ames mutagenicity data into amassed data tables is not very likely to assure public health and safety. Several areas where the development of additional information is suggested include:

1. application of new genotoxic assays to water concentrates (emphasis on mammalian cell assays)
2. development of tests for non-genotoxic methods to measure adverse health effects
3. innovative separation and qualitative analysis methods
4. more efficient monitoring techniques for operational performances
5. continued use of combined chemical separation and toxicological methods for guiding chemical identification

Specific goals of these study areas could include one or more of the following:

1. establishing a comparison index for chemical and toxicity characteristics with a "standard" water supply
2. identifying with more certainty the sources of unidentified health suspect agents
3. identifying structures of compounds causing biological test responses in cellular assays
4. providing a basis for testing (or not) residue mixtures or specific compounds using animal species
5. controlling the introduction of any newly identified toxic agents into the aquifer

MICROBIOLOGY MONITORING

Historically, the coliform bacteria have been used as indicators of the possible presence of the agents of infectious enteric disease in water and wastewater. Standards have been set for their number in waters intended for various uses and on the whole these standards have served public health agencies well. As pointed out in previous sections of this report, there has been some concern as to the universality of the coliform test because certain animal viruses and protozoan cysts are reported to be more resistant to chlorine than are the coliform bacteria. The direct measurement of animal viruses present in wastewater is cumbersome, expensive and does not lend itself to routine monitoring if a high level of organic debris is present. However, enteric virus recovery and enumeration methods are available at a cost of about \$100-\$500 per sample in low debris (filtered) waters. Perhaps some level of routine virus monitoring is feasible. There has been a great deal of interest in developing a monitoring system that would be specifically indicative of the presence of animal viruses; however, to date no acceptable surrogate has been identified.

The reported greater resistance of animal viruses to chlorine, as compared to coliform bacteria, varies considerably depending upon the conditions under which such measurements were made. For example, Ludovici, et al.[1] reported the results of virus and bacteria removal studies in which a filtered secondary effluent was chlorinated. They indicate that the difference in resistance between viruses and coliform bacteria is not great. In comparison Berg and Metcalf[2] describe the results of carefully controlled laboratory studies in which poliovirus has been shown to be about 400 times as resistant to chlorine as *E. coli.* The truth probably lies somewhere in between these two extremes.

Under normal circumstances in sewage effluents the ratio of coliforms to *in situ* animal viruses is in the range of 1,000,000:1. Thus the reduction of coliforms to low levels should be associated with a concomitant reduction in virus concentration. Berg and Metcalf[2] report total coliform to virus ratios of from 4:1 to 130:1 in chlorinated primary effluent. The time it takes to reduce the large numbers of coliforms in secondary effluents to an MPN of 2.2 or less will frequently be sufficient to reduce the small number of viruses present at least two or more orders of magnitude and such that they would not be detected even in large volumes of sample. The microbiological monitoring results from the Whittier Narrows project reflect this view.

From these considerations the monitoring for total coliforms in reclaimed water to be used for groundwater recharge should continue to be utilized as a measure of the sanitary quality of the reclaimed water at least until such time as more exact measures for the presence of animal viruses are developed. In cases of uncertainty perhaps the acceptable quality of reclaimed water should be based upon the presence of low numbers of coliforms in volumes of water greater than 100 mL.

The treatment process employed should also be carefully considered as part of the standard for water reuse. The process which produces the least microbial contamination most consistently should be the process of choice.

RELIABILITY

An important issue in treatment of wastewater for recharge is the question of reliability. Reliability is a measure of the degree of successful performance of a facility with respect to required conditions of operation[3]. In order to determine the reliability of a system, one must know what it is supposed to do under all relevant circumstances. Assuming required performance is specified in a list of water quality standards that water for recharge must meet, then there are various ways that meeting such standards might be accomplished. Generally, not all treated water need be used for recharge. It might be stored in a surface basin, analyzed to insure that standards are met, and only then be used for recharge. Such a system could be highly reliable as far as water quality is concerned. On the other hand, the treatment system itself could be designed with sufficient redundancy in treatment processes so that if one part of the system were not operating at design efficiency, another part of the system might safely handle the temporary overload.

Reliability for recharge can be enhanced through an appropriate operating philosophy. Water Factory 21, which treats wastewater to a high degree for injection, has developed such a philosophy to insure meeting appropriate standards[3]. The plant is operated under constant flow conditions so that hydraulic fluctuations through the plant are eliminated. Industrial contribution in the wastewater treated is minimized and efficient biological treatment is now practiced. In addition, Water Factory 21 can be shut down when poor quality water is received, when treatment processes fail, or when desirable for routine maintenance, as water need not be injected continuously. This flexibility should be possible with most recharge projects, and greatly enhances reliability in the delivery of water meeting given water quality requirements.

The groundwater basin itself can enhance the reliability of the overall system. Many chemicals are sorbed or otherwise partitioned between the water phase and solid phase in aquifers. This not only retards their rate of movement, but also attenuates the fluctuation in concentration of the constituents. Thus, occasional high concentrations of a given constituent in the recharged water, that may exceed given standards, are not as important as the average value. This also adds to the reliability of the overall system. Through proper design, operation, and analytical monitoring, treatment systems for groundwater recharge can be operated reliably. However, this does require a good understanding of the need for reliability by the operating personnel, as well as a higher degree of technical competence than normally required for operation of water or wastewater treatment plants. In addition, much greater attention to analytical monitoring of water quality is necessary so that unsuitable water can be prevented from contaminating the groundwater system.

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CHAPTER VIII

ADDITIONAL RESEARCH

There still is a degree of uncertainty regarding identifying and quantifying about 90 per cent of the residual organic fraction in reclaimed water. Also, the potential harmfulness of these compounds is uncertain. A framework for analyzing these uncertainties has been presented to help focus future efforts on the issues that are the most important for public health and economic benefit. Additional research on the following problems would allow decisions to be made with more confidence:

1. Chlorination of wastewater causes additional chlorinated organics to be in the reclaimed water. Other disinfectants should be tested to determine which ones produce the fewest stable, biologically-active byproducts. Ozone has been suggested as one possibility. Dechlorination shortly after adding chlorine may be another way to minimize byproducts. Recent epidemiological studies indicate this issue may be pivotal in understanding bladder cancer rates in chlorinated surface waters.

2. A hierarchal toxicology matrix that would be built up from simple *in vitro* "genesis" tests to lifetime whole animal bioassays on water concentrates should be devised. Once the correlations have been developed between parts of the matrix, the lower order test could be used in the future for low cost water quality surveillance. Possible screening regimens exist.

3. The matrix should be developed and validated on a relative basis by comparing a variety of concentrates, ranging from good quality groundwaters to good quality and poor quality conventionally treated surface waters to reclaimed waters.

4. Although cancer endpoints might be followed, other health endpoints of potentially higher risk and better detectability should be emphasized. These might be in the area of reproductive toxicology.

5. Biochemical markers of exposure to potential contaminants should also be examined in populations. These might include measurements of binding of certain substances to macromolecules, or bioaccumulation in adipose tissue as well as live animal bioassays using fish.

6. Identify with more certainty the sources of unidentified health suspect agents.

7. Identify structures of compounds causing biological test responses. in cellular assays.

8. Determine which portion of the total organic carbon should be removed by treatment modification or barrier.

CHAPTER IX
CONCLUSIONS AND RECOMMENDATIONS

1. As a general guideline, the Panel believes the best available quality water in an area should be reserved for drinking water use. Other factors notwithstanding, wastewater should not be used as a source unless it can be demonstrated that natural and engineered treatment can be expected to produce consistently a better quality of drinking water than other alternatives. Accordingly, before recharge projects are undertaken, other alternatives such as nonpotable reuse, conservation, other nonstructural measures, and modifications to water rights regulations should be thoroughly evaluated.

2. In the context of the charge given, the Panel concluded after reviewing the **Health Effects Study** that it was comfortable with continuation of the current Whittier Narrows groundwater replenishment project and with the safety of the product water. It felt that the risks, if any, were small and probably not dissimilar from those that could be hypothesized for commonly used surface waters. The Panel also suggested certain types of analyses and decision mechanisms that could be applied to future projects, which would potentially further reduce some of the uncertainties that remain or at least articulate those uncertainties more systematically to facilitate decision making.

3. Applying the reclaimed water to appropriate spreading basins probably is the most effective and least cost method to use the soil as further treatment before extracting the water for drinking. Recharge wells, however, may be more sensible if land is scarce or there is a need to prevent salt water intrusion.

4. The degree of treatment for any recharge site will depend upon the segregation of industrial wastes, the type of application to the soil, the type of soil formation, the rate of movement, the depth to the groundwater, the quality of the groundwater, the dilution available and the residence time in the ground down gradient until the first point of extraction.

5. There are treatment processes available that will provide adequate control of inorganic substances in wastewater used for reclamation. These include biological and lime-treatment, chemical coagulation with filtration and even reverse osmosis if necessary.

6. Use of adsorption prior to injection will provide good control of organic contaminants of concern especially the non-volatile fraction. Air stripping will more effectively reduce the volatile organics typified by many of the industrial solvents. Using reverse osmosis membranes will reduce the total dissolved organic carbon below 1 mg/L and essentially all identifiable trace organic compounds of significance should be absent in detectable concentrations. All this extra treatment, of course, will add extra cost especially for reverse osmosis.

7. Reclaimed water should be disinfected by a potent disinfectant as part of the treatment process prior to injection or spreading for percolation.

8. The disinfection process should not be one that would produce biologically or chemically stable byproducts that may be harmful. Ozonation may be a good candidate or dechlorination shortly after adding chlorine to the final plant effluent may minimize the formation of chlorinated hydrocarbons.

9. Monitoring of the biological quality of water should be conducted at the point of extraction and disinfection may also be necessary in many cases prior to delivery to consumers.

10. Prospective health surveillance of populations, at least initially, should be part of any project proposing to use reclaimed wastewater for recharging to the groundwater.

11. Analytical studies should emphasize application of biochemical tests of concentrates to determine whether likely harmful substances are present at low levels.

12. The currently used single chemical and simple *in vitro* toxicological evaluations are not likely to be responsive to the cosmic question of whether the unknown aggregated trace organic substances in reclaimed water would cause any meaningful risk to populations consuming water. This can only be addressed by whole animal tests on mixture concentrates and by retrospective surveillance of population. State-of-the-art toxicology studies in animals provide the only recognized methods for evaluating risk prior to human exposure.

13. Analytical chemistry investigation and monitoring should be continued on reclaimed wastewater as well as extracted groundwater to assure that concentrations of key identified substances, such as those in the Drinking Water Standards, are not exceeded and any other biologically-active chemicals are identified.

14. In addition, the state-of-the-art of chemical and biological monitoring, toxicology, treatment technology and epidemiology should be reviewed periodically and appropriate adjustments made in any reclaimed water projects monitoring and operation.

15. Treatment of groundwater that is removed for potable purposes is an option that deserves consideration. However, careful attention has to be given to the extra cost of treating and distributing extracted groundwater because it may be more costly than rigorous treatment of the reclaimed wastewater prior to recharge. Preferably every effort should be made to not degrade the existing groundwater quality with the recharging of reclaimed wastewater. This can be accomplished by treating just certain wastewater, by storing treated reclaimed wastewater in a surface basin, by analyzing it to insure that standards are met, and only then using it for recharge.