Comprehensive Water Resources Management Plan (CWRMP)

APPENDIX F

Volume 4 of 5
Acton, MA

March 2006
Revised June 2006

WOODARD & CURRAN
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APPENDIX F: INDIRECT POTABLE REUSE WORKING GROUP REPORT

INDIRECT POTABLE REUSE WORKING GROUP

Acton Board of Health - Telephone (978) 264-9634

FINAL REPORT

OF THE

ACTON INDIRECT POTABLE REUSE

WORKING GROUP

NOVEMBER 15, 2005

Executive Summary

Indirect Potable Reuse, which is groundwater recharge via surface or subsurface disposal in order to augment a potable aquifer, has been in practice across the United States for many years in both planned and unplanned fashions. In Massachusetts, according to the Reclaimed Water regulations now under review, Indirect Potable Reuse would be defined as a discharge of highly treated wastewater treatment plant effluent into the Zone II[1] of a wellfield, with no less than a one year travel time[2] from the point of discharge to the point of intake of the well(s), under normal hydrologic conditions.

The Indirect Potable Reuse Group, which met during the summer and early fall of 2005, evaluated information from regulatory and academic sources in an effort to explore the topic for possible future implementation to help solve water resources management difficulties in Acton.

After much discussion, four major areas of concern emerged:

1) Detection, removal and potential health effects of multiple classes of emerging contaminants
2) Timing of implementation in regards to technological, regulatory, and political timelines
3) Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields
4) Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

These four areas represent the foci of the unanswered questions regarding Indirect Potable Reuse and its potential for implementation in Acton. Knowing that a great percentage of these questions need answers, the Group developed a series of four recommendations through which the desired information may be discovered.

The recommendations of the Group are as follows:

1) Inclusion of the concept as a possible solution in the Comprehensive Water Resources Management Plan.

2) Continue to monitor academic and regulatory developments with Indirect Potable Reuse and their possible impact on Acton.

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[1] Zone II – that area of an aquifer which contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated

[2] Travel Time – a figure, calculated by computer modeling, which closely approximates the amount of time a water molecule will take to travel from one point to another in the ground under normal hydrologic conditions.

3) Development of a targeted public outreach and education program related to Indirect Potable Reuse, which could include the provision, if feasible and accepted by the community, of a small-scale pilot study through which "local" answers to important questions may be obtained.

4) In the event Indirect Potable Reuse is chosen for further study by the Town, a standing committee should be seated to direct these efforts. This committee should be similar in makeup to the Sewer Action Committee.

Group Report

Background

The Acton Indirect Potable Reuse Working Group was formed in May, 2005, as a sub-group of the Citizens Advisory Committee (CAC) for the Comprehensive Water Resources Management Plan (CWRMP). The Group was tasked with the evaluation of the concept of Indirect Potable Reuse, prior to any consideration of its implementation within Acton. The Group performed its duties under the following mission statement:

> "To evaluate the potential feasibility of the implementation of Indirect Potable Reuse of highly treated Wastewater Treatment Plant effluent through a discharge to the Zone II of a wellfield; the group will examine the issue from the "human" perspective, looking at the political and public relations impacts of any proposal. Those impacts can then be used to determine whether this concept is feasible as a discharge option within Acton."

The Group members are:

Art Gagne' –	Member of the CAC
Eric Hilfer –	ACES representative and member of the CAC
Joanne Bissetta –	Member of the Acton Board of Health
Greta Eckhardt –	Acton Resident
Pat Cumings –	Member of the CAC

Indirect Potable Reuse – The Concept

The reclamation of treated wastewater as a viable resource has been in practice, in many fashions, for over 50 years around the world. Most projects utilizing Indirect Potable Reuse are located in the western and southwestern United States. The closest planned project of significant size to Acton is the Upper Occoquan Sewage Authority, in suburban Washington D.C., which discharges highly treated effluent into a drinking water reservoir. Interest in Indirect Potable Reuse is growing as the grim picture of the scarcity of the world's water resources emerges. More and more communities are looking to innovative solutions, which allow them to recharge their own aquifers with the wastewater they are producing, thereby preserving the local hydrologic cycle.

Indirect Potable Reuse is only one facet of the larger concept of reclaimed water use. This holistic approach to preservation of the local hydrologic cycle includes reuse options for irrigation – residential, commercial, and agricultural; industrial cooling systems; process water in manufacturing facilities; toilet flushing; snowmaking; and fire protection systems. As greater awareness is achieved in regards to the growing scarcity of water resources, water reclamation practices, like Indirect Potable Reuse, are growing in popularity.

Acton CWRMP

The Acton Comprehensive Water Resources Management Plan (CWRMP) was undertaken as part of the acceptance of the Middle Fort Pond Brook Sewer Project by the Massachusetts Department of Environmental Protection (DEP); to determine the wastewater disposal needs for the entire Town, along with the integrated planning necessary to protect Acton's vital liquid resources for the next 20 years.

The CWRMP is guided by two groups working jointly to develop a cohesive plan. The Project Team – consisting of Acton Health Department staff and Woodard and Curran, Inc. engineers and scientists; and the Citizens Advisory Committee – a group of local stakeholders appointed by the Acton Board of Selectmen to represent the broadest possible range of views in regards to Acton's water resources.

As part of the project, wastewater disposal options were evaluated for centralized and decentralized sewer projects of varying sizes. As Acton is both regulatorily and environmentally limited for surface discharge locations, subsurface discharge must be the primary option examined. Subsurface disposal of treated wastewater requires soils with high permeability in order to efficiently dispose of the effluent from both a cost and footprint perspective. As Acton is solely reliant on groundwater aquifers for its public water supply and those aquifers are located in the most permeable soils, the concept of Indirect Potable Reuse was a concept that could not be ignored as a part of a 20 year water resources management plan.

Indirect Potable Reuse Working Group

A sub-group of the Citizens Advisory Committee was formed in May of 2005 to further examine the issues surrounding Indirect Potable Reuse. This group was established to bring together local stakeholders with a variety of viewpoints.

The group received information packets, consisting of published educational journal articles, copies of government-produced information, and newspaper articles all directly related to Indirect Potable Reuse. Copies of these packets are included in Appendix A of this report. The group met during the summer of 2005, to discuss the issues related to Indirect Potable Reuse in accordance with the group's mission statement.

Discussion

After a review of the academic and professional research presented, the group delineated four major areas of concern, each containing topics requiring further research. These four major areas of concern are:

1) Detection, removal and potential health effects of multiple classes of emerging contaminants
2) Timing of implementation in regards to technological, regulatory, and political timelines
3) Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields
4) Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

Detection and removal of multiple classes of emerging contaminants

Current research by multiple educational and governmental institutions have identified new classes of emerging contaminants in wastewaters, drinking waters, groundwaters, and surface waters. While research into the possible health effects of these categories of contaminants is ongoing, the absence of concrete toxicological and medical data cannot be ignored. These new classes of contaminants include pharmaceuticals, personal care products, their metabolites and their by-products. Some commonly identified compounds are: Triclosan – an antibiotic found in various antibacterial household products; Caffeine; and Estradiol – one of the key hormones in oral contraceptives.

Studies in Europe, Australia, and the United States are in varying stages of completion in regards to the prevalence of these compounds in wastewater treatment plant influent and effluent. The Town of Acton is participating in one of these studies, sponsored by the Johns Hopkins Bloomberg School of Public Health. Further information on this study is included in Appendix B. This study will report the prevalence and concentration of many of the most common classes of these emerging contaminants, allowing the Town to develop a baseline against which to measure future treatment and disposal options. Separate studies are evaluating the capacity of different wastewater treatment technologies and processes to reduce or eliminate these compounds from the waste stream. Initial results of both sets of studies are presented in some of the articles attached to this report in Appendix A. It must be noted, that as with all academic efforts in the scientific realm, these studies are part of a continuum of discovery following a three-step process: detection, assessment of health risks, development of removal strategies.

Timing of implementation in regards to technological, regulatory, and political timelines

Further pursuit of Indirect Potable Reuse as a reclaimed water strategy will require funding that is not currently allocated within the Comprehensive Water Resources Management Plan. The disbursement of this funding will be at the discretion of the citizens of Acton. While economics will affect the local progression of Indirect Potable Reuse, acceptance of IPR at the state and federal levels will also greatly impact any possible implementation or exploration.

As have been shown by other reclaimed water projects around the U.S., a significant public participation and education campaign must be successfully mounted as the first step of any plan. In Acton, this campaign should be spearheaded by an elected or appointed Town official, not a staff member. It is important that the residents of Acton sufficiently understand the concept of Indirect Potable Reuse so that they may both collectively and individually accept or reject the proposal. This local acceptance must also fit into the Town's broader water resources management strategy in regards to the treatment and disposal capacity necessary to provide a solution to the designated needs areas.

Developments on the regulatory front may have the greatest impact on the possibilities for implementation of Indirect Potable Reuse in Acton. The Commonwealth of Massachusetts is currently developing a new set of Reclaimed Water Regulations, which will govern the reuse of highly treated wastewater in a variety of modalities. Indirect Potable Reuse will, of course, be included as a component of these regulations. These regulations will govern the effluent quality required for an Indirect Potable Reuse discharge, and the economic implications of the level of treatment may be the ultimate determining factor in implementation.

From a technological standpoint, the field of wastewater treatment advances each day in its ability to reduce various compounds to increasingly lower concentrations in treatment plant effluent for reuse projects. While it is impossible to predict what effluent limitations would be placed on any proposed Indirect Potable Reuse project in Acton sometime in the future, it can be expected that proven technologies will be available to meet those limits. The current wastewater treatment plant on Adams Street is discharging some of the highest quality effluent in the Commonwealth. The plant consistently discharges effluent with a Total Nitrogen of less than 3 mg/L (where the EPA drinking water standard is 10 mg/L) and 0 colonies of fecal coliform bacteria. These two contaminants, total nitrogen and fecal coliform bacteria, are two of the most important health-impacting contaminants in the drinking water standards as they relate to wastewater treatment. A caveat to this section would be the inclusion of any classes of emerging contaminants in effluent limitations. As stated previously, studies are still underway to determine which treatment process will most efficiently remove which classes of compounds. Further study would be required, possibly at the local level, in order to determine the best course of action in this case.

Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields

The Town of Acton receives 95% of its drinking water from the five Acton Water District wellfields located across the community (see figure 1). As the implementation of Indirect Potable Reuse is evaluated against the needs areas identified in the Comprehensive Water Resources Management Plan, the possibility of lesser discharges spread across multiple wellfields should also be considered. This could allow for broader basin-wide recharge, which could be a benefit to stream flow; and it could also allow for greater proliferation of offsite wastewater disposal solutions for needs areas across Acton.

<u>Coupling implementation with increased water conservation and emerging contaminant source reduction efforts</u>

The possible implementation of an Indirect Potable Reuse project in Acton, and the public participation and education campaign that would precede such a project, could offer a unique outreach opportunities to promote citizen involvement in the protection of water resources. Awareness of the consequences of waterborne disposal of personal care products and pharmaceuticals could lead to a reduction of those products which, along with their metabolites and by-products, make up the classes of emerging contaminants mentioned previously, in the waste stream. As with any other water resources based initiative, it would offer the opportunity to augment the already successful education efforts undertaken by the Acton Water District.

Recommendations

As the Town looks towards the future, all options for beneficial reclamation of wastewater must be evaluated to provide solutions for the 2/3's of the Town identified as having a need for an off-site wastewater disposal solution. This includes Indirect Potable Reuse. No possible solution should be discarded prior to an intensive, citizen-driven, review process.

The group recognizes the contribution that Indirect Potable Reuse could make to the water resource management efforts in Acton. It could serve to recharge aquifers within "stressed" basins and it addresses one of the primary components of the Massachusetts Water Policy, which encourages "keeping water local" by preserving the local hydrologic cycle. Through its deliberations, the group is aware of a number of unanswered questions under each of the four major topic areas.

1) Detection, removal and potential health effects of multiple classes of emerging contaminants
2) Timing of implementation in regards to technological, regulatory, and political timelines
3) Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields
4) Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

As with any major environmental decision, the Town must weigh the risks against the benefits and determine whether to progress forward.

The "local" answers to the questions that arise under these four areas may only be fully answered with a small-scale pilot project developed under close coordination with EPA, DEP, academia, and local officials. This project, if feasible, would serve to provide more

specific answers to many questions, for which the answers may currently come from project implemented in the Western United States. This pilot project would require funding appropriations, and would be subject to the approval of elected officials and their constituents in Acton.
Should the Town choose to further explore implementation of Indirect Potable Reuse, a permanent committee, similar to the Sewer Action Committee, should be appointed by the Board of Selectmen to further evaluate implementation options. This committee should be chaired by an elected or appointed town official who is also a resident of the community. It should include representation from, at least, the following stakeholders:

- Acton Board of Selectmen
- Acton Board of Health
- Acton Citizens for Environmental Safety
- Acton Planning Board
- Acton Water District
- Acton Conservation Commission
- The current incarnation of the Wastewater Citizens Advisory Committee
- Residents from those areas who will benefit from the additional disposal capacity
- Acton residents-at-large

This committee should work with the Town's consultants to cultivate a public participation and education plan devoted to Indirect Potable Reuse, and if the response is positive, should work to bring the project to fruition.

Indirect Potable Reuse, as a concept, holds much promise, not only for the Town of Acton, but for many other communities across New England, as the reality of the scarcity of our liquid reserves becomes readily apparent.

INDIRECT POTABLE REUSE WORKING GROUP
Acton Board of Health - Telephone (978) 264-9634

Meeting Minutes

6/1/2005 Meeting
Room 126
Acton Town Hall

Attendees: *Brent Reagor, Acton Health Department (BR)
Jim Gagliard, Woodard and Curran (JG)
*Greta Eckhardt, Acton Resident, AWD Land-Water Use Committee (GE)
*Eric Hilfer, Acton Resident, ACES, CAC (EH)
Mary Michelman, Acton Resident, ACES (MM)
Peter Shanahan, Acton Resident (PS)
*Art Gagne, Acton Resident, CAC (AG)
*IPR Working Group Member

**With Attachments

The meeting was called to order at 7:15pm

BR introduced the IPR group, the mission statement, and a short synopsis of what is expected of the group by the CAC. He explained that the need for a disposal site for highly treated wastewater treatment plant effluent is the driving factor in the formation of this group.

The members of the group and guests introduced themselves.

The group discussed why the concept of Indirect Potable Reuse is emerging in New England, based upon local and regional hydrologic losses, encouragement from EOEA through the Massachusetts Water Policy, and advocacy from organizations like the New England Water Environment Association.

BR explained the group was seated to discuss this issue as a stakeholder input group, and the group is expected to give a written report to the CAC at their October meeting with one of three answers, along with justification for the answer:

1) Yes, Acton should pursue this concept
2) No, Acton should not pursue this concept
3) This concept is promising for Acton but additional questions must be answered

BR introduced 2 other members, Joanne Bissetta and Pat Cumings, who could not attend the meeting.

GE asked about the current status of regulations regarding reuse in Massachusetts based upon what she had read in the 2004 EPA Reuse Guidelines sections sent to the group. BR explained that MA currently uses a set of "Reclaimed Water Use Standards" set forth in a DEP policy document, and that the state is currently seating a committee to write a set of water reuse regulations.

MM asked is drinking water standards or wastewater standards are applied to effluent discharges in reuse situations. BR explained that drinking water standards are applied in these cases as the DEP develops the permitted limits of various constituents of effluent on a case-by-case basis.

MM and GE expressed concern regarding trace organic chemicals, pharmaceutical by-products, estrogen mimics in effluent. BR explained this is the major emerging issue and the Town is part of a nationwide surveillance study for these compounds being conducted by the Johns Hopkins School of Public Health and will be sampling at the wastewater treatment facility for a broad range of those compounds. PS explained that the USGS and other institutions have done surveillance studies in both surface waters and drinking water supplies and have found part-per trillion levels of some of these compounds in places like Atlanta and the lower Mississippi River basin.

PS explained that these emerging compounds exist currently in most areas of the country and we are just unaware because of the previous inability to analyze water specifically for these compounds.

MM asked about concentration of effluent on wellfields versus a broad distribution of onsite systems. BR, AG, and PS explained that onsite wastewater systems do not achieve levels of treatment anywhere near those of modern wastewater treatment facilities like Acton. GE brought up the inability of control over what people flush down the drain, BR mentioned that in a sewer system this can be somewhat controlled with dilution, and the ability to halt a discharge if harmful contaminants are found.

MM asked about local hydrologic loss within the Fort Pond Brook and Nashoba Brook associated with an IPR discharge at the High Street wellfields. PS stated that an IPR discharge with a shortened travel time from discharge point to well intake could actually benefit the local streams as withdrawals will not have as great as an impact. MM stated she would like to see this topic explored not only at Adams Street, but would rather see a distributed approach. The group continued to discuss the current status of Zone II discharges from both small package treatment facilities and onsite systems across Acton and the current impact of those systems on our wells.

BR stated that this group has also drawn much interest from both the public and private sectors and the group may have some observers or other participants from time to time.

AG and EH asked about the current treatment levels at the WWTF versus what they may have to be in order to achieve IPR. EH spoke about the Denver study mentioned in the EPA Reuse Guidelines on efficacy of treatment processes related to the removal of emerging contaminants. BR stated this is a major research issue now as a multitude of treatment technologies must be tested.

GE spoke about source reduction of contaminants and flow through conservation efforts and public education programs. The group shared favorable opinions on this subject and spoke about the research conducted into wastewater flows by the Health Department.

The group agreed that four major topic areas need to be discussed. In order of importance, they are:

1) Emerging contaminants – detection and removal
2) The timing of the implementation of the project and coincidence with regulatory, treatment technology, and political timelines
3) Source reduction efforts for water use and pollutant removal
4) Centralized IPR versus Decentralized IPR

The group agreed to meet approximately once every three weeks, with the coordination to come from BR. One of the next meetings will be held at the Acton WWTF.

BR thanked the members and guests for attending and stated the next meeting date will be sent out shortly.

The meeting adjourned at 845pm

Respectfully Submitted,

Brent L. Reagor

INDIRECT POTABLE REUSE WORKING GROUP

Acton Board of Health - Telephone (978) 264-9634

Meeting Minutes

6/30/2005 Meeting
Room 126
Acton Town Hall

Attendees: *Brent Reagor, Acton Health Department (BR)
*Greta Eckhardt, Acton Resident, AWD Land-Water Use Committee (GE)
*Eric Hilfer, Acton Resident, ACES, CAC (EH)
*Art Gagne, Acton Resident, CAC (AG)
*Joanne Bissetta, Acton Resident, BOH (JB)
Mary Michelman, Acton Resident, ACES (MM)

*IPR Working Group Member

The meeting was called to order at 7:32pm

The group reviewed the minutes from the previous meeting. Minor changes were made to the discussion on reuse and its impact on local hydrologic loss, along with a change in phrasing for one of the three possible answers the group may issue in its final report.

Discussion of the minutes spurred discussion of the title of the group. MM states we should change the title, AG and GE both stated that the most important title was the title of the final report. AG stated that if people do not understand what the title means, one of the hurdles we must overcome is education about the definition of indirect potable reuse.

The group discussed the issue of local hydrologic impacts related to a centralized IPR discharge. MM stated she would like to see more about this issue, but stated that an IPR discharge at the High Street wellfields may have a beneficial impact of mounding the groundwater and creating a hydrologic gradient, thereby preventing significant intrusion of contaminant plumes.

BR updated the group about the Johns Hopkins School of Public Health (JHSPH) study. The samples had been sent to Baltimore for analysis. He has also been asked to join the statewide Task Force that has been seated to author Water Reuse regulations for the Commonwealth. He also stated that the Metropolitan Area Planning Council (MAPC) is looking at all forms of water reuse, including greywater, stormwater, and wastewater along the lines of the Massachusetts Water Policy, and that MADEP is in the process of hiring a Watershed Outreach Coordinator to encourage reuse.

The group began a discussion of the four articles sent out with the packets. BR gave a short introduction of each article. GE stated she was surprised by two things: 1) the prevalence of caffeine, and the fact that the USGS study had positive results in every sample analyzed. AG stated that he believes the discovery of emerging contaminants in effluent will always be a continuum as new analytical methods are developed and new compounds are created. MM stated there is a lag time between production of new compounds and development of revised analytical methods and the presence of no data does not mean it is not harmful.

AG stated that the group is not conversant in the topics discussed in the scientific articles. EH stated the results from the JHSPH study will be of some help. AG would like to see more fact sheets and FAQ documents. GE would like to see guiding questions or points to consider sent out with the articles, prior to the meetings. BR agreed to do this for the current articles and any future research.

GE asked what would be considered the major classes of emerging compounds would be. BR stated, as he sees it, they are: Endocrine disruptors/mimics, Pharmaceutical compounds and their metabolites and by-products, and Personal care products and their by-products. However, compounds may be members of more than one class. AG stated that medicine disposal practices (i.e. flushing unused medications) may lead to detection of these contaminants at higher levels. BR stated that the State of Maine has developed a public relations campaign to discourage people from flushing unused medications for just that reason.

MM stated she was intrigued about research into the effects of wastewater treatment processes on the compounds in question. BR stated he would make sure to include information on that in a future packet. AG cautioned that with the continuum of discovery in science, Acton should be careful not to develop the "guinea pig" mentality. GE asked about heavy metals and pesticides in WWTF effluent. BR stated that these must come from an industrial source, and there are no so such sources currently connected or planned to be connected to the sewer system.

The group settled on July 20 and August 18 as the next two meeting dates.

The meeting adjourned at 8:54pm.

Respectfully Submitted,

Brent L. Reagor

INDIRECT POTABLE REUSE WORKING GROUP
Acton Board of Health - Telephone (978) 264-9634

Meeting Minutes

7/20/2005 Meeting
Room 121
Acton Town Hall

Attendees: *Brent Reagor, Acton Health Department (BR)
*Greta Eckhardt, Acton Resident, AWD Land-Water Use Committee (GE)
*Joanne Bissetta, Acton Resident, BOH (JB)

*IPR Working Group Member

The meeting was called to order at 7:30pm

Due to minimal attendance, the group decided that this meeting would not be held.

The meeting adjourned at 7:35pm.

Respectfully Submitted,

Brent L. Reagor

INDIRECT POTABLE REUSE WORKING GROUP
Acton Board of Health - Telephone (978) 264-9634

Meeting Minutes

8/18/2005 Meeting
Conference Room
Acton Wastewater Treatment Plan

Attendees: *Brent Reagor, Acton Health Department (BR)
*Greta Eckhardt, Acton Resident, AWD Land-Water Use Committee (GE)
*Art Gagne, Acton Resident, CAC (AG)
*Joanne Bissetta, Acton Resident, BOH (JB)
*Pat Cumings, Acton Resident, CAC (PC)

*IPR Working Group Member

The meeting was called to order at 7:40pm

The group toured the Acton Wastewater Treatment Facility. During the tour, applications of reuse in relation to the design of the current treatment facility were discussed.

After the tour, BR updated the group on the first meeting of the Massachusetts Reclaimed Water Task Force and the status of the new reclaimed water regulations.

The meeting adjourned at 8:45pm.

Respectfully Submitted,

Brent L. Reagor

INDIRECT POTABLE REUSE WORKING GROUP
Acton Board of Health - Telephone (978) 264-9634

Meeting Minutes

10/25/2005 Meeting
Room 126
Acton Town Hall

Attendees: *Brent Reagor, Acton Health Department (BR)
*Greta Eckhardt, Acton Resident, AWD Land-Water Use Committee (GE)
*Art Gagne, Acton Resident, CAC (AG)
*Joanne Bissetta, Acton Resident, BOH (JB)
*Eric Hilfer, Acton Resident, ACES (EH)
Mary Michelman, Acton Resident, ACES (MM)

*IPR Working Group Member

The meeting was called to order at 7:30pm

BR began by thanking the group for all their hard work throughout the past few months and requested that the review of the final report proceed sequentially through each section.

Multiple group members suggested the inclusion of a "Executive Summary" at the beginning of the report.

EH and GE asked about providing definitions for some of the technical water supply terms like travel time and Zone II.

AG suggested that the definitions be contained in footnotes.

MM suggested that Topic area #1: "Detection and removal of multiple classes of emerging contaminants" be expanded to include information about potential health effects.

GE and AG suggested that language be added to the discussion of Topic area #1 that quantifies that this process will always be a continuum of discovery.

Members of the group questioned who was meant by "The Town" throughout the document. It was explained that this was the citizens of Acton and elaboration would be included.

AG felt it was more important to stress the overall performance of the WWTF on Adams Street than information regarding one sample. This performance should be related to the drinking water standards set by EPA.

The group expressed its concern that the discussion of Topic #4 should be rephrased to be more of an "if…then" paragraph.

MM wanted the report to stress the importance of IPR as a method of wastewater disposal.

AG discussed the feasibility of a small-scale pilot program that would provide local answers to some of the important questions regarding the project.

The meeting adjourned at 9:10pm.

Respectfully Submitted,

Brent L. Reagor

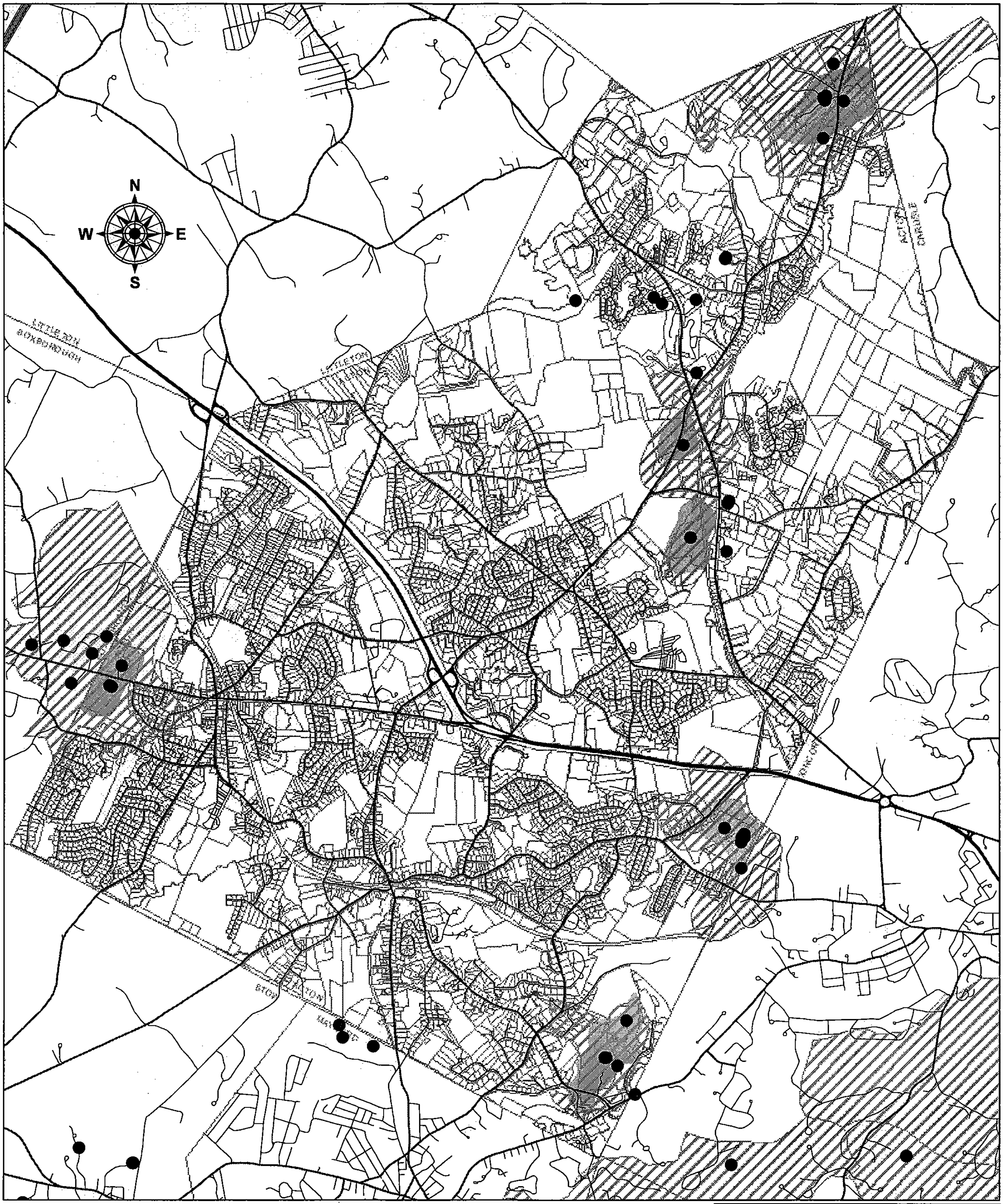


Figure 1:
Aquifer Resource Areas
Acton, MA

APPENDIX A

INFORMATIONAL PACKETS FROM MEETINGS

MEETING MINUTES

ACTON BOARD OF HEALTH

Douglas Halley
Health Director

472 Main Street
Acton, MA 01720

Telephone 978-264-9634
Fax 978-264-9630

Town of Acton
Comprehensive Water Resources Management Plan
Citizens Advisory Committee
Indirect Potable Reuse Working Group

Meeting #1
6/1/2005
Acton Town Hall, Room 126

Call to Order 7pm

I. Introductions

II. Working Group Mission Statement
--Comments from members

III. Timeline

IV. Goals

V. IPR Q&A

VI. Set meeting schedule

Adjourn by 830pm

MEMORANDUM

Acton Board of Health - Telephone (978) 264-9634

TO: Members of the Reuse Working Group

FROM: Brent L. Reagor, R.S.

RE: Info Packet
First Meeting Date

DATE: May 13, 2005

Enclosed with this memo you will find ~50 pages selected from the 2004 EPA Guidelines for Water Reuse. These are the pertinent pages dealing directly with the concept of Indirect Potable Reuse. This is your "master packet" for the duration of the sub-group. This packet will serve as a general reference, and as an introduction to the concepts we will discuss. If you have any questions about the content, please get in touch with me.

I would like to schedule the first meeting for June 1st or 2nd. I will send out an email on Monday, May 16 regarding this. I expect the meeting to start around 7 pm (or earlier if that suits everyone) and last 1.5 – 2 hours.

Welcome aboard!

2.6.3 Groundwater Recharge for Indirect Potable Reuse

As mentioned in Section 2.5.1, Methods of Groundwater Recharge, groundwater recharge via surface spreading or injection has long been used to augment potable aquifers. Although both planned and unplanned recharge into potable aquifers has occurred for many years, few health-related studies have been undertaken. The most comprehensive health effects study of an existing groundwater recharge project was carried out in Los Angeles County, California, in response to uncertainties about the health consequences of recharge for potable use raised by a California Consulting Panel in 1975-76.

In November 1978, the County Sanitation Districts of Los Angeles County (Districts) initiated the "Health Effects Study," a $1.4-million-project designed to evaluate the health effects of using treated wastewater for groundwater recharge based on the recommendations of the 1976 Consulting Panel. The focus of the study was the Montebello Forebay Groundwater Replenishment Project, located within the Central Groundwater Basin in Los Angeles County, California. Since 1962, the Districts' reclaimed water has been blended with imported river water (Colorado River and State Project water) and local stormwater runoff, and used for replenishment purposes. The project is managed by the Water Replenishment District of Southern California (WRD) and is operated by the Los Angeles County Department of Public Works. The Central Groundwater Basin is adjudicated; 85 groundwater agencies operate over 400 active wells. Water is percolated into the groundwater using 2 sets of spreading grounds: (1) the Rio Hondo Spreading Grounds consist of 570 acres (200 hectares) with 20 individual basins and (2) the San Gabriel River Spreading Grounds consist of 128 acres (52 hectares) with 3 individual basins and portions of the river. The spreading basins are operated under a wetting/drying cycle designed to optimize inflow and discourage the development of vectors.

From 1962 to 1977, the water used for replenishment was disinfected secondary effluent. Filtration (dual-media or mono-media) was added later to enhance virus inactivation during final disinfection. By 1978, the amount of reclaimed water spread averaged about 8.6 billion gallons per year (33×10^3 m^3 per year) or 16 percent of the total inflow to the groundwater basin with no more than about 10.7 billion gallons (40 million m^3) of reclaimed water spread in any year. The percentage of reclaimed water contained in the extracted potable water supply ranged from 0 to 11 percent on a long-term (1962-1977) basis (Crook *et al.*, 1990).

The primary goal of the Health Effects Study was to provide information for use by health and regulatory authorities to determine if the use of reclaimed water for the Montebello Forebay Project should be maintained at the present level, cut back, or expanded. Specific objectives were to determine if the historical level of reuse had adversely affected groundwater quality or human health, and to estimate the relative impact of the different replenishment sources on groundwater quality. Specific research tasks included:

- Water quality characterizations of the replenishment sources and groundwater in terms of their microbiological and chemical content.
- Toxicological and chemical studies of the replenishment sources and groundwater to isolate and identify organic constituents of possible health significance
- Field studies to evaluate the efficacy of soil for attenuating chemicals in reclaimed water
- Hydrogeologic studies to determine the movement of reclaimed water through groundwater and the relative contribution of reclaimed water to municipal water supplies
- Epidemiologic studies of populations ingesting reclaimed water to determine whether their health characteristics differed significantly from a demographically similar control population

During the course of the study, a technical advisory committee and a peer review committee reviewed findings and interpretations. The final project report was completed in March, 1984 as summarized by Nellor *et al.* in 1985. The results of the study did not demonstrate any measurable adverse effects on either the area groundwater or health of the people ingesting the water. Although the study was not designed to provide data for evaluating the impact of an increase in the proportion of reclaimed water used for replenishment, the results did suggest that a closely monitored expansion could be implemented.

In 1986, the State Water Resources Control Board, Department of Water Resources and Department of Health Services established a Scientific Advisory Panel on Groundwater Recharge to review the report and other pertinent information. The Panel concluded that it was comfortable with the safety of the product water and the continuation of the Montebello Forebay Project. The Panel felt that the risks, if any, were small and probably not dissimilar from those that could be hypothesized for commonly used surface waters.

Based on the results of the Health Effects Study and recommendations of the Scientific Advisory Panel, the Regional Water Quality Control Board in 1987 authorized an increase in the annual quantity of reclaimed water to be used for replenishment from 32,700 acre-feet per year to 50,000 acre-feet per year (20,270 gpm to 31,000 gpm or 1,280 to 1,955 l/s). In 1991, water reclamation requirements for the project were revised to allow for recharge up to 60,000 acre-feet per year (37,200 gpm or 2,350 l/s) and 50 percent reclaimed water in any one year as long as the running 3-year total did not exceed 150,000 acre-feet per year (93,000 gpm or 5,870 l/s) or 35 percent reclaimed water. The average amount of reclaimed water spread each year is about 50,000 acre-feet per year (31,000 gpm or 1,955 l/s). Continued evaluation of the project is being provided by an extensive sampling and monitoring program, and by supplemental research projects pertaining to percolation effects, epidemiology, and microbiology.

The Rand Corporation has conducted additional health studies for the project as part of an ongoing effort to monitor the health of those consuming reclaimed water in Los Angeles County (Sloss *et al.*, 1996 and Sloss *et. al.*, 1999). These studies looked at health outcomes for 900,000 people in the Central Groundwater Basin who are receiving some reclaimed water in their household water supplies. These people account for more than 10 percent of the population of Los Angeles County. To compare health characteristics, a control area of 700,000 people that had similar demographic and socioeconomic characteristics was selected, but did not receive reclaimed water. The results from these studies have found that, after almost 30 years of groundwater recharge, there is no association between reclaimed water and higher rates of cancer, mortality, infectious disease, or adverse birth outcomes.

The Districts, along with water and wastewater agencies and researchers in 3 western states, are currently conducting research to evaluate the biological, chemical, and physical treatment processes that occur naturally as the reclaimed water passes through the soil on the way to the groundwater. The SAT Project was developed to better understand the impact of SAT on water quality in terms of chemical and microbial pollutants (see Case Study 2.7.16). This work will continue to address emerging issues such as the occurrence and significance of pharmaceutically active compounds (including endocrine disruptors and new disinfection byproducts) and standardized monitoring techniques capable of determining pathogen viability. The Groundwater Replenishment (GWR) System is an innovative approach to keeping the Orange County, California, groundwater basin a reliable source for meeting the region's future potable water needs (Chalmers *et al.*, 2003). A joint program of the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD), the GWR System will protect the groundwater from further degradation due to seawater intrusion and supplement existing water supplies by providing a new, reliable, high-quality source of water to recharge the Orange County Groundwater Basin (see Case Study 2.7.15).

2.6.4 Direct Potable Water Reuse

Direct potable reuse is currently practiced in only one city in the world, Windhoek, Namibia. This city uses direct potable reuse on an intermittent basis only. In the U.S., the most extensive research focusing on direct potable reuse has been conducted in Denver, Colorado; Tampa, Florida; and San Diego, California. A considerable investment in potable reuse research has been made in Denver, Colorado, over a period of more than 20 years. This research included operation of a 1-mgd (44-l/s) reclamation plant in many different process modes over a period of about 10 years (Lauer, 1991). The product water was reported to be of better quality than many potable water sources in the region. The San Diego Total Resource Recovery Project was executed to demonstrate the feasibility of using natural systems for secondary treatment with subsequent advanced wastewater treatment to provide a water supply equivalent or better than the quality of imported water supplied to the region (WEF/AWWA, 1988). **Tables 2-11** and **2-12** show the advanced wastewater treatment effluent concentrations of minerals, metals, and trace organics for the San Diego Project.

Microbial analysis performed over a 2.5-year period, showed that water quality of advanced wastewater treatment effluent was low in infectious agents. Specifically, research showed:

- Spiking studies were conducted to determine the removal level of viruses. Results of 4 runs showed an overall virus removal rate through the primary, secondary, and advanced wastewater treatment plants of between 99.999 9 percent and 99.999 99 percent. Levels of removal were influenced by the number of viruses introduced. Viruses were not detected in more than 20.2 x 10^4 l of sample.

- Enteric bacterial pathogens (that is, *Salmonella*, *Shigella*, and *Campylobacter*) were not detected in 51 samples of advanced wastewater treatment effluent.

- Protozoa and metazoa of various types were absent

3.1.1 Preliminary Investigations

This is a fact-finding phase, meant to rough out physical, economic, and legal/institutional issues related to water reuse planning. The primary task is to locate all potential sources of effluent for reclamation and reuse and all potential markets for reclaimed water. It is also important to identify institutional constraints and enabling powers that might affect reuse. This phase should be approached with a broad view. Exploration of all possible options at this early planning stage will establish a practical context for the plan and also help to avoid creating dead-ends in the planning process.

Questions to be addressed in this phase include:

- What local sources of effluent might be suitable for reuse?
- What are the potential local markets for reclaimed water?
- What other nontraditional freshwater supplies are available for reuse?
- What are the present and projected reliability benefits of fresh water in the area?
- What are the present and projected user costs of fresh water in the area?
- What sources of funding might be available to support the reuse program?
- How would water reuse "integrate," or work in harmony with present uses of other water resources in the area?
- What public health considerations are associated with reuse, and how can these considerations be addressed?
- What are the potential environmental impacts of water reuse?
- What type of reuse system is likely to attract the public's interest and support?
- What existing or proposed laws and regulations affect reuse possibilities in the area?
- What local, state, or federal agencies must review and approve implementation of a reuse program?
- What are the legal liabilities of a purveyor or user of reclaimed water?

The major task of this phase involves conducting a preliminary market assessment to identify potential reclaimed water users. This calls for defining the water market through discussions with water wholesalers and retailers, and by identifying major water users in the market. The most common tools used to gather this type of information are telephone contacts and/or letters to potential reuse customers. Often, a follow-up phone contact is needed in order to determine what portion of total water use might be satisfied by reclaimed water, what quality of water is required for each type of use, and how the use of reclaimed water might affect the user's operations or discharge requirements.

This early planning stage is an ideal time to begin to develop or reinforce strong working relationships, among wastewater managers, water supply agencies, and potential reclaimed water users. These working relationships will help to develop solutions that best meet a particular community's needs.

Potential users will be concerned with the quality of reclaimed water and reliability of its delivery. They will also want to understand state and local regulations that apply to the use of reclaimed water. Potential customers will also want to know about constraints to using reclaimed water. They may have questions about connection costs or additional wastewater treatment costs that might affect their ability to use the product.

3.1.2 Screening of Potential Markets

The essence of this phase is to compare the unit costs of fresh water to a given market and the unit costs of reclaimed water to that same market. On the basis of information gathered in preliminary investigations, one or more "intuitive projects" may be developed that are clear possibilities, or that just "seem to make sense." For example, if a large water demand industry is located next to a wastewater treatment plant, there is a strong potential for reuse. The industry has a high demand for water, and costs to convey reclaimed water would be low. Typically, the cost-effectiveness of providing reclaimed water to a given customer is a function of the customer's potential demand versus the distance of the customer from the source of reclaimed water. In considering this approach, it should be noted that a concentration of smaller customers might represent a service area that would be as cost-effective to serve as a single large user. Once these anchor customers are identified, it is often beneficial to search for smaller customers located along the proposed path of the transmission system.

The value of reclaimed water – even to an "obvious" potential user will depend on the:

- Quality of water to be provided, as compared to the user's requirements
- Quantity of fresh water available and the ability to meet fluctuating demand
- Effects of laws that regulate reuse, and the attitudes of agencies responsible for enforcing applicable laws
- Present and projected future cost of fresh water to the user

These questions all involve detailed study, and it may not be cost-effective for public entities to apply the required analyses to every possible reuse scenario. A useful first step is to identify a wide range of candidate reuse systems that might be suitable in the area and to screen these alternatives. Then, only the most promising project candidates move forward with detailed evaluations.

In order to establish a comprehensive list of reuse possibilities, the following factors should be taken into account:

- Levels of treatment – if advanced wastewater treatment (AWT) is currently required prior to discharge of effluent, cost savings might be available if a market exists for secondary treated effluent.
- Project size – the scale of reuse can range from conveyance of reclaimed water to a single user up to the general distribution of reclaimed water for a variety of nonpotable uses.
- Conveyance network – different distribution routes will have different advantages, taking better advantage of existing rights-of-way, for example, or serving a greater number of users.

In addition to comparing the overall costs estimated for each alternative, several other criteria can be factored into the screening process. Technical feasibility may be used as one criterion, and the comparison of estimated unit costs of reclaimed water with unit costs of fresh water, as another. An even more complex screening process may include a comparison of weighted values for a variety of objective and subjective factors, such as:

- How much flexibility would each system offer for future expansion or change?
- How much fresh water use would be replaced by each system?
- How complicated would program implementation be, given the number of agencies that would be involved in each proposed system?
- To what degree would each system advance the "state-of-the-art" in reuse?
- What level of chemical or energy use would be associated with each system?
- How would each system impact land use in the area?

Review of user requirements could enable the list of potential markets to be reduced to a few selected markets for which reclaimed water could be of significant value. The Bay Area Regional Water Recycling Program (BARWRP) in San Francisco, California used a sophisticated screening and alternative analysis procedure. This included use of a regional GIS-based market assessment, a computer model to evaluate cost-effective methods for delivery, detailed evaluation criteria, and a spreadsheet-based evaluation decision methodology (Bailey *et al.*, 1998). The City of Tucson, Arizona, also used a GIS database to identify parcels such as golf courses, parks, and schools with a potential high demand for turf irrigation. In Cary, North Carolina, the parcel database was joined to the customer-billing database allowing large water users to be displayed on a GIS map. This process was a key element in identifying areas with high concentrations of dedicated irrigation meters on the potable water system (CDM, 1997). As part of an evaluation of water reclamation by the Clark County Sanitation District, Nevada, the alternatives analysis was extended beyond the traditional technical, financial, and regulatory considerations to include intangible criteria such as:

- Public acceptance including public education
- Sensitivity to neighbors
- Administrative agencies for the project
- Institutional arrangements to implement
- Impacts to existing developments as facilities are constructed

Source: Pai *et. al.*, 1996

3.1.3 Detailed Evaluation of Selected Markets

The evaluation steps contained in this phase represent the heart of the analyses necessary to shape a reuse program. At this point, a certain amount of useful data should be known including the present freshwater consumption and costs for selected potential users and a ranking of "most-likely" projects. In this phase, a more detailed look at conveyance routes and storage requirements for each selected system will help to refine preliminary cost estimates. Funding and benefit options can be compared, user costs developed, and a comparison made between the costs and benefits of fresh water versus reclaimed water for each selected system. The detailed evaluation will also look in more detail at the environmental, institutional, and social aspects of each project.

Questions that may need to be addressed as part of the detailed evaluation include:

- What are the specific water quality requirements of each user? What fluctuation can be tolerated?

- What is the daily and seasonal water use demand pattern for each potential user?

- Can fluctuations in demand best be met by pumping capacity or by using storage? Where would storage facilities best be located?

- If additional effluent treatment is required, who should own and operate the additional treatment facilities?

- What costs will the users in each system incur in connecting to the reclaimed water delivery system?

- Will industrial users in each system face increased treatment costs for their waste streams as a result of using reclaimed water? If so, is increased internal recycling likely, and how will this affect their water use?

- Will customers in the service area allow project costs to be spread over the entire service area?

- What interest do potential funding agencies have in supporting each type of reuse program being considered? What requirements would these agencies impose on a project eligible for funding?

- Will use of reclaimed water require agricultural users to make a change to their irrigation patterns or to provide better control of any irrigation discharges?

- What payback period is acceptable to users who must invest in additional facilities for onsite treatment, storage, or distribution of reclaimed water?

- What are the prospects of industrial source control measures in the area, and would institution of such measures reduce the additional treatment steps necessary to permit reuse?

- How "stable" are the potential users in each selected candidate reuse system? Are they likely to remain in their present locations? Are process changes being considered that might affect their ability to use reclaimed water?

Many of these questions can be answered only after further consultation with water supply agencies and prospective users. Both groups may seek more detailed information as well, including the preliminary findings made in the first 2 phases of effort. The City of Tampa set the following goals and objectives for their first residential reclaimed water project:

- Demonstrate customer demand for the water

- Demonstrate customer willingness to pay for the service

- Show that the project would pay for itself and not be subsidized by any utility customer not receiving reclaimed water

- Make subscription to the reclaimed water service voluntary

Source: Grosh *et. al.*, 2002

Detailed evaluations should lead to a preliminary assessment of technical feasibility and costs. Comparison among alternative reuse programs will be possible, as well as preliminary comparison between these programs and alternative water supplies, both existing and proposed. In this phase, economic comparisons, technical optimization steps, and environmental assessment activities leading to a conceptual plan for reuse might be accomplished by working in conjunction with appropriate consulting organizations.

3.2 Potential Uses of Reclaimed Water

Urban public water supplies are treated to satisfy the requirements for potable use. However, potable use (drinking, cooking, bathing, laundry, and dishwashing) represents only a fraction of the total daily residential use of treated potable water. The remainder may not require water of potable quality. In many cases, water used for nonpotable purposes, such as irrigation, may be drawn from the same ground or surface source as municipal supplies, creating an indirect demand on potable supplies. The *Guidelines* examine opportunities for substituting reclaimed water for potable water supplies where potable water quality is not required. Specific reuse opportunities include:

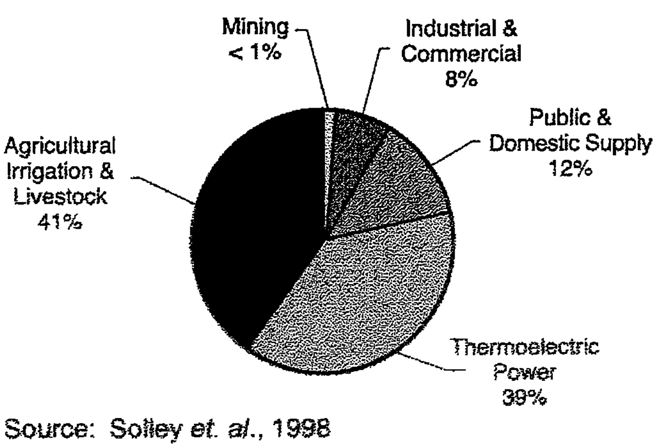
- Urban
- Industrial
- Agricultural
- Environmental and Recreational
- Groundwater Recharge
- Augmentation of Potable Supplies

The technical issues associated with the implementation of each of these reuse alternatives are discussed in detail in Chapter 2. The use of reclaimed water to provide both direct and indirect augmentation of potable supplies is also presented in Chapter 2.

3.2.1 National Water Use

Figure 3-2 presents the national pattern of water use in the U.S. according to the U.S. Geological Survey (Solley *et al.*, 1998). Total water use in 1995 was 402,000 mgd (152×10^7 m^3/d) with 341,000 mgd (129×10^7 m^3/d) being fresh water and 61,000 mgd (23×10^7 m^3/d) saline water. The largest freshwater demands were associated with agricultural irrigation/livestock and thermoelectric power, representing 41 and 39 percent, respectively, of the total freshwater use in the United States. Public and domestic water uses constitute 12 percent of the total demand.

Figure 3-2. 1995 U.S. Fresh Water Demands by Major Uses



Source: Solley *et. al.*, 1998

The remainder of the water use categories are mining and industrial/commercial with 8 percent of the demand. The 2 largest water use categories, thermoelectric power and agricultural irrigation, account for 80 percent of the total water use. These water uses present a great potential for supplementing with reclaimed water.

Figure 3-3 provides a flow chart illustrating the source, use, and disposition of fresh water in the U.S. Of the 341,000 mgd (129×10^7 m^3/d) of fresh water used in the U.S., only 29 percent is consumptively used and 71 percent is return flow. This amounts to a total of 241,000 mgd (91×10^7 m^3/d), of which 14 percent originates from domestic and commercial water use. Domestic wastewater comprises a large portion of this number.

Figure 3-4 shows estimated wastewater effluent produced daily in each state, representing the total potential reclaimed water supply from existing wastewater treatment facilities. **Figure 3-5** shows the estimated water demands by state in the United States. Estimated water demands are equal to the total fresh and saline withdrawals for all water-use categories (public supply, domestic, commercial, irrigation, livestock, industrial, mining, and thermoelectric power). Areas where high water demand exists might benefit by augmenting existing water supplies with reclaimed water. Municipalities in coastal and arid states, where water demands are high and freshwater supplies are limited, appear to have a reasonable supply of wastewater effluent that could, through proper treatment and reuse, greatly extend their water supplies.

Arid regions of the U.S. (such as the southwest) are candidates for wastewater reclamation, and significant reclamation projects are underway throughout this region. Yet, arid regions are not the only viable candidates for water reuse. Local opportunities may exist for a given municipality to benefit from reuse by extending local water supplies and/or reducing or eliminating surface water discharge. For example, the City of Atlanta, Georgia, located in the relatively water-rich southeast, has experienced water restrictions as a result of recurrent droughts. In south Florida, subtropical conditions and almost 55 inches (140 cm) per year of rainfall suggest an abundance of water; however, landscaping practices and regional hydrogeology combine to result in frequent water shortages and restrictions on water use. Thus, opportunities for water reclamation and reuse must be examined on a local level to judge their value and feasibility.

3.2.2 Potential Reclaimed Water Demands

Residential water demand can further be categorized as indoor use, which includes toilet flushing, cooking, laundry, bathing, dishwashing, and drinking; or outdoor use, of tourists, and seasons of high flow do not necessarily correspond with seasons of high irrigation demand. **Figure 3-9** illustrates the fluctuations in reclaimed water supply and irrigation demand in a southwest Florida community. Treatment facilities serving college campuses, resort areas, etc. also experience significant fluctuations in flow throughout the year. Where collection systems are prone to infiltration and inflow, significant fluctuations in flow may occur during the rainy season.

Information about flow quantities and fluctuations is critical in order to determine the size of storage facilities needed to balance supply and demand in water reuse systems. A more detailed discussion of seasonal storage requirements is provided in Section 3.5. Operational storage requirements to balance diurnal flow variations are detailed in Section 3.6.3.

3.3.2.4 Industrial Wastewater Contributions

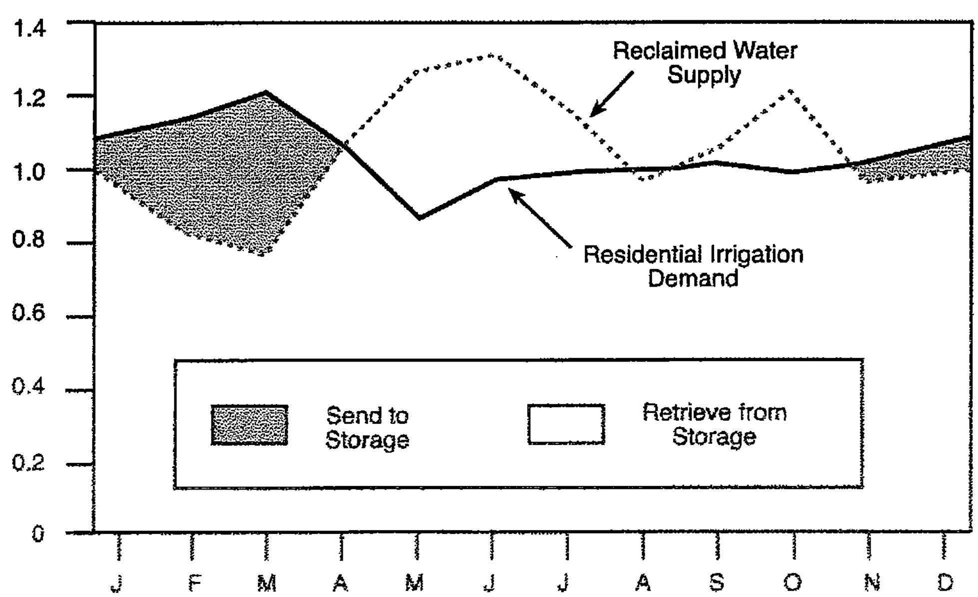
Industrial waste streams differ from domestic wastewater in that they may contain relatively high levels of elements and compounds, which may be toxic to plants and animals or may adversely impact treatment plant performance. Where industrial wastewater flow contributions to the WWTF are significant, reclaimed water quality may be affected. The degree of impact will, of course, depend on the nature of the industry. A rigorous pretreatment program is required for any water reclamation facility that receives industrial wastes to ensure the reliability of the biological treatment processes by excluding potentially toxic levels of pollutants from the sewer system. Planning a reuse system for a WWTF with substantial industrial flows will require identification of the constituents that may interfere with particular reuse applications, and appropriate monitoring for parameters of concern. Wastewater treatment facilities receiving substantial amounts of high-strength industrial wastes may be limited in the number and type of suitable reuse applications.

3.4 Treatment Requirements for Water Reuse

One of the most critical objectives in any reuse program is to ensure that public health protection is not compromised through the use of reclaimed water. To date there have not been any confirmed cases of infectious disease resulting from the use of properly treated reclaimed water in the U.S. Other objectives, such as preventing environmental degradation, avoiding public nuisance, and meeting user requirements, must also be satisfied, but the starting point remains the safe delivery and use of properly treated reclaimed water.

Protection of public health is achieved by: (1) reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in the reclaimed water, (2) controlling chemical constituents in reclaimed water, and/or (3) limiting public exposure (contact, inhalation, ingestion) to reclaimed water. Reclaimed water projects may vary significantly in the level of human exposure incurred, with a corresponding variation in the potential for health risks. Where human exposure is likely in a reuse application, reclaimed water should be treated to a high degree prior to its use. Conversely, where public access to

Figure 3-9. Reclaimed Water Supply vs. Irrigation Demand



a reuse site can be restricted so that exposure is unlikely, a lower level of treatment may be satisfactory, provided that worker safety is not compromised.

Determining the necessary treatment for the intended reuse application requires an understanding of the:

- Constituents of concern in wastewater
- Levels of treatment and processes applicable for reducing these constituents to levels that achieve the desired reclaimed water quality

3.4.1 Health Assessment of Water Reuse

The types and concentrations of pathogenic organisms found in raw wastewater are a reflection of the enteric organisms present in the customer base of the collection system. Chemical pollutants of concern may also be present in untreated wastewater. These chemicals may originate from any customer with access to the collection system, but are typically associated with industrial customers. Recent studies have shown that over-the-counter and prescription drugs are often found in wastewater.

The ability for waterborne organisms to cause disease is well established. Our knowledge of the hazards of chemical pollutants varies. In most cases, these concerns are based on the potential that adverse health effects may occur due to long-term exposure to relatively low concentrations. In addition, chemicals capable of mimicking hormones have been shown to disrupt the endocrine systems of aquatic animals.

In order to put these concerns into perspective with respect to water reclamation, it is important to consider the following questions.

- What is the intended use of the reclaimed water?

  Consideration should be given to the expected degree of human contact with the reclaimed water. It is reasonable to assume that reclaimed water used for the irrigation of non-food crops on a restricted agricultural site may be of lesser quality than water used for landscape irrigation at a public park or school, which in turn may be of a lesser quality than reclaimed water intended to augment potable supplies.

- Given the intended use of reclaimed water, what concentrations of microbiological organisms and chemicals of concern are acceptable?

  Reclaimed water quality standards have evolved over a long period of time, based on both scientific studies and practical experience. Chapter 4 provides a summary of state requirements for different types of reuse projects. While requirements might be similar from state to state, allowable concentrations and the constituents monitored are state-specific. Chapter 4 also provides suggested guidelines for reclaimed water quality as a function of use.

- Which treatment processes are needed to achieve the required reclaimed water quality?

  While it must be acknowledged that raw wastewater may pose a significant risk to public health, it is equally important to point out that current treatment technologies allow water to be treated to almost any quality desired. For many uses of reclaimed water, appropriate water quality can be achieved through conventional, widely practiced treatment processes. Advanced treatment beyond secondary treatment may be required as the level of human contact increases.

- Which sampling/monitoring protocols are required to ensure that water quality objectives are being met?

  As with any process, wastewater reuse programs must be monitored to confirm that they are operating as expected. Once a unit process is selected, there are typically standard Quality Assurance/Quality Control (QA/QC) practices to assure that the system is functioning as designed. Reuse projects will often require additional monitoring to prevent the discharge of substandard water to the reclamation system. On-line, real-time water quality monitoring is typically used for this purpose.

3.4.1.1 Mechanism of Disease Transmission

For the purposes of this discussion, the definition of disease is limited to illness caused by microorganisms. Health issues associated with chemical constituents in reclaimed water are discussed in Section 3.4.1.7. Diseases associated with microorganisms can be transmitted by water to humans either directly by ingestion, inhalation, or skin contact of infectious agents, or indirectly by contact with objects or individuals previously contaminated. The following circumstances must occur for an individual to become infected through exposure to reclaimed water: (a) the infectious agent must be present in the community and, hence, in the wastewater from that community; (b) the agents must survive, to a significant degree, all of the wastewater treatment processes to which they are exposed; (c) the individual must either directly or indirectly come into contact with the reclaimed water; and (d) the agents must be present in sufficient numbers to cause infection at the time of contact.

The primary means of ensuring reclaimed water can be used for beneficial purposes is first to provide the appropriate treatment to reduce or eliminate pathogens. Treatment processes typically employed in water reclamation systems are discussed below and in Section 3.4.2. Additional safeguards are provided by reducing the level of contact with reclaimed water. Section 3.6 discusses a variety of cross-connection control measures that typically accompany reuse systems.

The large variety of pathogenic microorganisms that may be present in raw domestic wastewater is derived principally from the feces of infected humans and primarily transmitted by consumption. Thus, the main transmission route is referred to as the "fecal-oral" route. Contaminated water is an important conduit for fecal-oral transmission to humans and occurs either by direct consumption or by the use of contaminated water in agriculture and food processing. There are occasions when host infections cause passage of pathogens in urine. The 3 principal infections leading to significant appearance of pathogens in urine are: urinary schistosomiasis, typhoid fever, and leptospirosis. Coliform and other bacteria may be numerous in urine during urinary tract infections. Since the incidence of these diseases in the U.S. is very low, they constitute little public health risk in water reuse. Microbial agents resulting from venereal infections can also be present in urine, but they are so vulnerable to conditions outside the body that wastewater is not a predominant vehicle of transmission (Feachem *et al.*, 1983 and Riggs, 1989).

3.4.1.2 Pathogenic Microorganisms and Health Risks

The potential transmission of infectious disease by pathogenic agents is the most common concern associated with reuse of treated municipal wastewater. Fortunately, sanitary engineering and preventive medical practices have combined to reach a point where waterborne disease outbreaks of epidemic proportions have, to a great extent, been controlled. However, the potential for disease transmission through water has not been eliminated. With few exceptions, the disease organisms of epidemic history are still present in today's sewage. The level of treatment today is more related to severing the transmission chain than to fully eradicating the disease agents.

Many infectious disease microbes affecting individuals in a community can find their way into municipal sewage. Most of the organisms found in untreated wastewater are known as enteric organisms; they inhabit the intestinal tract where they can cause disease, such as diarrhea. **Table 3-2** lists many of the infectious agents potentially present in raw domestic wastewater. These microbes can be classified into 3 broad groups: bacteria, parasites (parasitic protozoa and helminths), and viruses. Table 3-2 also lists the diseases associated with each organism.

a. Bacteria

Bacteria are microscopic organisms ranging from approximately 0.2 to 10 µm in length. They are distributed ubiquitously in nature and have a wide variety of nutritional requirements. Many types of harmless bacteria colonize in the human intestinal tract and are routinely shed in the feces. Pathogenic bacteria are also present in the feces of infected individuals. Therefore, municipal wastewater can contain a wide variety and concentration range of bacteria, including those pathogenic to humans. The numbers and types of these agents are a function of their prevalence in the animal and human community from which the wastewater is derived. Three of the more common bacterial pathogens found in raw wastewater are *Salmonella* sp, *Shigella* sp. and enteropathogenic *Escherichia coli* which have caused drinking water outbreaks with significant numbers of cases of hemolytic uremic syndrome (HUS) and multiple deaths (e.g. Walkerton, Ontario; Washington County, NY; Cabool, MO; Alpine, WY).

Bacterial levels in wastewater can be significantly lowered through either a "removal" or an "inactivation" process. The removal process involves the physical separation of the bacteria from the wastewater through sedimentation and/or filtration. Due to density considerations, bacteria do not settle as individual cells or even colonies. Typically, bacteria can adsorb to particulate matter or floc particles. These particles settle during sedimentation, secondary clarification, or during an advanced treatment process such as coagulation/flocculation/sedimentation using a coagulant. Bacteria can also be removed by using a filtration process that includes sand filters, disk (cloth) filters, or membrane processes. Filtration efficiency for a sand or cloth filter is dependent upon the effective pore size of the filtering medium and the presence of a "pre-coat" layer, usually other particulate matter. Because the pore sizes inherent to microfiltration and ultrafiltration membranes (including those membranes used in membrane bioreactors), bacteria are, to a large extent, completely removed due to size exclusion. Ultimately, the sedimented or filtered bacteria are removed from the overall treatment system through the sludge and backwash treatment system.

Table 3-2. Infectious Agents Potentially Present in Untreated Domestic Wastewater

Pathogen	Disease
Bacteria	
Shigella (spp.)	Shigellosis (bacillary dysentery)
Salmonella typhi	Typhoid fever
Salmonella (1700 serotypes spp.)	Salmonellosis
Vibro cholerae	Cholera
Escherichia coli (enteropathogenic)	Gastroenteritis and septicemia, hemolytic uremic syndrome (HUS)
Yersinia enterocolitica	Yersiniosis
Leptospira (spp.)	Leptospirosis
Campylobacter jejune	Gastroenteritis, reactive arthritis
Protozoa	
Entamoeba histolytica	Amebiasis (amebic dysentery)
Giardia lamblia	Giardiasis (gastroenteritis)
Cryptosporidium	Cryptosporidiosis, diarrhea, fever
Microsporidia	Diarrhea
Helminths	
Ascaris lumbricoides	Ascariasis (roundworm infection)
Ancylostoma (spp)	Ancylostomiasis (hookworm infection)
Necator americanus	Necatoriasis (roundworm infection)
Ancylostoma (spp.)	Cutaneous larva migrams (hookworm infection)
Strongloides stercoralis	Strongyloidiasis (threadworm infection)
Trichuris trichiura	Trichuriasis (whipworm infection)
Taenia (spp.)	Taeniasis (tapeworm infection)
Enterobius vermicularis	Enterobiasis (pinwork infection)
Echinococcus granulosus (spp.)	Hydatidosis (tapeworm infection)
Viruses	
Enteroviruses (polio, echo, coxsackie, new enteroviruses, serotype 68 to 71)	Gastroenteritis, heart anomolies, meningitis, others
Hepatitis A and E virus	Infectious hepatitis
Adenovirus	Respiratory disease, eye infections, gastroenteritis (serotype 40 and 41)
Rotavirus	Gastroenteritis
Parvovirus	Gastroenteritis
Noroviruses	Diarrhea, vomiting, fever
Astrovirus	Gastroenteritis
Calicivirus	Gastroenteritis
Coronavirus	Gastroenteritis

Source: Adapted from National Research Council, 1996; Sagik *et. al.*, 1978; and Hurst *et. al.*, 1989

Inactivation of bacteria refers to the destruction (death) of bacteria cells or the interference with reproductive ability using a chemical or energy agent. Such inactivation is usually referred to as disinfection. The most common disinfectants used in wastewater treatment are free chlorine, chloramines, ultraviolet (UV) light, and ozone. Chlorine, a powerful chemical oxidant, generally inactivates bacterial cells by causing physiological damage to cell membranes and damage to the internal cell components. Chloramines, chlorine substituted ammonia compounds, generally inactivate bacteria cells by disrupting DNA, thus causing direct cell death and/or inhibiting ability to reproduce. UV light also inactivates bacteria by damaging the DNA, thus inhibiting the ability to reproduce. Ozone, another powerful oxidant, can cause cell inactivation by direct damage to the cell wall and membrane, disruption of enzymatic reaction, and damage to DNA. The relative effectiveness of each chemical disinfectant is generally related to the product of disinfectant concentration and the disinfectant contact time. This product is commonly referenced as the "Ct" value. Tables of various Ct values required to inactivate bacteria (and other pathogens, such as viruses and protozoans) are readily available in the literature for clean (filtered) water applications. These Ct values are a function of temperature, pH, and the desired level of inactivation.

In recognition of the many constraints associated with analyzing wastewater for all of the potential pathogens that may be present, it has been common practice to use a microbial indicator or surrogate to indicate fecal contamination of water. Some bacteria of the coliform group have long been considered the prime indicators of fecal contamination and are the most frequently applied indicators used by state regulatory agencies to monitor water quality. The coliform group is composed of a number of bacteria that have common metabolic attributes. The total coliform groups are all gram-negative aspogenous rods, and most are found in feces of warm-blooded animals and in soil. Fecal coliforms are, for the most part, bacteria restricted to the intestinal tract of warm-blooded animals and comprise a portion of the total coliform group. Coliform organisms are used as indicators because they occur naturally in the feces of warm-blooded animals in higher concentrations than pathogens, are easily detectable, exhibit a positive correlation with fecal contamination, and generally respond similarly to environmental conditions and treatment processes as many bacterial pathogens. Where low levels of coliform organisms are used to indicate the absence of pathogenic bacteria, there is consensus among microbiologists that the total coliform analysis is not superior to the fecal coliform analysis. Specific methods have been developed to detect and enumerate *Escherichia coli* for use as a potential indicator organism.

b. Parasitic Protozoa and Helminths

The most common parasites in domestic untreated wastewater include several genera in the microspora, protozoa, trematode, and nematode families. Since the parasites cannot multiply in the environment, they require a host to reproduce and are excreted in the feces as spores, cysts, oocysts, or eggs, which are robust and resistant to environmental stresses such as dessication, heat, and sunlight. Most parasite spores, cysts, oocysts, and eggs are larger than bacteria and range in size from 1 µm to over 60 µm. While these parasites can be present in the feces of infected individuals who exhibit disease symptoms, carriers with unapparent infections can also excrete them, as may be the case with bacteria and viral infections as well. Furthermore, some protozoa such as *Toxoplasma* and *Cryptosporidium* are among the most common opportunistic infections in patients with acquired immunodeficiency syndrome (AIDS) (Slifko *et al.*, 2000). There are several helminthic parasites that occur in wastewater. Examples include the roundworm *Ascaris* as well as other nematodes such as the hookworms and pinworm. Many of the helminths have complex life cycles, including a required stage in intermediate hosts. The infective stage of some helminths is either the adult organism or larvae, while the eggs or ova of other helminths constitute the infective stage of the organisms. The eggs and larvae, which range in size from about 10 µm to more than 100 µm, are resistant to environmental stresses and may survive usual wastewater disinfection procedures. Helminth ova are readily removed by commonly used wastewater treatment processes such as sedimentation, filtration, or stabilization ponds. A 1992 study in St. Petersburg, Florida, showed helminths were completely removed in the secondary clarifiers (Rose and Carnahan, 1992).

In recent years, the protozoan parasites have emerged as a significant human health threat in regards to chlorinated drinking water. In particular, the protozoa such as *Giardia lamblia*, *Cryptosporidium pavum*, and *Cyclospora cayetanensis* have caused numerous waterborne and/or foodborne outbreaks. *Microsporidia* spp. have also been implicated as a waterborne pathogen (Cotte *et al.*, 1999).

Protozoan pathogens can be reduced in wastewater by the same previously described mechanisms of removal and inactivation. *Cryptosporidium* oocysts are 4 to 6 mm in diameter while *Giardia* cysts range between 8 to 16 mm in diameter. Due to the relatively large size compared to bacteria, the protozoa can be removed by properly designed and operated sedimentation and filtration systems commonly employed in wastewater and water treatment. In terms of inactivation, commonly used disinfectants such as chlorine are not as effective for inactivating the protozoa as compared to bacteria and viruses. **Table 3-3** shows the relative microbial resistance to disinfection compared to *E. coli*. For the chemical disinfectants, a higher Ct value is required to show an equal level of inactivation as compared to bacteria. Advanced disinfection using irradiation such as UV or electron beam treatments have been shown to be effective for inactivating the pathogens with the necessary fluence or dose being roughly equivalent to that required by some bacteria.

c. Viruses

Viruses are obligate intracellular parasites able to multiply only within a host cell and are host-specific. Viruses occur in various shapes and range in size from 0.01 to 0.3 µm in cross-section and are composed of a nucleic acid core surrounded by an outer coat of protein. Bacteriophage are viruses that infect bacteria as the host; they have not been implicated in human infections and are often used as indicators in seeded virus studies. Coliphages are host specific viruses that infect the coliform bacteria.

Enteric viruses multiply in the intestinal tract and are released in the fecal matter of infected persons. Not all types of enteric viruses have been determined to cause waterborne disease, but over 100 different enteric viruses are capable of producing infections or disease. In general, viruses are more resistant to environmental stresses than many of the bacteria, although some viruses persist for only a short time in wastewater. The Enteroviruses, Rotavirus, and the Enteric Adenoviruses, which are known to cause respiratory illness, gastroenteritis, and eye infections, have been isolated from wastewater. Of the viruses that cause diarrheal disease, only the Noroviruss and Rotavirus have been shown to be major waterborne pathogens (Rose, 1986) capable of causing large outbreaks of disease.

There is no evidence that the Human Immunodeficiency Virus (HIV), the pathogen that causes AIDS, can be transmitted via a waterborne route (Riggs, 1989). The results of one laboratory study (Casson *et al.*, 1992), where primary and undisinfected secondary effluent samples were inoculated with HIV (Strain IIIB) and held for up to 48 hours at 25° C (77° F), indicated that HIV survival was significantly less than Polio virus survival under similar conditions. A similar study by Casson *et al.* in 1997 indicated that untreated wastewater spiked with blood cells infected with the HIV exhibited a rapid loss of HIV, although a small fraction remained stable for 48 hours.

Similar to bacteria and protozoan parasites, viruses can be both physically removed from the wastewater or inactivated. However, due to the relatively small size of typical viruses, the sedimentation and filtration processes are less effective at removal. Significant virus removal can be achieved with ultrafiltration membranes, possibly in the 3- to 4-log range. However, for viruses, inactivation is generally considered the more important of the 2 main reduction methods. Due to the size and relatively noncomplex nature of viruses, most disinfectants demonstrate reasonable inactivation levels at relatively low Ct values. Interestingly, for UV light disinfection, relatively high fluence values are required to inactivate viruses when compared to bacteria and protozoans. It is believed that the protein coat of the virus shields the ribonucleic acid (RNA) from UV light.

3.4.1.3 Presence and Survival of Pathogens

a. Presence

Bacteria, viruses, and parasites can all be detected in wastewater. Studies of pathogens have reported average levels of 6.2, 5.8, and 5.3 log cfu/100ml of *Yersinia*, *Shigella*, and *Salmonella* detected in primary-clarified sewage influent over a 2-year period in a U.S. facility (Hench *et al.*, 2003). *Salmonella* may be present in concentrations up to 10,000/l. The excretion of *Salmonella typhi* by asymptomatic carriers may vary from 5×10^3 to 45×10^6 bacteria/g of feces. But there are few studies in recent years, which have directly investigated the presence of bacterial pathogens and have focused more often on the indicator bacteria. Concentrations excreted by infected individuals range from 10^6 cysts, 10^7 oocysts and as high as 10^{12} virus particle per gram of feces for *Giardia*, *Cryptosporidium*, and *Rotavirus*, respectively (Gerba, 2000). Pathogen levels in wastewater can vary depending on infection in the community.

Levels of viruses, parasites, and indicator bacteria reported in untreated and secondary treated effluents are shown in **Tables 3-4** and **3-5**. These tables illustrate the tremendous range in the concentrations of microorgan-

Table 3-3. Ct Requirements for Free Chlorine and Chlorine Dioxide to Achieve 99 Percent Inactivation of *E. Coli* Compared to Other Microorganisms

Microbe	Cl_2 Ct	% Greater Cl_2 Ct Requirement Compared to *E. Coli*	Chloramine Ct	% Greater Chloramine Ct Requirement Compared to *E. Coli*
E. Coli	0.6	NA	113	NA
Poliovirus	1.7	96%	1,420	170%
Giardia	54-250	196-199%	430-580	117-135%
Cryptosporidium	>7,200	>200%	>7,200	>194%

Adapted from: Maier, 2000

isms that may be found in raw and secondary wastewater.

The methods currently used to detect *Cryptosporidium* oocysts and *Giardia* cysts are limited since they cannot assess viability or potential infectivity. Therefore, the health risks associated with finding oocysts and cysts in the environment cannot be accurately ascertained from occurrence data and the risks remain unknown.

Dowd *et al.* (1998) described a polymerase chain reaction (PCR) method to detect and identify the microsporidia (amplifying the small subunit ribosomal DNA of microsporidia). They found isolates in sewage, surface waters, and ground waters. The strain that was most often detected was *Enterocytozoon bieneusi*, which is a cause of diarrhea and excreted from infected individuals into wastewater. Microsporidia spores have been shown to be stable in the environment and remain infective for days to weeks outside their hosts (Shadduck, 1989; Waller, 1980; Shadduck and Polley, 1978). Because of their small size (1 to 5 μm), they may be difficult to remove using conventional filtration techniques. However, initial studies using cell culture suggest that the spores may be more susceptible to disinfection (Wolk *et al.*, 2000).

Under experimental conditions, absorption of viruses and *E. coli* through plant roots, and subsequent acropetal translocation has been reported (Murphy and Syverton, 1958). For example, one study inoculated soil with Polio virus, and found that the viruses were detected in the leaves of plants only when the plant roots were damaged or cut. The likelihood of translocation of pathogens through trees or vines to the edible portions of crops is extremely low, and the health risks are negligible.

Table 3-4. Microorganism Concentrations in Raw Wastewater

Organism	Range in Average Concentrations (CFU, PFU or Cysts/Oocysts)
Fecal Coliforms/100L	105 to 105
Enterococci/100L	10^4 to 10^5
Shigella /100mL	1 to 10^3
Salmonella /100mL	10^2 to 10^4
Helminth ova/100mL	1 to 10^3
Enteric virus/100L	1 to 5 x10^3
Giardia cysts/100L	0.39 to 4.9x10^4
Cryptosporidium oocysts/100L	0.2 to 1.5 x10^3

Source: NRC, 1998 and Maier *et. al.*, 2000

Table 3-5. Microorganism Concentrations in Secondary Non-Disinfected Wastewater

Organism	Average Concentrations (CFU, PFU or Cysts/Oocysts per 100L)
Fecal Coliforms	7,764
Enterococci	2,186
Enteric virus	20 to 650
Giardia cysts	5 to 2,297
Cryptosporidium oocysts	140

Source: NRC, 1998

b. Survival

Most pathogens do not increase in numbers outside of their host, although in some instances the ova of helminths do not mature to the larval stage until they are in the soil. In all cases, the numbers decrease at various rates, depending on a number of factors including the inherent biologic nature of the agent, temperature, pH, sunlight, relative humidity, and competing flora and fauna. Examples of relative survival times for some pathogens are given in **Table 3-6**. These values are intended to indicate relative survival rates only, and illustrate the various persistence of selected organisms.

3.4.1.4 Pathogens and Indicator Organisms in Reclaimed Water

There have been a number of studies regarding the presence of pathogens and indicator organisms in reclaimed water and such studies continue as experience in this field expands. Koivunen *et al.* (2003) compared the reduction of fecal coliforms to the reduction of *Salmonella* by conventional biological treatment, filtration, and disinfection. Fecal coliform bacteria were present at 1000-fold greater concentration, and the *Salmonella* bacteria were reduced to non-detectable levels by advanced treatment (greater than 99.9 percent). Fecal coliform bacteria were a good, conservative indicator of such reductions. However, given the numbers of *Salmonellae* in secondary effluents and the fact that 18 carried multiple antibiotic resistance, the authors concluded that without proper additional advanced treatment, there may be a significant public health risk.

A year-long study investigated a conventional reuse treatment facility in St. Petersburg, Florida (Rose *et al.*, 1996). In this facility, deep-bed sand filtration and disinfection, with total chlorine residual (4 to 5 mg/L) were the barriers assessed through both monitoring of naturally occurring bacteria, protozoa, and viruses, as well as through seeded challenge studies. Removals were 5 log for human vi-

Table 3-6. Typical Pathogen Survival Times at 20-30 °C

Pathogen	Survival Time (days)		
	Fresh Water & Sewage	Crops	Soil
Viruses[a]			
Enteroviruses[b]	<120 but usually <50	<60 but usually <15	<100 but usually <20
Bacteria			
Fecal coliforms[a,c]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Salmonella spp.[a]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Shigella spp.[a]	<30 but usually <10	<10 but usually <5	---
Vibrio cholerae[d]	<30 but usually <10	<5 but usually <2	<20 but usually <10
Protozoa			
Entamoeba histolytica cysts	<30 but usually <15	<10 but usually <2	<20 but usually <10
Helminths			
Ascaris lumbricoides eggs	Many months	<60 but usually <30	Many months

a In seawater, viral survival is less and bacterial survival is very much less, than in fresh water.
b Includes polio-, echo-, and coxsackieviruses
c Fecal coliform is not a pathogen but is often used as an indicator organism
d *V. cholerae* survival in aqueous environments is a subject of current uncertainty.

Source: Adapted from Feacham *et. al.*, 1983

ruses and coliphage indicators, with anywhere from 1.5 to 3 log reductions by disinfection. A 3 log reduction for protozoa was achieved and greater than 1 log reduction was achieved for bacteria and indicators. Protozoan viability was not evaluated. In this study, *Enterococci* and *Clostridium* were not included as alternative indicators. Only the phage was used as a virus indicator. Seeded trials using bacteriophage demonstrated a 1.5 and 1.6 log reduction by filtration and disinfection, respectively.

A second study was done at the Upper Occoquan Sewage Authority (UOSA) in Fairfax County, Virginia. Samples were collected once per month for 1 year from 8 sites from the advanced wastewater reclamation plant (Rose *et al.*, 2000). The 8 sites were monitored for indicator bacteria, total and fecal coliforms, enterococci, *Clostridium*, coliphage (viruses which infect *E.coli*), human enteric viruses, and enteric protozoa. Multimedia filtration reduced the bacteria by approximately 90 percent, but did not effectively reduce the coliphage or enteroviruses. The enteric protozoa were reduced by 85 to 95.7 percent. Chemical lime treatment was the most efficient barrier to the passage of microorganisms (reducing these microorganisms by approximately 99.99 percent for bacteria, 99.9 percent for *Clostridium* and enteroviruses, and 99 percent for protozoa). Disinfection was achieved through chlorination (free chlorine residuals of 0.2 to 0.5 mg/l), and effectively achieved another 90 to 99 percent reduction. Overall, the plant was able to achieve a 5 to 7 log reduction of bacteria, 5 log reduction of enteroviruses, 4 log reduction of *Clostridium*, and 3.5 log reduction of protozoa. Total coliforms, enterococci, *Clostridium*, coliphage, *Cryptosporidium*, and *Giardia* were detected in 4 or fewer samples of the final effluent. No enteroviruses or fecal coliforms were detected. Protozoa appeared to remain the most resistant microorganisms found in wastewater. However, as with the St. Petersburg study, protozoan viability in these studies was not addressed.

Table 3-7 provides a summary of influent and effluent microbiological quality for the St. Petersburg and Upper Occaquan studies for enterovirus, *Cryptosporidium*, and *Giardia*. Enteroviruses were found 100 percent of the time in untreated wastewater. The enteric protozoa, *Cryptosporidium*, and *Giardia* were found from 67 to 100 percent of the time in untreated wastewater. *Giardia* cysts were found to be more prevalent, and at higher concentrations than oocysts in wastewater, perhaps due to the increased incidence of infection in populations compared to cryptosporidiosis and higher asymptomatic infections. Levels of oocysts in sewage are similar throughout the world (Smith and Rose, 1998). However, crops irrigated with wastewater of a poorer quality in

Table 3-7 Pathogens in Untreated and Treated Wastewater

City	Organism	Untreated Wastewater		Reclaimed Water	
		% Positive	Average Value	% Positive	Average Value
St. Petersburg, FL	Enterovirus (PFU/100l)	100	1,033	8	0.01
	Cryptosporidium (oocysts/100l)	67	1,456	17	0.75
	Giardia (cysts/100l)	100	6,890	25	0.49
Upper Occoquan, VA	Enterovirus (PFU/100l)	100	1,100	0	0
	Cryptosporidium (oocysts/100l)	100	1,500	8.3	0.037
	Giardia (cysts/100l)	100	49,000	17	1.1

Source: Walker-Coleman *et. al.*, 2002; Rose and Carnahan, 1992; Sheikh and Cooper, 1998; Rose *et. al.*, 2001; Rose and Quintero-Betancourt, 2002; and York *et. al.*, 2002

Israel contained more oocysts than cysts (Armon *et al.*, 2002).

The results of these studies indicate that the treatment processes employed are capable of significantly reducing or eliminating these pathogens.

The State of Florida recognizes that *Giardia* and *Cryptosporidium* are pathogens of increasing importance to water reclamation and now requires monitoring for these pathogens (Florida DEP, 1999). Results of this monitoring are presented in **Table 3-8**. The Florida facilities highlighted in this table generally feature secondary treatment, filtration, and high-level disinfection. **Table 3-9** includes the associated data from these facilities for TSS, turbidity, and total chlorine residual.

Visual inspection studies in Florida and elsewhere routinely found *Giardia* cysts and *Cryptosporidium* oocysts in reclaimed water that received filtration and high-level disinfection and was deemed suitable for public access uses. A number of more detailed studies which considered the viability and infectivity of the cysts and oocysts suggested that *Giardia* was likely inactivated by chlorine but 15 to 40 percent of detected *Cryptosporidium* oocysts may survive (Keller, 2002; Sheikh, 1999; Garcia, 2002; Genacarro, 2003; Quintero, 2003). Other studies evaluating UV and the electron beam as alternatives to chlorine disinfection found that both parasites were easily inactivated (Mofidi 2002 and Slifko 2001). Both *Giardia* cysts and *Cryptosporidium* oocysts required less than 10mJ/cm^2 for complete inactivation by UV (Mofidi 2002 and Slifko 2001).

In December 2003, the Water Environment Research Foundation (WERF) initiated a series of workshops on indicators for pathogens in wastewater, stormwater, and biosolids. The first workshop considered the state of science for indicator organisms. Potential indicators for further study were identified in an attempt to improve upon current indicator organism use and requirements. The results of this effort are summarized in **Table 3-10**. Subsequent phases of this effort will evaluate the usefulness of the selected list of indicators and compare them with current indicators. Detailed studies will then be conducted using the most promising indicators in field studies at various sites in the U.S.

3.4.1.5 Aerosols

Aerosols are defined as particles less than 50 µm in diameter that are suspended in air. Viruses and most pathogenic bacteria are in the respirable size range; hence, the inhalation of aerosols is a possible direct mean of human infection. Aerosols are most often a concern where reclaimed water is applied to urban or agricultural sites with sprinkler irrigation systems, or where it is used for cooling water make-up.

The concentration of pathogens in aerosols is a function of their concentration in the applied water and the aerosolization efficiency of the spray process. During spray irrigation, the amount of water that is aerosolized can vary from less than 0.1 percent to almost 2 percent, with a mean aerosolization efficiency of 1 percent or less. Infection or disease may be contracted indirectly by deposited aerosols on surfaces such as food, vegetation, and clothes. The infective dose of some pathogens is lower for respiratory tract infections than for infections via the gastrointestinal tract. Therefore, for some pathogens, inhalation may be a more likely route for disease transmission than either contact or ingestion.

The infectivity of an inhaled aerosol depends on the depth of the respiratory penetration and the presence of pathogenic organisms capable of infecting the respiratory sys-

Table 3-8. **Summary of Florida Pathogen Monitoring Data**

Statistic	*Giardia*	*Cryptosporidium*
Number of observations	69	68
% having detectable concentrations	58%	22%
25 percentile (#/100 l)	ND	ND
50 percentile (#/100 l)	4	ND
75 percentile (#/100 l)	76	ND
90 percentile (#/100 l)	333	2.3
Maximum (#/100 l)	3,096	282

Notes: (a) All numeric data are total numbers of cysts or oocysts per 100 L.
(b) ND indicates a value less than detection.

Source: Walker-Coleman, *et. al.*, 2002.

Table 3-9. **Operational Data for Florida Facilities**

Statistic	TSS (mg/l)	Turbidity (NTU)	Chlorine Residual (mg/l)
Minimum	0.19	0.31	1.01
10 percentile	0.4	0.45	1.9
25 percentile	0.8	0.65	2.32
50 percentile	1	0.99	4.1
75 percentile	1.76	1.36	5
90 percentile	2.1	1.8	7.1
Maximum	6	4.5	10.67

Source: Walker-Coleman *et. al.*, 2002

tem. Aerosols in the 2 to 5 µm size range are generally excluded from the respiratory tract, with some that are subsequently swallowed. Thus, if gastrointestinal pathogens are present, infection could result. A considerably greater potential for infection occurs when respiratory pathogens are inhaled in aerosols smaller than 2 µm in size, which pass directly to the alveoli of the lungs (Sorber and Guter, 1975).

One of the most comprehensive aerosol studies, the Lubbock Infection Surveillance Study (Camann *et al.*, 1986), monitored viral and bacterial infections in a mostly rural community surrounding a spray injection site near Wilson, Texas. The source of the irrigation water was undisinfected trickling filter effluent from the Lubbock Southeast water reclamation plant. Spray irrigation of the wastewater significantly elevated air densities of fecal coliforms, fecal streptococci, mycobacteria, and coliphage above the ambient background levels for at least 650 feet (200 meters) downwind. The geometric mean concentration of enteroviruses recovered 150 to 200 feet (44 to 60 meters) downwind was 0.05 pfu/m^3, a level higher than that observed at other wastewater aerosol sites in the U.S. and in Israel (Camann *et al.*, 1988). While disease surveillance found no obvious connection between the self-reporting of acute illness and the degree of aerosol exposure, serological testing of blood samples indicated that the rate of viral infections was slightly higher among members of the study population who had a high degree of aerosol exposure (Camann *et al.*, 1986).

For intermittent spraying of disinfected reclaimed water, occasional inadvertent contact should pose little health hazard from inhalation. Cooling towers issue aerosols continuously, and may present a greater concern if the water is not properly disinfected. Although a great deal of effort has been expended to quantify the numbers of fecal coliforms and enteric pathogens in cooling tower waters, there is no evidence that they occur in large num-

Table 3-10 Some Suggested Alternative Indicators for Use in Monitoring Programs

Parameter	Pathogen Presence
Viruses	F+ RNA coliphages
	Somatic coliphages
	Adenovirus
	JC virus
Bacteria	*E. coli*
	Enterococci
	Bifidobacteria
Parasites	*Clostridium perfringens*
	Sulfite reducing
	Clostridium spp.
Non-microbial indicators	Fecal sterols
Pathogens as possible indicators	*Cryptosporidium*
	Giardia

Source: WERF Workshop, 2003

bers, although the numbers of other bacteria may be quite large (Adams and Lewis, n.d.).

No documented disease outbreaks have resulted from the spray irrigation of disinfected, reclaimed water. Studies indicate that the health risk associated with aerosols from spray irrigation sites using reclaimed water is low (U.S. EPA, 1980b). However, until more sensitive and definitive studies are conducted to fully evaluate the ability of pathogens contained in aerosols to cause disease, the general practice is to limit exposure to aerosols produced from reclaimed water that is not highly disinfected. Exposure is limited through design or operational controls. Design features include:

- Setback distances, which are sometimes called buffer zones
- Windbreaks, such as trees or walls around irrigated areas
- Low pressure irrigation systems and/or spray nozzles with large orifices to reduce the formation of fine mist
- Low-profile sprinklers
- Surface or subsurface methods of irrigation

Operational measures include:

- Spraying only during periods of low wind velocity
- Not spraying when wind is blowing toward sensitive areas subject to aerosol drift or windblown spray
- Irrigating at off-hours, when the public or employees would not be in areas subject to aerosols or spray

All these steps would be considered part of a best management plan for irrigation systems regardless of the source of water used.

Most states with reuse regulations or guidelines include setback distances from spray areas to property lines, buildings, and public access areas. Although predictive models have been developed to estimate microorganism concentrations in aerosols or larger water droplets resulting from spray irrigation, setback distances are determined by regulatory agencies in a somewhat arbitrary manner, using levels of disinfection, experience, and engineering judgment as the basis.

3.4.1.6 Infectious Disease Incidence Related to Wastewater Reuse

Epidemiological investigations have focused on wastewater-contaminated drinking water supplies, the use of raw or minimally-treated wastewater for food crop irrigation, health effects to farm workers who routinely contact poorly treated wastewater used for irrigation, and the health effects of aerosols or windblown spray emanating from spray irrigation sites using undisinfected wastewater. These investigations have all provided evidence of infectious disease transmission from such practices (Lund, 1980; Feachem *et al.*, 1983; Shuval *et al.*, 1986).

Review of the scientific literature, excluding the use of raw sewage or primary effluent on sewage farms in the late 19th century, does not indicate that there have been no confirmed cases of infectious disease resulting from reclaimed water use in the U.S. where such use has been in compliance with all appropriate regulatory controls. However, in developing countries, the irrigation of market crops with poorly treated wastewater is a major source of enteric disease (Shuval *et al.*, 1986).

Occurrences of low level or endemic waterborne diseases associated with exposure to reclaimed water have been difficult to ascertain for several reasons:

- Current detection methods have not been sufficiently sensitive or specific enough to accurately detect low concentrations of pathogens, such as viruses and protozoa, even in large volumes of water.

- Many infections are often not apparent, or go unreported, thus making it difficult to establish the endemicity of such infections.

- The apparently mild nature of many infections preclude reporting by the patient or the physician.

- Current epidemiological techniques are not sufficiently sensitive to detect low-level transmission of these diseases through water.

- Illness due to enteroviral or parasite infections may not become obvious for several months or years.

- Once introduced into a population, person-to-person contact can become a secondary mode of transmission of many pathogens, thereby obscuring the role of water in its transmission.

Because of the insensitivity of epidemiological studies to provide a direct empirical assessment of microbial health risk due to low-level exposure to pathogens, methodologies have increasingly relied on indirect measures of risk by using analytical models for estimation of the intensity of human exposure and the probability of human response from the exposure. Microbial risk assessment involves evaluating the likelihood that an adverse health effect may occur from human exposure to one or more potential pathogens. Most microbial risk assessments in the past have used a framework originally developed for chemicals that is defined by 4 major steps: (1) hazard identification, (2) dose-response identification, (3) exposure assessment, and (4) risk characterization. However, this framework does not explicitly acknowledge the differences between health effects due to chemical exposure versus those due to microbial exposure. Those differences include acute versus chronic health effects, potential for person-to-person transmission of disease, and the potential need to account for the epidemiological status of the population (Olivieri, 2002).

Microbial risk analyses require several assumptions to be made. These assumptions include a minimum infective dose of selected pathogens, concentration of pathogens present, quantity of pathogens ingested, inhaled, or otherwise contacted by humans, and probability of infection based on infectivity models. The use of microbial risk assessment models have been used extensively by the U.S. Department of Agriculture (USDA) to evaluate food safety for pathogens such as Listeria Monocytogenes in ready to eat foods (USDA, n.d.). The World Health Organization (WHO) and Food and Agriculture Organization (FAO) also provide risk assessment methodologies for use in evaluating food safety (Codex Alimentarius).

In order to assess health risks associated with the use of reclaimed water, pathogen risk assessment models to assess health risks associated with the use of reclaimed water have been used as a tool in assessing relative health risks from microorganisms in drinking water (Cooper *et al.*, 1986; Gerba and Haas, 1988; Olivieri *et al.*, 1986; Regli *et al.*, 1991; Rose *et al.*, 1991; Gale, 2002) and reclaimed water (Asano and Sakaji, 1990; EOA, Inc., 1995; Rose and Gerba, 1991; Tanaka *et al.*, 1998; Patterson *et al.*, 2001). Most of the models calculated the probability of individual infection or disease as a result of a single exposure. One of the more sophisticated models calculates a distribution of risk over the population by utilizing epidemiological data such as incubation period, immune status, duration of disease, rate of symptomatic development, and exposure data such as processes affecting pathogen concentration (EOA, Inc., 1995).

At the present time, no wastewater disinfection or reclaimed water standards or guidelines in the U.S. are based on risk assessment using microorganism infectivity models. Florida is investigating such an approach and has suggested levels of viruses between 0.04 to 14/100 l, depending on the virus (ranging from Rotavirus infectivity to a less infectious virus), viable oocysts at 22/100 l, and viable cysts at 5/100 l (York and Walker-Coleman, 1999). Microbial risk assessment methodology is a useful tool in assessing relative health risks associated with water reuse. Risk assessment will undoubtedly play a role in future criteria development as epidemiological-based models are improved and refined.

3.4.1.7 Chemical Constituents

The chemical constituents potentially present in municipal wastewater are a major concern when reclaimed water is used for potable reuse. These constituents may also affect the acceptability of reclaimed water for other uses, such as food crop irrigation or aquaculture. Potential mechanisms of food crop contamination include:

- Physical contamination, where evaporation and repeated applications may result in a buildup of contaminants on crops
- Uptake through the roots from the applied water or the soil, although available data indicate that potentially toxic organic pollutants do not enter edible portions of plants that are irrigated with treated municipal wastewater (National Research Council, 1996)
- Foliar uptake

With the exception of the possible inhalation of volatile organic compounds (VOCs) from indoor exposure, chemical concerns are less important where reclaimed water is not to be consumed. Chemical constituents are a consideration when reclaimed water percolates into groundwater as a result of irrigation, groundwater recharge, or other uses. These practices are covered in Chapter 2. Some of the inorganic and organic constituents in reclaimed water are listed in **Table 3-11.**

a. Inorganics

In general, the health hazards associated with the ingestion of inorganic constituents, either directly or through food, are well established (U.S. EPA, 1976). EPA has set maximum contaminant levels (MCLs) for drinking water. The concentrations of inorganic constituents in reclaimed water depend mainly on the source of wastewater and the degree of treatment. Residential use of water typically adds about 300 mg/l of dissolved inorganic solids, although the amount added can range from approximately 150 mg/l to more than 500 mg/l (Metcalf & Eddy, 2002). As indicated in Table 3-11 the presence of total dissolved solids, nitrogen, phosphorus, heavy metals, and other inorganic constituents may affect the acceptability of reclaimed water for different reuse applications. Wastewater treatment using existing technology can generally reduce many trace elements to below recommended maximum levels for irrigation and drinking water. Uses in wetlands and recreational surface waters must also consider aquatic life protection and wetland habitat.

b. Organics

The organic make-up of raw wastewater includes naturally occurring humic substances, fecal matter, kitchen wastes, liquid detergents, oils, grease, and other substances that, in one way or another, become part of the sewage stream. Industrial and residential wastes may contribute significant quantities of synthetic organic compounds.

The need to remove organic constituents is related to the end use of reclaimed water. Some of the adverse effects associated with organic substances include:

- Aesthetic effects – organics may be malodorous and impart color to the water
- Clogging – particulate matter may clog sprinkler heads or accumulate in soil and affect permeability
- Proliferation of microorganisms – organics provide food for microorganisms
- Oxygen consumption – upon decomposition, organic substances deplete the dissolved oxygen content in streams and lakes. This negatively impacts the aquatic life that depends on the oxygen supply for survival
- Use limitation – many industrial applications cannot tolerate water that is high in organic content
- Disinfection effects – organic matter can interfere with chlorine, ozone, and ultraviolet disinfection, thereby making them less available for disinfection purposes. Further, chlorination may result in formation of potentially harmful disinfection byproducts
- Health effects – ingestion of water containing certain organic compounds may result in acute or chronic health effects.

The wide range of anthropogenic organic contaminants in streams influenced by urbanization (including wastewater contamination) includes pharmaceuticals, hormones, antioxidants, plasticizers, solvents, polynuclear aromatic hydrocarbons (PAHs), detergents, pesticides, and their metabolites (Kolpin *et al.*, 2002). The stability and persistence of these compounds are extremely variable in the stream/sediment environment. A recent comprehensive study of the persistence of anthropogenic and natural organic molecules during groundwater recharge suggests that carbamezepine may survive long enough to serve as a useful tracer compound of wastewater origin (Clara *et al.*, 2004).

Table 3-11. Inorganic and Organic Constituents of Concern in Water Reclamation and Reuse

Constituent	Measured Parameters	Reasons for Concern
Suspended Solids	Suspended solids (SS), including volatile and fixed solids	Organic contaminants, heavy metals, etc. are absorbed on particulates. Suspended matter can shield microorganisms from disinfectants. Excessive amounts of suspended solids cause plugging in irrigation systems.
Biodegradable Organics	Biochemical oxygen demand, chemical oxygen demand, total organic carbon	Aesthetic and nuisance problems. Organics provide food for microorganisms, adversely affect disinfection processes, make water unsuitable for some industrial or other uses, consume oxygen, and may result in acute or chronic effects if reclaimed water is u
Nutrients	Nitrogen, Phosphorus, Potassium	Nitrogen, phosphorus, and potassium are essential nutrients for plant growth and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesir
Stable Organics	Specific compounds (e.g., pesticides, chlorinated hydrocarbons)	Some of these organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of reclaimed water for irrigation or other uses. Chlorine reacts with man
Hydrogen Ion Concentration	pH	The pH of wastewater affects disinfection, coagulation, metal solubility, as well as alkalinity of soils. Normal range in municipal wastewater is pH = 6.5 - 8.5, but industrial waste can alter pH significantly.
Heavy Metals	Specific elements (e.g., Cd, Zn, Ni, and Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the reclaimed water for irrigation or other uses.
Dissolved Inorganics	Total dissolved solids, electrical Conductivity, specific elements (e.g., Na, Ca, Mg, Cl, and B)	Excessive salinity may damage some crops. Specific inorganics electrical conductivity ions such as chloride, sodium, and boron are toxic to specific elements (e.g., in some crops, sodium may pose soil permeability Na, Ca, Mg, Cl, and B problems).
Residual Chlorine	Free and combined chlorine	Excessive amounts of free available chlorine (>0.05 Chlorine chlorine mg/l) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed water is in a combined form, which does not cause crop damage. Some concerns are expre

Source: Adapted from Pettygrove and Asano, 1985

The health effects resulting from organic constituents are of primary concern for indirect or direct potable reuse. In addition, these constituents may be of concern where reclaimed water is utilized for food crop irrigation, where reclaimed water from irrigation or other beneficial uses reaches potable groundwater supplies, or where the organics may bioaccumulate in the food chain (e.g., in fish-rearing ponds).

Traditional measures of organic matter such as BOD, chemical oxygen demand (COD), and total organic carbon (TOC), are widely used as indicators of treatment efficiency and water quality for many nonpotable uses of reclaimed water. However, these measures have only indirect relevance related to evaluating toxicity and health effects. Sophisticated analytical instrumentation makes it possible to identify and quantify extremely low levels of organic constituents in water. Examples include gas chromatography/tandem mass spectrometry (GC/MS/MS) or high performance liquid chromatography/mass spectrometry (HPLC/MS). These analyses are costly and may require extensive and difficult sample preparation, particularly for nonvolatile organics.

Organic compounds in wastewater can be transformed into chlorinated organic species where chlorine is used for disinfection purposes. In the past, most attention was focused on the trihalomethane (THM) compounds; a family of organic compounds typically occurring as chlorine or bromine-substituted forms of methane. Chloroform, a commonly found THM compound, has been implicated in the development of cancer of the liver and kidney. Improved analytical capabilities to detect extremely low levels of chemical constituents in water have resulted in identification of several health-significant chemicals and disinfection byproducts in recent years. For example, the extremely potent carcinogen, N-nitrosodimethylamine (NDMA) is present in sewage and is produced when municipal wastewater effluent is disinfected with chlorine or chloramines (Mitch *et al*, 2003). In some situations, the concentration of NDMA present in reclaimed water exceeds action levels set for the protection of human health, even after reverse osmosis treatment. To address concerns associated with NDMA and other trace organics in reclaimed water, several utilities in California have installed UV/H2O2 treatment systems for treatment of reverse osmosis permeate.

Quality standards have been established for many inorganic constituents. Treatment and analytical technology has demonstrated the capability to identify, quantify, and control these substances. Similarly, available technology is capable of eliminating pathogenic agents from contaminated waters. On the basis of available information, there is no indication that health risks from using highly treated reclaimed water for potable purposes are greater than those from using existing water supplies (National Research Council, 1994). Yet, unanswered questions remain about organic constituents, due mainly to their potentially large numbers and unresolved health risk potentials related to long-term, low-level exposure. Assessment of health risks associated with potable reuse is not definitive due to limited chemical and toxicological data and inherent limitations in available epidemiological and toxicological methods. The results of epidemiological studies directed at drinking water have generally been inconclusive, and extrapolation methodologies used in toxicological assessments provide uncertainties in overall risk characterization (National Research Council, 1998).

3.4.1.8 Endocrine Disrupters

In addition to the potential adverse effects of chemicals described in Section 3.4.1.6, certain chemical constituents present in wastewater also can disrupt hormonal systems. This phenomenon, which is referred to as endocrine disruption, can occur through a variety of mechanisms associated with hormone synthesis, hormone receptor binding, and hormone transformation. As a result of the many mechanisms through which chemicals can impact hormone function, a large number of chemicals are classified as endocrine disrupters. However, the exact types of chemicals that are classified as endocrine disrupters vary among researchers. **Table 3-12** highlights a number of example sources of potential endocrine disrupters.

For example, the oxyanion, perchlorate, is an endocrine disrupter because it affects the thyroid system (U.S. EPA, 2002). The herbicide, atrazine, is an endocrine disrupter because it affects an enzyme responsible for hormone regulation (Hayes *et al.* 2002). A USGS project recently sampled 139 streams in 30 states for any 1 of 95 endocrine disrupters. The results indicated that 80 percent of the streams had at least 1 of these compounds (McGovern and McDonald, 2003). The topic of endocrine disruption has significant implications for a wide variety of chemicals used by industry, agriculture, and consumers. As a result, the EPA, the European Union (EU), and other government organizations are currently evaluating approaches for regulating endocrine-disrupting chemicals.

With respect to water reuse, the greatest concerns associated with endocrine disruption are related to a series of field and laboratory studies demonstrating that chemicals in wastewater effluent caused male fish to exhibit female characteristics (Purdom *et al.*, 1994; Harries *et al.*, 1996; Harries *et al.*, 1997). This process, which is referred to as feminization, has been attributed mostly to the presence of steroid hormones excreted by humans

(Desbrow *et al.*, 1998 and Snyder *et al.*, 2001). The hormones involved in fish feminization include the endogenous (*i.e.*, produced within the body) hormone 17b-estradiol as well as hormones present in pharmaceuticals (*e.g.*, ethinyl estradiol in birth control pills). Other chemicals capable of feminizing fish are also present in wastewater. These include nonylphenol and alkylphenol polyethoxylates, both of which are metabolites of nonionic detergents formed during secondary wastewater treatment (Ahel *et al.*, 1994).

The specific endocrine-disrupting chemicals in reclaimed water can be quantified using modern analytical methods. As indicated previously, the compounds most likely to be responsible for feminization of fish include steroid hormones (*e.g.*, 17b-estradiol and ethinyl estradiol) and detergents metabolites (*e.g.*, nonylphenol and alkylphenol polyethoxylates). Although these compounds cannot be quantified at the levels expected in reclaimed water with the gas chromatography/mass spectrometry (GC/MS) techniques routinely used to quantify priority pollutants, they can be measured with equipment available in many modern laboratories. For the hormones, analytical methods such as gas chromatography/tandem mass spectrometry (GC/MS/MS) (Ternes *et al.*, 1999, Huang and Sedlak, 2001), high performance liquid chromatography/mass spectrometry (HPLC/MS) (Ferguson *et al.*, 2001), or immunoassays (Huang and Sedlak, 2001 and Snyder *et al.*, 2001) are needed to detect the low concentrations present in wastewater effluent (*e.g.*, ethinyl estradiol concentrations are typically less than 2 υg/l in wastewater effluent). Although the endocrine-disrupting detergent metabolites are present at much higher concentrations than the hormones, their analysis also requires specialized analytical methods (Ahel *et al.*, 1994) not available from many commercial laboratories.

Bioassays can also be used to quantify the potential of reclaimed water to cause endocrine disruption. These methods are attractive because they have the potential to detect all of the difficult-to-measure endocrine-disrupting chemicals in 1 assay. The simplest bioassays involve *in vitro* tests, in which a hormone receptor from a mammalian cell is used to detect endocrine-disrupting chemicals. Among the different *in vitro* assays, the Yeast Estrogen Screen (YES) assay has been employed most frequently (Desbrow *et al.*, 1998). Comparisons between *in vitro* bioassays and chemical measurements yield

Table 3-12. Examples of the Types and Sources of Substances that have been Reported as Potential Endocrine-Disrupting Chemicals

Category	Examples of Substances	Examples of Uses	Examples of Sources
Polychlorinated Compounds	polychlorinated dioxins and polychlorinated biphenyls	industrial production of byproducts (mostly banned)	incineration and landfill runoff
Organochlorine Pesticides	DDT, dieldrin, and lindane	insecticides (many phased out)	agricultural runoff
Current Use Pesticides	atrazine, trifluralin, and permethrin	pesticides	agricultural runoff
Organotins	tributyltin	antifoulants on ships	harbors
Alkylphenolics	nonylphenol and octylphenol	surfactants (and their metabolites)	industrial and municipal effluents
Phthalates	dibutyl phthalate and butylbenzyl phthalate	plasticisers	industrial effluent
Sex Hormones	17-beta estradiol and estrone	produced naturally by animals	municipal effluents
Synthetic Steroids	ethinylestradiol	contraceptives	municipal effluents
Phytoestrogens	isoflavones, lignans, coumestans	present in plant material	pulp mill effluents

Source: Adapted from McGovern and McDonald, 2003 and Berkett and Lester, 2003 consistent results, indicating that steroid hormones are the most significant endocrine disrupting chemicals in wastewater effluent. Unfortunately, *in vitro* bioassays do not always detect compounds that disrupt hormone systems through mechanisms other than binding to hormone receptors. As a result, *in vivo* bioassays, usually performed with fish, may provide more accurate results. A clear dose-related response to various endocrine-disrupting compounds has been established in fish; however, little is known about species differences in sensitivity to exposure. Individual responses to exposure may also vary widely (Routledge *et al.*, 1998). Because many laboratories are unable to perform *in vivo* bioassays under the necessary conditions (*e.g.*, flow-through tests with rainbow trout), *in vivo* bioassays are not always practical. Available data suggest that nitrification/denitrification and filtration can reduce the concentrations of hormones and detergent metabolites while reverse osmosis lowers concentrations to levels that are unlikely to cause endocrine disruption (Huang and Sedlak, 2001 and Fujita *et al.*, 1996).

The current focus of research on disruption of the estrogen system may be attributable to the relative ease of detecting this form of endocrine disruption. As additional research is performed, other chemicals in wastewater effluent may be found to disrupt hormonal systems through mechanisms yet to be documented. For example, although results from *in vitro* bioassays suggest that the steroid hormones are most likely responsible for feminization of fish, it is possible that other endocrine disrupters contribute to the effect through mechanisms that cannot be detected by the bioassays.

The ecological implications associated with the feminization of fish are unknown. The potential of reclaimed water to cause endocrine disruption in humans is also unknown. It is anticipated that problems associated with endocrine disruption could occur, given prolonged consumption of substantial volumes of polluted water. The compounds in wastewater effluent that are believed to be responsible for feminization of fish may not pose a serious risk for humans because of differences between human and fish physiology. For example, the hormone 17b-estradiol is not used in the oral form in clinical applications because it would be metabolized before it could reach its target. Nevertheless, the evidence of endocrine disruption in wildlife and the absence of data about the effects of low-level exposure to endocrine disrupting compounds in humans has led to new scrutiny regarding endocrine-disrupting chemicals in reclaimed water.

3.4.2 Treatment Requirements

Untreated municipal wastewater may include contributions from domestic and industrial sources, infiltration and inflow from the collection system, and, in the case of combined sewer systems, urban stormwater runoff. The quantity and quality of wastewater derived from each source will vary among communities, depending on the number and type of commercial and industrial establishments in the area and the condition of the sewer system.

Levels of wastewater treatment are generally classified as preliminary, primary, secondary, and advanced. Advanced wastewater treatment, sometimes referred to as tertiary treatment, is generally defined as anything beyond secondary treatment. A generalized flow sheet for municipal wastewater treatment is shown in **Figure 3-10.**

In the last decade, significant advances were made in wastewater treatment equipment, design, and technology. For example, biological nutrient removal (BNR) processes have become more refined. Membranes are capable of producing higher quality effluent at higher flux rates and lower pressures than was possible before. Membrane bioreactors (MBRs) have shown to be effective in producing a high quality effluent, while greatly reducing a treatment plant's footprint. Microfiltration, used in some locations to replace conventional media filtration, has the advantage of effectively removing all parasite cysts (e.g., *Giardia* and *Cryptosporidium*). Advances in UV radiation technology have resulted in a cost competitive disinfection process capable of reducing the concentration of most pathogens to extremely low levels.

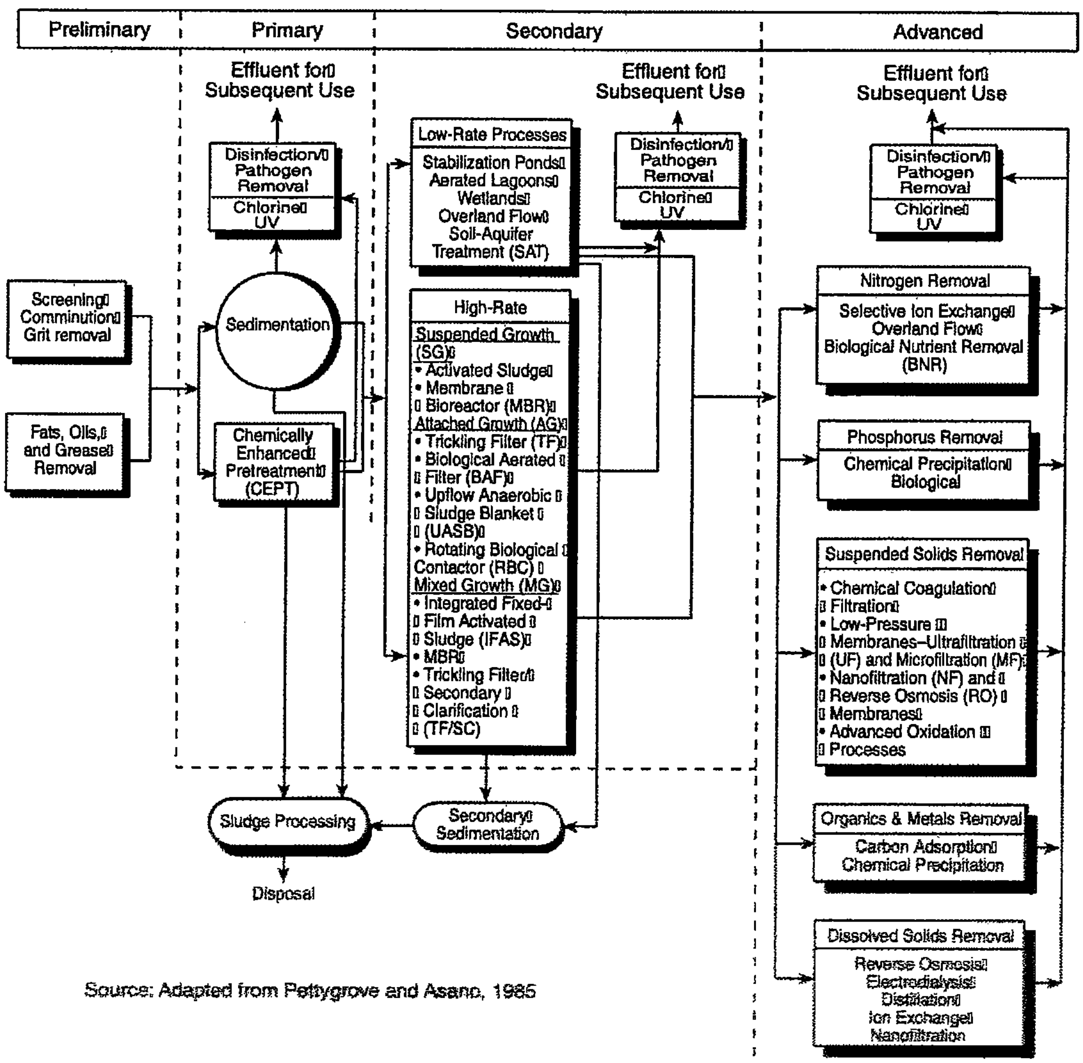
Wastewater treatment from raw to secondary is well understood and covered in great detail in other publications such as the Manual of Practice (MOP) 8, *Design of Municipal Wastewater Treatment Plants*, 4th Edition, (WEF, 1998). In this edition of the *Guidelines for Water Reuse* the discussion about treatment processes will be limited to those with a particular application to water reuse and reclamation. Such processes generally consist of disinfection and treatment beyond secondary treatment, although some limited access reuse programs may use secondary effluent without concern. It should be pointed out that treatment for particular pollutants at the water reclamation facility is not always the best answer. Source controls should also be investigated. In Orange County, California, 1,4-dioxane (listed as a probable human carcinogen based on animal studies) was found in 9 production wells at levels greater than the California action levels. This problem was solved by working with a treatment plant customer who voluntarily ceased discharge of 1,4-dioxane to the sewer system (Woodside and Wehner, 2002).

3.4.2.1 Disinfection

The most important process for the destruction of microorganisms is disinfection. In the U.S., the most common disinfectant for both water and wastewater is chlorine. Ozone and UV light are other prominent disinfectants used at wastewater treatment plants. Factors that should be considered when evaluating disinfection alternatives include disinfection effectiveness and reliability, capital costs, operating and maintenance costs, practicality (e.g., ease of transport and storage or onsite generation, ease of application and control, flexibility, complexity, and safety), and potential adverse effects. Examples of adverse effects include toxicity to aquatic life or formation of toxic or carcinogenic substances. The predominant advantages and disadvantages of disinfection alternatives are well known and have been summarized by the EPA in their Wastewater Technology Fact Sheets on Ultraviolet Disinfection (September 1999), Ozone Disinfection (September 1999), and Chlorine Disinfection (September 1999), Design Manual entitled, "Municipal Wastewater Disinfection" and Water Environment Federation (WEF) Manual of Practice FD-10 (1996).

The efficiency of chlorine disinfection depends on the water temperature, pH, degree of mixing, time of contact, presence of interfering substances, concentration and form of chlorinating species, and the nature and concentration of the organisms to be destroyed. In general, bacteria are less resistant to chlorine than viruses, which in turn, are less resistant than parasite ova and cysts.

Figure 3-10. Generalized Flow Sheet for Wastewater Treatment



Source: Adapted from Pettygrove and Asano, 1985

The chlorine dosage required to disinfect wastewater to any desired level is greatly influenced by the constituents present in the wastewater. Some of the interfering substances are:

- Organic constituents, which consume the disinfectant
- Particulate matter, which protects microorganisms from the action of the disinfectant
- Ammonia, which reacts with chlorine to form chloramines, a much less effective disinfectant species than free chlorine

In practice, the amount of chlorine added is determined empirically, based on desired residual and effluent quality. Chlorine, which in low concentrations is toxic to many aquatic organisms, is easily controlled in reclaimed water by dechlorination, typically with sulfur dioxide.

Chlorine is a regulated substance with a threshold quantity of 2,500 pounds (1130 kg). If a chlorine system contains a larger quantity of chlorine than the threshold quantity, a Risk Management Plan (RMP) must be completed. Two main factors of the RMP that prompt many municipalities to switch to alternative disinfection systems are: (1) the RMP is not a one-time requirement, it has to be updated every 5 years; and (2) concern over public reaction to the RMP, which requires that a "kill zone" be geographically defined around the treatment facility. This "kill zone" may include residential areas near the treatment plant. Thus, RMP requirements and decreasing chemical costs for commercial grade sodium hypochlorite have resulted in many municipalities switching from chlorine gas to commercial grade sodium hypochlorite to provide disinfection of their wastewater.

Ozone (O_3), is a powerful disinfecting agent and chemical oxidant in both inorganic and organic reactions. Due to the instability of ozone, it must be generated onsite from air or oxygen carrier gas. Ozone destroys bacteria and viruses by means of rapid oxidation of the protein mass, and disinfection is achieved in a matter of minutes. Ozone is a highly effective disinfectant for advanced wastewater treatment plant effluent, removing color, and contributing dissolved oxygen. Some disadvantages to using ozone for disinfection are: (1) the use of ozone is relatively expensive and energy intensive, (2) ozone systems are more complex to operate and maintain than chlorine systems, and (3) ozone does not maintain a residual in water.

UV is a physical disinfecting agent. Radiation at a wavelength of 254 mm penetrates the cell wall and is absorbed by the cellular nucleic acids. This can prevent replication by eliminating the organism's ability to cause infection. UV radiation is frequently used for wastewater treatment plants that discharge to surface waters to avoid the need for dechlorination prior to release of the effluent. UV is receiving increasing attention as a means of disinfecting reclaimed water for the following reasons: (1) UV may be less expensive than disinfecting with chlorine, (2) UV is safer to use than chlorine gas, (3) UV does not result in the formation of chlorinated hydrocarbons, and (4) UV is effective against *Cryptosporidium* and *Giardia*, while chlorine is not.

The effectiveness of UV radiation as a disinfectant (where fecal coliform limits are on the order of 200/100 ml) has been well established, and is used at small- to medium-sized wastewater treatment plants throughout the U.S. Today, UV radiation to achieve high-level disinfection for reuse operations is acceptable in some states. In recognition of the possible harmful effects of chlorine, the Florida Department of Environmental Protection (FDEP) encourages the use of alternative disinfection methods (FDEP, 1996). The WERF published a final report entitled, "Disinfection Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance." This report provides a broad-based discussion of the advantages and disadvantages of chlorine and UV, using an empirical model to determine the UV dose required for various levels of coliform inactivation. The report also includes cost information and a comparison of chlorination/dechlorination and UV systems (WERF, 1995). Studies in San Francisco, California, indicated that suspended solids play a major role in UV efficiency. This included the finding that, as the concentration of particles 7 mm and larger increase, the ability to achieve acceptable disinfection with UV decreases. Thus, filtration must be optimized to manage this problem (Jolis *et al.*, 1996).

The goal of UV disinfection in reuse applications typically is to inactivate 99.999 percent or more of the target pathogens (Swift *et al.*, 2002). The 2000 National Water Research Institute (NWRI) guidelines provide detailed guidance for the design of UV systems that will achieve high-level disinfection to meet some state standards for public access reuse. The 2000 NWRI guidelines also include a well-defined testing protocol and validation test as a means to provide reasonable assurance that the domestic wastewater treatment facility can meet the high-level disinfection criteria (NWRI and AWWA, 2000).

The Bethune Point WWTP in Daytona Beach, Florida, is the largest UV disinfection system in the state of Florida designed for reuse operations. This facility is also the first public access reuse facility in Florida with UV disinfection to be permitted for unrestricted public access (Elefritz, 2002). Placed into service in December 1999, the Bethune Point WWTP UV disinfection system is a medium pressure/high intensity system designed for a dose of 80mW-s/cm^2 (800 J/m^2) to achieve the high-level disinfection standard. The City of Henderson, Nevada water reclamation facility conducted collimated beam studies of a low pressure/high intensity UV disinfection system. The studies demonstrated that the disinfection goal of 20 fecal coliforms per 100 ml was achievable with a minimum UV dose of 200 J/m^2 (Smith and Brown, 2002).

Other disinfectants, such as onsite chlorine generation, gamma radiation, bromine, iodine, and hydrogen peroxide, have been considered for the disinfection of wastewater. These disinfectants are not generally used because of economical, technical, operational, or disinfection efficiency considerations.

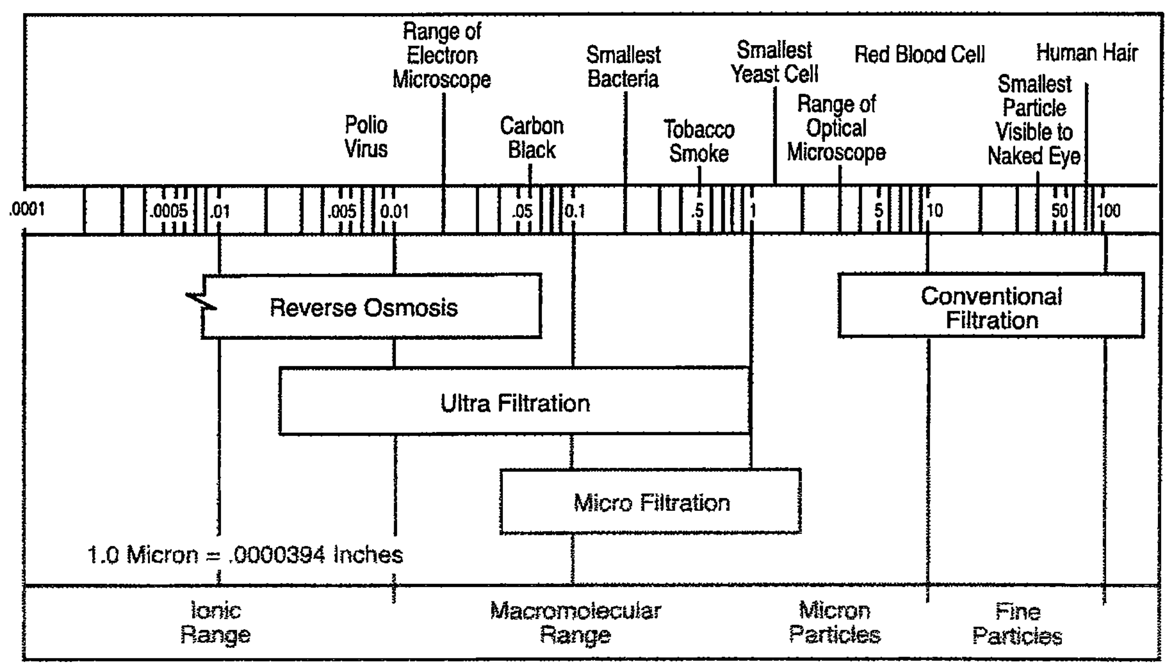
3.4.2.2 Advanced Wastewater Treatment

Advanced wastewater treatment processes are those beyond traditional secondary treatment. These processes are generally used when high quality reclaimed water is needed. Examples include: (1) urban landscaping, (2) food crops eaten raw, (3) contact recreation, and (4) many industrial applications. Individual unit processes capable of removing the constituents of concern are shown in **Figure 3-11**.

The principal advanced wastewater treatment processes for water reclamation are:

- Filtration – Filtration is a common treatment process used to remove particulate matter prior to disinfection. Filtration involves the passing of wastewater through a bed of granular media or filter cloth, which retain the solids. Typical media include sand, anthracite, and garnet. Removal efficiencies can be improved through the addition of certain polymers and coagulants.
- UV Treatment of NDMA – UV Treatment, considered an Advanced Oxidation Technology (AOT), is the only proven treatment to effectively reduce NDMA. The adsorption of ultraviolet light, even the UV portion of sunlight, by NDMA causes the molecule to disassociate into harmless fragments (Nagel *et al.*, 2001). A study done at West Basin Municipal Water District in Carson, California proved NDMA concentrations were reduced by both low and medium pressure UV (Nagel *et al.*, 2001).
- Nitrification – Nitrification is the term generally given to any wastewater treatment process that biologically converts ammonia nitrogen sequentially to ni-

Figure 3-11. Particle Size Separation Comparison Chart



Adapted from AWWA, 1990

trite nitrogen and nitrate nitrogen. Nitrification does not remove significant amounts of nitrogen from the effluent; it only converts nitrogen into another chemical form. Nitrification can be achieved in many suspended and attached growth treatment processes when the processes are designed to foster the growth of nitrifying bacteria. In the traditional activated sludge process, this is accomplished by designing the process to operate at a solids retention time (SRT) that is long enough to prevent slow-growing nitrifying bacteria from being wasted out of the system. Nitrification will also occur in trickling filters that operate at low BOD/TKN ratios either in combination with BOD removal, or as a separate advanced treatment process following any type of secondary treatment. A well-designed and -operated nitrification process will produce an effluent containing 1.0 mg/l or less of ammonia nitrogen.

- Denitrification – Denitrification is any wastewater treatment method that completely removes total nitrogen. As with ammonia removal, denitrification is usually best achieved biologically, in which case it must be preceded by nitrification. In biological denitrification, nitrate nitrogen is used by a variety of heterotrophic bacteria as the terminal electron acceptor in the absence of dissolved oxygen. In the process, the nitrate nitrogen is converted to nitrogen gas, which escapes to the atmosphere. The bacteria in these processes also require a carbonaceous food source. Denitrification can be achieved using many alternative treatment processes including variations of many common suspended growth and some attached growth treatment processes, provided that the processes are designed to create the proper microbial environment. Biological denitrification processes can be designed to achieve effluent nitrogen concentrations between 2.0 and 12 mg/l of nitrate nitrogen.

- Phosphorus Removal – Phosphorus can be removed from wastewater through chemical or biological methods, or a combination. The choice of methods will depend on site-specific conditions, including the amount of phosphorus to be removed and the desired effluent phosphorus concentration. Chemical phosphorus removal is achieved by precipitating the phosphorus from solution through the addition of iron, aluminum, or calcium salts. Biological phosphorus removal relies on the culturing of bacteria that will store excess amounts of phosphorus when exposed to anaerobic conditions, followed by aerobic conditions in the treatment process. In both cases, the phosphorus is removed from the treatment process with the waste sludge. Chemical phosphorus removal can attain effluent orthophosphorus concentrations of less than 0.1 mg/l, while biological phosphorus removal will usually produce an effluent phosphorus concentration between 1.0 and 2.0 mg/l.

- Coagulation-Sedimentation – Chemical coagulation with lime, alum, or ferric chloride followed by sedimentation removes SS, heavy metals, trace substances, phosphorus, and turbidity.

- Carbon Adsorption – One effective advanced wastewater treatment process for removing biodegradable and refractory organic constituents is granular activated carbon (GAC). Carbon adsorption can reduce the levels of synthetic organic chemicals in secondary effluent by 75 to 85 percent. The basic mechanism of removal is by adsorption of the organic compounds onto the carbon. Carbon adsorption proceeded by conventional secondary treatment and filtration can produce an effluent with a BOD of 0.1 to 5.0 mg/l, a COD of 3 to 25 mg/l, and a TOC of 1 to 6 mg/l. Carbon adsorption treatment will also remove several metal ions, particularly cadmium, hexavalent chromium, silver, and selenium. Activated carbon has been used to remove uncharged species, such as arsenic and antimony, from an acidic stream. Carbon adsorption has also been reported as an effective means of removing endocrine disrupting compounds (Hunter and Long, 2002).

- Membrane Processes – In recent years, the same factors that favor the use of membranes for potable water treatment (increasing demand, decreasing source water quality, and more stringent regulatory standards) are influencing their use in treating wastewaters prior to reuse. Improvements in membrane technologies which separate suspended solids, dissolved compounds, and human pathogens (protozoan cysts, bacteria and viruses) from reclaimed water have inspired greater confidence in the use of reclaimed water for purposes which include both direct and indirect human contact.

  Membrane filters became commercially available in 1927 from the Sartorius Company in Germany. Until the mid-1940s, these filters were used primarily to remove microorganisms and particles from air and water. The first viable reverse osmosis membrane was developed in 1960 by researchers at the University of California at Los Angeles (UCLA). The first commercial reverse osmosis (RO) treatment plant went into service in 1965 in Coalinga, California. The use of membrane filtration systems was initially limited to specialized applications including industrial separation processes and seawater desalination. By the 1980s, membrane technology was well established.

For many years, membranes were not used for wastewater treatment due to rapid fouling. Prior to 1990, there were a few notable exceptions, including a highly publicized 5-mgd RO system at the Water Factory 21 reclamation plant in Orange County, California. This system went into service in 1975. The plant used cellulose acetate membranes with lime clarification and multi-media filtration for pretreatment prior to the RO system. Another notable exception was a 3.3-mgd (12 x 10^3-m^3/d) Petromin plant in Riyadh, Saudia Arabia.

The large-scale use of membranes for wastewater reclamation did not become feasible until the1980s, when the Australian firm, Memtec, developed a hollow fiber microfiltration membrane system with an air backwash that could provide sustainable operation for wastewater. The Orange County Water District (California) began pilot testing in 1992 to investigate this new microfiltration system as pretreatment for reverse osmosis. The use of this new microfiltration system, followed by thin film composite RO membranes, proved to be a tremendous improvement over the then-conventional system of lime clarification, sand filtration, and cellulose acetate membranes. Between 1994 and 2000, over half a dozen new dual membrane water reclamation systems were constructed in California and Arizona.

Pressure-driven membrane treatment systems are broadly categorized by the size particles rejected by the membrane, or by the molecular weight cut off (MWCO). These classifications include:

Microfiltration (MF)	0.1 μm	or	500, 000 MWCO
Ultrafiltration (UF)	0.01 μm	or	20,000 MWCO
Nanofiltration (NF)	0.001 µm	or	200 MWCO
Reverse Osmosis (RO)	0.0001 µm	or	< 100 MWCO

Figure 3-11 shows a particle size separation comparison chart for conventional filtration, microfiltration, ultrafiltration, and reverse osmosis. **Tables 3-13a** and **3-13b** contain microfiltration and reverse osmosis removal data (Metcalf and Eddy, 2002).

MF systems are used to remove relatively large suspended particles including particulates, large colloids, and oil. This includes providing about 3 to 6 log (99.9 percent to 99.9999 percent) removal of bacteria. In wastewater treatment, MF systems can be used to replace secondary clarifiers and more conventional (sand) filters following biological treatment. UF membranes have smaller pore sizes than MF membranes and will provide complete removal of bacteria and protozoan cysts, and 4 to 6 log removal for viruses. Otherwise, UF membranes perform the same basic functions in wastewater applications as MF membranes. NF and RO, while retaining smaller particles including molecules and ions, require higher driving pressures, higher levels of pretreatment (prefiltration), and typically operate at lower recovery rates.

For wastewater treatment, the main emphasis has been on MF, UF, and RO membranes. MF and UF have the ability to remove biological contaminants (e.g., bacteria and viruses), and to reduce fouling on downstream reverse osmosis membranes. NF or RO systems are needed where the removal of colloidal and/or dissolved materials is required.

Membrane Bioreactors (MBRs)

MBRs typically consist of UF or MF membranes. These membranes are used to replace conventional gravity clarifiers, and return activated sludge systems in conventional activated sludge biological treatment systems. The membranes can be immersed directly into the aeration tanks, or the mixed liquor can be pumped to external pressure-driven membrane units. MBRs exhibit a number of unique advantages:

- Sludge settling characteristics no longer affect final effluent quality. Biological processes can be operated at much higher suspended solids concentrations and thereby provide greater treatment capacity per unit volume.
- MF and UF membranes provide nearly complete removal of protozoan cysts, suspended solids, and bacteria, as well as partial removal of viruses. In addition to removing suspended solids, UF membranes can retain large organic molecules, improving the biodegradation of otherwise resistant compounds such as grease or emulsified oils.
- Longer sludge ages (as long as 30 to 45 days) are possible, improving the biodegradation of resistant compounds and improving nitrification performance under adverse conditions (such as low temperature).
- Wasting occurs directly from the aeration basin, improving process control.
- Submerged MBR systems are well suited to upgrade existing systems with minimum new construction required and low impact to ongoing operations.

Table 3-13a. Microfiltration Removal Performance Data

Constituent	MF Influent (mg/l)	MF Effluent (mg/l)	Average Reduction (%)	Reduction Reported in Literature (%)
TOC	10-31	9-16	57	45-65
BOD	11-32	<2-9.9	86	75-90
COD	24-150	16-53	76	70-85
TSS	8-46	<0.5	97	95-98
TDS	498-622	498-622	0	0-2
NH_3-N	21-42	20-35	7	5-15
NO_3-N	<1-5	<1-5	0	0-2
PO_4^-	6-8	6-8	0	0-2
SO_4^{2-}	90-120	90-120	0	0-1
Cl^-	93-115	93-115	0	0-1
Turbidity	2-50 NTU	0.03-0.08 NTU	>99	---

[1] Data collected from the Dublin San Ramon Sanitary District for the period from April 2000 through December, 2000.
[2] Typical flux rate during test period was 1600 $l/m^2 \cdot d$.

Adapted from: Metcalf and Eddy, 2002

Table 3-13b. Reverse Osmosis Performance Data

Constituent	RO Influent (mg/l)	RO Effluent (mg/l)	Average Reduction (%)	Reduction Reported in Literature (%)
TOC	9-16	<0.5	>94	85-95
BOD	<2-9.9	<2	>40	30-60
COD	16-53	<2	>91	85-95
TSS	<0.5	~0	>99	95-100
TDS	498-622	9-19	---	90-98
NH_3-N	20-35	1-3	96	90-98
NO_3-N	<1-5	0.08-3.2	96	65-85
PO_4^-	8-Jun	0.1-1	~99	95-99
SO_4^{2-}	90-120	<0.5-0.7	99	95-99
Cl^-	93-115	0.9-5.0	97	90-98
Turbidity	0.03-0.08 NTU	0.03 NTU	50	40-80

[1] Data collected from the Dublin San Ramon Sanitary District for the period from April 1999 through December, 1999.
[2] Typical flux rate during test period was 348 $l/m^2 \cdot d$.

Adapted from: Metcalf and Eddy, 2002

Submerged membrane assemblies, either MF or UF, are typically composed of bundles of hollow fiber or flat sheets of microporous membranes. Filtrate is drawn through the membrane assemblies by means of a vacuum applied to the product side of the membrane. Turbulence on the exterior (feed side) is maintained by diffused aeration to reduce fouling.

Low-pressure membrane filtration (MF or UF) can be used following secondary clarification to provide a higher degree of solids removal. Operating in a conventional (pressurized) flow pattern, clarified effluent is further treated to remove particulate material (MF) or colloidal material (UF). Typical operating pressures range from 20 to 100 psi (100 to 700 KPa), and reject flows range from 2 to 50 percent. MF and UF membranes can be used to pre-treat flow prior to NF or RO treatment.

Higher-pressure NF and RO systems are used to remove dissolved organic and inorganic compounds. The smaller pore size (lower MWCO) results in higher quality product water, which may meet primary and secondary drinking water standards. The higher rates of rejection also result in increasing problems for disposing of the concentrate streams.

- Other Processes – Other advanced wastewater treatment processes of constituent removal include ammonia stripping, breakpoint chlorination for ammonia removal, and selective ion exchange for nitrogen removal.

3.4.3 Reliability in Treatment

A high standard of reliability, similar to water treatment plants, is required at wastewater reclamation plants. Because there is potential for harm (i.e., in the event that improperly treated reclaimed water is delivered to the use area), water reuse requires strict conformance to all applicable water quality parameters. The need for reclamation facilities to reliably and consistently produce and distribute reclaimed water of adequate quality and quantity is essential and dictates that careful attention be given to reliability features during the design, construction, and operation of the facilities.

A number of fallible elements combine to make up an operating water reclamation system. These include the power supply, individual treatment units, mechanical equipment, the maintenance program, and the operating personnel. An array of design features and non-design provisions can be employed to improve the reliability of the separate elements and the system as a whole. Back-up systems are important in maintaining reliability in the event of failure of vital components. Particularly critical units include the disinfection system, power supply, and various treatment unit processes.

For reclaimed water production, EPA Class I reliability is recommended as a minimum criteria. Class I reliability requires redundant facilities to prevent treatment upsets during power and equipment failures, flooding, peak loads, and maintenance shutdowns. Reliability for water reuse should also consider:

- Operator certification to ensure that qualified personnel operate the water reclamation and reclaimed water distribution systems
- Instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions
- A comprehensive quality assurance program to ensure accurate sampling and laboratory analysis protocol
- Adequate emergency storage to retain reclaimed water of unacceptable quality for re-treatment or alternative disposal
- Supplemental storage and/or water supply to ensure that the supply can match user demands
- A strict industrial pretreatment program and strong enforcement of sewer use ordinances to prevent illicit dumping into the collection system of hazardous materials or other materials that may interfere with the intended use of the reclaimed water
- A comprehensive operating protocol that defines the responsibilities and duties of the operations staff to ensure the reliable production and delivery of reclaimed water

Many states have incorporated procedures and practices into their reuse rules and guidelines to enhance the reliability of reclaimed water systems. Florida requires the producer of reclaimed water to develop a detailed operating protocol for all public access systems. This protocol must identify critical monitoring and control equipment, set points for chlorine and turbidity, actions to be taken in the event of a failure to achieve these limits, and procedures to clear the substandard water and return to normal operations (FAC 62-610). Washington is in the process of developing Water Reclamation Facilities Reliability Assessment Guidance, which includes an alarm and reliability checklist.

3.4.3.1 EPA Guidelines for Reliability

More than 30 years ago, before the Federal Water Quality Administration evolved into the EPA, it recognized the importance of treatment reliability, issuing guidelines entitled, "Federal Guidelines: Design, Operation and Maintenance of Waste Water Treatment Facilities" (Federal Water Quality Administration, 1970). These guidelines provided an identification and description of various reliability provisions and included the following concepts or principles regarding treatment plant reliability:

Table 4-11. Groundwater Recharge (1)

	Arizona	California(2)	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR (3)		Secondary treatment and basic disinfection		NR	NR	Oxidized, coagulated, filtered, and disinfected
BOD_5	NR		NS(4)		NR	NR	5 mg/l
TSS	NR		10.0 mg/l		NR	NR	5 mg/l
Turbidity	NR	Case-by-case basis	NS	Case-by-case basis	NR	NR	2 NTU (Avg) 5 NTU (Max)
Coliform	NR		NS		NR	NR	Total 2.2/100 ml (Avg) 23/100 ml (Max)
Total Nitrogen	NR		12 mg/l		NR	NR	NS

(1) All state requirements are for groundwater recharge via rapid-rate application systems. Additional regulations for recharge of potable aquifers are contained in Section 4.1.1.10 and Appendix A.
(2) Groundwater recharge in California and Hawaii is determined on a case-by-case basis
(3) NR - Not regulated by the state
(4) NS - Not specified by state regulations

ter defined as oxidized, coagulated, filtered, and disinfected. Total coliform is not to exceed 2.2/100 ml as a 7-day median and 23/100 ml in any sample. Weekly average BOD and TSS limits are set at 5 mg/l. Turbidity is not to exceed 2 NTU as a monthly average and 5 NTU in any sample. Additionally, groundwater monitoring is required and is based on reclaimed water quality and quantity, site-specific soil and hydrogeologic characteristics, and other considerations. Washington also specifies that reclaimed water withdrawn for nonpotable purposes can be withdrawn at any distance from the point of injection and at any time after direct recharge.

Florida requires that TSS not exceed 5.0 mg/l in any sample, be achieved prior to disinfection, and that the total nitrogen in the reclaimed water be less than 12 mg/l. Florida also requires continuous on-line monitoring of turbidity; however, no limit is specified.

4.1.1.10 Indirect Potable Reuse

Indirect potable reuse involves the use of reclaimed water to augment surface water sources that are used or will be used for public water supplies or to recharge groundwater used as a source of domestic water supply. Unplanned indirect potable water reuse is occurring in many river systems today. Many domestic wastewater treatment plants discharge treated effluent to surface waters upstream of intakes for domestic water supply treatment plants. Additionally, many types of beneficial reuse projects inadvertently contribute to groundwater augmentation as an unintended result of the primary activity. For example, irrigation can replenish groundwater sources that will eventually be withdrawn for use as a potable water supply. Indirect potable reuse systems, as defined here, are distinguished from typical groundwater recharge systems and surface water discharges by both intent and proximity to subsequent withdrawal points for potable water use. Indirect potable reuse involves the intentional introduction of reclaimed water into the raw water supply for the purposes of increasing the total volume of water available for potable use. In order to accomplish this objective, the point at which reclaimed water is introduced into the environment must be selected to ensure it will flow to the point of withdrawal. Typically the design of these systems assumes there will be little to no additional treatment in the environment after discharge, and all applicable water quality requirements are met prior to release of the reclaimed water.

Based on a review of the existing reuse regulations and guidelines, 4 of the 7 states (California, Florida, Hawaii, and Washington) have regulations or guidelines pertaining to indirect potable reuse. For groundwater recharge of potable aquifers, most of the states require a pretreatment program, public hearing requirements prior to project approval, and a groundwater monitoring program. Florida and Washington require pilot plant studies to be performed. In general, all the states that specify treatment processes require secondary treatment with filtration and disinfection. Washington is the only state that specifies the wastewater must be treated by reverse osmosis. California and Hawaii do not specify the type of treatment processes required and determine requirements on a case-by-case basis.

Most states specify reclaimed water quality limitations for TSS, nitrogen, total organic carbon (TOC), turbidity, and total coliform. Florida requires that TSS not exceed 5.0 mg/l in any sample and be achieved prior to disinfection. Florida and Washington require the total nitrogen in the reclaimed water to be less than 10 mg/l. Washington has a limit of 1 mg/l for TOC, while Florida's limit is set at 3 mg/l as a monthly average. Florida also requires an average limit of 0.2 mg/l for total organic halides (TOX). Turbidity limits vary greatly where specified. For example, Washington specifies a limit of 0.1 NTU as a monthly average and 0.5 NTU as a maximum at any time. Florida requires continuous on-line monitoring of turbidity; however, no limit is specified. Fecal coliform limits also vary greatly from state to state. Washington requires a limit of 1/100 ml for total coliform as a weekly median and a not to exceed limit of 5/100 ml in any one sample for direct injection into a potable aquifer. The states that specify reclaimed water quality limitations require the reclaimed water to meet drinking water standards.

Most states specify a minimum time the reclaimed water must be retained underground prior to being withdrawn as a source of drinking water. Washington requires that reclaimed water be retained underground for a minimum of 12 months prior to being withdrawn as a drinking water supply. Several states also specify minimum separation distances between a point of recharge and the point of withdrawal as a source of drinking water. Florida requires a 500-foot (150-meter) separation distance between the zone of discharge and potable water supply well. Washington requires the minimum horizontal separation distance between the point of direct recharge and point of withdrawal as a source of drinking water supply to be 2,000 feet (610 meters). **Table 4-12** shows the reclaimed water quality and treatment requirements for indirect potable reuse.

Florida includes discharges to Class I surface waters (public water supplies) as indirect potable reuse. Discharges less than 24 hours travel time upstream from Class I waters are also considered as indirect potable reuse. Surface water discharges located more than 24 hours travel time to Class I waters are not considered indirect potable reuse. For discharge to Class I surface waters or water contiguous to or tributary to Class I waters (defined as a discharge located less than or equal to 4 hours travel time from the point of discharge to arrival at the boundary of the Class I water), secondary treatment with filtration, high-level disinfection, and any additional treatment required to meet TOC and TOX limits is required. The reclaimed water must meet primary and secondary drinking water standards, except for asbestos, prior to discharge. TSS must not exceed 5.0 mg/l in any sample prior to disinfection and total nitrogen cannot exceed 10 mg/l as an annual average. The reclaimed water must also meet TOC limitations of 3 mg/l as a monthly average and 5 mg/l in any single sample. Outfalls for surface water discharges are not to be located within 500 feet (150 meters) of existing or approved potable water intakes within Class I surface waters.

4.1.2 Reclaimed Water Monitoring Requirements

Reclaimed water monitoring requirements vary greatly from state to state and again depend on the type of reuse. For unrestricted urban reuse, Oregon requires sampling for coliform daily, while for agricultural reuse of non-food crops, sampling for total coliform is only required once a week. Oregon also requires hourly monitoring of turbidity when a limit on turbidity is specified.

For unrestricted and restricted urban reuse, as well as agricultural reuse on food crops, Florida requires the continuous on-line monitoring of turbidity and chlorine residual. Even though no limits on turbidity are specified in Florida, continuous monitoring serves as an online surrogate for suspended solids. In addition, Florida requires that the TSS limit be achieved prior to disinfection and has a minimum schedule for sampling and testing flow, pH, chlorine residual, dissolved oxygen, TSS, CBOD, nutrients, and fecal coliform based on system capacity. Florida also requires an annual analysis of primary and secondary drinking water standards for reclaimed water used in irrigation for facilities greater than 100,000 gpd (4.4 l/s). Monitoring for *Giardia* and *Cryptosporidium* must also be performed with frequency dependent on system capacity. Other states determine monitoring requirements on a case-by-case basis depending on the type of reuse.

4.1.3 Treatment Facility Reliability

Some states have adopted facility reliability regulations or guidelines in place of, or in addition to, water quality

Table 4-12. Indirect Potable Reuse (1)

	Arizona	California(2)	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR (3)	Case-by-case basis	Advanced treatment, filtration, and high-level disinfection	Case-by-case basis	NR	NR	Oxidized, coagulated, filtered, reverse-osmosis treated, and disinfected
BOD_5	NR		20 mg/l		NR	NR	5 mg/l
TSS	NR		5.0 mg/l		NR	NR	5 mg/l
Turbidity	NR		NS (4)		NR	NR	0.1 NTU (Avg) 0.5 NTU (Max)
Coliform	NR		**Total** All samples less than detection		NR	NR	**Total** 1/100 ml (Avg) 5/100 ml (Max)
Total Nitrogen	NR		10 mg/l		NR	NR	10 mg/l
TOC	NR		3 mg/l (Avg) 5 mg/l (Max)		NR	NR	1.0 mg/l
Primary and Secondary Standards	NR		Compliance with most primary and secondary		NR	NR	Compliance with most primary and secondary

(1) Florida requirements are for the planned use of reclaimed water to augment surface water sources that will be used as a source of domestic water supply
(2) Indirect potable reuse in California and Hawaii is determined on a case-by-case basis
(3) NR - Not regulated by the state
(4) NS - Not specified by state regulations

requirements. Generally, requirements consist of alarms warning of power failure or failure of essential unit processes, automatic standby power sources, emergency storage, and the provision that each treatment process be equipped with multiple units or a back-up unit.

Articles 8, 9, and 10 of California's Title 22 regulations provide design and operational considerations covering alarms, power supply, emergency storage and disposal, treatment processes, and chemical supply, storage, and feed facilities. For treatment processes, a variety of reliability features are acceptable in California. For example, for all biological treatment processes, one of the following is required:

- Alarm (failure and power loss) and multiple units capable of producing biologically oxidized wastewater with one unit not in operation
- Alarm (failure and power loss) and short-term (24-hour) storage or disposal provisions and standby replacement equipment
- Alarm (failure and power loss) and long-term (20-day) storage or disposal provisions

Florida requires Class I reliability of treatment facilities when reclaimed water is used for irrigation of food crops and for restricted and unrestricted urban reuse. Class I reliability requires multiple treatment units or back-up units and a secondary power source. In addition, a minimum of 1 day of reject water storage is required to store reclaimed water of unacceptable quality for additional treatment. Florida also requires staffing at the water reclamation facility 24 hours/day, 7 days/week or 6 hours/day, 7 days/week. The minimum staffing requirement may be reduced to 6 hours/day, 7 days/week if reclaimed water is delivered to the reuse system only during periods when a qualified operator is present, or if additional reliability features are provided.

Florida has also established minimum system sizes for treatment facilities to aid in assuring the continuous production of high-quality reclaimed water. Minimum system size for unrestricted and restricted urban reuse and for use on edible crops is 0.1 mgd (4.4 l/s). A minimum system size is not required if reclaimed water will be used only for toilet flushing and fire protection uses.

Other states that have regulations or guidelines regarding treatment facility reliability include Georgia, Hawaii, Indiana, Massachusetts, North Carolina, Oregon, Utah, Washington, and Wyoming. Washington's guidelines pertaining to treatment facility reliability are similar to California's regulations. Georgia, Massachusetts, North Carolina, Oregon, and Wyoming require that multiple treatment units be provided for all essential treatment processes and a secondary or back-up power source be supplied.

4.1.4 Reclaimed Water Storage

Current regulations and guidelines regarding storage requirements are primarily based upon the need to limit or prevent surface water discharge and are not related to storage required to meet diurnal or seasonal variations in supply and demand. Storage requirements vary from state to state and are generally dependent upon geographic location and site conditions. For example, Florida requires a minimum storage volume equal to 3 days of the average design flow, while South Dakota requires a minimum storage volume of 210 days of the average design flow. The large difference in time is primarily due to the high number of non-irrigation days due to freezing temperatures in the northern states. In addition to the minimum storage requirement, Florida also requires that a water balance be performed based on a 1-in-10 year rainfall recurrence interval and a minimum of 20 years of climatic data to determine if additional storage is required beyond the minimum requirement of 3 days.

Most states that specify storage requirements do not differentiate between operational and seasonal storage, with the exception of Delaware, Georgia, and Ohio, which require that both operational and wet weather storage be considered. The majority of states that have storage requirements in their regulations or guidelines require that a water balance be performed on the reuse system, taking into account all inputs and outputs of water to the system based on a specified rainfall recurrence interval.

Presently, Florida is the only state with regulations or guidelines for aquifer storage and recovery (ASR) of reclaimed water. ASR systems using reclaimed water are required to meet the technical and permitting requirements of Florida's Department of Environmental Protection underground injection control program and obtain an underground injection control construction and operation permit in addition to the domestic wastewater permit. Water recovered from the ASR system must meet the performance standards for fecal coliform as specified for high-level disinfection. Specifically, the fecal coliform limits require 75 percent of samples to be below detection limits, and any single sample is not to exceed 25/100 ml before use in a reuse system. Preapplication treatment and disinfection requirements vary depending on the class of groundwater receiving injected reclaimed water, but may be as stringent as to require that reclaimed water meet primary and secondary drinking water standards and TOC and TOX limits prior to injection. Monitoring of the reclaimed water prior to injection and after recovery from the ASR system is required. In addition, a groundwater monitoring plan must be implemented before placing the ASR system into operation. The monitoring plan must be designed to verify compliance with the groundwater standards and to monitor the performance of the ASR system. As part of the monitoring plan, a measure of inorganics concentration (such as chlorides or total dissolved solids) and specific conductance of the water being injected, the groundwater, and the recovered water are required to be monitored. In some cases, an extended zone of discharge for the secondary drinking water standards and for sodium can be approved.

Injection wells and recovery wells used for ASR are to be located at least 500 feet from any potable water supply well. For potable water supply wells that are not public water supply wells, a smaller setback distance may be approved if it can be demonstrated that confinement exists such that the system will not adversely affect the quantity or quality of the water withdrawn from the potable water supply well. If the ASR well is located in the same aquifer as a public supply well, the permitting agencies may require a detailed analysis of the potential for reclaimed water entry into the public supply well.

4.1.5 Application Rates

When regulations specify application or hydraulic loading rates, the regulations generally pertain to land application systems that are used primarily for additional wastewater treatment for disposal rather than reuse. When systems are developed chiefly for the purpose of land treatment and/or disposal, the objective is often to dispose of as much effluent on as little land as possible;

Table 4-13. Suggested Guidelines for Water Reuse [1]

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Groundwater Recharge By spreading or injection into aquifers not used for public water supply	• Site-specific and use dependent • Primary (minimum) for spreading • Secondary [4] (minimum) for injection	• Site-specific and use dependent	• Depends on treatment and use	• Site-specific	• Facility should be designed to ensure that no reclaimed water reaches potable water supply aquifers • See Section 2.5 for more information. • For spreading projects, secondary treatment may be needed to prevent clogging. • For injection projects, filtration and disinfection may be needed to prevent clogging. • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by spreading into potable aquifers	• Secondary [4] • Disinfection [5] • May also need filtration [5] and/or advanced wastewater treatment [16]	• Secondary [4] • Disinfection [5] • Meet drinking water standards after percolation through vadose zone	Includes, but not limited to, the following: • pH - daily • Coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent • BOD - weekly • Turbidity - continuous	• 500 ft (150 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	• The depth to groundwater (i.e., thickness to the vadose zone) should be at least 6 feet (2 m) at the maximum groundwater mounding point. • The reclaimed water should be retained underground for at least 6 months prior to withdrawal. • Recommended treatment is site-specific and depends on factors such as type of soil, percolation rate, thickness of vadose zone, native groundwater quality, and dilution. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • See Sections 2.5 and 2.6 for more information. • The reclaimed water should not contain measurable levels of viable pathogens after percolation through the vadose zone. [12] • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by injection into potable aquifers	• Secondary [4] • Filtration [6] • Disinfection [6] • Advanced wastewater treatment [16]	Includes, but not limited to, the following: • pH = 6.5 - 8.5 • $\leq$ 2 NTU 8 • No detectable total coli/100 ml [9,10] • 1 mg/l Cl2 residual (minimum) [11] • $\leq$ 3 mg/l TOC • $\leq$ 0.2 mg/l TOX • Meet drinking water standards	Includes, but not limited to, the following: • pH - daily • Turbidity - continuous • Total coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent	• 2000 ft (600 m) to extraction wells. May vary depending on site-specific conditions.	• The reclaimed water should be retained underground for at least 9 months prior to withdrawal. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • Recommended quality limits should be met a the point of injection. • The reclaimed water should not contain measurable levels of viable pathogens after percolation through the vadose zone. [12] • See Sections 2.5 and 2.6 for more information. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus and protozoa inactivation. • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Augmentation of surface supplies	• Secondary [4] • Filtration [5] • Disinfection [6] • Advanced wastewater treatment [16]	Includes, but not limited to, the following: • pH = 6.5 - 8.5 • $\leq$ 2 NTU [8] • No detectable total coli/100 ml [9,10] • 1 mg/l Cl2 residual (minimum) [11] • $\leq$ 3 mg/l TOC • Meet drinking water standards	Includes, but not limited to, the following: • pH - daily • Turbidity - continuous • Total coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent	• Site-specific	• Recommended level of treatment is site-specific and depends on factors such as receiving water quality, time and distance to point of withdrawal, dilution and subsequent treatment prior to distribution for potable uses. • The reclaimed water should not contain measurable levels of viable pathogens. [12] • See Sections 2.6 for more information. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus and protozoa inactivation. • See Section 3.4.3 for recommended treatment reliability.

Footnotes

1. These guidelines are based on water reclamation and reuse practices in the U.S., and they are especially directed at states that have not developed their own regulations or guidelines. While the guidelines should be useful in may areas outside the U.S., local conditions may limit the applicability of the guidelines in some countries (see Chapter 8). It is explicitly stated that the direct application of these suggested guidelines will not be used by USAID as strict criteria for funding.

2. Unless otherwise noted, recommended quality limits apply to the reclaimed water at the point of discharge from the treatment facility.

3. Setback distances are recommended to protect potable water supply sources from contamination and to protect humans from unreasonable health risks due to exposure to reclaimed water.

4. Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contractors, and may include stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and TSS do not exceed 30 mg/l.

5. Filtration means the passing of wastewater through natural undisturbed soils or filter media such as sand and/or anthracite, filter cloth, or the passing of wastewater through microfilters or other membrane processes.

6. Disinfection means the destruction, inactivation, or removal of pathogenic microorganisms by chemical, physical, or biological means. Disinfection may be accomplished by chlorination, UV radiation, ozonation, other chemical disinfectants, membrane processes, or other processes. The use of chlorine as defining the level of disinfection does not preclude the use of other disinfection processes as an acceptable means of providing disinfection for reclaimed water.

7. As determined from the 5-day BOD test.

8. The recommended turbidity limit should be met prior to disinfection. The average turbidity should be based on a 24-hour time period. The turbidity should not exceed 5 NTU at any time. If TSS is used in lieu of turbidity, the TSS should not exceed 5 mg/l.

9. Unless otherwise noted, recommended coliform limits are median values determined from the bacteriological results of the last 7 days for which analyses have been completed. Either the membrane filter or fermentation-tube technique may be used.

10. The number of fecal coliform organisms should not exceed 14/100 ml in any sample.

11. Total chlorine residual should be met after a minimum contact time of 30 minutes.

12. It is advisable to fully characterize the microbiological quality of the reclaimed water prior to implementa tion of a reuse program.

13. The number of fecal coliform organisms should not exceed 800/100 ml in any sample.

14. Some stabilization pond systems may be able to meet this coliform limit without disinfection.

15. Commercially processed food crops are those that, prior to sale to the public or others, have undergone chemical or physical processing sufficient to destroy pathogens.

16. Advanced wastewater treatment processes include chemical clarification, carbon adsorption, reverse osmosis and other membrane processes, air stripping, ultrafiltration, and ion exchange.

17. Monitoring should include inorganic and organic compounds, or classes of compounds, that are known or uspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the drinking water standards.

CHAPTER 7

Public Involvement Programs

In the years since this manual was first developed, the world has seen ever-increasing demands for water, often from competing interests, and often in the face of declining water supplies. As a result, water quality and quantity have become important public topics in many arenas, and regulatory agencies often require some level of stakeholder involvement in water management decisions. This is strikingly different from the past when members of the public were often informed about projects only after final decisions had been made. Today, responsible leaders recognize the need to incorporate public values with science, technology, and legal aspects to create real, workable solutions tailored to meet specific needs.

In the area of water reuse, the opportunities for meaningful public involvement are many. This chapter provides an overview of the key elements of public planning, as well as several case studies illustrating public involvement and/or participation approaches.

7.1 Why Public Participation?

Public involvement or participation programs work to identify key audiences and specific community issues at a very early stage, offering information and opportunities for input in a clear, understandable way. Effective public involvement begins at the earliest planning stage and lasts through implementation and beyond.

Public participation begins with having a clear understanding of the water reuse options available to the community. Once an understanding of possible alternatives is developed, a list of stakeholders, including possible users, can be identified and early public contacts may begin. Why begin contacting stakeholders before a plan is in place? These citizen stakeholders can provide early indications regarding which reuse program will be best accepted on a community-wide level. Beyond that, informed citizens can help identify and resolve potential problems before they occur and develop alternatives that may work more effectively for the community.

In general, effective public participation programs invite two-way communication, provide education, and ask for meaningful input as the reuse program is developed and refined. Depending on the project, public involvement can involve limited contact with a number of specific users, or can be expanded to include the formation of a formal advisory committee or task force. Often, public information efforts begin by targeting the most impacted stakeholders. Over time, as an early education base is built among stakeholders, the education effort then broadens to include the public at large. Regardless of the audience, all public involvement efforts are geared to help ensure that adoption of a selected water reuse program will fulfill real user needs and generally recognized community goals including public health, safety, and program cost.

The term, "two-way communications flow" cannot be too highly emphasized. In addition to building community support for a reuse program, public participation can also provide valuable community-specific information to the reuse planners. Citizens have legitimate concerns, quite often reflecting their knowledge of detailed technical information. In reuse planning, especially, where one sector of "the public" comprises potential users of reclaimed water, this point is critical. Potential users *generally* know what flow and quality of reclaimed water are acceptable for their applications.

7.1.1 Informed Constituency

By taking time during the planning stages to meet with citizens, communities will have a much greater opportunity to develop a successful reuse program. Many citizens may have a pre-conceived notion about reclaimed water and its benefits. It is important to identify each stakeholder's issues and to address questions and concerns in a clear, matter-of-fact way. This two-way dialogue will lead to informed input regarding reuse alternatives.

A public participation program can build, over time, an informed constituency that is comfortable with the concept of reuse, knowledgeable about the issues involved in reclamation/reuse, and supportive of program implementation. Ideally, citizens who have taken part in the planning process will be effective proponents of the selected plans. Having educated themselves on the issues involved in adopting reclamation and reuse, they will also understand how various interests have been accommodated in the final plan. Their understanding of the decision-making process will, in turn, be communicated to larger interest groups – neighborhood residents, clubs, and municipal agencies – of which they are a part. Indeed the potential reuse customer who is enthusiastic about the prospect of receiving service may become one of the most effective means of generating support for a program. This is certainly true with the urban reuse programs in St. Petersburg and Venice, Florida. In these communities, construction of distribution lines is contingent on the voluntary participation of a percentage of customers within a given area.

In other communities where reuse has not been introduced in any form, the focus may begin with very small, specific audiences. For instance, a community may work closely with golf course owners and superintendents to introduce reuse water as a resource to keep the golf course in prime condition, even at times when other water supplies are low. This small, informed constituency can then provide the community with a lead-in to other reclaimed water options in the future. Golf course superintendents spread the word informally, and, as golfers see the benefits, the earliest of education campaigns has subtly begun. Later, the same community may choose to introduce an urban system, offering reclaimed water for irrigation use.

Since many reuse programs may ultimately require a public referendum to approve a bond issue for funding reuse system capital improvements, diligently soliciting community viewpoints and addressing any concerns early in the planning process can be invaluable in garnering support. Public involvement early in the planning process, even as alternatives are beginning to be identified, allows ample time for the dissemination and acceptance of new ideas among the constituents. Public involvement can even expedite a reuse program by uncovering any opposition early enough to adequately address citizen concerns and perhaps modify the program to better fit the community.

7.2 Defining the "Public"

Many contemporary analyses of public involvement define "the public" as comprising various subsets of "publics" with differing interests, motivations, and approaches to policy issues. For example, in discussing public participation for wastewater facilities and reuse planning the following publics may be identified: general public, potential users, environmental groups, special interest groups, home owners associations, regulators and/or regulating agencies, educational institutions, political leaders, and business/academic/community leaders. In an agricultural area, there may be another different set of publics including farmers.

For example, several government agencies in California held a Reuse Summit in 1994, at which they endorsed the creation of the public outreach effort by creating the following mission statement (Sheikh *et al.,* 1996):

> "To activate community support for water recycling through an outreach program of educating and informing target audiences about the values and benefits of recycled water."

During that summit they also identified 8 public audiences: Local Elected Officials, Regulatory Agency Staff, General Public, Environmental Community, City Planning Staffs, Agricultural Community, Schools, and Newspaper Editorial Boards.

From the outset of reuse planning, informal consultation with members of each of the groups comprising "the public", and formal presentations before them, should both support the development of a sound base of local water reuse information and, simultaneously, build a coalition that can effectively advocate reuse in the community. Keeping in mind that different groups have different interests at stake, each presentation should be tailored to the special needs and interests of the audience.

If a reuse program truly has minimal impact on the general public, limited public involvement may be appropriate. For example, use of reclaimed water for industrial cooling and processing – with no significant capital improvements required of the municipality – may require support only from regulatory, technical, and health experts, as well as representatives from the prospective user and its employees. Reuse for pastureland irrigation in isolated areas might be another example warranting only limited public participation.

7.3 Overview of Public Perceptions

One of the most tried and true methods of determining the public's perception of reuse programs is surveys. Surveys can determine whether or not there will be a large enough consumer base to sustain a program, if the program will be favorable enough to progress to the conceptual and design stage, and the overall success of the project after implementation. The following projects highlight different survey strategies and results across the nation.

7.3.1 Residential and Commercial Reuse in Tampa, Florida

A survey done by the City of Tampa for its residential reuse project included a direct mailing and public opinion survey. Information was sent to 15,500 potable water customers in the conceptual project area. Out of the pool of potential reuse customers, 84 percent of the residential users and 94 percent of the commercial users in the South Tampa area thought that reclaimed water was safe for residential and commercial landscape irrigation. Of the same group, 84 percent of the residential responders and 90 percent of the commercial responders replied that the project was appealing. The responses met the design criteria of 90 percent participation (Grosh *et al.*, 2002).

7.3.2 A Survey of WWTP Operators and Managers

A study done by Hall and Rubin in 2002 surveyed 50 wastewater operators and managers. Seventy percent of the responders stated that they believed that reuse would be an important part of their operation in 5 years. The majority (66 percent) thought that water reuse should be considered as an element of all water and wastewater expansion facility permits. Ninety percent wanted funding agencies to consider financial incentives to encourage more water reuse. **Table 7-1** lists the survey results (in percentages) to the inquiry for potential use alternatives for reclaimed water.

7.3.3 Public Opinion in San Francisco, California

The City of San Francisco, California, surveyed the general public to measure public acceptance of a proposed reclaimed water project. **Figures 7-1** and **7-2** graphically demonstrate the responses that were collected. The overall majority strongly felt that reclaimed water was beneficial. Figure 7-2 shows that the responders felt positively about all of the proposed uses of reclaimed water: fire fighting, irrigation of golf courses and parks, street cleaning, toilet flushing, and drought protection.

7.3.4 Clark County Sanitation District Water Reclamation Opinion Surveys

Clark County (Las Vegas, Nevada) conducted a series of 4 different surveys. The surveys included a face-to-face intercept survey at the Silver Bowl Park, a direct mail survey with local residents in the Silver Bowl Park area, a direct mail survey to local residents in the Desert Breeze Park vicinity, and face-to-face intercepts with attendees of the EcoJam Earth Day Event. A total of 883 persons participated in the survey (Alpha Communications Inc., 2001).

The majority (63.8 to 90.1 percent) of the responses were very positive, replying that the "...overall benefits of reclaimed water usage are very beneficial." There was a small minority who had concerns with "...environmental safety, bacteria, or germ build-up and general health risks to children" (Alpha Communications Inc., 2001). **Figure 7-3** shows a graphical representation of the average public opinion responses from the 4 surveys regarding reuse for 4 different uses: golf course irrigation, park irrigation, industrial cooling, and decorative water features.

Another portion of the survey asked if there were any benefits of using reclaimed water at park facilities. **Table 7-1** lists the responses.

There is no question that the public's enthusiasm for reuse (as noted in the cited studies) could reflect the hypothetical conditions set up by the survey questions and interviews used rather than signify a genuine willingness to endorse local funding of real programs that involve distribution of reclaimed water for nonpotable use in their neighborhood. Survey results do indicate, however, that, at least intellectually, "the public" is receptive to use of reclaimed water in well thought out programs. The results also support conclusions that this initial acceptance hinges in large measure on:

- The public's awareness of local water supply problems and perception of reclaimed water as having a place in the overall water supply allocation scheme
- Public understanding of the quality of reclaimed water and how it would be used
- Confidence in local management of the public utilities and in local application of modern technology
- Assurance that the reuse applications being considered involve minimal risk of accidental personal exposure

Table 7-1. Positive and Negative Responses to Potential Alternatives for Reclaimed Water

Use	Yes	No
Irrigation of Athletic Fields	84	16
Irrigation of Office Parks and Business Campuses	82	18
Irrigation of Highway Right-of-way	85	15
Residential Landscape Irrigation and Maintenance	74	26
Golf Course Irrigation	89	11
Irrigation of Agricultural Crops	82	18
Irrigation of Crops for Direct Human Consumption	30	70
Vehicle Wash Water	76	24
Concrete Production	90	10
Dust Control	82	18
Stream Augmentation	67	33
Toilet Flushing	80	20
Fire Protection	84	16
Ornamental Ponds/Fountains	56	44
Street Cleaning	87	13
Industrial Process Water	78	22
Wetland Creation	84	16
Pools/Spas	15	85
Potable Reuse – Direct	18	82
Potable Reuse – Indirect	40	60

Adapted from Hall and Rubin, 2002

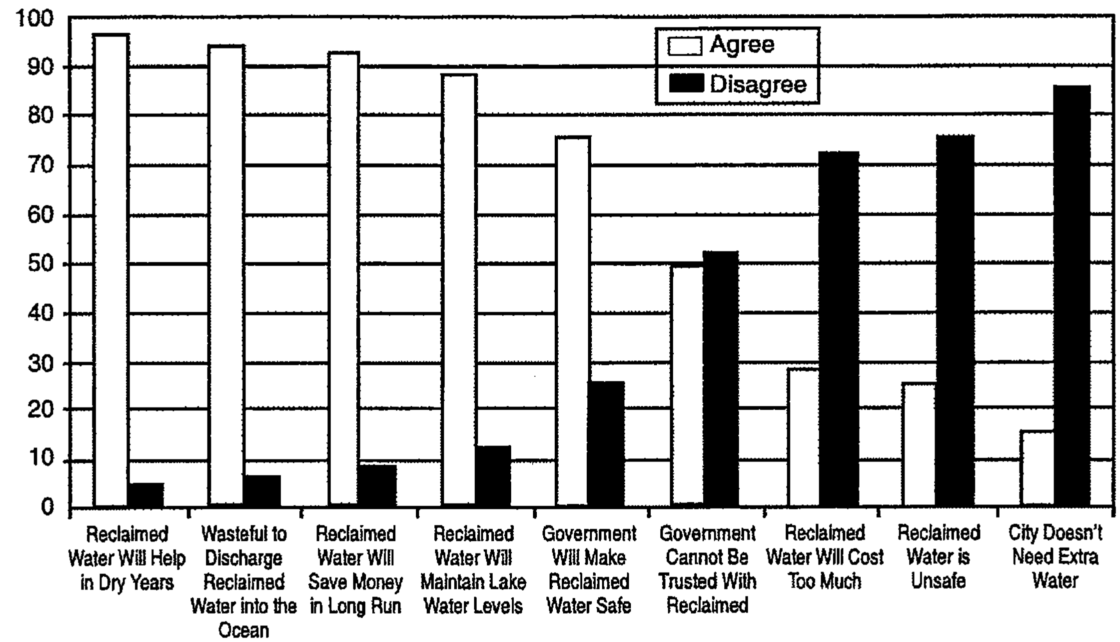
7.4 Involving the Public in Reuse Planning

Even where water reclamation is common, there is a need to establish a flow of information to and from potential reuse customers, so that they can have a clear understanding of the program and provide input regarding their needs and concerns. Equally important is the need to address these concerns and answer any questions in a timely manner. This can help assure the public that their issues are being heard and that reuse planners are being forthcoming in their efforts.

Probably the most important step in encouraging the public acceptance is to establish and communicate the expected project benefits. If the project is intended to extend water resources, then preliminary studies should address how much water will be made available through reclamation and compare the costs to those needed to develop other potable water sources. If reclamation costs are not competitive, then overriding non-economic issues must exist to equalize the value of the 2 sources. When reclamation is considered for environmental reasons, such as to reduce or eliminate surface water discharge, then the selected reuse alternative must also be competitive with other disposal options. Above all, the public must be aware of and understand all of the benefits.

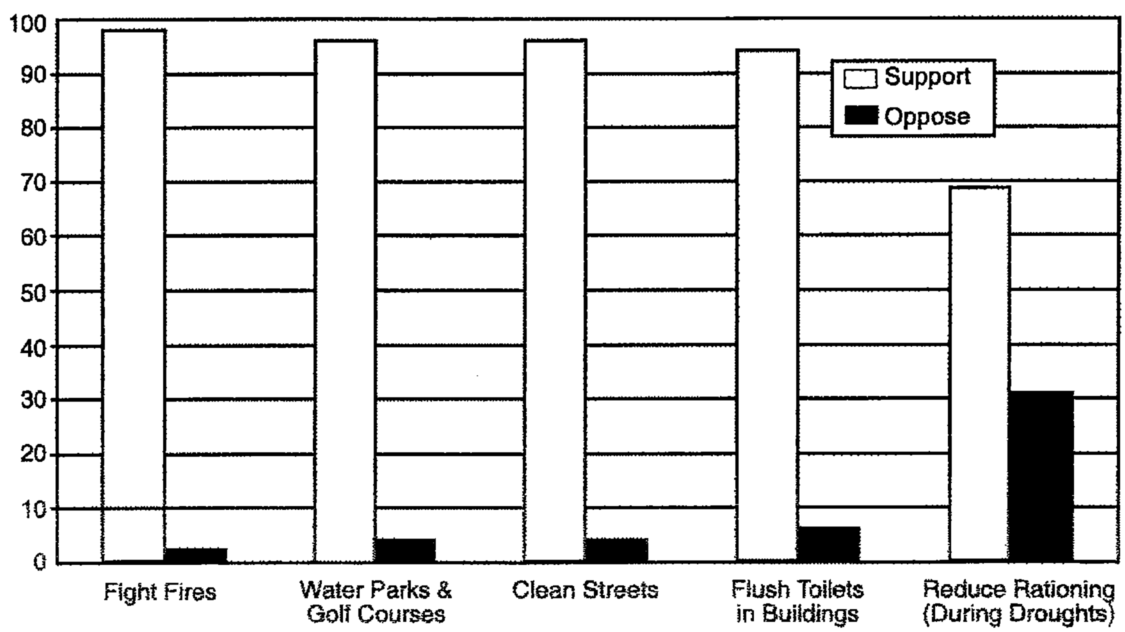
However, most potential reuse programs invoice choices among systems with widely different economical and environmental impacts, which are of varying degrees of

Figure 7-1. **Public Beliefs and Opinions**



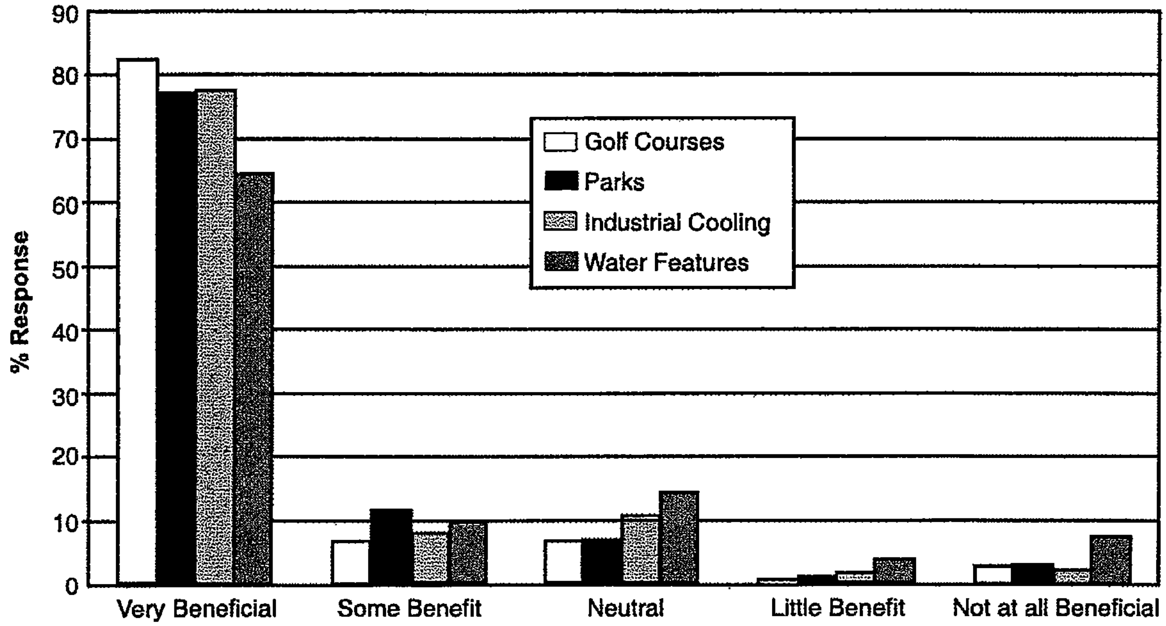
Adapted from Filice 1996

Figure 7-2. **Support of Recycled Water Program Activities**



Adapted from Filice 1996

Figure 7-3. Survey Results for Different Reuse



Data Source: Alpha Communications 2001

importance to many segments of the public. That is why development of the expected project benefits is so important because once they are firmly established, they become the plants of a public information program – the "why" the program is necessary and desirable. Without such validation, reclamation programs will be unable to withstand public scrutiny and the likelihood of project failure increases. In addition, only after the "why" is established can the "who" and "how" in public involvement truly be determined.

7.4.1 General Requirements for Public Participation

Figure 7-4 provides a flow chart of a public participation program for water reuse system planning.

The following items suggest an example approach that a community might consider in developing a reuse program. Note that information tools will vary depending upon how broad or involved an information program is needed.

- Determine, internally, the community's reuse goals and the associated options and/or alternatives to be further considered.

- Identify any scientific/technical facts that exist, or are needed, to help explain the issues and alternatives. If additional facts or studies are needed, consider beginning them in the earliest stages so that additional scientific data can be made available later in the process. Unanswered questions can damage the credibility of the program effort.

- Create a master list of stakeholders, including agencies, departments, elected officials, potential customers, and others who will be impacted in some way. It might be helpful to identify the level of interest different individuals and groups will have in the reuse planning process.

- Begin public outreach to specific target audiences in the form of informal meetings involving direct contact, limiting the number invited at any one time so that individual discussion is more easily accomplished

- Determine whether a task force or advisory committee is needed. If so, take steps to formally advertise and be sure to include representatives from the target audience groups. Plan a schedule and target date for reaching consensus on reuse alternatives; then plan well-prepared meetings that invite two-way communications. Bring in outside experts, such as scientists, to answer questions when needed.

Figure 7-4. Public Participation Program for Water Reuse System Planning

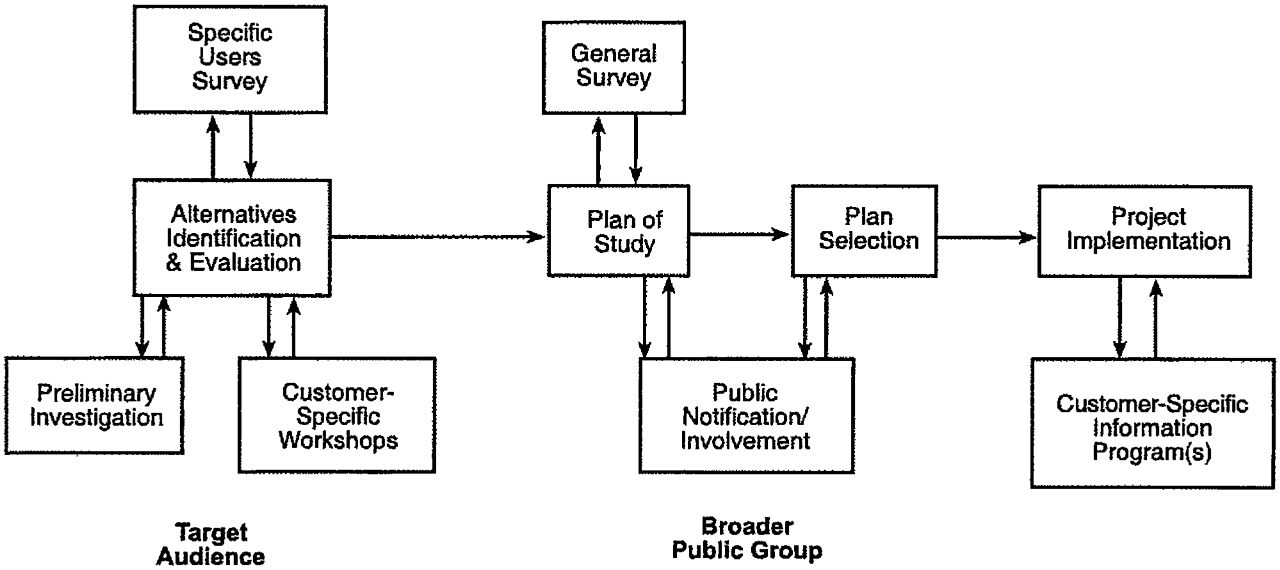


Table 7-2. Survey Results for Different Reuse

Purpose	Tools
Communitywide Education/Information	News media, editorial boards, program web site, traveling exhibits, brochures, educational videos, school programs, open houses
Direct Stakeholder or Citizen Contact	Neighborhood meetings, speeches and presentations to citizen/stakeholder groups, direct mail letters and surveys, program "hotlines" for answering information or managing construction complaints
Formalized Process	Public workshops, public meetings, presentations to elected bodies, public hearings, advisory committees, special task forces

From the task force or advisory committee, the community should be able to identify public issues that need further attention, and determine which additional public information tools will be needed. **Table 7-2** outlines a number of public information tools that can be used in the public participation process.

Once the issues are identified and public reaction is anticipated, the following tools may be useful in conveying information to the broader public:

- Citizen survey. Can be conducted via direct mail or telephone and might be accompanied by media releases to help increase the number of surveys returned or calls answered. In the early stages, a general distribution survey may be helpful in identifying level of interest, potential customers, and any initial concerns that the population might have. Where specific concerns are identified, later public information efforts can be tailored to address them. These tailored efforts could include participation by other public agencies that can provide information on water reuse and regulatory requirements, informal discussions with some potential users to determine interest or fill data gaps, and initial background reports to appropriate local decision- making bodies.
- As the program progresses to alternative identification and evaluation, another survey might be considered. This survey could help confirm earlier re-

sults, monitor the effectiveness of the ongoing education program, or target specific users. Note that the percentage of citizens who take the time to participate in a survey varies widely from one community to another. This should not be the only tool relied upon in gathering input.

- Open houses. Advertise periodic public open houses where information is made available and knowledgeable people are on hand to answer questions. Maps, displays, and brief slide demonstrations are all useful open house tools.

- Program website. Increasingly, citizens are turning to websites as important information sources. Such a website can be purely informational or it can invite citizens to ask questions. The website should be updated on a regular basis and can include: its own survey or results of a citizen survey, answers to frequently asked questions, information regarding other successful programs in nearby communities, or a slideshow-style presentation that outlines the program goals and alternatives being considered.

- Media relations. In addition to project news releases, it can be very helpful to spend extra time with reporters who will be covering the topic on a regular basis, providing added background data, plant tours, and informal updates at appropriate times. This helps to provide accurate, balanced reports. The media can also be helpful in making survey data known, and in posting maps of construction areas once program implementation is underway.

- Direct mail updates or occasional newspaper inserts. These updates allow the community to address questions or issues - not relying specifically on a media report.

- Briefings for government officials. Because water reclamation programs often end up with a vote by a city council, county commission, or other elected body, it is vital that each elected official be well-informed throughout the reuse planning process. Therefore, informal briefings for individual officials can be an invaluable tool. These briefings are often conducted prior to public workshops and formal votes, and allow questions to be answered in advance of a larger, public setting.

- Plant or project tours. During the education process, a tour of an existing project that is similar to the one proposed can be an especially useful tool in providing information to key stakeholders, such as an advisory committee, elected body, or the media.

Once a reuse program has been determined, additional public information efforts will be needed throughout the implementation phase, including notification to citizens prior to construction occurring near their home or business. Then, as the reuse program goes on-line, additional media relations and direct mailings will be needed. In the case of urban reuse, this will include information to help homeowners through the connection process.

The City of Tampa's residential reclaimed water project (Florida) is one example of a successful comprehensive public participation program. The City used the services of Roberts Communication to conduct a targeted public education program, which included the following elements (Grosh *et al.*, 2002):

- Opinion leader interviews

- Public opinion survey

- Speakers bureau

- Direct mail to potential customers

- Newsletter article for homeowner association newsletters

7.4.1.1 Public Advisory Groups or Task Forces

If the scope or potential scope of the reuse program warrants (e.g., reclaimed water may be distributed to several users or types of users, or for a more controversial use), a public advisory group or task force can be formed to assist in defining system features and resolving problem areas. In its regulations for full-scale public participation programs, EPA requires that such group membership contain "substantially equivalent" representation from the private (non-interested), organized, representative, and affected segments of the public. It is recommended that, for reuse planning, group membership provide representation from potential users and their employees, interest groups, neighborhood residents, other public agencies, and citizens with specialized expertise in areas (such as public health) that pertain directly to reclamation/reuse.

The advantage of an advisory group or task force is that it offers an opportunity to truly educate a core group that may later become unofficial "spokespersons" for the project. For such a group to be successful, members must see that their input is being put to meaningful use. Depending upon the community need, either an advisory committee or task force may be appropriate. Advisory committees are generally formed for an indeterminate period to continuously provide input regard-

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
California	• Determined on a case-by-case basis • Based on all relevant aspects of each project, including the following factors: treatment provided; effluent quality and quantity; spreading area operations; soil characteristics; hydrogeology; residence time and distance to withdrawal	•	•		•	•	•	
Florida	*Discharge to Class I surface waters and to water contiguous to or tributary to Class I waters (less than 4 hours travel time):* • Secondary treatment with filtration and high-level disinfection • Chemical feed facilities to be provided • 5 mg/l TSS	• Continuous on-line monitoring for turbidity before application of the disinfectant • Continuous monitoring for chlorine residual or for residual concentrations of other disinfectants • Treatment facilities designed to	• Class I reliability - requires multiple or backup treatment units and a secondary power source • For treatment facilities required to provide full treatment and disinfection - minimum reject storage	• System storage not required • If system storage is provided, at a minimum, system storage capacity shall be the volume equal to 3 times the portion of the average daily flow for which no alternative reuse or	• Reasonable assurances must be provided that the hydraulic loading rates used in the design must enable the system to comply with the requirements while meeting applicable surface water and	• Required • 1 upgradient well located as close as possible to the site without being affected by the site's discharge (background well) • 1 well at the edge of the zone of discharge down-gradient of the site	• Outfalls for surface water discharges not to be located within 500 feet of existing or approved potable water intakes within Class I surface waters • Zones of discharge not to extend closer than 500 feet to a potable water	• Involves the planned use of reclaimed water to augment Class F-1, G-1, or G-II groundwaters identified for potable water use and defined as groundwater recharge in regulations • Types of groundwater

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	(single sample) to be achieved prior to disinfection • Total nitrogen - 10 mg/l (maximum annual average) • Primary (except asbestos) and secondary drinking water standards must be met • pH to fall within range established in secondary drinking water standards • TOC - 3 mg/l (monthly average) - 5 mg/l (single sample) *Use of rapid-rate land application systems for projects considered reuse for groundwater recharge under 62-610.525:* • Secondary treatment with filtration and	meet the full treatment and disinfection requirements to sample for TOC and total organic halogen daily, 7 days per week • Total coliforms and TSS analyzed daily if treatment facility is required to meet bacteriological requirements of the drinking water standards • Parameters listed as primary drinking water standards that are imposed as reclaimed water limits to be analyzed monthly • Parameters listed as secondary drinking water standards that are imposed	capacity equal to 3 day's flow at the average daily permitted flow of the treatment plant or the average daily permitted flow of the reuse system, whichever is less • If full treatment and disinfection is not required, the capacity requirement for reject storage shall be reduced to one day's flow • Reject storage will not be required if another permitted reuse system or effluent disposal system is capable of discharging the reject water in accordance with requirements	disposal system is permitted • Water balance required with volume of storage based on a 10-year recurrence interval and a minimum of 20 years of climatic data • Not required if alternative system is incorporated into the system design to ensure continuous facility operation	groundwater quality standards • A groundwater mounding analysis is to be included in the engineering report for projects involving discharges to groundwater and should provide reasonable assurances that the proposed project will function as intended and will not result in excessive mounding of groundwaters, increases in surface water elevations, property damage or interference with reasonable use of property within the affected area	(compliance well) • 1 well downgradient from the site and within the zone of discharge (intermediate well) • 1 well located adjacent to unlined storage ponds or lakes • Other wells may be required depending on site-specific criteria • Quarterly monitoring required for water level, nitrate, total dissolved solids, arsenic, cadmium, chloride, chromium, lead, fecal coliform, pH, and sulfate • Monitoring may be required for additional	supply well • 1,000 foot setback distance from injection well used for salinity barrier control to potable water supply wells *Injection facilities:* • 500 feet to potable water supply wells that are existing or have been approved; Class I surface waters; or Class II surface waters • Setback distance to Class I and Class II surface waters reduced to 100 feet if high-level disinfection is provided • 100 feet to buildings not part of the treatment facility, utilities	recharge systems include injection of reclaimed water into Class F-1, G-1, or G-II groundwaters, specific rapid-rate land application systems, use of reclaimed water to create barriers to the landward or upward migration of salt water within Class F-1, G-1, or G-II groundwaters and discharge to surface waters which are directly connected to Class F-1, G-I or G-II groundwaters • Indirect potable reuse involves the planned use of reclaimed water to

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	high-level disinfection • Chemical feed facilities to be provided • 5 mg/l TSS (single sample) to be achieved prior to disinfection • Total nitrogen - 10 mg/l (maximum annual average) • Primary (except asbestos and bacteriological parameters) and secondary drinking water standards must be met • pH to fall within range established in secondary drinking water standards *Groundwater recharge by injection of Class G-1 and F-1 groundwaters and Class G-II groundwaters containing 3000 mg/l or less of*	as reclaimed water limits to be analyzed quarterly • pH - daily • Except for total coliforms and pH, 24-hour composite samples to be used for parameters listed as primary or secondary drinking water standards • Unregulated organic contaminants to be sampled annually for some types of projects • Monitoring for *Giardia* and *Cryptosporidium* required quarterly or one time during each 2-year period depending on type of project • Parameters to be monitored and sampling frequency to	• Minimum system size of 0.1 mgd • Staffing - 24 hrs/day, 7 days/wk for systems required to provide full treatment and disinfection - reduced staffing requirement to 6 hrs/day, 7 days/wk may be approved for systems not required to provide full treatment with diversion of reclaimed water to reuse system only during periods of operator presence and other provisions for increased reliability			parameters based on site-specific conditions and groundwater quality	system or municipal operations • 100 feet to site property line • Some setback distances may be reduced if certain treatment requirements are met and assurances are provided	augment surface water resources which are used or will be used for public water supplies and includes discharges to Class I surface waters and discharges to other surface waters which are directly or indirectly connected to Class I surface waters • Public notification and public hearing requirements in place for projects involving surface water discharges and underground injection • Pilot testing is required for all projects that are required to provide full treatment and disinfection

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	TDS: • Same treatment and water quality requirements as discharge to Class I surface waters except additional requirement for total organic halogen must be met • Total organic halogen (TOX) - 0.2 mg/l (monthly average) - 0.3 mg/l (single sample • Alternative TOC and TOX limitations may be approved if certain conditions are met *Groundwater recharge by injection of Class G-II groundwaters containing greater than 3000 mg/l of TDS:* • Same treatment and water quality requirements	be identified in wastewater facility permit • Minimum schedule for sampling and testing based on system capacity						

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	as discharge to Class I surface waters except TOC and secondary drinking water requirements do not apply • Limitations to be met before injection to groundwater or discharge to surface waters							
Hawaii	• Determined on a case-by-case basis • Reclaimed water used for groundwater recharge by surface or subsurface application shall be at all times of a quality that fully protects public health • Projects that are over an aquifer classified as potable, where the application rates exceed the consumptive	• Determined on a case-by-case basis	• Multiple or standby units required of sufficient capacity to enable effective operation with any one unit out of service • Alarm devices required for loss of power, high water levels, failure of pumps or blowers, high head loss on filters, high effluent turbidity, loss of coagulant or polymer feed, and loss of	• 20 days storage required unless it can be demonstrated that another time period is adequate or that no storage is necessary • Storage requirements based on water balance using at least a 30-year record • Reject storage required with a volume equal to 1 day of flow at the average daily design flow		• Required • Groundwater monitoring system may consist of a number of lysimeters and/or monitoring wells depending on site size, site characteristics, location, method of discharge, and other appropriate considerations • One well upgradient and two wells downgradient for project sites		• Department of Health evaluation of proposed groundwater recharge projects and expansion of existing projects made on an individual case basis where the use of recycled water involves a potential risk to public health • Evaluation based on all relevant aspects of each project including

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	evapotranspiration of the vegetative cover, will be designated as a recharge project		chlorine residual • Standby power source required for treatment plant and distribution pump stations	• Emergency system storage not required where an alternate effluent disposal system has been approved		500 acres or more • One well within the wetted field area for each project whose surface area is greater than or equal to 1,500 acres • One lysimeter per 200 acres • One lysimeter for project sites that have greater than 40 but less than 200 acres • Additional lysimeters may be necessary to address concerns of public health or environmental protection as related to variable characteristics of the subsurface or of the operations of the project		treatment provided, effluent quality and quantity, effluent or application spreading area operation, soil characteristics, hydrogeology, residence time, and distance to withdrawal • A public hearing or a public referendum is required for the DOH to review a request to augment a potable water supply by recharging the potable water supply aquifer with recycled water
Massachusetts	• Secondary • Filtration (possibly)	• pH - weekly or daily • BOD - weekly	• EPA Class I Reliability standards may	• Immediate, permitted discharge		*A groundwater monitoring plan is required and*	• No wastewater discharges will be permitted in	• Refers to discharges into aquifer

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	• Disinfection • pH 6 - 9 • BOD - less than 10 mg/l or 30 mg/l • Turbidity - less than 2 NTU or 5 NTU • Fecal coliform - median of no detectable colonies/100 ml over continuous, running 7-day sampling periods, not to exceed 14/100 ml or 200/100 ml • TSS - 5 mg/l or 10 mg/l • Total nitrogen - less than 10 mg/l • Class I Groundwater Permit Standards (SDWA Drinking Water Standards)	• Turbidity - continuous • Fecal coliform - daily or twice per week • Metals - quarterly • TSS - weekly or twice per week • Nitrogen - once or twice per week • MS-2 phage - quarterly • Total culturable viruses - quarterly • Variable testing requirements • UV intensity or chlorine residual - daily	be required • Two independent and separate sources of power • Unit redundancy • Additional storage	alternatives are required for emergency situations		*must accomplish the following goals:* • Evaluates upgradient (background) groundwater quality • Evaluates the performance of land use components that are considered part of the treatment process • Evaluates the overall impact of the project on local groundwater quality • Acts as an early warning system between the discharge and sensitive receptors	the Zone I of any public water supply well defined as the area encompassing a maximum 400-foot radius around the wellhead (assuming a greater than 100,000 gpd withdrawal rate) • Discharging to Zone IIs, defined as the entire extent of the aquifer deposits which could fall within and upgradient from the production well's capture zone based on the predicted drawdown after 180-day drought conditions at the approved pumping rate, will be permitted in circumstances where it is	recharge areas as defined by Zone II boundaries of community water systems and groundwater discharges that will recharge reservoirs or tributaries to reservoirs • New treatment plants located in approved Zone IIs with less than a 2 year groundwater travel time to the public water supply well must treat to the more rigorous of the two standards described • Existing treatment plants that can demonstrate 4 or 5 feet of separation and where the well has not shown any evidence of water quality

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Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
							necessary to replenish streamflow, enhance the productivity and capacity of an aquifer, and/or improve upon or mitigate poor existing environmental conditions	degradation may maintain the lesser standard
Washington	• Oxidized, coagulated, filtered, reverse-osmosis treated and disinfected • Total coliform - 1/100 ml (7-day median) - 5/100 ml (single sample) • 5 mg/l BOD and TSS (7-day mean) • Turbidity - 0.1 NTU (monthly mean) - 0.5 NTU (maximum) • Total nitrogen - 10 mg/l as N (annual mean) • TOC - 1.0 mg/l	• Point of compliance is the point of direct recharge of reclaimed water into the underground • BOD – 24-hour composite samples collected at least daily • TSS - 24 hour composite samples collected at least daily • Total coliform - grab samples collected at least daily and at a time when wastewater	• Warning alarms independent of normal power supply • Back-up power source • Emergency storage: short-term, 1 day; long-term, 20 days • Multiple treatment units or storage or disposal options • Qualified personnel available or on call at all times the system is operating	• Storage required when no approved alternative disposal system exists • Storage volume established by determining storage period required for duration of a 10-year storm, using a minimum of 20 years of climatic data • At a minimum, system storage capacity should be the volume equal to 3 times that		• Will be required and based on reclaimed water quality and quantity, site specific soil and hydrogeologic characteristics and other considerations • For direct recharge into potable groundwater aquifers, monitoring wells, at a minimum, shall be located at points 500 feet and 1,000 feet (plus or minus	• The minimum horizontal separation distance between the point of direct recharge and withdrawal as a source of drinking water supply shall be 2,000 feet	• Defined as direct recharge to potable groundwater aquifers • Reclaimed water shall be retained underground for a minimum of 12 months prior to being withdrawn as a source of drinking water supply • Project evaluation based on all relevant aspects of each project, including treatment and

(1) Distances are from edge of wetted perimeter unless otherwise noted.

Table A-10. Indirect Potable Reuse

State	Reclaimed Water Quality and Treatment Requirements	Reclaimed Water Monitoring Requirements	Treatment Facility Reliability	Storage Requirements	Loading Rates	Groundwater Monitoring	Setback Distances	Other
	(monthly mean) • Water quality criteria for primary contaminants (except nitrate), secondary contaminants, radionuclides and carcinogens listed in Table 1 in Chapter 173-200 WAC and any other maximum contaminant levels pursuant to Chapter 246-290 WAC must be met • Minimum chlorine residual of 1 mg/l after a contact time of 30 minutes based on peak hourly flow • A chlorine residual of at least 0.5 mg/l to be maintained in the reclaimed water during conveyance to the point of recharge	characteristics are most demanding on the treatment facilities and disinfection procedures • Continuous on-line monitoring of turbidity and chlorine residual • TOC - 24-hour composite samples collected at least daily • Primary contaminants (except total coliform organisms), secondary contaminants, radionuclides, and carcinogens - 24-hour composite samples collected at least quarterly • Total nitrogen - grab or 24-hour composite samples		portion of the average daily flow for which no alternative reuse or disposal system is permitted		10 percent) along the groundwater flow path from the point of recharge to the nearest point of withdrawal of groundwater used as a source of drinking water supply • Groundwater shall be sampled for TOC and primary contaminants, secondary contaminants, radionuclides, and carcinogens listed in Table 1 in Chapter 173-200 WAC • Samples from monitoring wells shall be collected at least quarterly		treatment reliability provided, reclaimed water quality and quantity, use or potential use of groundwater, operation and management of the recharge facilities, soil characteristics, hydrogeology, residence time of the reclaimed water in the underground prior to withdrawal and distance from the recharge area to nearest point of withdrawal • A pilot plant study shall be performed prior to implementation of direct recharge into a potable groundwater aquifer

(1) Distances are from edge of wetted perimeter unless otherwise noted.

ACTON BOARD OF HEALTH

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Health Director

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Town of Acton
Comprehensive Water Resources Management Plan
Citizens Advisory Committee
Indirect Potable Reuse Working Group

Meeting #2
6/30/2005
Acton Town Hall, Room 126

Call to Order 730pm

I. Introductions

II. Minutes from 6/1/05

III. Update on Reuse Activities

IV. Discussion of the four major topics focusing on Emerging Contaminants

1) Emerging contaminants – detection and removal
2) The timing of the implementation of the project and coincidence with regulatory, treatment technology, and political timelines
3) Source reduction efforts for water use and pollutant removal
4) Centralized IPR versus Decentralized IPR

V. Discuss future meeting dates and sites

Adjourn by 845pm

INDIRECT POTABLE REUSE WORKING GROUP
Acton Board of Health - Telephone (978) 264-9634

Meeting Minutes

6/1/2005 Meeting
Room 126
Acton Town Hall

Attendees: *Brent Reagor, Acton Health Department (BR)
Jim Gagliard, Woodard and Curran (JG)
*Greta Eckhardt, Acton Resident, AWD Land-Water Use Committee (GE)
*Eric Hilfer, Acton Resident, ACES, CAC (EH)
Mary Michelman, Acton Resident, ACES (MM)
Peter Shanahan, Acton Resident (PS)
*Art Gagne, Acton Resident, CAC (AG)
*IPR Working Group Member

**With Attachments

The meeting was called to order at 7:15pm

BR introduced the IPR group, the mission statement, and a short synopsis of what is expected of the group by the CAC. He explained that the need for a disposal site for highly treated wastewater treatment plant effluent is the driving factor in the formation of this group.

The members of the group and guests introduced themselves.

The group discussed why the concept of Indirect Potable Reuse is emerging in New England, based upon local and regional hydrologic losses, encouragement from EOEA through the Massachusetts Water Policy, and advocacy from organizations like the New England Water Environment Association.

BR explained the group was seated to discuss this issue as a stakeholder input group, and the group is expected to give a written report to the CAC at their October meeting with one of three answers, along with justification for the answer:

1) Yes, Acton should pursue this concept
2) No, Acton should not pursue this concept
3) This concept is promising for Acton but additional questions must be answered prior to implementation

BR introduced 2 other members, Joanne Bissetta and Pat Cumings, who could not attend the meeting.

GE asked about the current status of regulations regarding reuse in Massachusetts based upon what she had read in the 2004 EPA Reuse Guidelines sections sent to the group. BR explained that MA currently uses a set of "Reclaimed Water Use Standards" set forth in a DEP policy document, and that the state is currently seating a committee to write a set of water reuse regulations.

MM asked is drinking water standards or wastewater standards are applied to effluent discharges in reuse situations. BR explained that drinking water standards are applied in these cases as the DEP develops the permitted limits of various constituents of effluent.

MM and GE expressed concern regarding trace organic chemicals, pharmaceutical by-products, estrogen mimics in effluent. BR explained this is the major emerging issue and the Town is part of a nationwide surveillance study for these compounds being conducted by the Johns Hopkins School of Public Health and will be sampling at the wastewater treatment facility for a broad range of those compounds. PS explained that the USGS and other institutions have done surveillance studies in both surface waters and drinking water supplies and have found part-per trillion levels of some of these compounds in places like Atlanta and the lower Mississippi River basin.

PS explained that these emerging compounds exist currently in most areas of the country and we are just unaware because of the previous inability to analyze water specifically for these compounds.

MM asked about concentration of effluent on wellfields versus a broad distribution of onsite systems. BR, AG, and PS explained that onsite wastewater systems do not achieve levels of treatment anywhere near those of modern wastewater treatment facilities like Acton. GE brought up the inability of control over what people flush down the drain, BR mentioned that in a sewer system this can be somewhat controlled with dilution, and the ability to halt a discharge if harmful contaminants are found.

MM asked about local hydrologic loss within the Fort Pond Brook and Nashoba Brook associated with an IPR discharge at the High Street wellfields. PS explained that an IPR discharge with a shortened travel time from discharge point to well intake would actually benefit the local streams as the withdrawals will not have as great as an impact. MM stated she would like to see this topic explored not only at Adams Street, but would rather see a distributed approach. The group continued to discuss the current status of Zone II discharges from both small package treatment facilities and onsite systems across Acton and the current impact of those systems on our wells.

BR stated that this group has also drawn much interest from both the public and private sectors and the group may have some observers or other participants from time to time.

AG and EH asked about the current treatment levels at the WWTF versus what they may have to be in order to achieve IPR. EH spoke about the Denver study mentioned in the EPA Reuse Guidelines on efficacy of treatment processes related to the removal of emerging contaminants. BR stated this is a major research issue now as a multitude of treatment technologies must be tested.

GE spoke about source reduction of contaminants and flow through conservation efforts and public education programs. The group shared favorable opinions on this subject and spoke about the research conducted into wastewater flows by the Health Department.

The group agreed that four major topic areas need to be discussed. In order of importance, they are:

1) Emerging contaminants – detection and removal
2) The timing of the implementation of the project and coincidence with regulatory, treatment technology, and political timelines
3) Source reduction efforts for water use and pollutant removal
4) Centralized IPR versus Decentralized IPR

The group agreed to meet approximately once every three weeks, with the coordination to come from BR. One of the next meetings will be held at the Acton WWTF.

BR thanked the members and guests for attending and stated the next meeting date will be sent out shortly.

The meeting adjourned at 845pm

Respectfully Submitted,

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Brent L. Reagor

Environ. Sci. Technol. **2002**, *36*, 1202–1211

Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999–2000: A National Reconnaissance

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To provide the first nationwide reconnaissance of the occurrence of pharmaceuticals, hormones, and other organic wastewater contaminants (OWCs) in water resources, the U.S. Geological Survey used five newly developed analytical methods to measure concentrations of 95 OWCs in water samples from a network of 139 streams across 30 states during 1999 and 2000. The selection of sampling sites was biased toward streams susceptible to contamination (i.e. downstream of intense urbanization and livestock production). OWCs were prevalent during this study, being found in 80% of the streams sampled. The compounds detected represent a wide range of residential, industrial, and agricultural origins and uses with 82 of the 95 OWCs being found during this study. The most frequently detected compounds were coprostanol (fecal steroid), cholesterol (plant and animal steroid), *N,N*-diethyltoluamide (insect repellant), caffeine (stimulant), triclosan (antimicrobial disinfectant), tri(2-chloroethyl)phosphate (fire retardant), and 4-nonylphenol (nonionic detergent metabolite). Measured concentrations for this study were generally low and rarely exceeded drinking-water guidelines, drinking-water health advisories, or aquatic-life criteria. Many compounds, however, do not have such guidelines established. The detection of multiple OWCs was common for this study, with a median of seven and as many as 38 OWCs being found in a given water sample. Little is known about the potential interactive effects (such as synergistic or antagonistic toxicity) that may occur from complex mixtures of OWCs in the environment. In addition, results of this study demonstrate the importance of obtaining data on metabolites to fully understand not only the fate and transport of OWCs in the hydrologic system but also their ultimate overall effect on human health and the environment.

Introduction

The continued exponential growth in human population has created a corresponding increase in the demand for the Earth's limited supply of freshwater. Thus, protecting the integrity of our water resources is one of the most essential environmental issues of the 21st century. Recent decades have brought increasing concerns for potential adverse human and ecological health effects resulting from the production, use, and disposal of numerous chemicals that offer improvements in industry, agriculture, medical treatment, and even common household conveniences (*1*). Research has shown that many such compounds can enter the environment, disperse, and persist to a greater extent than first anticipated. Some compounds, such as pesticides, are intentionally released in measured applications. Others, such as industrial byproducts, are released through regulated and unregulated industrial discharges to water and air resources. Household chemicals, pharmaceuticals, and other consumables as well as biogenic hormones are released directly to the environment after passing through wastewater treatment processes (via wastewater treatment plants, or domestic septic systems), which often are not designed to remove them from the effluent (*2*). Veterinary pharmaceuticals used in animal feeding operations may be released to the environment with animal wastes through overflow or leakage from storage structures or land application (*3*). As a result, there are a wide variety of transport pathways for many different chemicals to enter and persist in environmental waters.

Surprisingly, little is known about the extent of environmental occurrence, transport, and ultimate fate of many synthetic organic chemicals after their intended use, particularly hormonally active chemicals (*4*), personal care products, and pharmaceuticals that are designed to stimulate a physiological response in humans, plants, and animals (*1, 5*). One reason for this general lack of data is that, until recently, there have been few analytical methods capable of detecting these compounds at low concentrations which might be expected in the environment (*6*). Potential concerns from the environmental presence of these compounds include abnormal physiological processes and reproductive impairment (*7–12*), increased incidences of cancer (*13*), the development of antibiotic-resistant bacteria (*14–17*), and the potential increased toxicity of chemical mixtures (*18*). For many substances, the potential effects on humans and aquatic ecosystems are not clearly understood (*1, 2, 19*).

The primary objective of this study is to provide the first nationwide reconnaissance of the occurrence of a broad suite of 95 organic wastewater contaminants (OWCs), including

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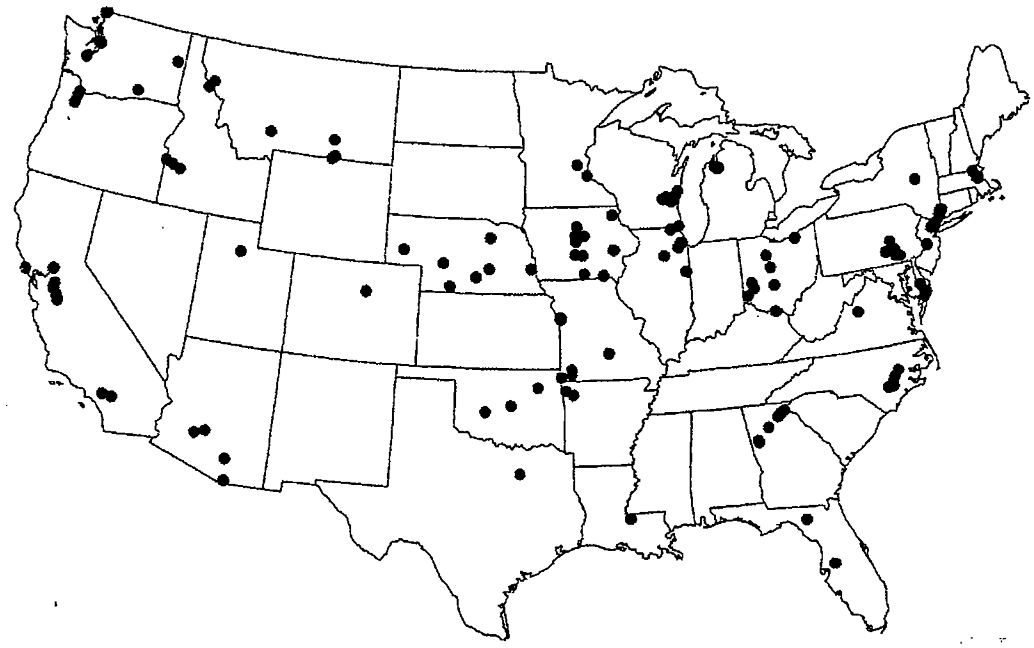

FIGURE 1. Location of 139 stream sampling sites.

many compounds of emerging environmental concern, in streams across the United States. These OWCs are potentially associated with human, industrial, and agricultural wastewaters and include antibiotics, other prescription drugs, nonprescription drugs, steroids, reproductive hormones, personal care products, products of oil use and combustion, and other extensively used chemicals. The target OWCs were selected because they are expected to enter the environment through common wastewater pathways, are used in significant quantities, may have human or environmental health implications, are representative or potential indicators of certain classes of compounds or sources, and/or can be accurately measured in environmental samples using available technologies. Although these 95 OWCs are just a small subset of compounds being used by society, they represent a starting point for this investigation examining the transport of OWCs to water resources of the United States.

This paper describes the analytical results available from 139 streams sampled during 1999–2000 (Figure 1). The results are intended to determine if OWCs are entering U.S. streams and to estimate the extent of their co-occurrence in susceptible waters. In addition, this study provides a focal point for the development and testing of new laboratory methods for measuring OWCs in environmental samples at trace levels, an interpretive context for future assessments of OWCs, and a means for establishing research priorities and future monitoring strategies. More complete interpretations, including an evaluation of the role of potential sources of contamination, will follow in subsequent papers.

Site Selection and Sampling

Little data were available on the occurrence of most of the targeted OWCs in U.S. streams at the onset of this investigation. Therefore, the selection of sampling sites primarily focused on areas considered susceptible to contamination from human, industrial, and agricultural wastewater. The 139 stream sites sampled during 1999–2000 (Figure 1) represent a wide range of geography, hydrogeology, land use, climate, and basin size. Specific information on the individual sampling sites is provided elsewhere (*20*).

All samples were collected by U.S. Geological Survey personnel using consistent protocols and procedures designed to obtain a sample representative of the streamwaters using standard depth and width integrating techniques (*21*). At each site, a composite water sample was collected from about 4–6 vertical profiles which was split into appropriate containers for shipment to the participating laboratories. For those bottles requiring filtration, water was passed through a 0.7 μm, baked, glass-fiber filter in the field where possible, or else filtration was conducted in the laboratory. Water samples for each chemical analysis were stored in precleaned-amber, glass bottles and collected in duplicate. The duplicate samples were used for backup purposes (in case of breakage of the primary sample) and for laboratory replicates. Following collection, samples were immediately chilled and sent to the laboratory. To minimize contamination of samples, use of personal care items (i.e. insect repellents, colognes, perfumes), caffeinated products, and tobacco were discouraged during sample collection and processing.

Each stream site was sampled once during the 1999–2000 study period. Samples collected in 1999 were analyzed for a subset of the OWCs based on the watershed land-use characteristics. Samples collected in 2000 were analyzed for the complete suite of OWCs. The analytical results for each stream sample are available elsewhere (*20*).

Analytical Methods

To determine the environmental extent of 95 OWCs (Table 1) in susceptible streams, five separate analytical methods were used. Each method was developed independently in different laboratories, with somewhat different data objectives, such as identifying hormones versus identifying antibiotics. As a result of these differing objectives, varying approaches were used in the development of the five analytical methods. For example, select methods (Methods 1–3 below) used filtered water for solid-phase extraction (SPE) with liquid chromatography/mass spectrometry positive-ion electrospray (LC/MS-ESI(+)) analysis, while others (Methods 4 and 5 below) used whole-water continuous liquid–liquid extraction (CLLE) with capillary gas chromatography/mass spectrometry (GC/MS) analysis.

All methods use selected ion monitoring (SIM) for improved sensitivity, thus, only the target compounds were reported with no attempt to report data for nontarget

TABLE 1. Summary of Analytical Results of Streams Sampled for 95 Organic Wastewater Contaminants[i]

chemical (method)	CASRN	*N*	RL (μg/L)	freq (%)	max (μg/L)	med (μg/L)	use	MCL or *HAL* (23) (μg/L)	lowest LC_{50} for the most sensitive indicator species (μg/L)/no. of aquatic studies identified (24)
					Veterinary and Human Antibiotics				
carbodox (1)	6804-07-5	104	0.10	0	ND	ND	antibiotic	–	–/1
chlortetracycline (1)	57-62-5	115	0.05	0	ND	ND	antibiotic	–	88000[a]/3
chlortetracycline (2)	57-62-5	84	0.10	2.4	0.69	0.42	antibiotic	–	88000[a]/3
ciprofloxacin (1)	85721-33-1	115	0.02	2.6	0.03	0.02	antibiotic	–	–/0
doxycycline (1)	564-25-0	115	0.1	0	ND	ND	antibiotic	–	–/0
enrofloxacin (1)	93106-60-6	115	0.02	0	ND	ND	antibiotic	–	40[b]/29
erythromycin-H_2O (1)	114-07-8	104	0.05	21.5	1.7	0.1	erythromycin metabolite	–	665000[b]/35
lincomycin (1)	154-21-2	104	0.05	19.2	0.73	0.06	antibiotic	–	–/0
norfloxacin (1)	70458-96-7	115	0.02	0.9	0.12	0.12	antibiotic	–	–/6
oxytetracycline (1)	79-57-2	115	0.1	0	ND	ND	antibiotic	–	102000[a]/46
oxytetracycline (2)	79-57-2	84	0.10	1.2	0.34	0.34	antibiotic	–	102000[a]/46
roxithromycin (1)	80214-83-1	104	0.03	4.8	0.18	0.05	antibiotic	–	–/0
sarafloxacin (1)	98105-99-8	115	0.02	0	ND	ND	antibiotic	–	–/0
sulfachloropyridazine (2)	80-32-0	84	0.05	0	ND	ND	antibiotic	–	–/0
sulfadimethoxine (1)	122-11-2	104	0.05	0	ND	ND	antibiotic	–	–/5
sulfadimethoxine (2)	122-11-2	84	0.05	1.2	0.06	0.06	antibiotic	–	–/5
sulfamerazine (1)	127-79-7	104	0.05	0	ND	ND	antibiotic	–	100000[c]/17
sulfamerazine (2)	127-79-7	84	0.05	0	ND	ND	antibiotic	–	100000[c]/17
sulfamethazine (1)	57-68-1	104	0.05	4.8	0.12	0.02	antibiotic	–	100000[c] 17
sulfamethazine (2)	57-68-1	84	0.05	1.2	0.22	0.22	antibiotic	–	100000[c]/17
sulfamethizole (1)	144-82-1	104	0.05	1.0	0.13	0.13	antibiotic	–	–/0
sulfamethoxazole (1)	723-46-6	104	0.05	12.5	1.9	0.15	antibiotic	–	–/0
sulfamethoxazole (3)	723-46-6	84	0.023	19.0	0.52	0.066	antibiotic	–	–/0
sulfathiazole (1)	72-14-0	104	0.10	0	ND	ND	antibiotic	–	–/0
sulfathiazole (2)	72-14-0	84	0.05	0	ND	ND	antibiotic	–	–/0
tetracycline (1)	60-54-8	115	0.05	0	ND	ND	antibiotic	–	550000[b]/3
tetracycline (2)	60-54-8	84	0.10	1.2	0.11	0.11	antibiotic	–	550000[b]/3
trimethoprim (1)	738-70-5	104	0.03	12.5	0.71	0.15	antibiotic	–	3000[c]/4
trimethoprim (3)	738-70-5	84	0.014	27.4	0.30	0.013	antibiotic	–	3000[c]/4
tylosin (1)	1401-69-0	104	0.05	13.5	0.28	0.04	antibiotic	–	–/0
virginiamycin (1)	21411-53-0	104	0.10	0	ND	ND	antibiotic	–	–/0
					Prescription Drugs				
albuterol (salbutamol) (3)	18559-94-9	84	0.029	0	ND	ND	antiasthmatic	–	–/0
cimetidine (3)	51481-61-9	84	0.007	9.5	0.58[d]	0.074[d]	antacid	–	–/0
codeine (3)	76-57-3	46	0.24	6.5	0.019	0.012	analgesic	–	–/0
codeine (4)	76-57-3	85	0.1	10.6	1.0[d]	0.2[d]	analgesic	–	–/0
dehydronifedipine (3)	67035-22-7	84	0.01	14.3	0.03	0.012	antianginal	–	–/0
digoxin (3)	20830-75-5	46	0.26	0	ND[d]	ND[d]	cardiac stimulant	–	10000000[a]/24
digoxigenin (3)	1672-46-4	84	0.008	0	ND	ND	digoxin metabolite	–	–/0
diltiazem (3)	42399-41-7	84	0.012	13.1	0.049	0.021	antihypertensive	–	–/0
enalaprilat (3)	76420-72-9	84	0.15	1.2	0.046[d]	0.046[d]	enalapril maleate (antihypertensive) metabolite	–	–/0
fluoxetine (3)	54910-89-3	84	0.018	1.2	0.012[d]	0.012[d]	antidepressant	–	–/0
gemfibrozil (3)	25812-30-0	84	0.015	3.6	0.79	0.048	antihyperlipidemic	–	–/0
metformin (3)	657-24-9	84	0.003	4.8	0.15[d]	0.11[d]	antidiabetic	–	–/0
paroxetine metabolite (3)	–	84	0.26	0	ND[d]	ND[d]	paroxetine (antidepressant) metabolite	–	–/0
ranitidine (3)	66357-35-5	84	0.01	1.2	0.01[d]	0.01[d]	antacid	–	–/0
warfarin (3)	81-81-2	84	0.001	0	ND	ND	anticoagulant	–	16000[c]/ 33
					Nonprescription Drugs				
acetaminophen (3)	103-90-2	84	0.009	23.8	10	0.11	antipyretic	–	6000[e]/ 14
caffeine (3)	58-08-2	84	0.014	61.9	6.0	0.081	stimulant	–	40000[e]/ 77
caffeine (4)	58-08-2	85	0.08	70.6	5.7	0.1	stimulant	–	40000[e]/ 77
cotinine (3)	486-56-6	84	0.023	38.1	0.90	0.024	nicotine metabolite	–	–/0
cotinine (4)	486-56-6	54	0.04	31.5	0.57	0.05	nicotine metabolite	–	–/0
1,7-dimethylxanthine (3)	611-59-6	84	0.018	28.6	3.1[d]	0.11[d]	caffeine metabolite	–	–/0
ibuprofen (3)	15687-27-1	84	0.018	9.5	1.0	0.20	antiinflammatory	–	–/0
					Other Wastewater-Related Compounds				
1,4-dichlorobenzene (4)	106-46-7	85	0.03	25.9	4.3	0.09	deodorizer	75	1100[e]/190
2,6-di-*tert*-butylphenol (4)	128-39-2	85	0.08	3.5	0.11[d]	0.06[d]	antioxidant	–	–/2
2,6-di-*tert*-butyl-1,4-benzoquinone (4)	719-22-2	85	0.10	9.4	0.46	0.13	antioxidant	–	–/0
5-methyl-1H-benzotriazole (4)	136-85-6	54	0.10	31.5	2.4	0.39	antiocorrosive	–	–/0
acetophenone (4)	98-86-2	85	0.15	9.4	0.41	0.15	fragrance	–	155000[e]/21
anthracene (4)	120-12-7	85	0.05	4.7	0.11	0.07	PAH	–	5.4[e]/188
benzo[a]pyrene (4)	50-32-8	85	0.05	9.4	0.24	0.04	PAH	0.2	1.5[e]/428
3-*tert*-butyl-4-hydroxy anisole (4)	25013-16-5	85	0.12	2.4	0.2[e]	0.1[e]	antioxidant	–	870[e]/14
butylated hydroxy toluene (4)	128-37-0	85	0.08	2.4	0.1[e]	0.1[e]	antioxidant	–	1440[e]/15
bis(2-ethylhexyl) adipate (4)	103-23-1	85	2.0	3.5	10[f]	3[f]	plasticizer	400	480[e]/5
bis(2-ethylhexyl) phthalate (4)	117-81-7	85	2.5	10.6	20[f]	7[f]	plasticizer	6	7500[e]/309

TABLE 1. (Continued)

chemical (method)	CASRN	*N*	RL (μg/L)	freq (%)	max (μg/L)	med (μg/L)	use	MCL or *HAL* (*23*) (μg/L)	lowest LC_{50} for the most sensitive indicator species (μg/L)/no. of aquatic studies identified (*24*)
					Other Wastewater-Related Compounds				
bisphenol A (4)	80-05-7	85	0.09	41.2	12	0.14	plasticizer	–	3600[e]/26
carbaryl (4)	63-25-2	85	0.06	16.5	0.1[d]	0.04[d]	insecticide	*700*	0.4[a]/1541
***cis*-chlordane** (4)	5103-71-9	85	0.04	4.7	0.1	0.02	insecticide	2	7.4[b]/28
chlorpyrifos (4)	2921-88-2	85	0.02	15.3	0.31	0.06	insecticide	*20*	0.1[a]/1794
diazinon (4)	333-41-5	85	0.03	25.9	0.35	0.07	insecticide	*0.6*	0.56[a]/1040
dieldrin (4)	60-57-1	85	0.08	4.7	0.21	0.18	insecticide	0.2	2.6[c]/1540
diethylphthalate (4)	84-66-2	54	0.25	11.1	0.42	0.2	plasticizer	–	12000[c]/129
ethanol,2-butoxy-phosphate (4)	78-51-3	85	0.2	45.9	6.7	0.51	plasticizer	–	10400[e]/7
fluoranthene (4)	206-44-0	85	0.03	29.4	1.2	0.04	PAH	–	74[e]/216
lindane (4)	58-89-9	85	0.05	5.9	0.11	0.02	insecticide	0.2	30[c]/1979
methyl parathion (4)	298-00-0	85	0.06	1.2	0.01	0.01	insecticide	*2*	12[a]/888
4-methyl phenol (4)	106-44-5	85	0.04	24.7	0.54	0.05	disinfectant	–	1400[e]/74
naphthalene (4)	91-20-3	85	0.02	16.5	0.08	0.02	PAH	*20*	910[c]/519
N,N-diethyltoluamide (4)	134-62-3	54	0.04	74.1	1.1	0.06	insect repellant	–	71250[c]/9
4-nonylphenol (4)	251-545-23	85	0.50	50.6	40[g]	0.8[g]	nonionic detergent metabolite	–	130[e]/135
4-nonylphenol monoethoxylate (4)	–	85	1.0	45.9	20[g]	1[g]	nonionic detergent metabolite		14450[a]/4
4-nonylphenol diethoxylate (4)	–	85	1.1	36.5	9[g]	1[g]	nonionic detergent metabolite	–	5500[a]/6
4-octylphenol monoethoxylate (4)	–	85	0.1	43.5	2[g]	0.2[g]	nonionic detergent metabolite	–	–/0
4-octylphenol diethoxylate (4)	–	85	0.2	23.5	1[g]	0.1[g]	nonionic detergent metabolite	–	–/0
phenanthrene (4)	85-01-8	85	0.06	11.8	0.53	0.04	PAH	–	590[a]/192
phenol (4)	108-95-2	85	0.25	8.2	1.3[f]	0.7[f]	disinfectant	*400*	4000[c]/2085
phthalic anhydride (4)	85-44-9	85	0.25	17.6	1[f]	0.7[f]	plastic manufacturing	–	40400[c]/5
pyrene (4)	129-00-0	85	0.03	28.2	0.84	0.05	PAH	–	90.9[a]/112
tetrachloroethylene (4)	127-18-4	85	0.03	23.5	0.70[d]	0.07[d]	solvent, degreaser	5	4680[c]/147
triclosan (4)	3380-34-5	85	0.05	57.6	2.3	0.14	antimicrobial disinfectant	–	180[e]/3
tri(2-chloroethyl) phosphate (4)	115-96-8	85	0.04	57.6	0.54	0.1	fire retardant	–	66000[b]/8
tri(dichlorisopropyl) phosphate (4)	13674-87-8	85	0.1	12.9	0.16	0.1	fire retardant	–	3600[b]/9
triphenyl phosphate (4)	115-86-6	85	0.1	14.1	0.22	0.04	plasticizer	–	280[c]/66
					Steroids and Hormones				
***cis*-androsterone** (5)	53-41-8	70	0.005	14.3	0.214	0.017	urinary steroid	–	–/0
cholesterol (4)	57-88-5	85	1.5	55.3	10[d]	1[d]	plant/animal steroid	–	–/0
cholesterol (5)	57-88-5	70	0.005	84.3	60[h]	0.83	plant/animal steroid	–	–/0
coprostanol (4)	360-68-9	85	0.6	35.3	9.8[d]	0.70[d]	fecal steroid	–	–/0
coprostanol (5)	360-68-9	70	0.005	85.7	150[h]	0.088	fecal steroid	–	–/0
equilenin (5)	517-09-9	70	0.005	2.8	0.278	0.14	estrogen replacement	–	–/0
equilin (5)	474-86-2	70	0.005	1.4	0.147	0.147	estrogen replacement	–	–/0
17α-ethynyl estradiol (5)	57-63-6	70	0.005	15.7	0.831	0.073	ovulation inhibitor	–	–/22
17α-estradiol (5)	57-91-0	70	0.005	5.7	0.074	0.03	reproductive hormone	–	–/0
17β-estradiol (4)	50-28-2	85	0.5	10.6	0.2[d]	0.16[d]	reproductive hormone	–	–/0
17β-estradiol (5)	50-28-2	70	0.005	10.0	0.093	0.009	reproductive hormone	–	–/0
estriol (5)	50-27-1	70	0.005	21.4	0.051	0.019	reproductive hormone	–	–/0
estrone (5)	53-16-7	70	0.005	7.1	0.112	0.027	reproductive hormone	–	–/11
mestranol (5)	72-33-3	70	0.005	10.0	0.407	0.074	ovulation inhibitor	–	–/0
19-norethisterone (5)	68-22-4	70	0.005	12.8	0.872	0.048	ovulation inhibitor	–	–/0
progesterone (5)	57-83-0	70	0.005	4.3	0.199	0.11	reproductive hormone	–	–/0
stigmastanol (4)	19466-47-8	54	2.0	5.6	4[d]	2[d]	plant steroid	–	–/0
testosterone (5)	58-22-0	70	0.005	2.8	0.214	0.116	reproductive hormone	–	–/4

[a] *Daphnia magna* (water flea) – 48 h exposure LC_{50}. [b] Other species and variable conditions. [c] *Oncorhynchus mykiss* (rainbow trout) – 96 h exposure LC_{50}. [d] Concentration estimated – average recovery <60%. [e] *Pimephales promelas* (fathead minnow) – 96 h exposure LC_{50}. [f] Concentration estimated – compound routinely detected in laboratory blanks. [g] Concentration estimated – reference standard prepared from a technical mixture. [h] Concentration estimated – value greater than highest point on calibration curve. [i] Compounds suspected of being hormonally active are in bold (*4, 22*). CASRN, Chemical Abstracts Service Registry Number; *N*, number of samples; RL, reporting level; freq, frequency of detection; max, maximum concentration; med, median detectable concentration; MCL, maximum contaminant level; HAL, health advisory level; LC_{50}, lethal concentration with 50% mortality; ND, not detected; –, not available; PAH, polycyclic aromatic hydrocarbon.

compounds. Target compounds within each method were selected from the large number of chemical possibilities based upon usage, toxicity, potential hormonal activity, and persistence in the environment. Some compounds that fit the above criteria, however, could not be included (such as amoxicillin, roxarsone, polybrominated diphenyl ethers) because they were either incompatible with the corresponding method or reference standards were not available. Positive identification of a compound required elution within the expected retention time window. In addition, the sample spectra and ion abundance ratios were required to match that of the reference standard compounds. The base-peak ion was used for quantitation, and, if possible, two qualifier ions were used for confirmation. After qualitative criteria were met, compound concentrations were calculated from 5 to 8 point calibration curves (generally from 0.01 to 10.0 μg/L) using internal standard quantitation. Methods 1 and 2 process calibration standards through the extraction procedure, which generally corrects concentrations for method losses but not matrix effects. Methods 3–5 do not extract calibration standards, thus the reported concentrations are not corrected for method losses. Reporting levels (RLs) were determined for each method by either an evaluation of instrument response, calculation of limit of detection, or from a previously published procedure (*25*). RLs were adjusted based on experience with the compounds in each method, known interferences, or known recovery problems.

The following descriptions are intended to provide a brief overview of the five analytical methods used for this study. More comprehensive method descriptions are provided elsewhere (*26–28*) or will be available in subsequent publications.

Method 1. This method targets 21 antibiotic compounds (Table 1) in 500-mL filtered water samples using modifications from previously described methods (*26, 29*). The antibiotics were extracted and analyzed by tandem SPE and single quadrapole, LC/MS-ESI(+) using SIM. To prevent the tetracycline antibiotics from complexing with Ca^{2+} and Mg^{2+} ions and residual metals on the SPE cartridges, 0.5 mg of disodium ethylenediaminetetraacetate (Na_2EDTA; $C_{10}H_{14}O_8$-Na_2N_2−H_2O) was added to each water sample. Sample pH was adjusted to 3 using concentrated H_2SO_4. The tandem SPE included an Oasis Hydrophilic–Lipophilic-Balance (HLB) cartridge (60 mg) followed by a mixed mode, HLB-cation exchange (MCX) cartridge (60 mg) (Waters Inc., Milford, MA). The HLB and MCX cartridges were conditioned with ultrapure H_2O, CH_3OH, and CH_3OH with 5% NH_4OH. The HLB cartridge was attached to the top of the MCX cartridge, and the sample was passed through the SPE cartridges using a vacuum extraction manifold. The cartridges were eluted with CH_3OH, and the MCX cartridge was eluted separately using CH_3OH with 5% NH_4OH. The eluate was spiked with 500 ng of $^{13}C_6$-sulfamethazine (internal standard), vortexed, and evaporated to 20 μL using N_2 and a water bath of 55° C. Three hundred μL of 20 mM of $NH_4C_2H_3OO$ (pH 5.7) was added to sample eluate, vortexed, transferred to a glass chromatography vial, and frozen until analysis. Samples were extracted as a set of 11 environmental samples, one duplicate sample, two fortified ultrapure water spikes (check standards), and two ultrapure water blanks.

Method 2. This method targets eight antibiotic compounds (Table 1) in filtered water samples. Complete details of this method have been described previously (*26*). The antibiotics were extracted and analyzed using SPE and SIM LC/MS-ESI(+). Samples were prepared for extraction by adding $^{13}C_6$-sulfamethazine and meclocycline as surrogate standards, Na_2EDTA, and H_2SO_4. Target compounds were extracted using 60-mg HLB cartridges preconditioned with CH_3OH, NHCl, and distilled H_2O. Target compounds were eluted with CH_3OH into a test tube containing the internal standard, simatone. The extracts were then concentrated under N_2 to approximately 50 μL, and mobile phase A (10 mM $NH_4H_2O_2$ in 90/10 water/CH_3OH with 0.3% CH_2O_2) was added. The resulting solutions were transferred to amber autosampler vials to prevent photodegradation of tetracyclines (*30*). Mobile phase conditions are described in detail elsewhere (*26*).

For each compound, the proton adduct of the molecular ion (M + H)+ and at least one confirming ion were acquired using LC/MS-ESI(+). All mass spectral conditions are described in detail elsewhere (*26*). Quantitation was based on the ratio of the base peak ion (M + H)+ of the analyte to the base peak of the internal standard. Standard addition was used for quantitation where each sample was analyzed with and without the addition of a 0.5 μg/L spike to correct for suppression of the electrospray signal.

Method 3. This method targets 21 human prescription and nonprescription drugs and their select metabolites (Table 1) in filtered water samples. Compounds were extracted from 1 L water samples using SPE cartridges that contain 0.5 g of HLB (flow rate of 15 mL/min). After extraction, the adsorbed compounds were eluted with CH_3OH followed by CH_3OH acidified with $C_2HCl_3O_2$. The two fractions were reduced under N_2 to near dryness and then combined and brought to a final volume of 1 mL in 10% C_2H_3N:90% H_2O buffered with $NH_4H_2O_2/CH_2O_2$.

Compounds were separated and measured by high-performance liquid chromatography (HPLC) using a polar (neutral silanol) reverse-phase octylsilane (C8) HPLC column (Metasil Basic 3 μm, 150 × 2.0 mm; Metachem Technologies). The compounds were eluted with a binary gradient of mobile phase A (aqueous $NH_4H_2O_2/CH_2O_2$ buffer; 10 mM, pH 3.7) and mobile phase B (100% C_2H_3N).

Method 4. This method (*27, 28*) targets 46 OWCs (Table 1) in unfiltered water. One-liter whole-water samples were extracted using CLLE with CH_2Cl_2. Distilled solvent was recycled through a microdroplet dispersing frit to improve extraction efficiency. Samples were extracted for 3 h at ambient pH and for an additional 3 h at pH 2. The extract was concentrated under N_2 to 1 mL and analyzed by capillary-column GC/MS. Available standards for the 4-nonylphenol compounds were composed of multiple isomers, and thus, laboratory standards for these compounds as well as octylphenol ethoxylates were prepared from technical mixtures.

Method 5. This method (*28*) targets 14 steroid compounds including several biogenic and synthetic reproductive hormones (Table 1). The CLLE extracts from the previously analyzed samples of Method 4 were derivatized and reanalyzed. Analysis of steroid and hormone compounds by GC/MS is enhanced by derivatization to deactivate the hydroxyl and keto functional groups. The technique used in this study is the formation of trimethylsilyl (TMS) ethers of the hydroxyl groups and oximes of the keto groups. Samples were stored in a silanizing reagent to prevent hydrolysis of the derivatives back to the free compound. Surrogate standards ($d_4$estradiol and $d_7$cholesterol) were added to the samples prior to derivatization to evaluate method performance. After derivatization, the samples were analyzed by GC/MS.

Quality Assurance Protocol. At least one fortified laboratory spike and one laboratory blank was analyzed with each set of 10–16 environmental samples. Most methods had surrogate compounds added to samples prior to extraction to monitor method performance. A summary of recoveries for target compounds and surrogate compounds in environmental samples (Table 2) indicates the general proficiency of the methods. The RL (Table 1) is equivalent to the lowest concentration standard that could be reliably quantitated. The compound concentrations reported below the RL or the lowest calibration standard were estimated as indicated in Figure 2. The concentration of compounds with <60% recovery, routinely detected in laboratory blanks, or prepared with technical grade mixtures, was also considered estimated (Table 1).

The laboratory blanks were used to assess potential sample contamination. Blank contamination was not subtracted from environmental results. However, environmental concentrations within twice the values observed in the set blank were reported as less than the RL.

A field quality assurance protocol was used to determine the effect, if any, of field equipment and procedures on the concentrations of OWCs in water samples. Field blanks, made from laboratory-grade organic free water, were submitted for about 5% of the sites and analyzed for all of the 95 OWCs. Field blanks were subject to the same sample processing, handling, and equipment as the stream samples. To date, one field blank had a detection of coprostanol and testosterone, one field blank had a detection of naphthalene and tri(dichloroisopropyl)phosphate, and one field blank had

TABLE 2. Summary of Quality Assurance/Quality Control Results for Target and Surrogate Compounds[b]

compound	spike concn (μg/L)	mean % recovery	% RSD
	Method 1		
target compounds	1.0	99.0	12.1
	Method 2		
target compounds	1.0	97.5	12.2
$^{13}C_6$-sulfamethazine	1.0	80.0	20.0
meclocycline	1.0	80.0	20.0
	Method 3		
target compounds	0.5	85.1	11.6
C_{13}-phenacetin	1.0	96.8	14.0
	Method 4		
target compounds	1.0	81.0	11.0
d_{21}-BHT	2.0	63.0	25.0
n-nonylphenol	2.0	83.0	20.0
	Method 5		
target compounds	NA	NA	NA
d_4-estradiol[a]	0.047	128.8	42.0
d_3-testosterone[a]	0.051	148.5	47.3
d_7-cholesterol[a]	0.053	116.9	55.9

[a] Surrogate standard added after CCLE extraction but prior to derivitization. [b] RSD, relative standard deviation; NA, not currently available.

a detection of naphthalene, 4-nonylphenol, phenol, 4-*tert*-octylphenol monoethoxylate, and ethanol,2-butoxy-phosphate. Most of these detections were near their respective RLs verifying the general effectiveness of the sampling protocols used for this study. In addition all field blanks had low level concentrations of cholesterol being measured using Method 5 (median concentration = 0.09 μg/L) documenting its ubiquitous nature in the environment. Cholesterol concentrations from 0.005 to 0.18 μg/L obtained through Method 5 were set to less than the RL.

Compounds that were measured by more than one analytical method (Table 1; Figure 3) also were used to evaluate the results for this study. The presence or absence of these compounds were confirmed in 100% of the determinations for sulfamerazine, and sulfathiazole; 98.8% for oxytetracycline, sulfadimethoxine, sulfamethazine, and tetracycline; 98.6% for cholesterol and coprostanol; 97.6% for chlortetracyline; 95.7% for 17β-estradiol; 94.4% for cotinine; 94.0% for trimethoprim; 89.1% for sulfamethoxazole; 86.4% for codeine; and 83.3% for caffeine. The comparisons for codeine, caffeine, and cotinine may have been affected by the differing extractions (SPE versus CLLE) as well as differing types of sample (filtered versus whole water).

An interlaboratory comparison of Methods 1 and 3 was conducted using two reagent water blanks and 24 reagent water spikes prepared at concentrations ranging from 0.5 to 1.1 μg/L for two frequently detected antibiotics (sulfamethoxazole and trimethoprim). The results demonstrated that both methods are accurately confirming the presence of sulfamethoxazole and trimethoprim in water, with the measured concentrations being within a factor of 3 or better of the actual concentrations for these compounds. No false positives or false negatives occurred for this experiment.

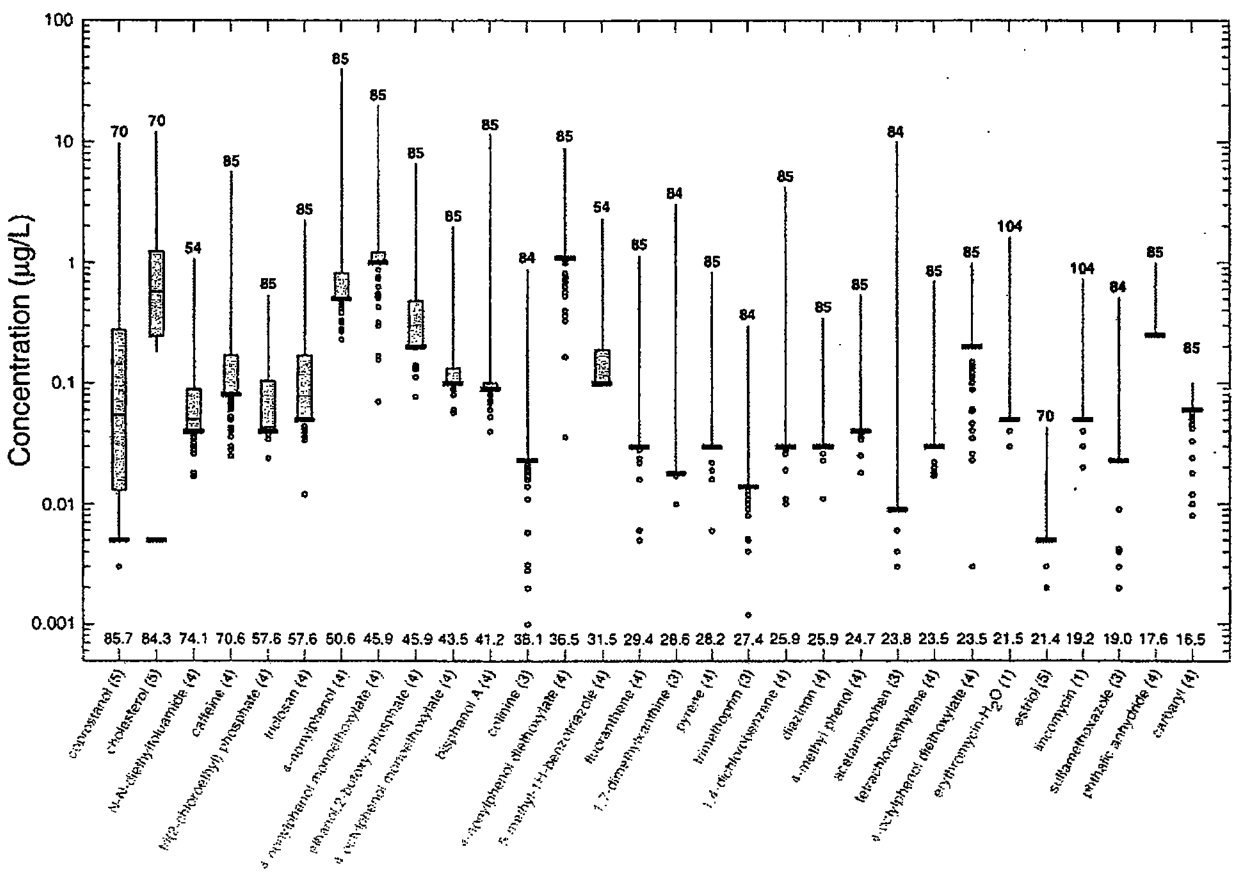

FIGURE 2. Measured concentrations for the 30 most frequently detected organic wastewater contaminants. Boxplots show concentration distribution truncated at the reporting level. Estimated values below the reporting level are shown. Estimated maximum values for coprostanol and cholesterol obtained from Method 5 (Table 1) are not shown. The analytical method number is provided (in parentheses) at the end of each compound name. An explanation of a boxplot is provided in Figure 3.

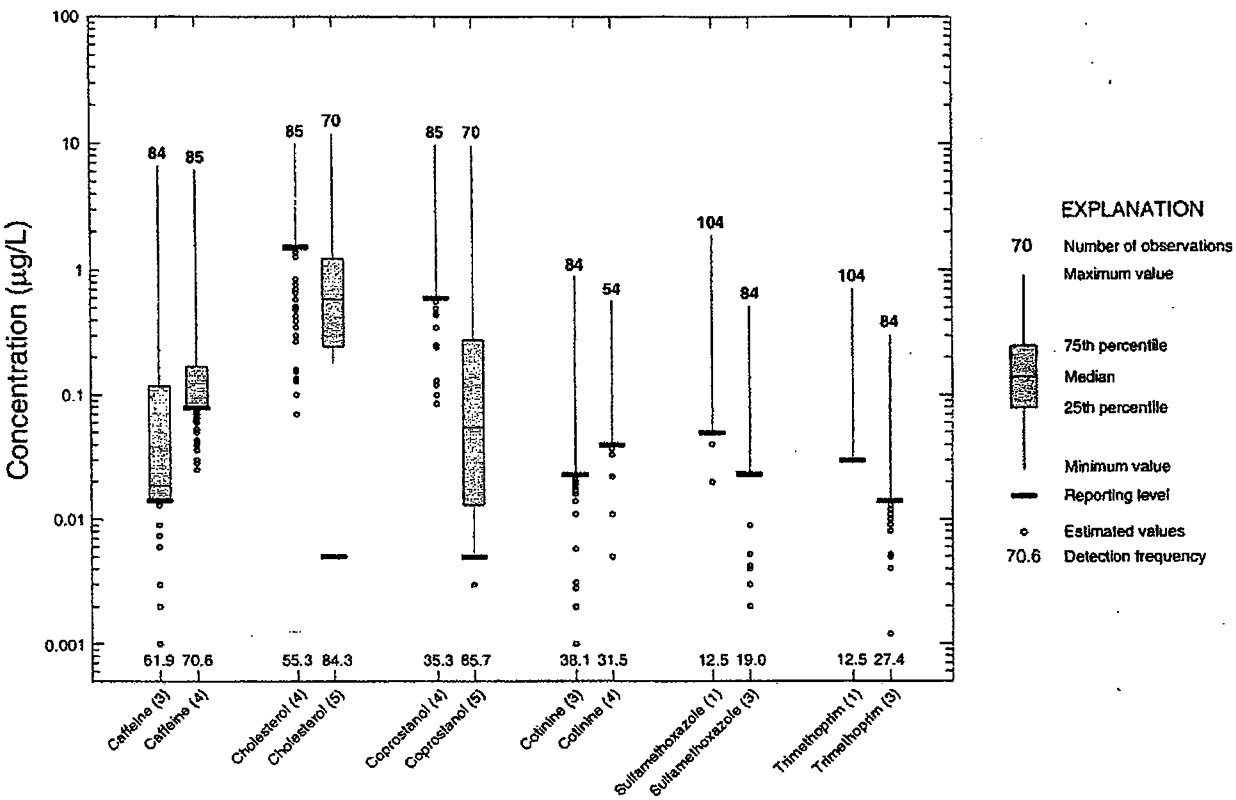

FIGURE 3. Comparison of concentrations of select compounds that were measured using two different methods with significantly different reporting levels. Boxplots show concentration distribution truncated at the reporting level. Estimated values below the reporting level are shown. Estimated maximum values for chloesterol and coprostanol obtained from Method 5 (Table 1) are not shown. The analytical method number is provided (in parentheses) at the end of each compound name.

Results and Discussion

One or more OWCs were found in 80% of the 139 streams sampled for this study. The high overall frequency of detection for the OWCs is likely influenced by the design of this study, which placed a focus on stream sites that were generally considered susceptible to contamination (i.e. downstream of intense urbanization and livestock production). In addition, select OWCs (such as cholesterol) can also be derived from nonanthropogenic sources. Furthermore, some of the OWCs were selected because previous research (*28*) identified them as prevalent in the environment. Thus, the results of this study should not be considered representative of all streams in the United States. A previous investigation of streams downstream of German municipal sewage treatment plants also found a high occurrence of OWCs (*31*).

A large number of OWCs (82 out of 95) were detected at least once during this study (Table 1). Only eight antibiotics and five other prescription drugs were not detected in the samples analyzed (Table 1). Measured concentrations were generally low (median detectable concentrations generally <1 µg/L, Table 1), with few compounds exceeding drinking-water guidelines, health advisories, or aquatic-life criteria (Table 1). The concentration of benzo[*a*]pyrene exceeded its maximum contaminant level (MCL) of 0.2 µg/L at one site and bis(2-ethylhexyl)phthalate concentrations exceeded its MCL of 6.0 µg/L at five sites. In addition, aquatic-life criteria were exceeded for chlorpyrifos (Table 1) at a single site. However, many of the 95 OWCs do not have such guidelines or criteria determined (Table 1). In fact, much is yet to be known about the potential toxicological effects of many of the OWCs under investigation (*1*). For many OWCs, acute effects to aquatic biota appear limited because of the low concentrations generally occurring in the environment (*24, 32–34*). More subtle, chronic effects from low-level environmental exposure to select OWCs appear to be of much greater concern (*1*). Such chronic effects have been documented in the literature (*34–38*). In addition, because antibiotics are specifically designed to reduce bacterial populations in animals, even low-level concentrations in the environment could increase the rate at which pathogenic bacteria develop resistance to these compounds (*15–17, 39*).

The 30 most frequently detected compounds represent a wide variety of uses and origins including residential, industrial, and agricultural sources (Figure 2, Table 1). Only about 5% of the concentrations for these compounds exceeded 1 µg/L. Over 60% of these higher concentrations were derived from cholesterol and three detergent metabolites (4-nonyphenol, 4-nonylphenol monoethoxylate, and 4-nonylphenol diethoxylate). The frequent detection of cotinine, 1,7-dimethylxanthine, erythromycin-H_2O, and other OWC metabolites demonstrate the importance of obtaining data on degradates to fully understand the fate and transport of OWCs in the hydrologic system. In addition, their presence suggests that to accurately determine the overall effect on human and environmental health (such as pathogen resistance and genotoxicity) from OWCs, their degradates should also be considered. The presence of the parent compound and/or their select metabolites in water resources has previously been documented for OWCs (*40, 41*) as well as other classes of chemicals such as pesticides (*42, 43*).

Many of the most frequently detected compounds (Figure 2) were measured in unfiltered samples using Method 4. Thus, their frequencies of detection may be somewhat higher because concentrations being measured include both the dissolved and particulate phases, whereas concentrations measured by Methods 1–3 include just the dissolved phase. For example, about 90% of the coprostanol discharged from

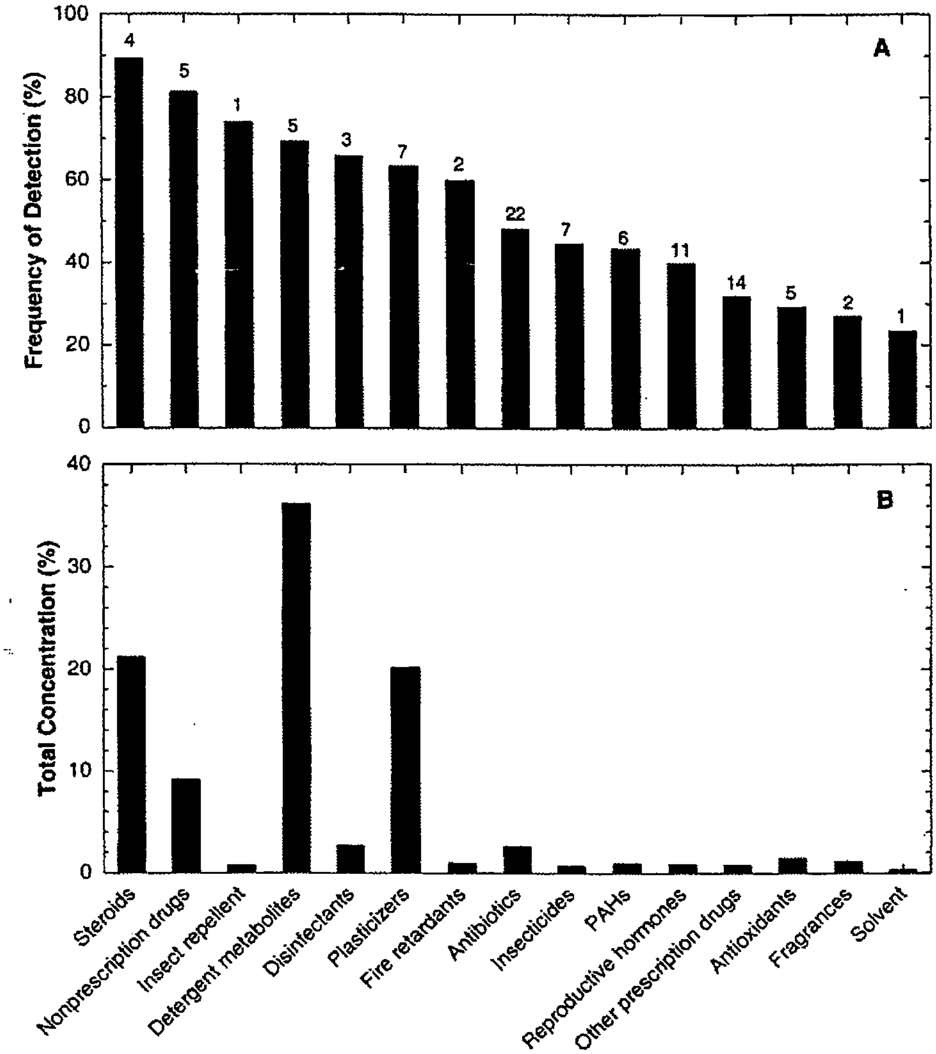

FIGURE 4. Frequency of detection of organic wastewater contaminants by general use category (4A), and percent of total measured concentration of organic wastewater contaminants by general use category (4B). Number of compounds in each category shown above bar.

sewage effluents has been shown to be associated with particulate matter (*44*). Thus, the concentration and frequency of detection for select compounds would likely have been reduced if sample filtration had taken place.

Variations in RL also influence the frequency of OWC detection (Figure 2). For example, the detection of 4-nonylphenol would likely have been much greater if an order of magnitude lower RL (similar to other OWCs) could have been achieved. The effect of RL on frequencies of detection is more clearly demonstrated by comparison of concentrations of select compounds that were measured using multiple analytical methods (Figure 3). As expected, the frequency of detection for a given compound was higher with the lower RL. The only exception being caffeine, where filtration of Method 3 may have reduced caffeine concentrations compared to that of the unfiltered Method 4. Figures 2 and 3 also demonstrate the importance of estimated values (*45*) below the RL. Clearly the numerous estimated concentrations illustrate that the current RLs are not low enough to accurately characterize the total range of OWC concentrations in the stream samples and that the frequencies of detection for this study are conservative.

To obtain a broader view of the results for this study, the 95 OWCs were divided into 15 groups based on their general uses and/or origins. The data show two environmental determinations: frequency of detection (Figure 4A) and percent of total measured concentration (Figure 4B) for each group of compounds. These two views show a vastly different representation of the data. In relation to frequency of detection, there were a number of groups that were frequently detected, with seven of the 15 groups being found in over 60% of the stream samples (Figure 4A). However, three groups (detergent metabolites, plasticizers, and steroids) contributed almost 80% of the total measured concentration (Figure 4B).

For those groups of compounds that have received recent public attention—namely antibiotics, nonprescription drugs, other prescription drugs, and reproductive hormones (*1, 2, 10*)—nonprescription drugs were found with greatest frequency (Figure 4A). Antibiotics, other prescription drugs, and reproductive hormones were found at relatively similar frequencies of detection. The greater frequency of detection for nonprescription drugs may be at least partially derived from their suspected greater annual use compared to these other groups of compounds. When toxicity is considered, measured concentrations of reproductive hormones may have greater implications for health of aquatic organisms than measured concentrations of nonprescription drugs. Previous research has shown that even low-level exposure (<0.001 μg/L) to select hormones can illicit deleterious effects in aquatic species (*7, 46, 47*).

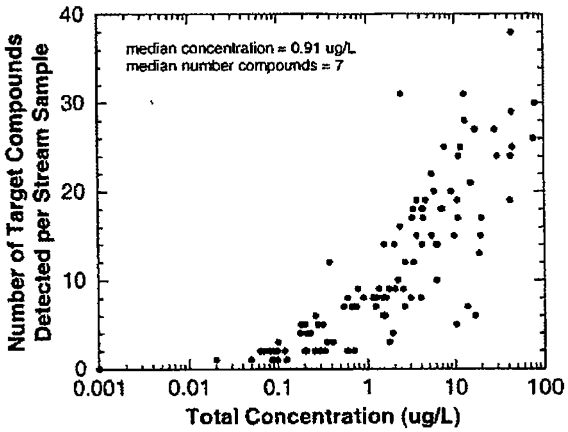

FIGURE 5. Relation between total concentration (summation from all detections) and number of organic wastewater contaminants found per water sample (Spearman's rank correlation coefficient = 0.94, $P < 0.001$).

Mixtures of various OWCs were prevalent during this study, with most (75%) of the streams sampled having more than one OWC identified. In fact, a median of seven OWCs were detected in these streams, with as many as 38 compounds found in a given streamwater sample (Figure 5). Because only a subset of the 95 OWCs were measured at most sites collected during the first year of study, it is suspected that the median number of OWCs for this study is likely underestimated. Although individual compounds were generally detected at low-levels, total concentrations of the OWCs commonly exceeded 1 μg/L (Figure 5). In addition, 33 of the 95 target OWCs are known or suspected to exhibit at least weak hormonal activity with the potential to disrupt normal endocrine function (*4, 7, 8, 10, 12, 22, 36, 37, 48–50*), all of which were detected in at least one stream sample during this study (Table 1). The maximum total concentration of hormonally active compounds was 57.3 μg/L. Aquatic species exposed to estrogenic compounds have been shown to alter normal hormonal levels (*7, 48, 51*). Thus, the results of this study suggest that additional research on the toxicity of the target compounds should include not only the individual OWCs but also mixtures of these compounds. The prevalence of multiple compounds in water resources has been previously documented for other contaminants (*52, 53*). In addition, research has shown that select chemical combinations can exhibit additive or synergistic toxic effects (*54–56*), with even compounds of different modes of action having interactive toxicological effects (*57*).

The results of this study document that detectable quantities of OWCs occur in U.S. streams at the national scale. This implies that many such compounds survive wastewater treatment (*1, 6, 58*) and biodegradation (*59*). Future research will be needed to identify those factors (i.e. high use and chemical persistence) that are most important in determining the occurrence and concentration of OWCs in water resources.

Although previous research has also shown that antibiotics (*60*), other prescription drugs (*1, 2, 19, 61–63*), and nonprescription drugs (*1, 40, 62, 64*) can be present in streams, this study is the first to examine their occurrence in a wide variety of hydrogeologic, climatic, and land-use settings across the United States. Much is yet to be learned pertaining to the effects (particularly those chronic in nature) on humans, plants, and animals exposed to low-level concentrations of pharmaceuticals and other OWCs. Furthermore, little is known about the potential interactive effects (synergistic or antagonistic toxicity) that may occur from complex mixtures of these compounds in the environment. Finally, additional research also needs to be focused on those OWCs not frequently detected in this stream sampling. Select OWCs may be hydrophobic and thus may be more likely to be present in stream sediments than in streamwater (*65, 66*). For example, the low frequency of detection for the tetracycline (chlortetracycline, doxycycline, oxytetracycline, tetracycline) and quinolone (ciprofloxacin, enrofloxacin, norfloxacin, sarafloxacin) antibiotics is not unexpected given their apparent affinity for sorption to sediment (*66*). In addition, select OWCs may be degrading into new, more persistent compounds that could be transported into the environment instead of (or in addition to) their associated parent compound.

Acknowledgments

The authors wish to acknowledge the USGS scientists and field technicians who provided essential assistance to this project by identifying candidate stream sites across the United States and in collecting and processing stream samples. In addition, the authors thank Michele Lindsey, Jeff Cahill, and Greg Brown for their important contributions to developing the analytical methods being used. The authors also acknowledge Steffanie Keefe for her efforts in compiling the existing ecotoxicological data, Jessica Hopple for her assistance in generating select figures for this paper, and Kymm Barnes for her assistance in compiling the water-quality data for this study. This project was supported by the U.S. Geological Survey, Toxic Substances Hydrology Program. The use of trade, firm, or brand names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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Received for review June 12, 2001. Revised manuscript received November 26, 2001. Accepted December 12, 2001.

ES011055J

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The Science of the Total Environment 311 (2003) 135–149

the Science of the Total Environment

An International Journal for Scientific Research into the Environment and its Relationship with Man

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Pharmaceuticals and personal care products (PPCPs) in surface and treated waters of Louisiana, USA and Ontario, Canada

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Received 9 March 2002; accepted 2 January 2003

Abstract

A newly developed analytical method was used to measure concentrations of nine pharmaceuticals and personal care products (PPCPs) in samples from two surface water bodies, a sewage treatment plant effluent and various stages of a drinking water treatment plant in Louisiana, USA, and from one surface water body, a drinking water treatment plant and a pilot plant in Ontario, Canada. The analytical method provides for simultaneous extraction and quantification of the following broad range of PPCPs and endocrine-disrupting chemicals: naproxen; ibuprofen; estrone; 17β-estradiol; bisphenol A; clorophene; triclosan; fluoxetine; and clofibric acid. Naproxen was detected in Louisiana sewage treatment plant effluent at 81–106 ng/l and Louisiana and Ontario surface waters at 22–107 ng/l. Triclosan was detected in Louisiana sewage treatment plant effluent at 10–21 ng/l. Of the three surface waters sampled, clofibric acid was detected in Detroit River water at 103 ng/l, but not in Mississippi River or Lake Pontchartrain waters. None of the other target analytes were detected above their method detection limits. Based on results at various stages of treatment, conventional drinking-water treatment processes (coagulation, flocculation and sedimentation) plus continuous addition of powdered activated carbon at a dosage of 2 mg/l did not remove naproxen from Mississippi River waters. However, chlorination, ozonation and dual media filtration processes reduced the concentration of naproxen below detection in Mississippi River and Detroit River waters and reduced clofibric acid in Detroit River waters. Results of this study demonstrate that existing water treatment technologies can effectively remove certain PPCPs. In addition, our study demonstrates the importance of obtaining data on removal mechanisms and byproducts associated with PPCPs and other endocrine-disrupting chemicals in drinking water and sewage treatment processes.

Keywords: Pharmaceuticals; Endocrine disruptors; Sewage treatment plant effluent; Natural waters; Drinking water treatment

1. Introduction

Recent studies indicate the potential widespread occurrence of low-level concentrations (ng–μg/l) of pharmaceuticals, hormones, and other organic sewage contaminants and their metabolites in the aquatic environment (Guillette, 1995; Desbrow et al., 1998; Halling-Sørensen et al., 1998; Ternes, 1998; Daughton and Ternes, 1999; Sedlak et al., 2000; Boyd and Grimm, 2001; Kolpin et al.,

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doi:10.1016/S0048-9697(03)00138-4

Table 1
Target analytes

Name	Trade name examples	CAS#	Purity (%)	Stock concentration (mg/l)	Commercial use	Chemical name
Clofibric acid	NA	882-09-7	97.0	10.17	Metabolite of lipid regulator	2-(4-Chlorophenoxy)-2-methyl-propanoic acid
Naproxen	Naprosyn, Aleve	22204-53-1	100.6	10.02	Anti-inflammatory, analgesic	(αS)-6-Methoxy-α-methyl-2-naphthaleneacetic acid
Ibuprofen	Advil, Motrin	15687-27-1	99.8	30.08	Anti-inflammatory	α-Methyl-4-(2-methylpropyl) benzene-acetic acid
Acetaminophen	Tylenol	103-90-2	>99.0	100.08	Analgesic	*N*-(4-Hydroxyphenyl)acetamide
Caffeine	Caffeine	58-08-2	>99.9	99.9	Stimulant	3,7-Dihydro-1,3,7-trimethyl-1*H*-purine-2,6-dione
Fluoxetine[a]	Prozac	54910-89-3	100.0	357.6	Antidepressant	*N*-Methyl-γ-[4-(trifluoromethyl) phenoxy]benzenepropanamine
Clorophene	Santophen 1	120-32-1	NA	5.08	Disinfectant	4-Chloro-2-(phenylmethyl)phenol
Triclosan	Ster-Zac	3380-34-5	97.0	5.06	Antibacterial, disinfectant	5-Chloro-2-(2,4-dichlorophenoxy) phenol
Bisphenol A	Bisphenol A	80-05-7	>99.0	5.11	Plastics intermediate, fungicide	4,4′-(1-Methylethylidene) bisphenol
Estrone	Estrol, Femidyn	53-16-7	>99.0	10.14	Steroid	3-Hydroxyestra-1,3,5(10)-trien-17-one
17β-Estradiol	Estrace, Estraderm	50-28-2	>98.0	9.99	Steroid	(17β)-Estra-1,3,5(10)-triene-3,17-diol

All chemicals were obtained from Sigma Chemical Corporation (St. Louis, MO). Stock concentrations were prepared in dichloromethane. NA, not available.

[a] Purchased as fluoxetine hydrochloride.

2002). Many of these compounds are suspected or potential endocrine-disrupting chemicals. Pharmaceuticals and personal care products (PPCPs) describe a large class of chemical contaminants that can originate from human usage and excretions, and veterinary applications of a variety of products, such as over-the-counter and prescription medications, and fungicides and disinfectants used for industrial, domestic, agricultural and livestock practices (Daughton and Ternes, 1999). PPCPs and their metabolites are continually introduced into aquatic environs and are prevalent at detectable concentrations (Kolpin et al., 2002), which can affect water quality and ecosystem health and potentially impact drinking water supplies (Roefer et al., 2000; Trussell, 2001). The long-term effects of continuous, low-level exposure to PPCPs and their metabolites are not well understood (Daughton and Ternes, 1999).

Effluents from sewage treatment plants contain a variety of PPCPs (Daughton and Ternes, 1999). Studies have shown that the transformation processes for specific PPCP compounds can vary in a sewage treatment plant, depending on the characteristics of the sewage, weather conditions, and the design and operation of the treatment processes (Ternes, 1998; Johnson and Sumpter, 2001). Upon discharge of treated sewage into a receiving water body, residual PPCPs can be diluted and blended with contaminants from other discharge points, as well as runoff and seepage. These same receiving water bodies also can serve as drinking water sources. Recent studies aimed at investigating drinking-water treatment methods for PPCPs have demonstrated that conventional treatment processes (coagulation, flocculation and sedimentation) are not effective methods, but other treatment processes, such as oxidation with chlorine and ozone, activated carbon and membrane filtration, can be effective in removing antibiotics (Adams et al., 2002) and other selected pharmaceuticals (Ternes et al., 2002).

A list of target analytes representing a variety of PPCPs was developed for this study (Table 1).

To date, there is no universally accepted method for the analysis of PPCPs in aquatic environs. Several analytical approaches have been utilized, including gas chromatography/mass spectrometry (GC/MS), gas chromatography/mass spectrometry/mass spectrometry (GC/MS/MS), GC with high-resolution mass spectrometry, liquid chromatography-ultraviolet detection (LC-UV), liquid chromatography/mass spectrometry (LC/MS) and liquid chromatography/mass spectrometry/mass spectrometry (LC/MS/MS) (Desbrow et al., 1998; Barber et al., 2000; Laganá et al., 2000; Möder et al., 2000; Huang and Sedlak, 2001; Kolpin et al., 2002). The decision to use GC or LC is usually based on the physicochemical characteristics of the target analyte. Many PPCPs contain polar functional groups and/or are thermally labile and do not lend themselves readily to GC analysis. Thus, most GC methods for polar PPCPs must incorporate a derivatization step to overcome these limitations. LC is generally applicable to more polar compounds, in contrast to GC. The use of MS for detection in either case gives a second dimension of information, which can be used to confirm the identity of the targeted compound through its mass spectrum. Nonetheless, PPCPs include a broad range of molecules of differing polarity and functionality, and hence pose a significant analytical challenge.

The objective of this study was to develop a method for quantifying the concentration of a target list of a variety of PPCPs in surface and treated waters of Louisiana, USA and Ontario, Canada. This paper provides a method for analyzing the following diverse list of PPCP compounds in natural and treated water samples: a metabolite (clofibric acid) of a lipid regulator; two analgesics (naproxen and ibuprofen); two steroids (estrone and 17β-estradiol); a chemical intermediate in the synthesis of commercial products (bisphenol A); one disinfectant (clorophene); an antibacterial additive (triclosan); and an antidepressant (fluoxetine). The target list of PPCPs is inclusive of bisphenol A, an intermediate, due to its ubiquitous nature and its endocrine-disrupting potential. The method was used to determine concentrations of the target PPCPs in surface water samples from the Mississippi River and Lake Pontchartrain in Louisiana, and the Detroit River in Ontario. The method was also used to analyze treated water samples from a sewage treatment plant in Louisiana, several stages of drinking water treatment plants in Louisiana and Ontario, and a pilot drinking-water treatment plant in Ontario.

2. Site selection and sampling

Surface water samples were collected from the Mississippi River in New Orleans, Louisiana during September–November 2001 (Fig. 1, Site #1). The Mississippi River extends from northern Minnesota to the Gulf of Mexico and drains 41% of the conterminous United States in an area where 27% of the population resides (Meade, 1996). The mean annual discharge of the lower Mississippi River near New Orleans is 13 500 m^3/s (Meade, 1996). The Mississippi River receives a variety of organic wastes from urban areas, farms, factories and individual households. Approximately 70 US cities rely on the Mississippi River as a source of drinking water. Surface water samples were collected from the Mississippi River at a site outside of direct influence of discharge points of known private or municipal sewage treatment plants.

Surface water samples were also collected on the southern shore of Lake Pontchartrain (Fig. 1, Site #2), which is located within the Lake Pontchartrain estuary in the central Gulf Coast region adjacent to New Orleans, Louisiana. Lake Pontchartrain is influenced by riverine discharges (228 m^3/s) as well as stormwater drainage and freshwater diversion from the Mississippi River through the Bonnet Carre spillway (Flowers and Isphording, 1990; Argyrou et al., 1997). Lake Pontchartrain is not used as a municipal drinking water source.

Sewage plant effluent samples were collected during February and March 2002 from the Jefferson Parish East Bank Wastewater Treatment Plant (Fig. 1, Site #3), which discharges treated sewage effluent into the Mississippi River. The plant is located in metropolitan New Orleans, Louisiana, approximately 5 km west of the city line. The plant uses conventional secondary wastewater treatment and operates at an annual average flow of 125 000 m^3/day. Treated sewage samples were collected prior to chlorination of the effluent (STP1), as shown in Fig. 2a.

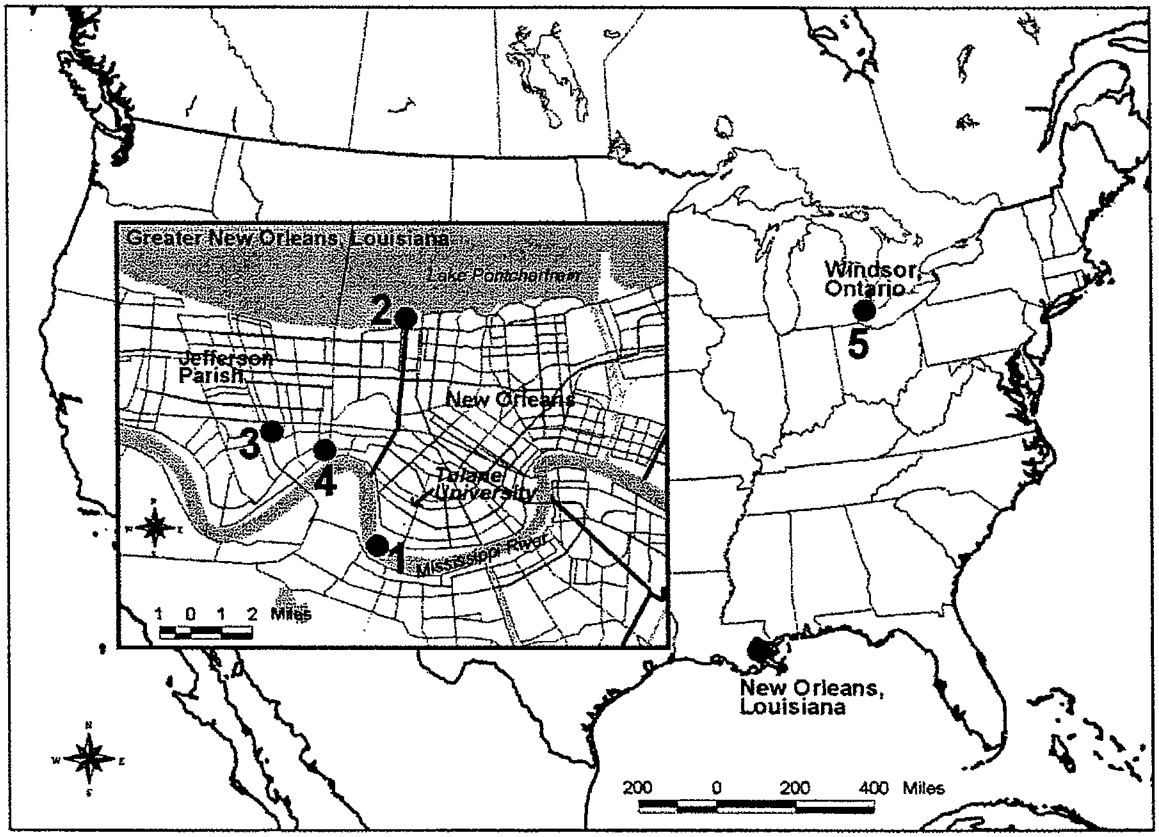

Fig. 1. Sampling sites in greater New Orleans, Louisiana and Windsor, Ontario. Site #1, Mississippi River, Louisiana; Site #2, Lake Pontchartrain, Louisiana; Site #3, Jefferson Parish East Bank Wastewater Treatment Plant, Louisiana; Site #4, Jefferson Parish East Bank Water Treatment Plant, Louisiana; Site #5, A.H. Weeks Water Treatment Plant and ENWIN Pilot Plant, Ontario.

Water samples were collected from various stages of the Jefferson Parish East Bank Water Treatment Plant (Fig. 1, Site #4), which relies on the Mississippi River as its source. The drinking water treatment plant is located approximately 2.5 km west of the New Orleans city line. The plant operates at a maximum flow of 330 000 m^3/day and uses conventional treatment, which includes coagulation (alum and cationic polyelectrolyte polymer), flocculation and sedimentation. The treated water is disinfected by chlorination prior to filtration, and chloramination prior to distribution (Fig. 2b). High-load organic pollutants are removed from the raw water by adding powdered activated carbon (PAC) at a concentration of 2 mg/l. Samples were collected at the plant inlet (JP1), after PAC addition and conventional treatment (JP2), and after chlorination, filtration and storage (JP3), as shown in Fig. 2b.

In Canada, water samples were collected in January 2002 at the A.H. Weeks Water Treatment Plant (Fig. 1, Site #5) in Windsor, Ontario, which relies on the Detroit River as its source. The drinking water treatment plant operates at a maximum flow of 227 000 m^3/day and uses ozonation, conventional treatment (alum and Percol LT22 as coagulants) and chlorination prior to distribution (Fig. 2c). Samples were collected from the Detroit River at the plant inlet (WO1) and after treatment at the plant outlet (WO2), as shown in Fig. 2c. Samples were also collected at the ENWIN Pilot Plant (Fig. 2D), which was located at the same

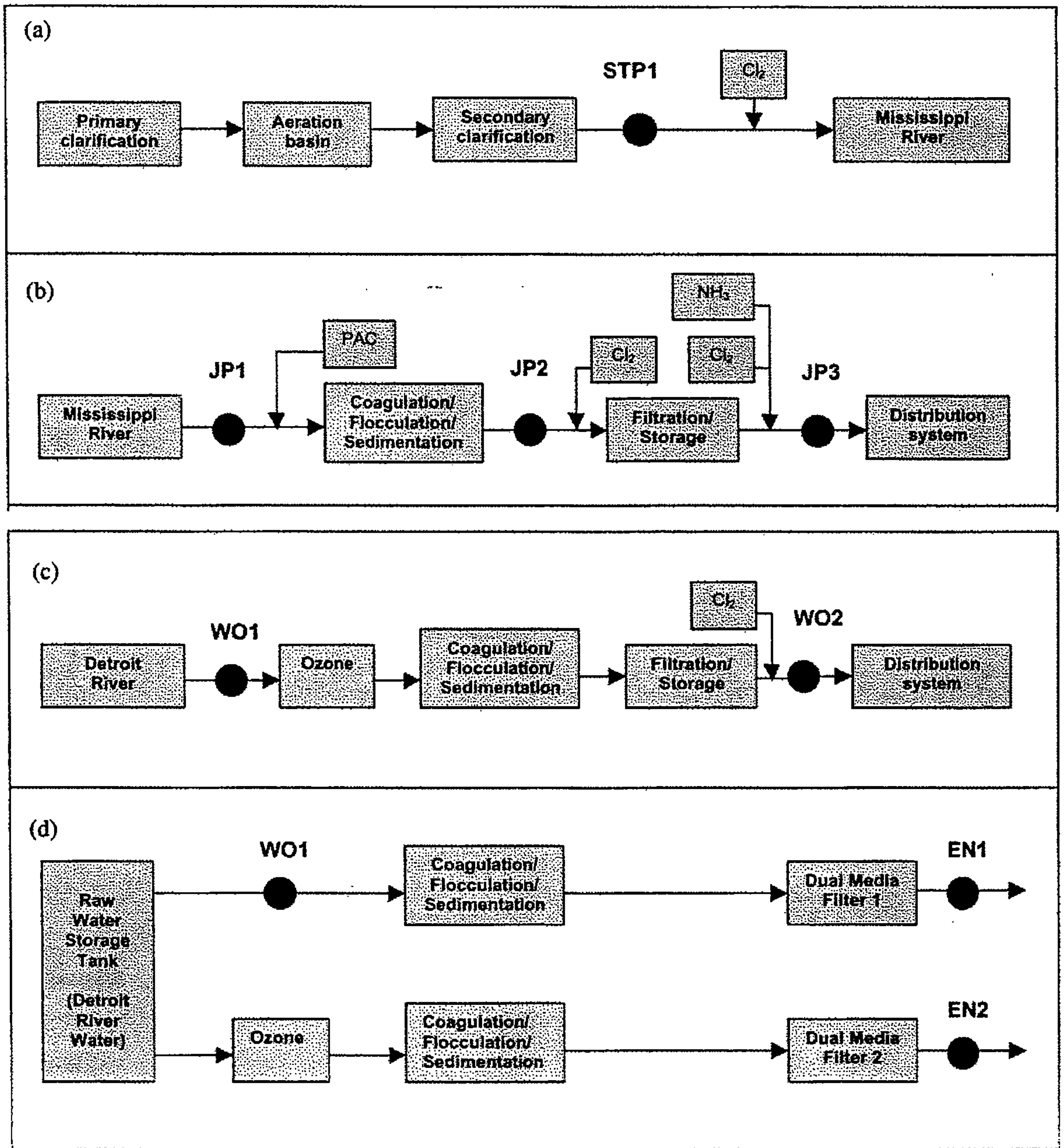

Fig. 2. Process flow diagrams for sewage and drinking water treatment plants in Louisiana and Ontario (● indicates sampling location). (a) Jefferson Parish East Bank Wastewater Treatment Plant, Louisiana (Fig. 1, Site #3); (b) Jefferson Parish East Bank Water Treatment Plant, Louisiana (Fig. 1, Site #4); (c) A.H. Weeks Water Treatment Plant, Ontario (Fig. 1, Site #5); and (d) ENWIN Pilot Plant, Ontario (Fig. 1, Site #5)

site as the A.H. Weeks Water Treatment Plant and used to test treatment processes for the Detroit River water source (WO1). Water samples were collected at the outlet of the pilot plant following conventional treatment and dual media filtration (EN1) and at the outlet of a similar process train preceded by ozonation (EN2), as shown in Fig. 2d.

For all sites, a total of 8 l was collected as grab samples using pre-cleaned 4-l amber glass containers. Louisiana samples were stored on ice during transport to the laboratory and were processed within 7 days. Samples collected from the Canadian plants were acidified prior to shipping and were analyzed immediately upon arrival at Tulane University. A method blank using ultra-pure laboratory water further purified by passing through a SPE disk prior to use (see below) was performed for each batch of samples collected from the sewage and drinking water treatment plants.

3. Analytical methods

A relative response factor (RRF) standard solution of all reference standards was prepared in dichloromethane (DCM) and methanol, with concentrations of each analyte ranging between 5 and 100 mg/l. The RRF standard consisted of the compounds summarized in Table 1 (except fluoxetine hydrochloride, which was prepared separately) and three deuterated surrogate compounds (bisphenol A-d_{14}, estrone-d_4 and acetaminophen-d_4). Fluoxetine was not as stable as our other target analytes; therefore, fluoxetine standards were prepared from the solid material just prior to use. The surrogate standard was prepared in DCM at concentrations between 5 and 100 mg/l prior to adding it to the RRF standard. Phenanthrene-d_{10} (99.3% purity, AccuStandard Inc, New Haven, CT) was chosen as the internal standard, since it was not affected by the derivatization step in the analytical procedure, as discussed below. Phenanthrene-d_{10} was prepared in DCM at a concentration of 495.4 mg/l and added to the sample after the final concentration step and after derivatization.

Sampling bottles and all glassware used for sample collection and preparation were cleaned by washing with soap, soaking in a 5% Contrad solution (Decon Laboratories Inc, Bryn Mawr, PA) and in hydrochloric acid (2 N), and then ashing at 450 °C. All laboratory materials were either made of glass or Teflon to avoid sample contamination. Teflon containers were cleaned in the same manner as glassware, but without ashing. Ultra-pure water was produced in the laboratory by filtering tap water through activated carbon, followed by a mixed-bed deionization tank and ultra-filtration membrane system, and then ultraviolet light exposure (US Filter, Modulab UF/UV, CA, USA). Analysis of ultra-pure water used for spiked recovery experiments and method blanks showed low-level background contamination with bisphenol A. Once this was determined, the procedure was modified to include further purification of the ultra-pure water by passing it through a SPE disk. All solvents were GC grade.

3.1. Solid-phase extraction

The targeted PPCP compounds were isolated from water samples by solid-phase extraction using a polar SDB-XC Empore disk (3M Corporation, St. Paul, MN). Surface water samples, sewage treatment plant effluent samples and untreated drinking water treatment plant samples were pumped through 1.0- and 0.2-μm glass fiber filters (47 mm in diameter, Millipore Corporation, Bedford, MA) to remove particulate matter prior to solid-phase extraction. Pre-filtration was not necessary for water samples collected at the outlet of the drinking water treatment plants. Extraction disks were pre-conditioned with 50 ml of methanol, 50 ml of DCM, 50 ml of methanol and 10 ml of ultra-pure water. If samples were not previously acidified, the pH was adjusted to <2.0 using 12 N HCl prior to spiking with the surrogate standard (0.5 ml/l sample). Samples were then drawn through the extraction disks using vacuum aspiration at an approximate flow rate of 100 ml/min. The disks were then air-dried and the targeted compounds were extracted from the disks by eluting with 50 ml of methanol, 50 ml of DCM and 50 ml of methanol. The extracts were concentrated to an approximate volume of 1 ml using a RapidVap® with mild heat (50 °C) and a gentle stream of nitrogen gas.

The concentrated organic extracts were passed through a column containing 3 g of pre-washed silica gel to remove dissolved interfering compounds (e.g. humic acids) from some samples. The silica gel was then washed with three bed volumes each of DCM and methanol. This clean-up step was added to the analytical procedure after a method revision in the course of this research, and therefore was not applied to all samples. The silica gel-treated samples were carefully evaporated to a volume of 1 ml under the same conditions described previously.

3.2. Derivatization

Derivatization was used to enhance the thermal stability of clofibric acid, which thermally degraded in the GC injection port, and reduce the polarity of specific target analytes (clofibric acid, ibuprofen and naproxen) to facilitate GC analysis. Given the sensitivity of the derivatization reagent [*N*,*O*-bis(trimethylsilyl)-triflouroacetamide in the presence of trimethylchlorosilane; BSTFA; Supelco Inc, Bellefonte, PA] to moisture, and because Na_2SO_4 was not effective at removing traces of water dissolved in methanol, all samples were placed in GC autosampler vials and completely dried under a stream of N_2 prior to derivatization. Derivatization was achieved by dissolving the dried sample residue in 1 ml of BSTFA reagent mixture. The closed vial was then heated at 80 °C for 20 min. Finally, 10 μl of the internal standard (phenanthrene-d_{10}) was added to the sample prior to instrumental analysis.

For the RRF and instrument detection limit experiments, the working standards were carefully dried, dissolved in the BSTFA reagent mixture and derivatized as described here. A 1-ml aliquot of known concentration was prepared for each target compound and analyzed by GC/MS. This same sample was then dried and derivatized as described previously. The derivatized sample was analyzed by GC/MS and the chromatogram was checked for both the non-derivatized and derivatized forms of the analyte. If the derivatization was incomplete, the percentage completion was determined by comparing the peak areas. Caffeine and fluoxetine, lacking the appropriate functional groups, exhibited no response to derivatization. Estrone was derivatized to 84.7% completion. All other analytes were derivatized to 100% completion.

3.3. GC/MS conditions

Samples were analyzed by GC/MS (Agilent 6890 GC and 5972 MSD) under the following conditions. Splitless 2-μl injections were made onto a DB-5MS column (25 m with 0.25-μm film thickness and 0.25 mm i.d.) at a constant flow rate of 1 ml/min. The GC oven was operated from 100 °C (0-min hold) at 5 °C/min to 165 °C (5-min hold), then at 2 °C/min to 175 °C (0-min hold) and at 10 °C/min to 320 °C (5-min hold) for a total run time of 42.5 min. The injector and detector temperatures were 230 and 300 °C, respectively. The MS was operated in +EI mode using selected ion monitoring (SIM) for sensitivity. Table 2 summarizes the SIM conditions.

3.4. Quantification

Quantification of the targeted PPCP compounds was conducted by comparing peak areas of the most intensive ion of each compound with that of the internal standard. Compound identification was confirmed by GC retention time and qualifier ions (usually molecular ion and one or two fragment ions) as shown in Table 2. Baseline interference was observed at or near the retention time of estrone. As part of the method development, ion ratios were monitored, enabling discrimination between interference and the proper response for estrone. In addition, qualifier ions were re-evaluated for the steroid compounds as compared to methods employed by the authors in previous research (Boyd and Grimm, 2001). Before each sequence of samples, response factors were calculated separately from the analysis of the RRF and its dilutions, 1:10, 1:20 and 1:200.

Fig. 3a shows the GC/MS chromatogram of the RRF stock solution containing the target compounds. Fig. 3b shows the chromatogram of a sample collected from the inlet of Jefferson Parish East Bank Water Treatment Plant representing raw Mississippi River water (Fig. 2b, JP1). It identifies

Table 2
Selected ion monitoring (SIM) program for targeted and standard analytes

SIM group	Type	Name	Molecular weight	Retention time (min)	Target ion	Qualifier ion 1	Qualifier ion 2
1	TGT	Clofibric acid–TMS	286	17.66	128	143	286
1	TGT	Ibuprofen-TMS	278	19.61	263	278	234
2	SS	Acetaminophen-d_4–TMS	227	ND	227	–	–
2	SS	Acetaminophen-d_4–TMS(2)	299	19.79	284	299	–
2	TGT	Acetaminophen–TMS(2)	295	19.83	280	295	206
3	IS	Phenanthrene-d_{10}	188	26.11	188	160	–
3	TGT	Caffeine	194	27.30	194	109	–
3	TGT	Fluoxetine	309	ND	309	104	–
4	TGT	Clorophene–TMS	290	28.39	290	292	275
4	TGT	Naproxen–TMS	302	30.77	243	302	185
5	TGT	Triclosan–TMS	360	31.33	200	360	362
6	SS	Bisphenol A-d_{16}	244	ND	226	–	–
6	SS	Bisphenol A-d_{15}–TMS(1)	315	ND	315	–	–
6	SS	Bisphenol A-d_{14}–TMS(2)	386	32.08	368	386	–
6	TGT	Bisphenol A–TMS(2)	372	32.17	357	372	–
7	SS	Estrone-d_4–TMS	346	36.21	346	220	–
7	TGT	Estrone–TMS	342	36.21	342	327	257
7	TGT	Estrone-d_4	274	ND	274	–	–
8	TGT	17β-Estradiol–TMS(2)	416	36.43	416	285	–

IS, internal standard; ND, not detected; SS, surrogate standard; TGT; targeted analyte; TMS, Trimethylsilyl derivative. Note that (1) or (2) after TMS refers to the mono- or di-derivative, respectively.

the response of the target ion and two qualifier ions of naproxen.

3.5. Limits of detection and determination

The instrument detection limits for all compounds were determined by serial dilution of the RRF and fluoxetine standard solutions. The diluted solutions were prepared by weighing a known amount of working standard into an autosampler crimp-top vial and adding a known mass of BSTFA derivatization reagent and a known amount of internal standard. In this way, the injected mass of each compound could be calculated. Instrument detection limits are reported in Table 3.

3.6. Recoveries

Natural water samples were collected from three surface water bodies, and treated water samples were collected from the effluent of a sewage treatment plant and various stages of treatment from two drinking water treatment plants and a pilot plant. As such, sample matrices were diverse and surrogate standards were added to samples to monitor matrix effects. Spiked recoveries were measured for each compound, including surrogates using ultra-pure laboratory water. Three 1-l laboratory samples were spiked with 1 ml each of a RRF and a fluoxetine standard. The spiked samples were extracted and analyzed using solid-phase extraction, derivatization and GC/MS as described previously. Results were compared to non-extracted RRF and fluoxetine standard solutions. For quantification, the samples and the standard solution were spiked with 10 μl of the internal standard.

Recoveries for most compounds were greater than 47%. Exceptions were acetaminophen and caffeine. Acetaminophen was repeatedly not detected, whereas caffeine exhibited low recovery (2.8%). These low recoveries were attributed to incomplete retention of these compounds on the extraction disk. Recovery rates for the surrogate compounds bisphenol A-d_{14} and estrone-d_4 were greater than 95%. The recovery rate for acetamin-

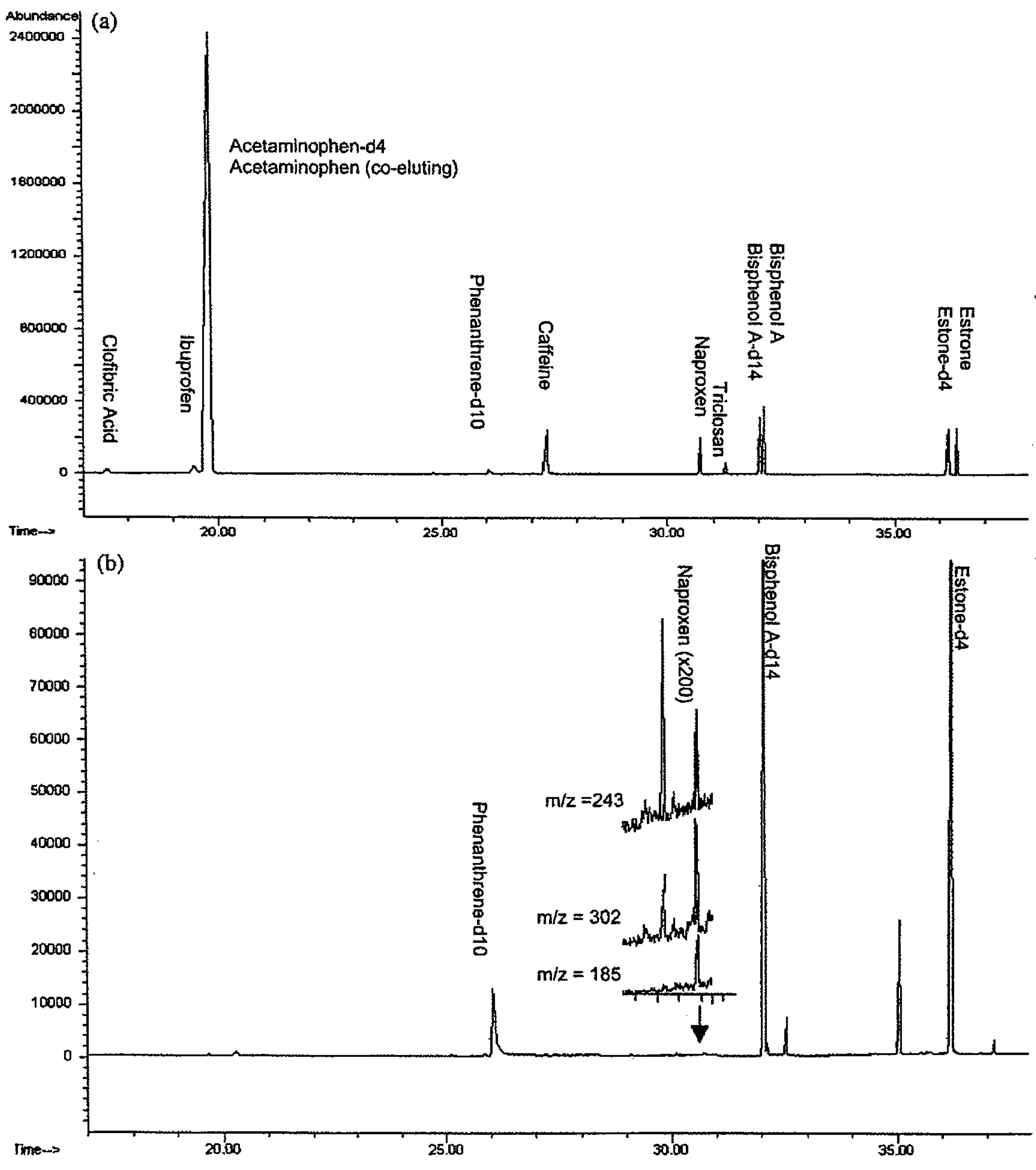

Fig. 3. GC/MS chromatograms: (a) relative response factor standard containing all target compounds (except fluoxetine and chlorophene); (b) inlet sample (JP1) for Jefferson Parish East Bank Water Treatment Plant (Site #4, Fig. 1).

ophen-d_4 could not be determined, as GC/MS analysis repeatedly showed non-detection for this compound. Acetaminophen and caffeine were therefore not included in the final list of target analytes for this method. Recovery rates and method detection limits for the target compounds are summarized in Table 3.

In contrast to spiked recovery experiments with ultra-pure water, for which the recovery was greater than 95% for estrone-d_4 and bisphenol A-d_{14}, recoveries of deuterated compounds were slightly decreased in most surface water samples, which was attributed to the presence of high loads of dissolved organic matter and other matrix complexities. Samples collected from the Louisiana sewage treatment plant and the Louisiana drinking-water treatment plant were filtered through a silica gel column to remove dissolved organic matter. This clean-up step was not applied to samples from the Canadian plants and it had no significant effect on recovery of the target analytes. Water samples that were disinfected with chlorine at the drinking water treatment plants were quenched with 40–50 mg/l of sodium sulfite to avoid reaction of chlorine residuals with the surrogate standard compounds. Samples that were stored in the refrigerator for several days exhibited improved surrogate standard recovery, which was attributed to the dissipation of free chlorine prior to sample analysis.

4. Results and discussion

Sampling results for the nine targeted PPCP compounds are summarized in Table 4 Tables 5–

Table 4
PPCPs in surface waters in Louisiana

PPCP compound	Concentration in surface water (ng/l)			
	Mississippi River		Lake Pontchartrain	
Clofibric acid	ND	ND	ND	ND
Ibuprofen	ND	ND	ND	ND
Fluoxetine	ND	ND	ND	ND
Clorophene	ND	ND	ND	ND
Naproxen	37	39	107	22
Triclosan	ND	ND	ND	ND
Bisphenol A	NQ	NQ	NQ	NQ
Estrone	ND	ND	ND	ND
17β-Estradiol	ND	ND	ND	ND
Bisphenol A-d_{14} (%)[a]	68.0	75.0	67.0	67.0
Estrone-d_4 (%)[a]	103.4	119.4	88.3	124.6
Acetaminophen-d_4 (%)[a]	ND	ND	ND	ND

Samples were collected from the shores of the Mississippi River (Fig. 1, Site #1) and from the shores of Lake Pontchartrain (Fig. 1, Site #2). No silica gel cleanup was used during sample preparation. ND, not detected (see MDLs in Table 3); NQ, not quantified.

[a] Percentage recovery of surrogate standard.

Table 3
Detection limits and percentage recovery

	IDL (ng/l)	Completion of derivatization (%)	Method development			Revised method		
			MDL (ng/l)	Recovery (%)	R.S.D. (%)	MDL (ng/l)	Recovery (%)	R.S.D. (%)
Clofibric acid	3	100	0.6	60.8	12.6	0.8	44.2	26.5
Ibuprofen	13	100[b]	3.5	47.1	26.9	2.6	63.0	12.3
Acetaminophen	45	100	ND	ND	ND	ND	ND	ND
Caffeine	24	0	107.1	2.8	3.6	319.3	0.9	1.1
Fluoxetine	178	0	25.8	86.1	7	25.4	87.7[a]	–
Chlorophene	0.6	100	0.1	71.7	5.9	0.1	108.9[a]	–
Naproxen	3	100	0.4	87.9	2.8	0.4	102.9	17.8
Triclosan	1	100	0.2	53.8	24	0.2	60.1	22.8
Bisphenol A	0.6	100	0.1	99.7	3.5	0.1	95.6	39.5
Estrone	3	84.7	0.4	91.9	5.1	0.3	130.3	22.3
17β-Estradiol	1	100	0.1	90.5	9.1	0.1	117.6	14.8

Method development does not include silica gel clean-up. Revised method includes silica gel clean-up. Completion of derivatization was based on comparison of underivatized peak area and derivatized peak area. IDL, instrument detection limit; MDL, method detection limit; ND, not detected; R.S.D., relative standard deviation. MDL was based on a 2-μl injection from a 1-ml extract of an 8-l sample. Percentage recovery is based on non-extracted RRF and fluoxetine standard.

[a] Due to fast degradation of this compound, the value of only one sample was considered.

[b] Assumed completion. Underivatized ibuprofen did not elute from the GC

Table 5
PPCPs in sewage treatment plant effluent in Louisiana

PPCP compound	Concentration at STP1 (ng/l)	
Clofibric acid	ND	ND
Ibuprofen	ND	ND
Fluoxetine	ND	ND
Clorophene	ND	ND
Naproxen	106	81
Triclosan	21	10
Bisphenol A	ND	ND
Estrone	ND	ND
17β-Estradiol	ND	ND
Bisphenol A-d_{14} (%)[a]	13.6	13.9
Estrone-d_4 (%)[a]	52.6	28.9
Acetaminophen-d_4 (%)[a]	1.1	1.2

Samples were collected at the Jefferson Parish East Bank Wastewater Treatment Plant (Fig. 1, Site #3). Sampling location is shown in Fig. 2a. Sample preparation included silica gel clean-up. ND, not detected (see MDLs in Table 3).

[a] Percentage recovery of surrogate standard.

7. Results are discussed with regard to occurrence of these nine compounds in surface waters in Louisiana and Ontario, in the effluent of a sewage treatment plant, and during various stages of removal by drinking water treatment processes.

4.1. Surface waters

Results for Louisiana and Ontario surface waters are shown in Tables 4, 6 and 7. Naproxen, which is a common prescription pain reliever, was detected in Mississippi River (Table 4 and JP1 in Table 6), Lake Pontchartrain (Table 4) and Detroit River (WO1 in Table 7) waters at concentrations ranging from 22 to 107 ng/l. These observations are similar to findings reported by Ternes (1998) and Ternes et al. (1999) for German, Canadian and Brazilian surface waters. Clofibric acid, which is a metabolite of the lipid regulator clofibrate (as one of several in this class), was detected in Detroit River water (WO1 in Table 7) at a concentration of 103 ng/l, similar to findings for European surface waters (Stan et al., 1994; Stumpf et al., 1996; Ternes, 1998; Daughton and Ternes, 1999). The absence of clofibric acid in Mississippi River and Lake Pontchartrain waters could be attributed to the declining use of clofibrate in the United States (WHO, 1996).

17β-Estradiol was observed to be below the method detection limit (Table 3) of 0.1 ng/l for all samples collected from surface waters. Other investigators have reported 17β-estradiol in surface

Table 6
PPCPs at Jefferson Parish East Bank drinking water treatment plant in Louisiana, USA

PPCP compound	Concentration at water treatment plant (ng/l)					
	Mississippi R. (JP1)		Precipitator (JP2)		Finished water (JP3)	
Clofibric acid	ND	ND	ND	ND	ND	ND
Ibuprofen	ND	ND	ND	ND	ND	ND
Fluoxetine	ND	ND	ND	ND	ND	ND
Clorophene	ND	ND	ND	ND	ND	ND
Naproxen	64	65	63	68	ND	ND
Triclosan	ND	ND	ND	ND	ND	ND
Bisphenol A	NQ	NQ	NQ	NQ	NQ	ND
Estrone	ND	ND	ND	ND	ND	ND
17β-Estradiol	ND	ND	ND	ND	ND	ND
Bisphenol A-d_{14} (%)[a]	62.8	65.2	46.0	81.3	94.9	18.6
Estrone-d_4 (%)[a]	130.1	68.3	118.1	99.3	106.7	17.7
Acetaminophen-d_4 (%)[a]	0.2	0.2	0.2	ND	0.1	ND

Samples were collected at Jefferson Parish East Bank Water Treatment Plant in Louisiana, USA (Fig. 1, Site #4). Sampling locations at the plant are shown in Fig. 2b. ND, not detected (see MDLs in Table 3); NQ, not quantified.

[a] Percent recovery of surrogate standard. Sample preparation included silica gel clean-up.

Table 7
PPCPs at drinking water treatment plant and pilot plant in Ontario, Canada

PPCP compound	Concentration at water treatment plant (ng/l)			
	Full-scale plant		ENWIN pilot plant	
	Detroit R. water (WO1)	Finished water (WO2)	Filter 1 (EN1)	Filter 2 (EN2)
Clofibric acid	103	ND	ND	ND
Ibuprofen	ND	ND	ND	ND
Fluoxetine	ND	ND	ND	ND
Clorophene	ND	ND	ND	ND
Naproxen	63	ND	ND	ND
Triclosan	ND	ND	ND	ND
Bisphenol A	NQ	NQ	NQ	NQ
Estrone	ND	ND	ND	ND
17β-Estradiol	ND	ND	ND	ND
Bisphenol A-d_{14} (%)[a]	66.7	93.6	80.2	91.5
Estrone-d_4 (%)[a]	77.2	90.7	82.1	74.6
Acetaminophen-d_4 (%)[a]	ND	0.2	ND	ND

Samples were collected at the A.H. Weeks Water Treatment Plant and ENWIN pilot plant in Ontario, Canada (Fig. 1, Site #5). Sampling locations are shown in Fig. 2c,d. Sample preparation did not include silica gel clean-up. ND, not detected (see MDLs in Table 3). NQ, not quantified.

[a] Percentage recovery of surrogate standard.

waters at concentrations ranging from 0.2 to 2.6 ng/l (Snyder et al., 1999; Ternes et al., 1999). More data are therefore needed to determine the occurrence of 17β-estradiol and other PPCPs at lower concentrations in Louisiana and Ontario surface waters.

Ibuprofen, fluoxetine, triclosan, estrone and 17β-estradiol were not detectable in Mississippi River surface waters in our analyses. This observation is consistent with another study, which used multiple analytical techniques to determine PPCP target analytes (Barnes et al., 2002). Detectable but non-quantifiable levels of bisphenol A were found in several of our Mississippi River samples. In contrast, Barnes et al. (2002) were able to detect bisphenol A at a concentration of 60 ng/l in their analysis of Mississippi River surface waters. These contrasting results suggest a need to include bisphenol A as a target analyte in natural water samples.

4.2. Sewage treatment plant effluent

Results for samples collected from the effluent of the Louisiana sewage treatment plant (Table 5) indicate naproxen at concentrations of 81 and 106 ng/l. This sewage treatment plant discharges effluent into the Mississippi River and these naproxen concentrations are approximately 2.5-fold greater than naproxen detected in Mississippi River water. Other investigators (Ternes, 1998; Stumpf et al., 1999) have reported similar findings for naproxen in wastewater effluent, ranging from 20 to 520 ng/l. Results of this study also indicate triclosan in the Louisiana sewage treatment plant effluent at concentrations ranging from 10 to 21 ng/l. Triclosan is added as an antibacterial agent to detergents and it has been reported in sewage treatment plant effluents at concentrations up to 650 ng/l (Paxéus, 1996; Lindström et al., 2002). For this study, samples were collected prior to chlorination of the effluent at the sewage treatment plant. As such, results from this study do not necessarily indicate the quality of the final treated water as discharged into the Mississippi River. Results from this Tulane study also indicate that no other targeted PPCPs were detected in the effluent from the sewage treatment plant.

4.3. Drinking water treatment processes

Samples collected at the inlet of the drinking water treatment plants in Louisiana (JP1 in Table 6) and Ontario (WO1 in Table 7) contained naproxen at concentrations ranging from 63 to 65 ng/l. Samples collected at the precipitator of the Louisiana plant (JP2 in Table 6) exhibited naproxen concentrations of 63–68 ng/l, which indicates that the conventional treatment processes and 2-mg/l PAC addition do not remove naproxen from Mississippi River water. Adams et al. (2002) reported no significant removal of selected antibiotics with alum or ferric salt coagulation. Similarly, Ternes et al. (2002) reported no significant elimination of selected pharmaceuticals using iron chloride coagulation. Adams et al. (2002) also reported 25–50% removal of antibiotics from Missouri River water in batch experiments with a PAC dosage of 5 mg/l, and >90% removal for a PAC dosage of 50 mg/l. For the Louisiana drinking-water treatment plant, routine addition of 2 mg/l of PAC, which is used for the removal of natural organic matter in Mississippi River water, does not appear effective in reducing low-level concentrations of naproxen.

Samples collected after chlorination at the Louisiana drinking water treatment plant (JP3 in Table 6) exhibited non-detectable concentrations of naproxen and all other targeted compounds prior to discharge into the distribution system. A sample collected at the Ontario water plant following ozonation, conventional treatment and chlorination (WO2 in Table 7) exhibited non-detectable concentrations of all the target PPCP compounds. Samples collected from the Ontario pilot plant following conventional treatment plus dual media filtration (EN1 in Table 7) and ozonation (EN2 in Table 7) also exhibited non-detectable concentrations for all of the target PPCP compounds. Ternes et al. (2002) reported variable results in reducing concentrations of selected pharmaceuticals using ozone, and Adams et al. (2002) reported reduction of seven spiked (50 μg/l) antibiotics in distilled water and Missouri River water following laboratory chlorination and ozonation. Results from these studies and our results therefore indicate that oxidation (e.g. chlorination and ozonation) and sorption (dual media) processes may be effective treatments for reducing the concentration of naproxen that was observed in Mississippi River and Detroit River waters. Further research is needed to understand the removal processes and the possible formation of byproducts associated with these and other PPCP compounds.

Most of the water samples collected at the Louisiana and Ontario drinking-water treatment plants exhibited non-quantifiable but detectable concentrations of bisphenol A. These observations may be attributed to low-level contamination of the ultra-pure water used for sample preparation in the laboratory, or possible contamination in the plant (Krishnan et al., 1993). More data are therefore needed to determine if containers and/or chemical conveyor systems contribute to low-level bisphenol A contamination in drinking water treatment and distribution systems.

4.4. Application of method

The analytical method developed for this research is suitable for quantitative determination of nine functionally different PPCP compounds from diverse matrices. The method was successfully applied for the analysis of surface waters, wastewater effluent and treated water samples. Application of this method is limited to analysis of the targeted PPCP compounds only. Additional quantities of these compounds could be present in water samples, either in conjugated or other metabolic forms. Further method development would be required to include other chemical forms (e.g. breakdown products or disinfection byproducts) to the list of targeted compounds developed for this study.

Acknowledgments

The authors wish to acknowledge the generous support of the Center for Bioenvironmental Research at Tulane and Xavier Universities and the Tulane University School of Engineering. The authors are grateful to contributions provided by Wayne Koffskey of the Jefferson Parish Water

Treatment Plant, Ron Huffman of the Jefferson Parish Wastewater Treatment Plant, Saad Jasim and Samar Mazloum of the Windsor Utilities Commission and ENWIN Utilities. The authors also wish to acknowledge assistance by Richard Campanella of the Center for Bioenvironmental Research, contributions by Tulane undergraduate students Apryl Scott and Rhonda Hattar, and support from the Louisiana Alliance for Minority Participation at Tulane University.

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Environ. Sci. Technol. **2004**, *38*, 3533–3541

Occurrence of Antimicrobials in the Final Effluents of Wastewater Treatment Plants in Canada

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To investigate the occurrence of antimicrobials in the final effluents from wastewater treatment plants (WWTPs) in Canada, analytical methods were developed or modified from previously described methods using solid-phase extraction followed by liquid chromatography–electrospray ionization tandem mass spectrometry. Thirty-one antimicrobials from the macrolide, quinolone, quinoxaline dioxide, sulfonamide, and tetracycline classes were investigated in the final (treated) effluents from eight WWTPs, located in five Canadian cities. Ciprofloxacin, clarithromycin, erythromycin-H_2O, ofloxacin, sulfamethoxazole, sulfapyridine, and tetracycline were frequently detected in the effluents. The detection of sulfapyridine in effluents is the first report of this compound in environmental samples. Antimicrobials used exclusively for veterinary applications or treatment of livestock, such as carbadox, olaquindox, and chlortetracycline were not detected in the WWTP final effluents. There appear to be differences in the relative concentrations of antimicrobials detected in WWTP final effluents in Canada relative to concentrations reported previously in northern Europe, particularly for quinolone and sulfonamide compounds. These data may reflect differences in prescription patterns in Canada and northern Europe. The antimicrobials frequently detected in WWTP effluents appear to be those prescribed heavily in Canada for medical applications, and these compounds should be considered priority compounds for monitoring in surface water near WWTP discharges. The concentrations of antimicrobials detected in WWTP final effluents did not exceed 1 μg/L; levels that are unlikely to affect the growth and survival of aquatic organisms.

Introduction

The occurrence and biological impacts of pharmaceutically active compounds in the environment is an emerging issue (*1, 2*). The concern over the release of antimicrobials into the environment is related primarily to the potential for the development of antimicrobial resistance among microorganisms (*3, 4*). Residues of antimicrobials may also be directly toxic to microorganisms (*5*). Antimicrobials are used for the therapeutic treatment of bacterial diseases in humans, and some are also applied to animals such as cattle, swine, poultry, and fish for growth promotion and for disease prophylaxis and treatment. Antimicrobials used to treat humans in hospitals or by prescription are ultimately excreted into domestic sewage and are discharged to wastewater treatment plants (WWTPs). Treatment of raw wastewater (which includes a mix of domestic sewage, industrial wastewater, and stormwater runoff, depending on the WWTPs) may remove a proportion of these compounds, but there is the potential for residues of antimicrobials to be released in treated effluent into the aquatic environment (*1*).

The classes of antimicrobials included in this study include the macrolides, quinolones, quinoxaline dioxides, sulfonamides, and tetracyclines (Table 1). The lactam class of antimicrobials, including penicillins and cephalosporins, are used for treatment of both humans and animals. However, due to the chemically unstable β-lactam ring, members of the lactam class of antimicrobials readily undergo hydrolysis (*6, 7*). These compounds were not detected in WWTP effluent, surface water, or groundwater samples in Germany, as reported by Hirsch et al. (*8*). Trimethoprim is an antimicrobial compound commonly used to treat both humans and animals. However, we previously reported the distribution of trimethoprim in WWTP effluents and adjacent surface water (*9*). Therefore, penicillins, cephalosporins, and trimethoprim were not included in the present study.

Macrolides are produced by various *Streptomyces* strains and are used for treatment of both humans and animals. Quinolones are used to treat a wide variety of bacterial infections in humans and are also used to treat livestock and fish in the aquaculture industry (*10, 11*). The class of quinoxaline dioxide antimicrobials includes quindoxin, carbadox, cyadox, and olaquindox. Quindoxin has been removed from the market because of its photoallergic properties (*12*). Carbadox has been used in the treatment and prevention of porcine infectious diseases and as a growth promoter for swine (*13*). Aloquindox is used for similar purposes in the swine industry. Sulfonamides have become the most widely used class of antimicrobials in the world since their development in 1968 (*14, 15*). Sulfonamides are widely used for both humans and livestock. Some sulfonamide residues are of concern because of their potential carcinogenicity. For instance, sulfamethazine is a thyroid carcinogen (*15*). Since the first member, chlortetracycline, was developed in 1984, eight tetracyclines have been developed for clinical use (*16*). These compounds are currently used for treatment of livestock and in aquaculture.

In 1980s, Watts et al. (*17*) reported the presence of several antimicrobials (such as erythromycin, sulfamethoxazole, and tetracycline) in river water samples. Since then, a variety of methods have been developed for the analysis of antimicrobials in environmental samples (*18–22*). These methods have been used to investigate the occurrence and distribution of antimicrobials in Europe (*23, 24*). However, except for data on selected antimicrobials as part of a survey of pharmaceuticals and endocrine disruptor substances in surface water in the United States (*25*), there are few data from North America. In particular, there are no data on the discharges of antimicrobials in domestic sewage in North America. The objective of this study was to obtain data on antimicrobial residues in the final effluents from WWTPs in Canada. These data will direct future studies on the fate of antimicrobials in the aquatic environment, including surface water and groundwater. In this study, 31 antimicrobials belonging to the macrolide, quinolone, quinoxaline dioxide, sulfonamide, and tetracycline classes were investigated in

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10.1021/es030653q CCC: $27.50
Published on Web 05/26/2004

TABLE 1. Antimicrobials Investigated in the Effluents of WWTPs in Canada

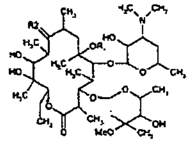
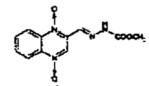
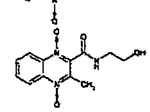
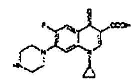
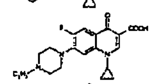
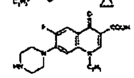
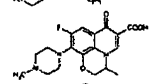
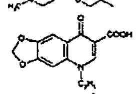
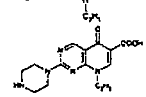
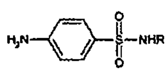
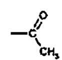
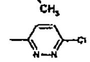
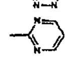
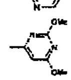
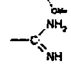
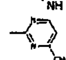
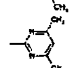
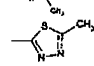
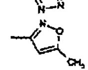
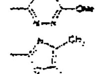
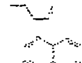
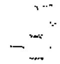
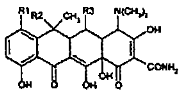
Class	antimicrobial	CASRN[a]	Structure
Macrolides 	Clarithromycin	81103-11-9	R_1=CH_3, R_2=O
	Erythromycin	114-07-8	R_1=H, R_2=O
	Roxithromycin	80214-83-1	R_1=H, R_2=$NOCH_2OCH_2CH_2OCH_3$
Quinoxaline-di-oxides	Carbadox	6804-07-5	
	Olaquindox	23696-28-8	
Quinolones	Ciprofloxacin	85721-33-1	
	Enrofloxacin	93106-60-6	
	Norfloxacin	70458-96-7	
	Ofloxacin	82419-36-1	
	Oxolinic acid	14698-29-4	
	Pipemidic acid	51940-44-4	
Sulfonamides 	Sulfacetamide	144-80-9	
	Sulfachloropyridazine	80-32-0	
	Sulfadiazine	68-35-9	
	Sulfadimethoxine	122-11-2	
	Sulfaguanidine	57-67-0	
	Sulfamerazine	127-79-7	
	Sulfamethazine	57-68-1	
	Sulfamethizole	144-82-1	
	Sulfamethoxazole	723-46-6	
	Sulfamethoxypyridazine	80-35-3	
	Sulfamoxole	729-99-7	
	Sulfapyridine	144-83-2	
	Sulfaquinoxaline	59-99-7	
	Sulfathiazole	72-14-0	
	Sulfisomidin	515-64-0	
	Sulfisoxazole	127-69-5	

TABLE 1 (Continued)

Class	atimicrobial	CASRN[a]	Structure		
Tetracyclines			R1	R2	R3
	Chlortetracycline	57-62-5	Cl	OH	H
	Doxycycline	564-25-0	H	H	OH
	Oxytetracycline	79-57-2	H	OH	OH
	Tetracycline	60-54-8	H	OH	H

[a] Chemical Abstracts Service Registry Number.

TABLE 2. Operational Parameters and Sampling Dates for WWTPs Sampled in Five Canadian Cities in 2002

plant ID	population served	1st treatment	2nd treatment	hydraulic retention (h)	solids retention (d)	design flow (m^3/d)	disinfection method	sampling date (mm/dd/yy)
A	720 000	+	+	23	na[a]	356 000	UV	10/08/2002
B	180 000	+	+	10	na	97 000	UV	10/08/2002
C	850 000	+	trickling filters, solids contact, secondary clarification	7[b]	1.6−2.4	580 000[b]	chlorine, seasonal	10/15/2002
D	575 000	+	none	2[c]		574 000[c]	none, deep sea outfall	10/21/2002
H	120 000	+	activated sludge	12−20	4−8	64 000	chlorine, seasonal	05/06/2002
I	630 000	+	activated sludge	12−18	4−6	55 000	chlorine, seasonal	04/24/2002
J	79 000	+	activated sludge	15−22	6−10	64 000	UV, seasonal	07/16/2002
K	123 000	+	none	8−12	-	164 000	Chlorine, seasonal	07/19/2002

[a] na, data not available. [b] Average annual flow conditions reported. Peak wet weather HRT = 3.7 d and flow = 1 088 640 m^3/d. [c] Average annual flow conditions reported for 2002.

the final effluents of eight WWTPs sampled in 2002 in five Canadian cities. Solid-phase extraction (SPE) methods were developed to extract the antimicrobial compounds from the effluents. Analytical methods based on liquid chromatography−electrospray ionization tandem mass spectrometry (LC−ESI-MS/MS) were either adapted from previously published methods or (in the case of macrolide, quinolone, and quinoxaline dioxide compounds) were developed for this study.

Experimental Section

Reference Standards. Clarithromycin, roxithromycin, carbadox, norfloxacin, oxolinic acid, pipemidic acid, sulfacetamide, sulfachloropyridazine, sulfadiazine, sulfadimethoxine, sulfaguanidine, sulfamerazine, sulfamethazine, sulfamethizole, sulfamethoxazole, sulfamethoxypyridazine, sulfamoxole, sulfapyridine, sulfaquinoxaline, sulfathiazole, sulfisoxazole, chlortetracycline, doxycycline, oxytetracycline, and tetracycline were purchased from Sigma (St. Louis, MO). Erythromycin, olaquindox, ciprofloxacin, enrofloxacin, and ofloxacin were purchased from ICN Biomedicals (Aurora, OH). Sulfisomidin was purchased from Sigma-Aldrich Canada (Oakville, ON, Canada).

Anhydro-erythromycin, a major degradation product of erythromycin (*26*), was not commercially available, so it was generated by acidification transformation from erythromycin using the method described by Sacher et al. (*27*). All standards were dissolved in methanol and diluted to final stock solutions at a concentration of 20 μg/mL and then stored in a freezer. Working standard solutions were diluted from the stock solutions for sample analysis.

Sample Collection. Samples of the final effluents (7 L from each WWTP) were collected in 2002 as "grab" samples from eight WWTPs in five cities in Canada (the term cities is used for convenience as the WWTPs in the Greater Vancouver Regional District are located in two different municipalities and serve more than one city), including the Greater Vancouver Regional District in the province of British Columbia ($n = 2$); Calgary in the province of Alberta ($n = 2$); and Burlington, Peterborough, and Windsor in the province of Ontario ($n = 4$). Five WWTPs were located in major cities with populations >500 000. Detailed information on the WWTPs and the sampling dates are summarized in Table 2. The WWTPs had either primary or secondary treatment processes and used either chlorine or UV disinfection. Note that all WWTPs were given ID codes for the purposes of reporting of the data. All samples were collected in 4-L amber glass bottles that had been prewashed with a sequence of soap and water, distilled water, acetone, and hexane. During collection, the bottles were rinsed with sample three times before a final sample was collected. After collection, samples were either extracted immediately or were shipped to Trent University, where they were stored at 4 °C for a maximum period of 2 d before extraction; that is, 3 d since collection.

Sample Preparation. To remove suspended material, aqueous samples were vacuum filtered through 1.0-μm glass microfiber filters that had been prewashed with hexane/dichloromethane (1:1) in a Soxhlet apparatus for 2 h. After filtration, the aqueous samples were extracted for different classes of antimicrobials with Oasis HLB cartridges (Waters, Oakville, ON, Canada), which are 6-mL/500 mg hydrophilic−lipophilic balance SPE cartridges. Sample volumes of 1 L were chosen based on breakthrough tests using spiked effluent samples. Antimicrobials were extracted using one of the following two SPE methods:

Method 1: Used To Extract Macrolide Antimicrobials. SPE cartridges were preconditioned sequentially with 6 mL of acetone, 6 mL of methanol, and 6 mL of water (pH 6.0). The effluent samples (1 L) were acidified to pH 6.0 with 3.0 M H_2SO_4 and were passed through the cartridges at a rate of approximately 10 mL/min. After passage of the samples, each cartridge was eluted with three 2-mL vol of methanol. The eluates were collected in a 10-mL test tube and were concentrated with a vacuum centrifuge and then reconstituted to 1.0 mL with methanol.

Method 2: Used To Extract quinolone, Quinolone Dioxide, Sulfonamide, and Tetracycline Antimicrobials. The SPE extraction procedure was adapted from a previously described method (*28*) where the chelating agent, disodium ethylenediamine tetraacetate (Na_2EDTA), was added to samples to improve recovery efficiency. Briefly, the SPE cartridges were preconditioned sequentially with 6 mL of acetone, 6 mL of methanol and 6 mL of 50 mM Na_2EDTA (pH 3.0). The effluent samples (1 L) were acidified to pH 3.0 with 3.0 M H_2SO_4, followed by addition of Na_2EDTA (0.5 g). Samples were then passed through the SPE cartridges at a rate of approximately 10 mL/min. After passage of the samples, each cartridge was eluted with three 2-mL volumes of methanol. The eluates were collected in a 10-mL test tube, concentrated with a vacuum centrifuge, and then reconstituted to 1.0 mL with 20% aqueous methanol.

Analytical Methods. Chromatographic separation of analytes was conducted using an Alliance 2690 liquid chromatograph (Waters, Milford, MA). The flow rate was 0.2 mL/min at room temperature, and the injection volume was 20 μL. Mass spectrometry was performed using a Quattro LC tandem quadrupole mass spectrometer (Micromass, Manchester, U.K.) equipped with a Z-Spray electrospray ionization (ESI) source and operated in positive-ion mode. Nitrogen was used as the drying and nebulizing gas at flow rates of 500 and 70 L/h, respectively. The collision-induced dissociation was carried out using 1.0×10^{-3} mbar argon in a hexapole collision cell. MassLynx v 3.5 software was applied for data acquisition and processing. The mass spectrometer was operated in selected reaction monitoring (SRM) mode with unit resolution on both of the first and second analyzers. A dwell time of 200 ms per ion pair was used, and the inter-channel delay was 10 ms. Table 3 summarizes the optimized ESI-MS/MS conditions for analysis of antimicrobials.

Method 1 for Macrolide Antimicrobials. The three macrolides were separated with a Genesis C_{18} column (2.1 × 50 mm, 3 μm) (Jones Chromatography Lt., Hengoed, Mid Glamorgan, U.K.). Acetonitrile (A) and 20 mM aqueous ammonium acetate (0.05% formic acid, pH 5) (B) were used as mobile-phase solvents. The gradient was increased from 35 to 75% A in 5 min, then ramped to 100% in 2 min, and hold at 100% A for 2 min. The source and desolvation temperatures were 90 and 350 °C, respectively.

Method 2 for Quinolone and Quinoxaline Dioxide Antimicrobials. The eight analytes were separated with a Genesis C_{18} column (2.1 × 150 mm, 3 μm) (Jones Chromatography Lt., Hengoed, Mid Glamorgan, U,K.). Acetonitrile (A) and 20 mM aqueous ammonium acetate (0.1% formic acid, pH 4.0) (B) were used as mobile-phase solvents. The same mobile-phase solvents as in method 1 were used in this method. The gradient was increased from 12−55% A in 8 min to 100% in 2 min, and then held for 2 min at 100% A. The source and desolvation temperatures were 90 and 350 °C, respectively.

Method 3 for Sulfonamide Antimicrobials. The 16 sulfonamide compounds were separated with the same column and mobile-phase solvents as in method 2. The gradient was increased from 18 to 32% A in 14 min, then ramped to 100% in 1 min, and held at 100% A for 2 min. The source and desolvation temperatures were 90 and 380 °C, respectively.

Method 4 for Tetracycline Antimicrobials. The chromatographic separation of the four tetracycline analytes was conducted on the same column as used in method 1. Acetonitrile (A) and 20 mM aqueous ammonium acetate (0.1% formic acid and 4 mM oxalic acid) (B) were used as mobile-phase solvents. The gradient was increased from 25 to 35% A in 6 min, then ramped to 100% in 2 min, and held at 100% for 2 min. The source and desolvation temperatures were optimized at 90 and 380 °C, respectively.

TABLE 3. Optimal ESI-MS/MS Conditions for Analysis of Antimicrobials in WWTP Effluents

analyte	precursor ion, $[M + H]^+$ (m/z)	product ion (m/z)	capillary voltage (kV)	cone voltage (kV)	collision energy (eV)
clarithromycin	748	158	4.0	30	28
erythromycin-H_2O	716	158	4.0	30	31
roxithromycin	837	158	4.0	30	35
carbadox	263	231	3.0	40	12
olaquindox	264	143	3.0	25	30
ciprofloxacin	332	314	3.0	30	20
enrofloxacin	360	342	3.0	38	21
norfloxacin	320	302	3.0	40	21
ofloxacin	362	344	3.0	42	20
oxolinic acid	262	244	3.0	35	18
pipemidic acid	304	217	3.0	40	22
sulfacetamide	215	156	4.0	25	11
sulfachloro-pyridazine	285	156	4.0	30	16
sulfadiazine	251	156	4.0	25	18
sulfadimethoxine	311	156	4.0	35	22
sulfaguanidine	215	156	4.0	25	11
sulfamerazine	265	156	4.0	30	20
sulfamethazine	279	186	4.0	30	21
sulfamethizole	271	156	4.0	35	17
sulfamethoxazole	254	156	4.0	30	17
sulfamethoxy-pyridazine	281	156	4.0	35	20
sulfamoxole	268	156	4.0	25	16
sulfapyridine	250	156	4.0	30	20
sulfaquinoxaline	301	156	4.0	25	18
sulfathiazole	256	156	4.0	30	17
sulfisomidin	279	124	4.0	38	24
sulfisoxazole	268	156	4.0	25	16
chlortetracycline	479	444	3.5	30	26
doxycycline	445	428	3.5	30	20
oxytetracycline	461	426	3.5	25	19
tetracycline	445	410	3.5	32	19

Quantification. Quantitative analysis of the antimicrobials was performed using LC−ESI-MS/MS with selected reaction monitoring (SRM). The optimal conditions for MS/MS analysis of the compounds and the precursor, $[M + H]^+$, and product ions monitored in SRM mode are summarized in Table 3. Electrospray ionization tandem mass spectrometry is susceptible to suppression or enhancement of ion signals as a result of matrix effects induced by sample co-extractives. In the absence of stable isotope-labeled surrogate standards for quantitation, we prepared a series of standard solutions ($n = 5$) by spiking the analytes into each of the filtered effluent samples under investigation and these samples were extracted by SPE and analyzed by LC−ESI-MS/MS. Analytical data from the spiked samples were used to construct standard calibration curves for quantifying the analytes in unspiked samples. Unspiked samples of each final effluent were analyzed in triplicate. These calibration curves compensated for both variations in the SPE recoveries and matrix effects that can either suppress or enhance signals with LC−ESI-MS/MS analytical instrumentation (*29*).

Recovery experiments with spiked samples of effluent collected from plant J on April 21, 2002, were performed to determine the precision and accuracy of the method. The method detection limit was defined as the lowest concentration of an analyte that yielded an ion signal with a signal-to-noise ratio of 3:1 in the sample matrix. Table 4 lists recoveries and their relative standard deviations (RSDs) as well as method detection limits (MDLs) of the antimicrobials in STP effluent. Note that limits of detection (LOD) and limits of quantitation (LOQ) for the analytes will vary from sample to sample of sewage because of the complexity of the sample

TABLE 4. Percent Recoveries (± RSD) and Method Detection Limits (MDL) for Antimicrobials Spiked into WWTP Effluent[a]

antimicrobial	% recovery (± RSD)	MDL (μg/L)	antimicrobial	% recovery (± RSD)	MDL (μg/L)
sulfacetamide	82 (8)	0.004	clarithromycin	73 (9)	0.001
sulfachloropyridazine	77 (7)	0.001	Erythromycin-H_2O	78 (8)	0.001
sulfadiazine	76 (8)	0.003	roxithromycin	87 (6)	0.001
sulfadimethoxine	78 (7)	0.001	carbadox	83 (8)	0.005
sulfaguanidine	72 (6)	0.005	olaquindox	78 (7)	0.006
sulfamerazine	79 (8)	0.003	ciprofloxacin	92 (5)	0.001
sulfamethazine	81 (7)	0.001	enrofloxacin	88 (6)	0.008
sulfamethizole	78 (10)	0.002	norfloxacin	96 (9)	0.005
sulfamethoxazole	89 (8)	0.001	ofloxacin	95 (9)	0.002
sulfamethoxypyridazine	75 (10)	0.001	oxolinic acid	86 (5)	0.005
sulfamoxole	80 (6)	0.001	pipemidic acid	85 (7)	0.007
sulfapyridine	90 (8)	0.001	chlortetracycline	85 (10)	0.004
sulfaquinoxaline	80 (5)	0.001	doxycycline	99 (7)	0.002
sulfathiazole	74 (6)	0.004	oxytetracycline	81 (6)	0.006
sulfisomidin	83 (9)	0.003	tetracycline	79 (8)	0.002
sulfisoxazole	80 (7)	0.001			

[a] Final effluent collected from Plant J in April, 2002. Recoveries are the average of triplicate analyses of fortified concentrations of 0.2 and 1.0 μg/L

matrix. The method of calibration described above compensates for these variations in detection limits.

Results and Discussion

Extraction. Tetracyclines tend to form strong complexes with multivalent cations and bind to protein and silanol groups (*30*). Chelating agents such as EDTA, oxalic acid, and citric acid are usually applied to decrease the tendency for tetracyclines to bind to cations in the matrix (*31*). In our study, Na_2EDTA was used as a chelating agent to extract tetracyclines together with quinolone, quinoxaline dioxide, and sulfonamide antimicrobials in one SPE process. The recoveries of quinolone antimicrobials were also improved with the addition of Na_2EDTA (*28*).

Analytical Methods. Time-scheduled chromatograms of standards (left panel) and examples of WWTP effluent samples (right panel) of antimicrobials are illustrated in Figures 1 and 2. The majority of the macrolide, quinolone, and tetracycline analytes were detected in sewage effluents (Figure 1), and a few of the 16 sulfonamide analytes were detected (Figure 2).

When tetracyclines are separated by liquid chromatography, oxalic acid is usually added to the mobile phase to improve resolution and peak shape (*32, 33*). Unfortunately, nonvolatile oxalic acid may accumulate in the ESI source when LC–ESI-MS/MS techniques are used. In LC–MS applications with an atmospheric pressure chemical ionization (APCI) source, an elevated probe temperature has been used to reduce this accumulation (*33, 34*) since oxalic acid decomposes to carbon dioxide and water above 200 °C. However, this technique can be applied to an electrospray ionization source with off-axis or orthogonal spray sampling configuration to reduce the buildup of residues from nonvolatile mobile-phase buffers (*20*). Therefore, electrospray ionization was applied in this study, and the ESI was operated at a relatively high temperature (380 °C) when tetracyclines were analyzed.

Occurrence of Antimicrobials. (I) Macrolides. Next to the penicillins, macrolides are the second most frequently prescribed class of antimicrobials in Canada, particularly clarithromycin, followed by azithromycin and erythromycin (*35*). In this study, erythromycin was detected in all of the WWTP final effluents examined (Table 5), while clarithromycin and roxithromycin were detected in six of the eight WWTPs. Erythromycin is readily dehydrated by loss of one water molecule and its dehydration product has been detected predominantly in the environment (*8*). Therefore, the concentrations of erythromycin were reported in this study as its dehydration product, erythromycin-H_2O.

In Germany, macrolides have been detected in all WWTP effluents investigated, and erythromycin-H_2O and roxithromycin were detected at higher concentrations than reported here. However, clarithromycin was reported at similar concentrations to those measured in this study, with a median concentration of 0.14 μg/L and a maximum concentration of 0.26 μg/L in the German study (*8*). Roxithromycin and erythromycin-H_2O were detected in WWTP effluents in Germany at median concentrations of 0.68 and 2.5 μg/L and maximum concentrations of 1.00 and 6.0 μg/L, respectively (*8*). The lower median concentrations detected in WWTPs effluents in Canada as compared with those in Germany probably reflect differences in prescription patterns for macrolide antimicrobials in the two countries. Unfortunately, only the relative prescription rates of antimicrobials are available in Canada, so it is not possible to confirm this hypothesis.

A survey of streams in the United States conducted in 1999–2000 showed that the frequencies of detection of erythromycin-H_2O and roxithromycin were 21.5% and 4.8%, but clarithromycin was not included in the study (*25*). Erythromycin-H_2O was detected at a concentration of 0.049 μg/L in a groundwater sample in Germany (*27*).

(II) Quinolones. Although quinolones are prescribed less often than macrolides, these compounds are still the fourth most prescribed class of antimicrobials in Canada (*35*). In particular, ciprofloxacin has dominated the Canadian and global quinolone markets since its entry in the late 1980s. Ciprofloxacin, listed as number 32 among the top prescribed medications in 2001, represented about 50% of the prescriptions of quinolines in Canada in 2000 and 2001 (*35*). Levofloxacin, norfloxacin, and ofloxacin are also frequently prescribed in Canada.

Reflecting the relative rates of prescription of quinolone antimicrobials in Canada, ciprofloxacin, norflaxacin, and ofloxacin were detected in WWTP effluents, with ciprofloxacin and ofloxacin most frequently detected (Table 5). Ciprofloxacin was detected even though it has been shown to be readily biodegradable in activated sludge (*36*). Ciprofloxacin is also a biologically active metabolite derived by de-ethylation from enrofloxacin (*37, 38*). However, the ciprofloxacin detected in the effluents is most probably from its direct therapeutic usage rather than from the degradation of enrofloxacin, because enrofloxacin was not detected in any of the effluents and is not a major quinolone antimicrobial

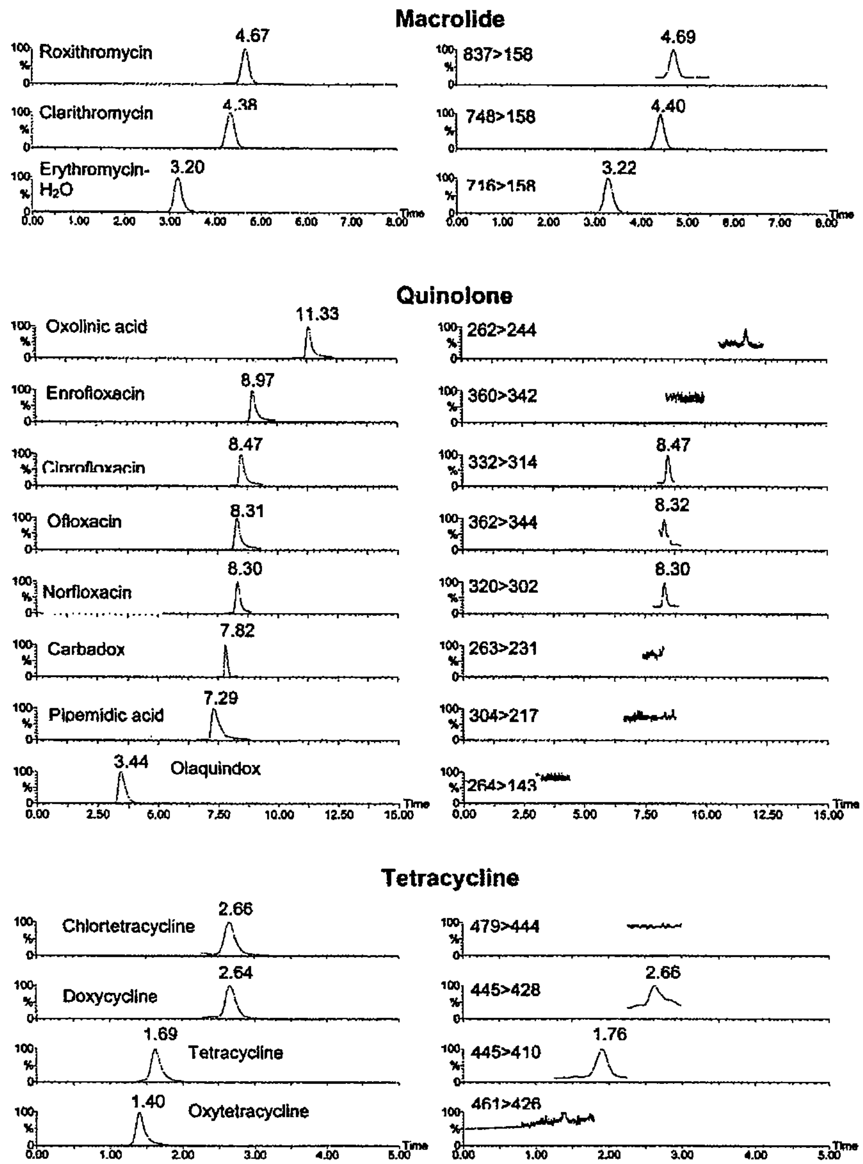


FIGURE 1. Time-scheduled SRM chromatograms of standards (left panels) and samples (right panels) of macrolides, quinolones, and tetracyclines.

prescribed in Canada (*35*). Oxolinic acid and pipemidic acid were not detected in any of the effluents either (Table 5), probably due to their low therapeutic usage.

Ciprofloxacin and norfloxacin were detected at concentrations of 0.045–0.108 and 0.048–0.120 μg/L, respectively, in sewage effluents in Switzerland (*21*). Norfloxacin was detected at similar concentrations in the present study from Canada, but ciprofloxacin was detected at higher concentrations. This may be due to different prescription rates for quinolones in Canada and Switzerland. For example, each of ciprofloxacin and norfloxacin contributes to 42–48% of the total domestic consumption of quinolones in Switzerland. However, in Canada, ciprofloxacin is much more highly prescribed than norfloxacin (*35*).

Campagnolo et al. (*39*) investigated antimicrobial residues in animal waste and water resources proximal to large-scale swine and poultry-feeding operations. They did not detect ciprofloxacin or norfloxacin. An investigation of pharmaceuticals, including some quinolones in rivers and streams in the United States, showed that ciprofloxacin and norfloxacin were detected at very low frequencies (2.6 and 0.9%, respectively) and that enrofloxacin and sarafloxacin were not detected (*25*).

(III) Quinoxaline Dioxides. Carbadox and olaquindox are mainly used as growth promoters for animals rather than as human medicines. Carbadox was approved in the 1970s for use in Canada and the United States to promote growth in swine as well as to prevent and treat dysentery and other conditions. However, Health Canada announced the cease sale order in August of 2001 after receiving reports of misuse and accidental contamination. Along with carbadox and olaquindox, several other antimicrobials (e.g., chlortetracycline, penicillin, sulfamethazine, salinomycin, and tylosin) are commonly used for growth promotion of animals in Canada. Carbadox and olaquindox were not detected in any of the effluents in this study, although they are heavily used as growth promoters for animals. Carbadox was not detected in streams in the United States (*25*), possibly because this compound is rapidly degraded (*40*).

(IV) Sulfonamides. Sulfonamides are the most frequently prescribed antimicrobials for use in humans. This class is also used in animals (primarily as sulfanitran, sulfamethazine

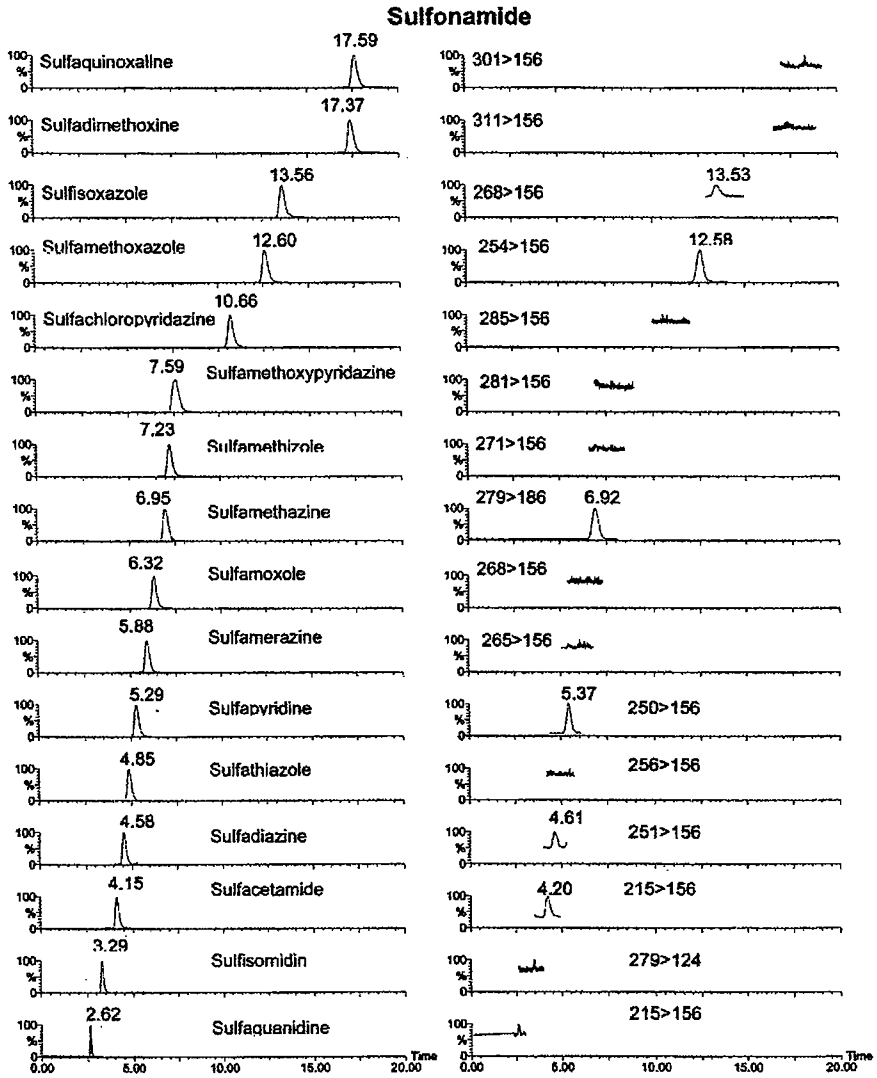


FIGURE 2. Time-scheduled SRM chromatograms of standards (left panels) and a sample (right panels) of sulfonamides.

and sulfaquinoxaline, which are licensed for use as medicating feed ingredients in Canada). Sulfonamides have a high potential to resist degradation and are hydrophilic enough to be transferred into the aquatic environment (*41*). Holm et al. (*42*) reported detecting sulfanilamide, sulfaguanidine, sulfadiazine, sulfadimidine, and sulfamethizol in groundwater downgradient of a landfill in Denmark.

In this study, sulfacetamide, sulfadiazine, sulfamethazine, sulfamethoxazole, sulfapyridine, and sulfisoxazole were detected in at least one of the WWTP effluents examined (Table 5). In particular, sulfamethoxazole and sulfapyridine were detected in all effluents. Sulfamethoxazole has been detected frequently in sewage effluents in Germany, at a median concentration of 0.4 μg/L and a maximum concentration of 2.0 μg/L (*8*), which are generally higher than the concentrations detected in this study in Canada. In the same study in Germany, sulfamethazine was not detected in any effluents, compared with detection in only one effluent of eight reported in this study. Thirteen sulfonamides were investigated in municipal wastewater in Germany in another study by Hartig et al. (*43*). Sulfamethizole, sulfadiazine, and sulfamethoxazole were detected at concentrations of 0.006, 0.081, and 1.500 μg/L, respectively, in the secondary effluent of a WWTP in Berlin, which are all higher than concentrations measured in the present study on Canadian WWTP effluents.

Sulfadimethoxine, sulfamethazine, sulfamethizole, and sulfamethoxazole were detected in streams in the United States, and the frequency of detection for sulfamethoxazole was as high as 19% (*25*). Sulfamethoxazole was detected at concentrations of 0.030–0.085 μg/L in surface water in Germany (*43*). Sulfamethoxazole is also the most frequently detected sulfonamide in groundwater and has been detected at concentrations up to 0.22 and 0.41 μg/L in the United States (*22*) and in Germany (*27*), respectively. The high usage of the combination of sulfamethoxazole and trimethoprim contributes to the frequent detection of sulfamethoxazole. Trimethoprim is also one the most frequently detected neutral drugs in the environment (*9*).

Next to sulfamethoxazole, sulfapyridine was the other most frequently detected sulfonamide in this study, but it has not been investigated previously in environmental samples, including WWTP final effluents. Sulfapyridine is used to control dermatitis herpetiformis (Duhring's disease), but it is relatively ineffective for other kinds of bacterial infections (*14*). In addition, sulfapyridine is a major metabolite of sulfasalazine, which is commonly used in the treatment of rheumatoid arthritis and inflammatory bowel disease (*44*). Sulfasalazine is a conjugate of 5-aminosalicylic acid and sulfapyridine linked by an azo bond; and sulfasalazine is metabolized by the bacterial azoreductases enzymes in the colon, reducing the azo bond and releasing these two

TABLE 5. Summary of Analytical Results for Antimicrobials in the Final (Treated) Effluents from Eight WWTPs in Five Canadian Cities

antimicrobial	no. >MDL[a,b]	median (μg/L)	maximum (μg/L)
	Macrolides		
clarithromycin	6	0.087	0.536
Erythromycin-H_2O	8	0.080	0.838
roxithromycin	6	0.008	0.018
	Quinolones		
ciprofloxacin	7	0.118	0.400
norfloxacin	4	0.050	0.112
ofloxacin	8	0.094	0.506
	Sulfonamides		
sulfacetamide	3	0.064	0.151
sulfadiazine	1	0.019	0.019
sulfamethazine	1	0.363	0.363
sulfamethoxazole	8	0.243	0.871
sulfapyridine	8	0.081	0.228
sulfisoxazole	5	0.019	0.034
	Tetracyclines		
doxycycline	2	0.038	0.046
tetracycline	7	0.151	0.977

[a] Method detection limit. [b] The following antimicrobials were not detected: enrofloxacin, oxolinic acid, pipemidic acid, carbadox, olaquindox, sulfachloropyridazine, sulfadimethoxine, sulfaguanidine, sulfamerazine, sulfamethizole, sulfamethoxypyridazine, sulfamoxole, sulfaquinoxaline, sulfathiazole, sulfisomidine, chlorotetracycline, oxytetracycline.

components (*45*). Further studies should focus on tracing the sources and environmental fate of this compound.

Sulfadiazine, sulfamerazine, and sulfamethoxazole have been detected in wastewater from swine operations at concentrations of 76, 77, and 69 μg/L (*46*). However, these sulfonamides, except for sulfamethoxazole, were not frequently detected in the WWTP effluents from this study.

(V) Tetracyclines. Tetracyclines are rapidly metabolized and moreover form relatively stable complexes with metal cations (*47*). However, in this study, doxycycline and tetracycline were detected in the WWTP effluents, with tetracycline having the highest frequency of detection (Table 5). Chlortetracycline and oxytetracycline were not detected (Table 5). Surprisingly, none of the four tetracyclines investigated here were detected in WWTP effluents in Germany (*8*).

Chlortetracycline and oxytetracycline are mainly used as growth promoters for livestock. They are two of the 10 antimicrobials licensed as growth promoters for livestock in the United States (*48*), explaining their detection at high concentrations in wastewater lagoons on swine farms (*39*). Chlortetracycline, oxytetracycline, and tetracycline were detected at very low frequencies (1.2–2.4%) in streams in the United States using one analytical method and were not detected with another analytical method (*25*).

This study revealed the presence of several classes of antimicrobials in treated effluent discharged from the eight Canadian WWTPs studied. The proportions of different classes of antimicrobials prescribed for humans in Canada are in the following order: broad spectrum penicillins (32%), macrolides (24%), cephalosporins (16%), quinolones (11%), trimethoprim combinations (9%), and tetracyclines (8%) (*35*). Sulfonamides were not included in the above statistical information although they are an important class of antimicrobials. Penicillins and cephalosporins were not included in the present study because it was presumed that they degrade rapidly in WWTPs (*8*). Our previous studies have shown that trimethoprim is commonly detected in WWTP effluents and adjacent receiving waters in Canada (*9*

Compounds from the macrolide, quinolone, and tetracycline classes were detected in all of the WWTPs sampled, reflecting their importance as antimicrobials prescribed for humans. These WWTPs were sampled in different months, from April to November 2002. Seasonal variations occur in the prescription of antimicrobials, with more prescriptions in the winter and fewer in the summer (*35*). Therefore, seasonal changes in consumption may have affected the occurrence of antimicrobials in this survey of Canadian WWTPs. However, WWTP effluents are constantly changing in composition in response to temporal changes in loading rates. Since no untreated (raw) effluents were sampled from the WWTPs, it was not possible to estimate the extent of removal of the antimicrobials by sewage treatment. Our previous studies have shown that pharmaceuticals are poorly removed in Canadian WWTPs with hydraulic retention times <12 h (*49*).

The antimicrobials detected in this study reflected human usage rather than the treatment of animals. For example, antimicrobials heavily used for veterinary applications (such as carbadox, olaquindox, chlortetracycline, etc.) were not detected in the effluents. However, when monitoring surface waters and groundwater, it will be necessary to include antimicrobials used in livestock and veterinary applications since agricultural runoff may be a significant source.

Potential Impacts of Antimicrobials. The most frequently detected antimicrobials in WWTP effluents sampled in Canada included ciprofloxacin, clarithromycin, erythromycin-H_2O, ofloxacin, sulfamethoxazole, sulfapyridine, and tetracycline. The concentrations of these compounds in WWTP final effluents did not exceed 0.9 μ/L. Using a dilution factor of 1:10 recommended by the U.S. Federal Drug Administration for estimating the maximum expected concentrations in surface water from effluent data (*50*), the maximum concentrations of antimicrobials expected in surface water near Canadian WWTPs would be <0.09 μg/L. These estimates are consistent with our preliminary data on the concentrations of antimicrobials in samples of surface water collected near WWTPs in the lower Great Lakes region, where the highest concentration detected was 0.099 μg/L of sulfamethoxazole (*51*).

The lethal concentrations (i.e., LC_{50} values) of antimicrobials to fish and aquatic invertebrates are usually in the high milligrams per liter range (*52, 53*), and sublethal effects (i.e., reduced reproduction) occur in aquatic invertebrates exposed to low milligrams per liter concentrations of antimicrobials (*54*). Therefore, antimicrobial compounds are unlikely to induce acute toxicity in aquatic animals near sewage discharges. However, antimicrobials induce toxic effects in aquatic plants and microorganisms at micrograms per liter concentrations (*5, 55, 56*). For instance, the EC_{10} values for reductions in wet weight, frond number, and chlorophyll *a* in duckweed, *Lemna gibba* exposed to sulfamethoxazole were reported as 17, 11, and 36 μg/L, respectively (*55*). Kümmerer et al. (*56*) showed that ciprofloxacin and ofloxacin induced 50% growth inhibition of the Gram-negative bacterium, *Pseudomonas putida*, at concentrations of 80 and 10 μg/L, respectively. The data presented in this study indicate that the concentrations of antimicrobials that occur in the final effluents of WWTPs and adjacent surface waters in Canada are unlikely to be high enough to impact the growth and survival of plants or bacteria. However, it cannot be ruled out that chronic exposure of bacteria and other microorganisms to antimicrobials will contribute to the development of antibiotic resistance in the environment (*3*

Acknowledgments

This project was supported by the Natural Sciences and Engineering Research Council of Canada through its Strategic

Grants Program. The authors acknowledge the scientists and staff in Environment Canada; Alberta Environment; the Greater Vancouver Regional District; and the Cities of Calgary, Peterborough, and Windsor for their assistance in collecting the samples. We especially thank John Kennedy of the Environmental Protection Division, Peterborough, ON. We also thank Robert Letcher of the Great Lakes Institute for Environmental Research and John Struger in Environment Canada for providing laboratory facilities for on-site sample preparation. We thank Shaun O'Toole for his assistance in sample collection and preparation.

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Received for review October 9, 2003. Revised manuscript received April 21, 2004. Accepted April 27, 2004.

ES030653Q

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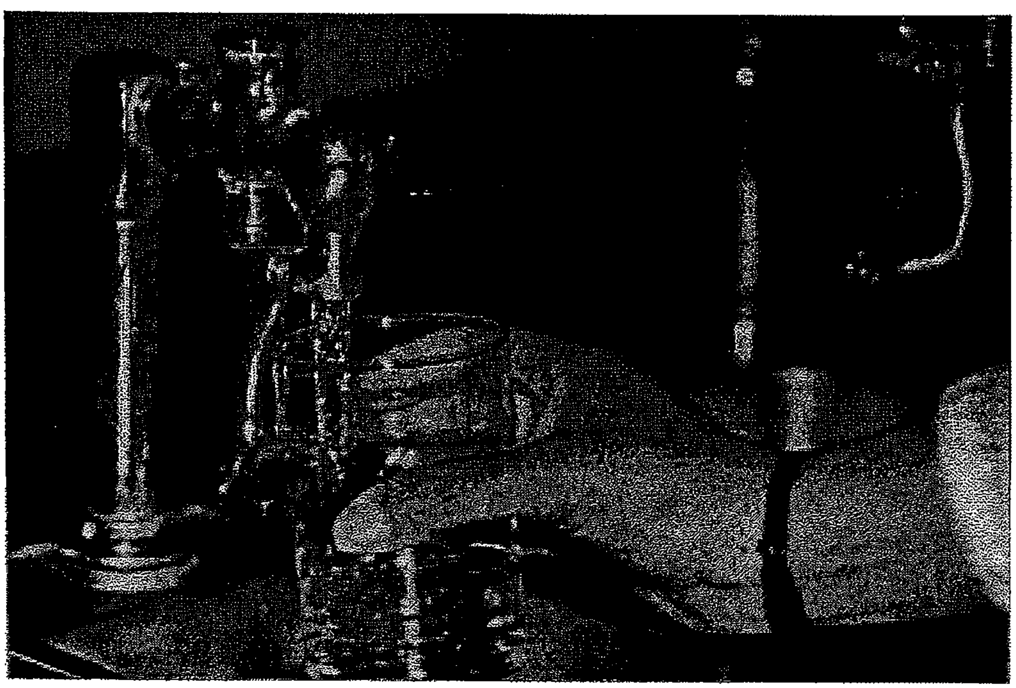
Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes



Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes

I. Introduction

The purpose of this document is to provide a description of methods for the removal of endocrine disruptor chemicals (EDCs) from drinking water. Many of the potential EDCs may be present in surface waters or groundwaters. A number of drinking water treatment processes are available and may be used to remove many of the potential EDCs. This document presents treatment processes for large municipalities as well as small communities to remove specific EDCs from drinking water. References are provided with links to retrieve documents via the Internet, where available.

II. Background

A growing body of scientific research indicates that man-made industrial chemicals and pesticides may interfere with the normal functioning of human and wildlife endocrine systems. A hormone is defined as any substance in the body that is produced by one organ then carried by the bloodstream to have an effect in another organ. The primary function of hormones, or the endocrine system, is to maintain a stable environment within the body; this is often referred to as homeostasis. The endocrine system also controls reproduction and growth. Recently, public concern has focused on the possible hormonal effects of some environmental pollutants on wildlife and humans. These chemicals, referred to collectively as endocrine disruptors, comprise a wide range of substances including pesticides (methoxychlor), surfactants (nonylphenol), plasticizers (diethylphthalate), and organohalogens (PCBs and dioxin). Many industrial chemicals and pesticides have undergone extensive toxicological testing; however, since the purpose of this testing was not to find some subtle endocrine effects these potential effects may not have been revealed. The persistence of some pesticides in the aquatic environment may pose a threat to the human population, especially if such substances occur in the nation's drinking water sources. As a result of this growing concern, the 1996 Safe Drinking Water Act (SDWA) Amendments and the Food Quality Protection Act require EPA to develop a screening and testing program to determine which chemical substances have possible endocrine disrupting effects in humans.

A. *Endocrine Disruptor Chemicals*

The term "endocrine disruptors" is used to describe substances that are not produced in the body but act by mimicking or antagonizing natural hormones. It is thought that EDCs may be responsible for some reproductive problems in both women and men as well as for the increases in the frequency of certain types of cancer. EDCs have also been linked to developmental deficiencies and learning disabilities in children. Because hormone receptor systems are similar in humans and animals, effects observed in wildlife species raise concerns of potential human health effects. During fetal development and early childhood, low-dose exposure to EDCs may have profound effects not observed in adults such as reduced mental capacity and genital malformations. Evaluating potential low-dose effects of environmental estrogenic compounds has been identified as a major research priority.

III. Descriptions of Specific EDCs

In this section, the potential EDCs are grouped by chemical class. Descriptions of the EDCs provide the Chemical Abstract Registry Number, a brief description of the chemical, its major uses, the major human exposure routes, health effects, water solubility, environmental persistence, occurrence/detection in water sources, drinking water standards, and statutes that regulate the substance in water. The best available technology (BAT) as determined by laboratory testing for removal of specific EDCs from water is indicated when this has been determined. In this document the term "BAT" is NOT used in a regulatory context. That is to say, we do not intend to suggest that the reader is obligated to use a particular technology as a regulatory requirement.

A. *Pesticide Residues*

A number of pesticides have been implicated as endocrine disruptors, primarily in aquatic and wildlife species. Agricultural runoff is responsible for the presence of most pesticides found in surface waters. The pesticide concentrations in surface waters tend to be highest after the first storm following application. Pesticides may also enter source water from accidental spills, in wastewater discharges, or as runoff from urban and suburban areas. Because pesticides are known to be potentially highly toxic compounds, the maximum contaminant level (MCL) has been established for each of these substances. These limits were originally established on the basis of known toxicologic effects; however, in the future the MCLs may be set at even lower concentrations if adverse endocrine effects are detected due to their presence. Again, this document does not infer that the reader is obligated to attain an MCL, rather this information is presented to demonstrate how future research on EDCs may eventually impact some MCLs.

DDT

DDT [CASRN - 50-29-3] is an organochlorine insecticide used mainly to control mosquito-borne malaria. It is the common name of the technical product that is a mixture of three isomers of DDT and contains 65 to 80% p,p'-DDT. It is very soluble in fats and most organic solvents and practically insoluble in water. In the U.S., DDT is currently used only for public health emergencies as an insecticide under Public Health Service supervision and by the USDA or military for health quarantine. EPA banned use of DDT in food in 1972 and use in nonfoods in 1988. At present no U.S. companies are producing DDT. The primary supporting evidence for adverse health effects in humans comes from an epidemiological study performed by Rogan in North Carolina in which blood levels of DDE (a metabolite of DDT) were determined in pregnant women. Once the blood levels were determined for each woman, neurologic testing was then performed on the infants that were born from these pregnancies. A very strong correlation was found linking increased blood levels of DDE with poor performance of the neurologic tests by these infants (Rogan, 1986). Strong correlation of maternal serum levels of DDE, a metabolite of DDT, with defects in muscular tone and hyporeflexia was observed in their children. More convincing evidence of endocrine effects has been observed in an ecological setting. The initial reports were of egg shell thinning in bald eagles as well as vitellogenin (a protein that is normally only produced in the livers of female amphibians and fish) production in male African clawed frogs (Palmer and Palmer, 1995). Primary exposure routes for humans are inhalation, ingestion, and dermal contact.

In spite of the 1972 ban of DDT in the U.S., human exposure to DDT is potentially high due to its prior extensive use and the persistence of DDT and its metabolites in the environment. DDT has been detected in air, rain, soil, water, animal and plant tissues, food, and the work environment. Breakdown products in the soil environment are DDE and DDD, which are also highly persistent. Due to its extremely low solubility in water, DDT is mainly retained by soils and soil fractions with higher proportions of soil organic matter. While it is generally immobile or only very slightly mobile, DDT may leach into groundwater over long periods of time. DDT may reach surface waters primarily by runoff, atmospheric transport, drift, or by direct application. DDT has been widely detected in ambient surface water sampling in the U.S. at a median level of one nanogram/L (part per trillion). DDT is regulated by EPA under the Clean Water Act (CWA). Effluent discharge guidelines and water quality criteria have been set under the CWA.

Endosulfan

Endosulfan [CASRN - 115-29-7] is a chlorinated hydrocarbon insecticide which acts as a poison for a wide variety of insects and mites on contact. Although it may be used as a wood preservative, it is used primarily on a wide variety of food crops, including tea, coffee, fruits, and vegetables, as well as on rice, cereals, maize, sorghum, or other grains. Human exposure to endosulfan is primarily through breathing air, drinking water, eating food, or working where endosulfan is used. Exposure to endosulfan mainly affects the central nervous system. The effects of long-term/low-dose exposure are unknown. The most convincing evidence of endocrine effects in mammals is taken from laboratory animal studies in which doses of 5 mg/kg/day resulted in reduced sperm counts and altered testicular enzyme levels in male rats (Sinha, 1995).

Endosulfan has been found in at least 143 of the 1,416 National Priorities List sites identified by the EPA. Although not easily dissolved in water, when released to water, endosulfan isomers hydrolyze readily in alkaline conditions and more slowly in acidic conditions. Endosulfan has been detected at levels of 0.2 to 0.8 µg/L in groundwater, surface water, rain, snow, and sediment samples. Large amounts of endosulfan can be found in surface water near areas of application. The EPA recommends that the amount of endosulfan in lakes, rivers, and streams should not be more than 74 ppb. Humans can become exposed to endosulfan by drinking water contaminated with it.

Methoxychlor

Methoxychlor [CASRN - 72-43-5] is an organochlorine insecticide that is effective against a wide range of pests encountered in agriculture, households, and ornamental plants. It is registered for use on fruits, vegetables, and forage crops. The use of methoxychlor has increased significantly since DDT was banned in 1972. It is similar in structure to DDT, but it has a relatively low toxicity and relatively low persistence in biological systems. Methoxychlor is not highly soluble in water. Methoxychlor is highly toxic to fish and aquatic invertebrates. Levels of methoxychlor can accumulate in algae, bacteria, snails, clams, and some fish, but it is usually transformed into other substances and rapidly released from their bodies. The most probable routes of exposure for humans are inhalation or dermal contact during home use, and ingestion of food or drinking water contaminated with methoxychlor. Short-term exposure above the MCL causes central nervous system depression, diarrhea, and damage to liver, kidney, and heart tissue. Evidence suggests that high doses of technical methoxychlor or its metabolites may have estrogenic effects.

The risk of human exposure via groundwater should be slight, but it may be greater if application rates are very high, or if the water table is very shallow. At present the strongest evidence of endocrine effects due to methoxychlor is taken from laboratory studies in which the relatively low dose of 0.5 μg/kg/day caused reduced fertility in mice (Welch, 1969).

In an EPA pilot groundwater survey, methoxychlor was found in a number of wells in New Jersey and at extremely low concentrations in water from the Niagara River, the James River, and an unnamed Lake Michigan tributary. Methoxychlor will most likely reach surface waters via runoff. Methoxychlor was detected in drinking water supplies in rural South Carolina. EPA set a limit of methoxychlor in drinking water at 0.04 ppm. EPA advises that children should not drink water containing more than 0.05 ppm for more than one day and that adults should not drink water containing more than 0.2 ppm for longer periods of time.

B. Highly Chlorinated Compounds

Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls [CASRN - 1336-36-3] are a group of manufactured organic compounds that include 209 different chemical forms known as congeners. This high number of many different chemical forms is possible because from one to ten chlorine atoms can attach to the carbon atoms that make up the basic chemical structure of this family of compounds. PCBs are thermally stable, resistant to oxidation, acids, bases, and other chemical agents. PCBs tend to be more soluble in lipid-based solvents than in water; however, among the 209 congeners there is a wide range of water solubility and lipid solubility with the lesser chlorinated congeners being more water soluble. In the environment, PCBs can be contaminated with dibenzofurans, dioxins, and polychlorinated naphthalenes. Since 1974, all PCB manufacturing has been banned and previous use in electrical capacitors and transformers has been greatly reduced. Because of their chemical-resistant properties, PCBs have persisted in the environment in large quantities despite the manufacturing ban. The primary routes of potential human exposure to PCBs are ingestion of food and water as well as through dermal contact. There is extensive human data which show a strong association of low birth weights and shortened gestation with PCB exposure in humans (Taylor, 1987 and Patandin, 1998). In addition, extensive neurologic testing of children who experienced exposure to PCBs prior to birth revealed impaired motor function and learning disorders (Jacobsen, 1996). Studies have indicated that PCBs concentrate in human breast milk.

PCB releases from prior industrial uses and the persistence of the compounds in the environment have resulted in widespread water and soil contamination. They have been found in at least 383 of the 1,430 National Priorities List sites identified by the EPA. The PCBs with a high degree of chlorination are resistant to biodegradation and appear to be degraded very slowly in the environment. PCB concentrations in water are higher for the lower chlorinated PCBs because of their greater water solubility. PCBs have been found in runoff, sediments, soil, creek water, leachate, in an underground oil-water layer, and in pond effluents. Concentrations in these locations have ranged from 4 to 440,000 μg/L. In water, small amounts of PCBs may remain dissolved, but most adhere to organic particles and sediments. PCBs in water bioaccumulate in fish and marine mammals and can reach levels several orders of magnitude higher than levels found in the water. EPA regulates PCBs under the CWA and has established water quality criteria and toxic pollutant effluent standards. Based on the carcinogenicity of PCBs, EPA published a MCL Goal for PCBs at zero and the MCL of 0.5 μg/L (0.5 ppb) under the SDWA.

Dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin TCDD)

Dioxin is considered an EDC on the basis of its effects that occur during pregnancy which result in many malformations observed in the offspring of many species including humans. Dioxin [CASRN - 1746-01-6] is a contaminant formed during the manufacture of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), an herbicidal compound that comprised about 50% of the defoliant Agent Orange, and 2,4,5-T derivatives, as well as other chemicals synthesized using 2,4,5-trichlorophenol. Dioxins may also be formed during incineration of chlorinated industrial compounds such as plastic and medical waste. Dioxin is one of the most acutely toxic compounds synthesized by modern chemistry. TCDD is the most toxic member of the 75 dioxins that exist and is the one most studied. It is almost insoluble in water. TCDD is stable in water, dimethylsulfoxide, 95% ethanol, or acetone. It can undergo a slow photochemical and bacterial degradation, though normally it is extremely stable. Dioxin is degraded when heated in excess of 500°C or when exposed to ultraviolet radiation under specific conditions. TCDD has no known commercial applications but is used as a research chemical. TCDD has been found in at least 91 of 1,467 National Priorities List sites identified by the EPA. Dioxins are widespread environmental contaminants. They bioaccumulate throughout the food web because of their lipophilic properties and slow metabolic destruction. The primary source of dioxin exposure to humans is from food.

Furan

Furan [CASRN - 110-00-9] is classified as a cyclic, dienic ether; it is a colorless, flammable liquid. It is insoluble in water, but is soluble in alcohol, ether, and most common organic solvents. Furan is used primarily as an intermediate in the synthesis and production of other organic compounds, including agricultural chemicals (insecticides), stabilizers, and pharmaceuticals. The primary route of potential human exposure to furan is inhalation.

Furan was detected in 1 of 63 industrial effluents at a concentration of less than 10 µg/L. Furan was detected in a creek in the Niagara River watershed and in the Niagara River.

C. Alkylphenols and Alkylphenol Ethoxylates

Nonylphenol (NP) [CASRN - 25154-52-3]/[84852-15-3] and octylphenol are the largest volume alkylphenol products manufactured in the U.S. Alkylphenols (APs) such as nonylphenol and octylphenol are mainly used to make alkylphenol ethoxylate (APE) surfactants. These surfactants are the primary active ingredients in industrial chemicals that are used as cleaning and sanitizing agents. Nonylphenol ethoxylates (NPE) account for approximately 80% of total APE use with total U.S. production exceeding 500 million pounds per year. Alkylphenols are also used as plasticizers, in the preparation of phenolic resins, polymers, heat stabilizers, antioxidants, and curing agents. APEs do not break down completely in sewage treatment plants or in the environment. The most widely used NPEs have nine- or ten-member carbon chains attached to the ethoxylate group. Thus, the great majority of NPEs in use are easily dissolved in water. Human exposure to APs and APEs may occur through contaminated drinking water that has been extracted from polluted waters. At present there is no conclusive evidence that APs or APEs cause adverse health effects in humans; however, there are many reports of alkylphenols causing production of a female-associated liver protein, vitellogenin, in male fish (Jobling, 1995).

Investigations of NP levels in rivers have found values varying between 2 µg/L in the Delaware River in Philadelphia to 1000 µg/L in the

Rhine, and 1000 µg/L in a tributary of the Savannah River. Drinking water is frequently taken from rivers and can easily become contaminated with alkylphenols. Analysis of many drinking water samples in the U.S. has found an overall average concentration of alkylphenolic compounds of 1 µg/L. Studies in the U.S. show NPE removal from wastewater ranging from 92 to 99% with minor seasonal variations. NPE concentrations in discharges after treatment are reportedly low, varying between 50 and 200 ppb. Draft EPA water quality guidelines for nonylphenol in freshwater are 6.6 ppb water (four-day average) and 25 ppb (one-hour average), and in saltwater, they are 1.6 ppb (four-day average) and 6.2 ppb (one-day average).

D. Plastic Additives

Bisphenol A

Bisphenol A [CASRN - 80-05-7] is an industrial chemical used to synthesize epoxy resins or polycarbonate plastic. Human exposure to the potential endocrine disrupting effects of bisphenol A may occur when this chemical leaches out of the plastic due to incomplete polymerization, or breakdown of the polymer upon heating. Polycarbonates are commonly used for food and drink packaging materials and infants are the subgroup of the population that is most highly exposed to this compound. Bisphenol A is also used in plastic dental fillings.

Bisphenol A is a solid which has low volatility at ambient temperatures. It has a water solubility of 120-300 mg/L. Its water solubility increases with alkaline pH values. Releases of bisphenol A into the environment are mainly in wastewater from plastics-producing industrial plants and from landfill sites that contain large quantities of plastics. Bisphenol A does not bioaccumulate in aquatic organisms to any appreciable extent. If released into acclimated water, bisphenol A would biodegrade. In untreated water, bisphenol A may biodegrade after a sufficient adaptation period, it may adsorb extensively to suspended solids and sediments, or it may break down upon exposure to light.

Diethyl Phthalate (DEP)

Diethyl Phthalate [CASRN - 84-66-2] is a synthetic substance that is commonly used to increase the flexibility of plastics used to make toothbrushes, automobile parts, tools, toys, and food packaging. It is also used in cosmetics, insecticides, and aspirin. DEP can be released fairly easily from these products since it is not part of the polymer. Plastic materials containing DEP in waste disposal sites constitute the major reservoir of DEP in the environment. If released to water, DEP is expected to undergo aerobic biodegradation. Humans are exposed to DEP through consumer products and plastics, contaminated air, or contaminated drinking water and foods.

There is evidence which shows a strong correlation with impaired reproductive performance in multigeneration studies in rodents (Wine, 1997); however, endocrine effects associated with DEP exposure in humans have not been reported.

DEP has accumulated and persisted in the sediments of the Chesapeake Bay for over a century. DEP has been detected in surface water samples from Lake Ponchartrain and the lower Tennessee River, as well as other industrial river basins. Surface water samples collected along the length of the Mississippi River contained DEP in significant concentrations. DEP has been detected in groundwater in New York State public water system wells, near a solid waste landfill site in Norman, OK, and at sites in Fort Devens, MA, Boulder, CO, Lubbock, TX, and Phoenix, AZ. DEP has been identified in drinking water in the following cities: Miami, Philadelphia, Seattle, Lawrence, New York City, and New Orleans.

Di(2-ethylhexyl) Phthalate (DEHP)

Di(2-ethylhexyl) Phthalate [CASRN - 117-81-7] is a manufactured chemical that is used primarily as one of several plasticizers in polyvinyl chloride (PVC) resins that make plastics more flexible. It is the most commonly used of a group of related chemicals called phthalates or phthalic acid esters. DEHP is also used in inks, pesticides, cosmetics, and vacuum pump oil. DEHP is everywhere in the environment because of its use in plastics in large quantities, but it evaporates into air and dissolves in water at very low rates. The primary routes of potential human exposure to DEHP are inhalation, ingestion, and dermal contact in occupational settings and from air, from consumption of drinking water, food, and food wrapped in PVC. It is easily dissolved in body fluids such as saliva and plasma. DEHP is biodegradable, but it tends to partition into sediment where it is relatively persistent. It also tends to bioconcentrate in aquatic organisms. Because of its low vapor pressure, human exposure to DEHP in either water or air appears to be minimal.

DEHP has been detected frequently in surface water, groundwater, and finished drinking water in the U.S. at concentrations in the low ppb range. Groundwater in the vicinity of hazardous waste sites may be contaminated with DEHP. EPA regulates DEHP under the CWA and the SDWAA. DEHP is included on lists of chemicals for which water quality criteria have been established under the CWA. EPA classifies DEHP as a water priority pollutant and has set the MCL Goal at zero. EPA has set the MCL at six parts DEHP per billion parts of drinking water (six ppb).

IV. Water Treatments for EDC Removal

Water suppliers use a variety of treatment processes to remove contaminants from drinking water. Individual processes may be arranged as series of processes applied in a sequence. Water utilities select a treatment train that is most appropriate for the contaminants found in the source water. The most commonly used processes include flocculation, sedimentation, filtration, and disinfection for surface water. Some treatment trains also include ion exchange and adsorption. These conventional processes are inefficient for substantially reducing certain pesticide concentrations and other EDCs.

The processes described later in this section can be used for removal of EDCs as specified, either individually or as a class of compounds. The feasibility of using the various techniques will depend on the size of the system and the cost effectiveness. The two major concerns regarding technologies for small systems are affordability and technical complexity (which determine the needed skills for the system operators).

A. Water Treatment Techniques

Activated Carbon (Granular and Powdered)

Activated carbon is similar to charcoal in composition, but its surface has been altered to enhance its sorption properties. Activated carbon is made from a variety of materials including wood, coal, peat, sawdust, bone, and petroleum distillates. For use in drinking water treatment plants activated carbon produced from wood and coal is most commonly used. The base carbon material is dehydrated then carbonized through slow heating in the absence of air. It is then activated by oxidation at high temperatures (200 to 1000°C), resulting in a highly porous, high surface area per unit mass material. The activation process is considered a two-step procedure in which amorphous material is burned off and pore size is increased. Typically, GACs have surface areas ranging from 500 to 1400 square meters/gram.

GAC treatment removes contaminants via the physical and chemical process of sorption. The contaminants accumulate within the pores and the greatest efficiency is attained when the pore size is only slightly larger than the material being adsorbed. Removal efficiencies for many organic contaminants are good to excellent. Water quality parameters such as dissolved organic matter, pH, and temperature can significantly affect the removal efficiency of GAC. However, for GAC treatment of drinking water it is necessary to reduce the total organic carbon (TOC) of the treated water through the preliminary steps of coagulation/filtration before treatment with GAC. Its removal efficiencies change drastically once the bed nears exhaustion, as contaminant breakthrough occurs. GAC beds can be reactivated by removing the granular carbon from the water treatment chambers, drying the material then placing it in large furnaces that heat the material to 1200 to 1400°F. This heating process removes any residual of contaminants from the pores and again enlarges the pore size. This feature and the high temperatures needed to attain reactivation should be kept in mind when considering claims of some manufacturers that flushing point-of-use (POU) GAC filters with hot water will reactivate units or increase operating efficiency. The increased temperatures that are reached with hot water DO NOT in any manner achieve reactivation.

The performance of GAC for specific contaminants is determined in the laboratory by trial runs and is performed one chemical at a time. The following text is presented to provide the reader with a basic understanding of how the relative capacity of activated carbon to remove a chemical from water (a liquid phase) was determined. Data are gathered within a laboratory setting and determined on the basis of one chemical at a time. This document is not intended to equip the reader to perform laboratory-scale studies to derive values for specific compounds that may be of interest to them. The Freundlich equation can be used to indicate the efficiency of GAC/PAC treatment. The Freundlich equation is expressed as:

$$Q_e = K \times C^n{}_e$$

where Q_e is the equilibrium capacity of the carbon for the target compound, (µg/g), C_e is the equilibrium liquid-phase concentration of the target compound (µg/L), and K and $^{1/n}$ are the Freundlich coefficients in $(\mu g/g)(L/\mu g)^{1/n}$ and dimension-less units, respectively. The K values that are determined for each chemical are a means of expressing the "abilility" of a particular GAC to remove a chemical.

Typically when K values that are greater than 200 are attained the process is considered to be economically feasible. In addition, the process of GAC can be fine tuned, that is, certain basic parameters such as pH, temperature or choice of carbon source can be altered to increase efficiency of the process when certain critical contaminants such as pesticides must be removed.

Maintenance--Careful monitoring and testing are required to ensure that all contaminants are removed. The carbon media must be replaced regularly. The replacement intervals depend on the type of contaminant, concentration, rate of water usage, and the type of carbon used in the system. There is potential for bacterial growth on the adsorbed organic chemicals; routine maintenance must be performed. When POU devices are used for compliance for small systems, programs for long-term operation, maintenance, and monitoring must be provided by the water utility.

Powdered activated carbon (PAC) also functions by adsorption of contaminants from water onto a solid phase material, in this case powdered carbon. PAC differs from GAC in that the powdered carbon is added to the water in a large tank, a period of time is provided for adsorption of the contaminants to occur, then the powdered carbon is later removed in a filtration process. This process also differs from GAC in that PAC needs to be added continually to the process; however, the process is less expensive and less technically demanding but it is more labor intensive. PAC is more adaptable to short-term applications rather than as a continual use process. For contaminants such as pesticides which are mostly used during a six-week period in late spring and summer, PAC may be a particularly useful choice. The water being treated comes into contact with much less carbon material per unit volume treated, so the process is not as efficient as GAC.

GAC is the BAT for removal of all of the selected EDCs that are discussed in this document. However, since other technologies are used in the multistep process of drinking water treatment, a brief discussion is included for those processes that enhance the performance of GAC.

Coagulation/Filtration

Coagulation/Filtration processes involve the addition of chemicals like iron salts, aluminum salts, with and without anionic, cationic, or anionic-cationic polymers that coagulate and destabilize particles suspended in the water. The suspended particles are ultimately removed via clarification and/or filtration. Conventional filtration includes pretreatment steps of chemical coagulation, rapid mixing, and flocculation, followed by floc removal via sedimentation or flotation. After clarification, the water is filtered using common filter media such as sand, dual-media, and tri-media. Direct filtration has several effective variations, but all include a pretreatment of chemical coagulation, followed by rapid mixing. The water is filtered through dual- or mixed-media using pressure or gravity filtration units.

Lime Softening

In the lime-softening (LS) process, the pH of the water being treated is raised sufficiently to precipitate calcium carbonate and, if necessary, magnesium hydroxide to reduce water hardness. The chemical groups that contain most of the EDCs are not affected by LS.

Point-of-Use/Point-of-Entry Treatments

The SDWA identifies both point-of-entry (POE) and POU treatment units as options for compliance technologies for small systems. A POU treatment device treats only the water at a particular tap or faucet, resulting in other taps in the facility serving untreated water. POU devices are typically installed at the kitchen tap. POU devices are listed as compliance technologies for inorganic contaminants, synthetic organic contaminants, and radionuclides. POU devices are not listed for volatile organic contaminants because they do not address all routes of exposure. POE treatment units treat all of the water entering a facility (household or other building), resulting in treated water from all taps. POE devices are still considered emerging technologies because of waste disposal and cost considerations.

POE and POU treatment units often use the same technological concepts as those used in central treatment processes, but on a much smaller scale. Technologies that are amenable to the POU and POE scale treatment include activated alumina, GAC, reverse osmosis, ion exchange, and air stripping.

When POU and POE units are used by a public water system to comply with the National Primary Drinking Water Regulations (NPDWRs), the SDWA requires that the units be owned, controlled, and maintained by the public water system or by a person under contract with the public water system. This is to ensure that the units are properly operated and maintained to comply with the MCL or treatment techniques. This will also ensure that the units are equipped with the required mechanical warnings to automatically alert the customers to the occurrence of operational problems.

B. Discussion of Water Treatment Techniques for Specific EDC Removal

The EDCs addressed in this document that are included in the NPDWRs as drinking water contaminants are methoxychlor, DDT and DDE, endosulfan, PCBs, DEP, and DEHP. The EDCs in this section are grouped by chemical class. Removal techniques for the EDCs not listed in the NPDWRs will be based on removal of similar contaminants that are listed.

The treatment processes are described with considerations of advantages, limitations, and special considerations. The actual choice of a process to include in a treatment train will ultimately depend on the source water quality, the nature of the contaminant to be removed, the required quality of the finished water, and the size of the drinking water system.

Methoxychlor

The BAT for removal of methoxychlor from drinking water is GAC. Steiner and Singley (1979) have tested a wide range of water treatment processes and found GAC to be the most efficient for removal of methoxychlor. They found that over a broad range of concentrations (ranging from 1 mg/mL to 25 mg/mL) the GAC process could remove sufficient quantities of methoxychlor so that the finished water met MCL requirements which is 0.1 mg/mL.

Endosulfan

The BAT for removal of endosulfan from drinking water is GAC. In the Dobbs and Cohen report "Carbon Adsorption for Toxic Organics," EPA/600/8-80/023, the following K values, as determined by the Freundlich equation and actual test were determined: alpha-endosulfan-6135, beta-endosulfan-1990, endosulfan sulfate-2548. For small system compliance, GAC, POU-GAC, and PAC can be used to remove endosulfan from drinking water supplies. Please see Table 1.

DDT

The BAT for removal of DDT from drinking water is GAC. In the Dobbs and Cohen report "Carbon Adsorption for Toxic Organics," EPA/600/8-80/023, the following K values, as determined by the Freundlich equation and actual test were determined: DDT has a K value of 10,449 µg/g $(L/\mu g)^{1/n}$ which is sufficiently above the cutoff point of 200 µg/g $(L/\mu g)^{1/n}$ to be judged an effective treatment method and DDE (a DDT metabolite with endocrine activity) of 18,000 µg/g $(L/\mu g)^{1/n}$.

Diethyl Phthalate

The BAT for removal of diethyl phthalate from drinking water is GAC. In the Dobbs and Cohen report "Carbon Adsorption for Toxic Organics," EPA/600/8-80/023, the following K value, as determined by the Freundlich equation and actual test for diethyl phthalate yielded a K value of 17,037 µg/g $(L/\mu g)^{1/n}$.

Di-(2ethylhexyl) Phthalate (DEHP)

The BAT for removal of DEHP from drinking water is GAC. In the Dobbs and Cohen report "Carbon Adsorption for Toxic Organics," EPA/ 600/8-80/023, the following K value, as determined by the Freundlich equation and the test was determined. DEHP has a K value of 8,308 µg/g $(L/\mu g)^{1/n}$ which is one of the highest values established among the 130 compounds that they tested; GAC is very effective for the removal of DEHP from drinking water.

PCBs

In the Dobbs and Cohen report two studies were reported for PCB-1221 and PCB-1232. The K value determined for PCB-1221 was 1,922 µg/g $(L/\mu g)^{1/n}$ and the K value for PCB-1232 was 4,067 µg/g $(L/\mu g)^{1/n}$. Both mixtures are among the lesser chlorinated groups containing 21 and 32% chlorine, respectively. Relative to other PCB mixtures they are more hydrophilic and hence would have lower K values than the commercial PCB mixtures, Aroclor 1242, 1248, 1254, and 1260. The most troublesome PCB environmental mixtures tend to be derivatives of this later group of compounds; therefore, GAC should be a very effective method for removal of environmental PCB compounds from drinking water.

Dioxin

Dioxin is not water soluble, hence it is not likely to be present in untreated drinking water unless it would be attached to sediment in raw water. Because most conventional water treatment methodologies such as coagulation-sedimentation and filtration are effective in removing sediment, it is likely that these processes would be very effective in the removal of the contaminant, dioxin.

Alkylphenols and Alkylphenol Ethoxylates

GAC is best used for removal of these contaminants from drinking water. Previous laboratory-scale testing for removal of nonylphenol with GAC has yielded K values of 19,406 at a water pH of 7.0. For consistency of removal of synthetic organic chemicals, GAC, POU-GAC, and PAC are recommended for small system compliance. GAC devices include pour-through for treating small volumes, faucet-mounted for POU, in-line for treating large volumes at several faucets, and high volume commercial units for treating community water supply systems. Careful selection of the type of carbon is based on the specific contaminants in the water and the manufacturer's recommendations. Site-specific conditions may affect the percentage removal using these techniques, including the presence of "competing" contaminants. Source water-specific testing will be needed to ensure adequate removal. For GAC, surface waters may require pre-filtration. PAC is most applicable to those systems that already have a process train including mixing basins, precipitation or sedimentation, and filtration.

Table 1. Isotherm Constants for Selected EDCs

Chemical	Isotherm Constants (K value)	1/N	Calculated Value µg/gm $(L/\mu g)^{1/N}$*
Alpha-endosulfan	194	.50	6,135
Beta-endosulfan	615	.83	1,990
Endosulfan sulfate	686	.81	2,548
DDT	332	.50	10,499
DDE	232	.37	18,000
Diethyl phthalate (DEP)	110	.27	17,037
Diethylhexyl phthalate (DEHP)	11,300	1.50	8,308
PCB-1221	242	.70	1,922
PCB-1232	630	.73	4,067
Nonylphenol	250	.37	19,406

*Any value above 200 is considered to be economically feasible.

ACTON BOARD OF HEALTH

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Town of Acton
Comprehensive Water Resources Management Plan
Citizens Advisory Committee
Indirect Potable Reuse Working Group

Meeting #3
7/20/2005
Acton Town Hall, Room 121

Call to Order 730pm

I. Introductions

II. Minutes from 6/30/05

III. Update on Reuse Activities

IV. Review of articles from 6/30/05 meeting

V. Review of new Articles

  a. Discussion of the four major topics

    1) Emerging contaminants – detection and removal
    2) The timing of the implementation of the project and coincidence with regulatory, treatment technology, and political timelines
    3) Source reduction efforts for water use and pollutant removal
    4) Centralized IPR versus Decentralized IPR

VI. Future meeting dates, sites, and topics

Adjourn by 845pm

MEMORANDUM

Acton Board of Health - Telephone (978) 264-9634

TO: Indirect Potable Reuse Working Group

FROM: Brent L. Reagor, R.S.

RE: Meeting #3
7/20/2005

DATE: July 12, 2005

Enclosed with this memo you will find the packet for the next meeting. Contents are as follows:

1) Agenda
2) 6/30/2005 minutes
3) Article summations for the previous packet's articles
4) Article summation for 2 articles in this packet
5) The two articles for which the summation is included
6) A series of fact sheets and short easy to understand pieces as requested by the group

Even though I have included summations, please read through the articles as there is a significant amount of information which cannot be properly summarized.

If you have any questions, or cannot make the meeting, please let me know.

INDIRECT POTABLE REUSE WORKING GROUP

Acton Board of Health - Telephone (978) 264-9634

Meeting Minutes

6/30/2005 Meeting
Room 126
Acton Town Hall

Attendees: *Brent Reagor, Acton Health Department (BR)
*Greta Eckhardt, Acton Resident, AWD Land-Water Use Committee (GE)
*Eric Hilfer, Acton Resident, ACES, CAC (EH)
*Art Gagne, Acton Resident, CAC (AG)
*Joanne Bissetta, Acton Resident, BOH (JB)
Mary Michelman, Acton Resident, ACES (MM)

*IPR Working Group Member

The meeting was called to order at 7:32pm

The group reviewed the minutes from the previous meeting. Minor changes were made to the discussion on reuse and its impact on local hydrologic loss, along with a change in phrasing for one of the three possible answers the group may issue in its final report.

Discussion of the minutes spurred discussion of the title of the group. MM states we should change the title, AG and GE both stated that the most important title was the title of the final report. AG stated that if people do not understand what the title means, one of the hurdles we must overcome is education about the definition of indirect potable reuse.

The group discussed the issue of local hydrologic impacts related to a centralized IPR discharge. MM stated she would like to see more about this issue, but stated that an IPR discharge at the High Street wellfields may have a beneficial impact of mounding the groundwater and creating a hydrologic gradient, thereby preventing significant intrusion of contaminant plumes.

BR updated the group about the Johns Hopkins School of Public Health (JHSPH) study. The samples had been sent to Baltimore for analysis. He has also been asked to join the statewide Task Force that has been seated to author Water Reuse regulations for the Commonwealth. He also stated that the Metropolitan Area Planning Council (MAPC) is looking at all forms of water reuse, including greywater, stormwater, and wastewater along the lines of the Massachusetts Water Policy, and that MADEP is in the process of hiring a Watershed Outreach Coordinator to encourage reuse

The group began a discussion of the four articles sent out with the packets. BR gave a short introduction of each article. GE stated she was surprised by two things: 1) the prevalence of caffeine, and the fact that the USGS study had positive results in every sample analyzed. AG stated that he believes the discovery of emerging contaminants in effluent will always be a continuum as new analytical methods are developed and new compounds are created. MM stated there is a lag time between production of new compounds and development of revised analytical methods and the presence of no data does not mean it is not harmful.

AG stated that the group is not conversant in the topics discussed in the scientific articles. EH stated the results from the JHSPH study will be of some help. AG would like to see more fact sheets and FAQ documents. GE would like to see guiding questions or points to consider sent out with the articles, prior to the meetings. BR agreed to do this for the current articles and any future research.

GE asked what would be considered the major classes of emerging compounds would be. BR stated, as he sees it, they are: Endocrine disruptors/mimics, Pharmaceutical compounds and their metabolites and by-products, and Personal care products and their by-products. However, compounds may be members of more than one class. AG stated that medicine disposal practices (i.e. flushing unused medications) may lead to detection of these contaminants at higher levels. BR stated that the State of Maine has developed a public relations campaign to discourage people from flushing unused medications for just that reason.

MM stated she was intrigued about research into the effects of wastewater treatment processes on the compounds in question. BR stated he would make sure to include information on that in a future packet. AG cautioned that with the continuum of discovery in science, Acton should be careful not to develop the "guinea pig" mentality. GE asked about heavy metals and pesticides in WWTF effluent. BR stated that these must come from an industrial source, and there are no so such sources currently connected or planned to be connected to the sewer system.

The group settled on July 20 and August 18 as the next two meeting dates.

The meeting adjourned at 8:54pm.

Respectfully Submitted,

____

Brent L. Reagor

INDIRECT POTABLE REUSE WORKING GROUP
Acton Board of Health - Telephone (978) 264-9634

Article Summation – Packet #2

Article #1:
"Pharmaceuticals and personal care products (PPCPs) in surface and treated waters of Louisiana, USA and Ontario, Canada". The Science of the Total Environment. v. 311, 2003, pgs 135-149.

Key Points

- Normal drinking water treatment processes when combined with chlorination and/or ozonation are effective at removing Naproxen and Triclosan present in surface water sources
- PPCPs include a broad range of dissimilar molecules, which present a challenge in selecting an analytical method
- Naproxen and Triclosan survive through normal wastewater treatment processes

Article #2
"Occurrence of Antimicrobials in the Final Effluents of Wastewater Treatment Plants in Canada". Environmental Science and Technology. v. 38 n. 13, 2004, pgs 3533-3541.

Key Points

- Frequency of antibiotic prescription is related to the prevalence of antibiotics in wastewater treatment plant effluents
- Penicillin and cephalosporin degrade quickly during the wastewater treatment process
- Wastewater treatment plants with hydraulic retention times of less than 12 hours are poor at removing pharmaceuticals
- Detection of these compounds at the less than 1 microgram/liter (part per billion) is not enough to cause acute exposure effects on plants, animals, or bacteria, but this study does not take into account chronic exposure effects

Article #3

Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes. EPA-625-R-00-015, USEPA, March, 2001.

Key Points

- The use of granular and powdered activated carbon is the most common and well-accepted treatment process for removal of the endocrine disruptors listed within this document
- GAC is usually installed along with other, more common, water treatment technologies to complete the treatment train associated with drinking water treatment

Article #4

"Pharmaceuticals, Hormones, and other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance". Environmental Science and Technology. v. 36, n. 6, 2002, pgs. 1202-1211.

Key Points

- This study was directly focused on surveillance in surface waters and did not look at wastewater treatment facilities or discharges specifically. Therefore, the source of the compounds detected could include runoff from residential, industrial, or agricultural operations; wastewater treatment facility discharges; industrial operations/discharges; or other means
- One or more of the 95 compounds selected for this surveillance study were detected in 80% of the 139 streams sampled throughout 1999-2000
- Nonprescription drugs were found with greater frequency than any of the prescription drug classes
- Multiple samples had more than 1 compound detected
- This study did not evaluate the preference of some compounds for adsorption to sediment and their presence outside the water column

INDIRECT POTABLE REUSE WORKING GROUP

Acton Board of Health - Telephone (978) 264-9634

PLEASE TRY TO READ THE ARTICLES USING THESE KEY POINTS AS A GUIDE. THERE IS STILL VALUABLE INFORMATION IN THE ARTICLES.

Article Summation – Packet #3

Article #1

"Evaluation of the Fate of Synthetic and Natural Hormones in a Full Municipal Wastewater Treatment Plant". Proceedings of the 2004 WEF Annual Conference. New Orleans, LA October 4-6, 2004.

Key Points

- The plant at which this study was conducted is similar in design and function, though it is design to treat over 4 million gallons per day, where the Acton facility is only permitted for 0.29 million gallons per day

- The compounds in this study are excreted in an inactive state, but are degraded by microbes present in feces and wastewater to release the active estrogen compounds into the waste stream

- The three hormones selected for this study experienced removal rates by standard wastewater treatment practices anywhere from 76.4% to 93.2%

- These hormones have an affinity for adsorption onto suspended particulate matter, which therefore leads to greater sequestration in the treatment process as the sludge was removed

- Fate of estrogen compounds in UV disinfection treatment units requires further study as a slight increase was seen in estrogen compound concentration after UV disinfection

Article #2

"EDCs in Wastewater: What's the Next Step?". Proceedings of the 2004 WEF Annual Conference. New Orleans, LA October 4-6, 2004.

Key Points

- SRT = Sludge retention time
- HRT = Hydraulic retention time
- AOP = Activated oxygen processes
- NF/RO = Nanofiltration/Reverse Osmosis
- The longer it takes to process the wastewater through the treatment plant, the higher the level of biodegradation of endocrine disruptors
- Higher percentages of EDC removal will lead to increased sludge disposal costs, as the compounds must go somewhere
- The hazardous forms of endocrine disruptors are formed when their parent compounds, which are not necessarily hazardous, are partially broken down during through contact with wastewater and treatment processes.
- Certain treatment processes (activated sludge-type) seem to be more effective at removal of endocrine disruptors
- Processes that use membranes to filter wastewater are named based upon the size of the pores in the membrane ranging from standard Microfiltration, to Ultrafiltration, Nanofiltration, and Reverse Osmosis. These technologies hold promise in EDC removal as they retain the particulate matter of increasingly smaller sizes, which many EDCs are attracted to
- Determining which technologies and at which level to employ the selected technology(s) will be a site-specific decision based upon the EDC characteristics of the raw wastewater and the space and money available for wastewater treatment
- Activated carbon, which is currently used by the Acton Water District at certain wells to remove VOCs from the water supply, is being studied as a possible treatment process for EDC removal
- Significantly more health effects from EDCs have been demonstrated in wildlife than in humans

EVALUATION OF THE FATE OF SYNTHETIC AND NATURAL HORMONES IN A FULL MUNICIPAL WASTEWATER TREATMENT PLANT

Nazim Cicek *, Kathleen Londry, Jan A. Oleszkiewicz, Yoomin Lee
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ABSTRACT

The impact of a full-scale municipal wastewater treatment plant (WWTP), and each of the treatment units within the stream, on the removal of endocrine-disrupting compounds was evaluated by tracking three estrogenic compounds: 17-β-estradiol (E2, natural); estrone (E1, natural, metabolite of E2); and 17-α-ethinylestradiol (EE2, synthetic). The overall performance of the WWTP compared well with other plants, as 90.5% removal of E1+E2, and 76.4% removal of EE2 were observed. The activated sludge units reduced the concentration of E1+E2, and EE2 in the liquid phase by 88.2% and 44.6%, respectively. Additional removal of soluble phase estrogens (68% and 62% for E1+E2 and EE2, respectively) was observed in the equalization basin prior to UV disinfection. Although not statistically significant, the UV treatment process appeared to result in a slight increase in soluble phase estrogens. The aqueous phase of the tertiary lagoon sludge contained higher levels of estrogens compared to the lagoon influent. This was attributed to the possible de-sorption of particulate matter-bound estrogens during storage in the lagoon.

KEYWORDS

Estrogens, endocrine disrupting compounds, hormones, municipal wastewater treatment plant, activated sludge treatment, effluent

INTRODUCTION

There is a growing concern about the impact of natural and synthetic hormones on the safety of freshwater supplies. Hormones such as estrogens have been shown to be released from a wide variety of wastewater treatment plants (WWTPs), and although they are present in very low concentrations (ng/L), these amounts can be sufficient to disrupt endocrine systems of aquatic species such as fish (Johnson and Sumpter, 2001). EDCs released in domestic sewage treatment plant effluents are causing male fish, living immediately downstream of discharge, to be feminized through the development of unusual testes, production of an egg protein precursor normally found only in females, depressed circulating sex hormone levels, and reduced gonad sizes (Desbrow, et al., 1998, Purdom, et al., 1994, Snyder, et al., 2001). Estrogenic compounds include 17-β-estradiol (E2) which is the natural estrogen, and 17-α-ethynylestradiol (EE2) which is a synthetic estrogen and the main component of birth control pills, both of which are excreted in human urine and feces (Desbrow [illegible] 998). In addition, E2 is transformed biologically and [illegible] estrone (E1) which [illegible] estrogenic but [illegible] importance than E2 and EE2 because of its relatively lower estrogenicity (Johnson, 2001). These compounds are excreted as inactive conjugates, but microbes in feces and wastewater readily de-conjugate these compounds, thereby releasing the actively estrogenic forms either in the collection systems or within the WWTP (Desbrow, 1998). Public awareness of the existence of endocrine-disrupting compounds (EDCs) in WWTPs is growing and municipalities worldwide are anticipating future requirements for removal of EDCs in treatment plants.

Surveys of domestic WWTP in various cities in Europe, North and South America reveal that a wide range of concentrations of estrogens are present in WWTP effluents (Baronti, et al., 2000, Belfroid, et al., 1999, Desbrow, et al., 1998, Kolpin et al., 2002, Snyder, et al., 2001, Ternes, et al., 1999). Typical values are in the low ng/L range for E2 or less than ng/L range for EE2, which is at or close to the limit of detection even with the most sensitive techniques. The removal of estrogens in WWTP and their transport out into the environment has been shown to depend on the design and operational characteristics of the treatment plant (Lee et al. 2004), yet little is known about the potential to increase estrogen removal, or the key processes or parameters to increase net removal of estrogens (Johnson et al. 2000).

Most research that has been done in WWTPs is with activated sludge processes and suggests 64-88% removal efficiency for E2 (Baronti, et al., 2000, Johnson, et al., 2000, Nasu, et al., 2001, Ternes, et al., 1999). The synthetic estrogen, EE2 appears to be removed less than the natural E2, which is consistent with its more stable chemical structure. In a study recently conducted on 18 WWTPs across Canada, a wide range of removal efficiencies were observed for E1, E2, and EE2. These range from 15% to 98% for E1, 9% to 99% for E2, and -637 to 80% for EE2 (Conor Pacific, 1999). The substantial variability across wastewater treatment plants along with reports of increasing levels of EE2 underlines the complexity of EDC behavior in such environments.

Assessing the fate of EDCs requires a comprehensive and structured sampling plan in order to determine the removal rates and processes in each unit operation of a WWTP. Very little is known about the impact of each wastewater treatment unit within WWTPs on the fate of hormones, or the factors that could assist in their removal and thereby mitigate their environmental impact. Municipal treatment plants, such as the one found in Brandon, Manitoba, Canada, offer an excellent model system in which to study the fate of these compounds, from their introduction to the plant from human waste, through the various treatment options, to the final effluent and sludge. With this as a focus, the objective of the present research study was to evaluate the overall effect of the WWTP on the concentrations of E2, E1, and EE2 and identify the impact of each treatment unit process on the removal and overall fate of E1, E2 and EE2. The compounds of interest were analyzed in both aqueous on particulate phases. Attempts were made to isolate and quantify estrogens form wastewater sludge to construct a unit treatment based mass balance.

METHODOLOGY

WWTP Sampling

Eight different sample types were collected from the WWTP at Brandon in either grab (sample locations 1, 2, 3, and 4) or 24hr composite (sample locations 5, 6, 7, and 8) fashion (Figure 1). The plant is centered around two non-nitrifying aerobic sequencing batch reactors (SBRs) with a total hydraulic retention time (HRT) of approximately 6 hours and solids retention time (SRT) of less than 1.2 days. General characteristics of the incoming wastewater on the days of sampling are presented in Table 1.

Figure 1 – Layout of wastewater treatment plant and sampling locations

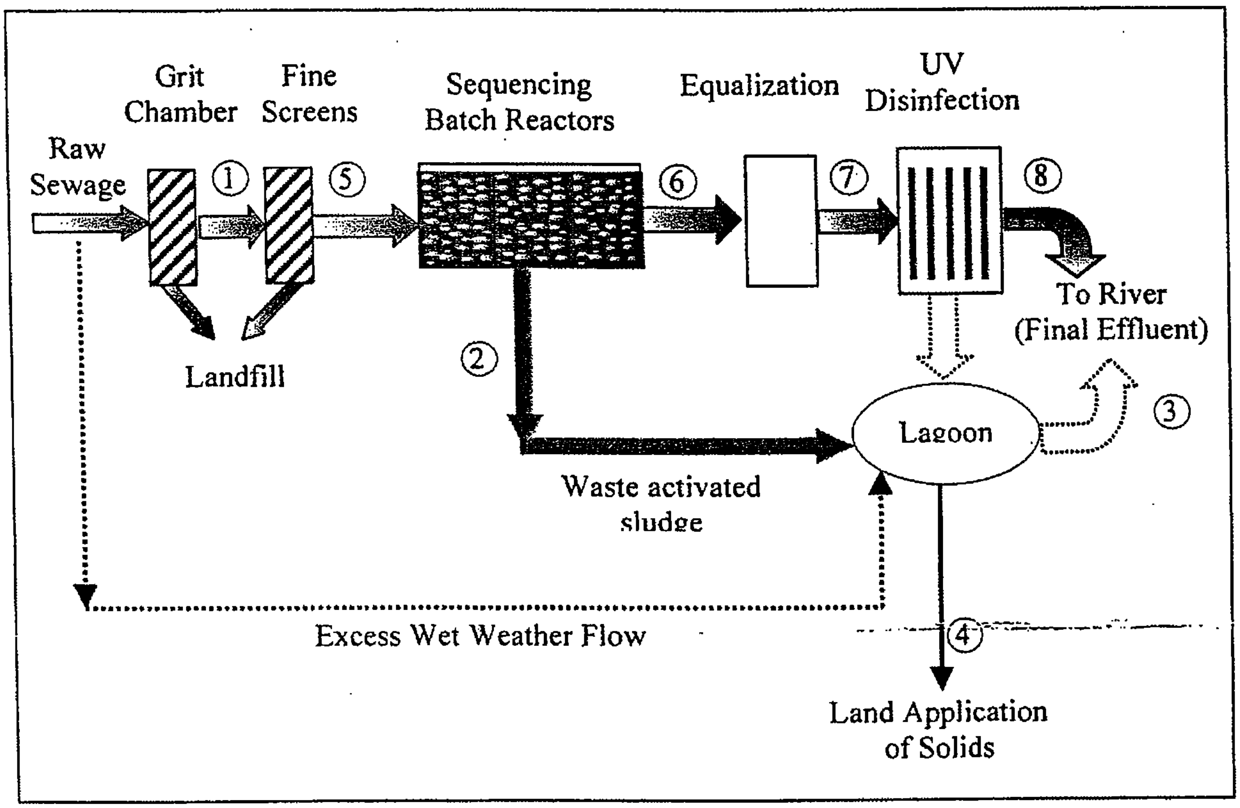


Table 1 - General raw wastewater characteristics for the sampling period

Date	Daily Influent Flow	pH	TSS	COD	NH3	Wastewater Temp.
	(m^3/d)		(mg/l)	(mg/l)	(mg/l)	(^{o}C)
20-May	16,523	7.38	160	227	22.50	10.8
21-May	16,622	7.57	177	410	22.50	12.4

All containers used in this study were glass and were acid washed and rinsed with 50% methanol to prevent adsorption of estrogens (unless otherwise stated). In addition, methanol (20 ml, HPLC grade) was added to the 4L collection bottles to help reduce loss of estrogens onto glass surfaces. Four composite samplers (sampling for 24 hours, at 330 ml per hour) were used simultaneously during sampling. Water in each carboy was dispensed into smaller (4 L) bottles and transported in coolers packed with ice to the University of Manitoba.

Sample Preparation and Analysis

Liquid samples (1, 3, 5, 6, 7, 8 + supernatant from 2, 4). Each of the eight WWTP samples was filtered at least four times as replicate sub-samples. Each 1L sub-sample was sequentially filtered through 2.5 μm then 0.7 μm GF/C (glass fiber) filters. The filtrate was refrigerated for less than 24 hrs before solid phase extraction (SPE) was performed. SPE cartridges (LC-18, 6 mL, 0.5 g, Supelco) were pre-conditioned with 5 mL acetone then 10 mL Milli-Q water. Samples were filtered at < 20 min L^{-1}; then estrogens were eluted with acetone (4 x 3 ml). All samples were stored frozen (-20°C) for as little time as possible between treatment steps. As a prelude to the testing of the WWTP, the procedures were tested by spiking estrogens (from a stock solution containing E1, E2, and EE2 at 100 ng/mL in acetone) directly into water to final concentrations of 1, 10 or 100 ng/L for each estrogen. Recoveries from the entire procedure averaged 82%.

The GF/C filters were combined and extracted with acetone by accelerated solvent extraction (ASE). An ASE 400 instrument (Dionex) was used to extract filters or sludges from 11 ml cells (filled with Ottawa Sand, Fisher Scientific) with acetone (HPLC grade, Fisher Scientific) at 2000 psi and 100°C (1 cycle, 5 min heat, 5 min static, 60% flush, 90 sec purge). In a test of the extraction procedure, filters were directly spiked with 0, 1, 10, or 100 ng each of E1, E2, and EE2, extracted, and analyzed. Average recoveries were similar for all three estrogens at approximately 79%.

Sludge samples (2. 4) Sludge samples could not be filtered directly, so they were first centrifuged (10 000 x g, 15 min) in acid-washed and methanol-rinsed plastic centrifuge bottles. The supernatant was decanted and pooled in graduated cylinders, then filtered and analyzed as described for the liquid samples. The pellets were transferred to glass vials, frozen, and lyophilized. The wet and dry weights were recorded, and the dried sludge was extracted with acetone by ASE as above. Some sludge samples were spiked with estrogens [illegible] ng E1, E2, EE2 prior to centrifuging, to test recovery.

Sample processing. Acetone extracts (from SPE or ASE extractions) were concentrated under a stream of N_2 at 37°C. Each extract was applied to a new silica gel column (1 g silica gel (baked 150°C 8h then deactivated with 15 µl H_2O) suspended in 5 ml hexanes:acetone (65:35) in a pipette with a glass wool plug. Estrogens were eluted with 5 ml hexanes:acetone, and the eluent was concentrated under N_2 at 37°C. To remove particulates (including silica gel) the sample was filtered through a 0.2 µm PTFE filter into a glass vial with Teflon-lined cap.

Samples were derivatized with 100 µl MSTFA (N-Methyl-N-(trimethyl-silyl) trifluoro-acetamide, Sigma) and 10 µl pyridine for 2 h at 65°C, then dried under N_2, and re-suspended in 100-500 µl hexanes. Blanks and standards (100 ng each of E1, E2, EE2) were prepared with each set of samples derivatized. Samples were analyzed within 10 days of derivatization.

Analysis. The TMS-derivatives of E1, E2 and EE2 were analyzed by gas chromatography-mass spectrometry (GC-MS-MS). A Varian 3800 GC with a Saturn 2000 mass spectrometer was used with a DB-5ms column (30 m x 0.25 mm x 0.25 µm) with a 1 m x 0.53 mm precolumn. Samples of 2-4 µl were injected in splitless mode at 80°C and the injector was heated to 250°C at 200°C/min. The oven temperature program was 80°C for 1.5 min, increased to 180°C at 50°C/min, then increased to 300°C at 20°C/min and held for 5 min. The MS had a transfer line at 250°C, EI ion source of 70 eV, and ion trap temperature of 200°C. The MS-MS was performed for E1 using a precursor ion of 342 and quantifying using the daughter ions 244, 245 and 257. The MS-MS was performed for E2 using a precursor ion of 416 and quantifying using the daughter ions 285 and 326. The MS-MS for EE2 used a precursor ion of 425 and quantifying using the daughter ions 193, 231, and 407. Estrogens were quantified by comparison of peak areas to standard calibration curves generated daily using standards of 10-200 pg E2 and EE2, and confirmed with check standards and blanks.

RESULTS AND DISCUSSION

Overall Reduction of Estrogens in the WWTP

In the analysis of the data, special consideration was given to the relationship between E2 and E1, as oxidation of E2 to E1 occurs quickly yet reversibly. Thus E1 and E2 were examined both individually and as a paired set. Table 2 summarizes the overall removal of E1, E2, and EE2 in the wastewater treatment plant. The influent values for E1 and E2 compare well with previously reported studies involving wastewater treatment plants in Germany, Brazil and Italy (Baronti et al. 2000, Ternes et al., 1999). Effluent concentrations for E1 and E2 are generally lower than those reported in British wastewater treatment plant discharges (Desbrow et al. 1998), but within the ranges reported elsewhere. On the other hand, EE2 concentrations in the influent and effluent appear higher than those reported in studies conducted in Europe and Brazil, but are comparable with results reported in other Canadian wastewater treatment plants (Baronti et al. 2000, Ternes et al., 1999, Lee et al 2004). This could be attributed to societal similarities in terms of the use of the synthetic hormone EE2 in Canadian cities, as opposed to differences in this regard with other parts of the world. The overall estrogen removal performance of the plant compared well with other plants (Lee et al. 2004). As expected, E[illegible] and E1 were removed to a greater extent than EE2

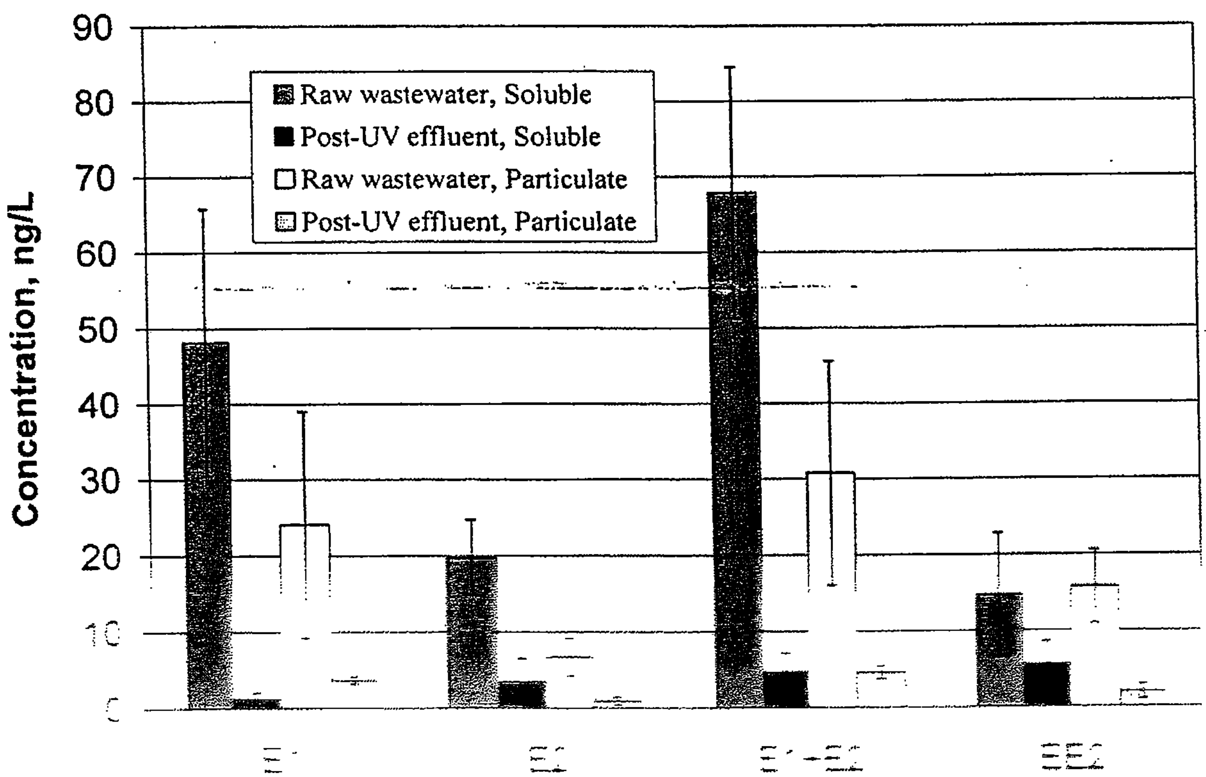
(90.5% versus 76.4%, respectively), which is also in agreement with previous research elsewhere (Baronti, et al., 2000, Johnson, et al., 2000, Nasu, et al., 2001, Ternes, et al., 1999). Nevertheless, EE2 removal was greater than reported in most plants across Canada (Conner Pacific, 1999).

Table 2 - Overall reduction of selected Estrogens in the WWTP

Estrogen	Raw wastewater (Soluble + Particulate) ng/L	Post-UV Effluent (Soluble + Particulate) ng/L	Overall Reduction %
E1	72.26	4.91	93.2
E2	26.45	4.43	83.3
E1+E2	98.71	9.34	90.5
EE2	30.42	7.63	76.4

As apparent in Figure 2, a larger fraction of EE2 (approximately 52 %) entered the plant in particulate form as E1 and E2 (33% and 25%, respectively). This was expected, since EE2 has a higher affinity for the solids phase, which would also indicate that much of the EE2 removal could be attributed to adsorption to suspended solids within the plant. The effluent discharged to the receiving river contained similar amounts of estrogens in aqueous and particulate bound phases. This is significant, as solid bound estrogens are often ignored in research studies involving the analysis of wastewater treatment plant effluents.

Figure 2 – Comparative reduction of estrogens in the particulate and soluble phase

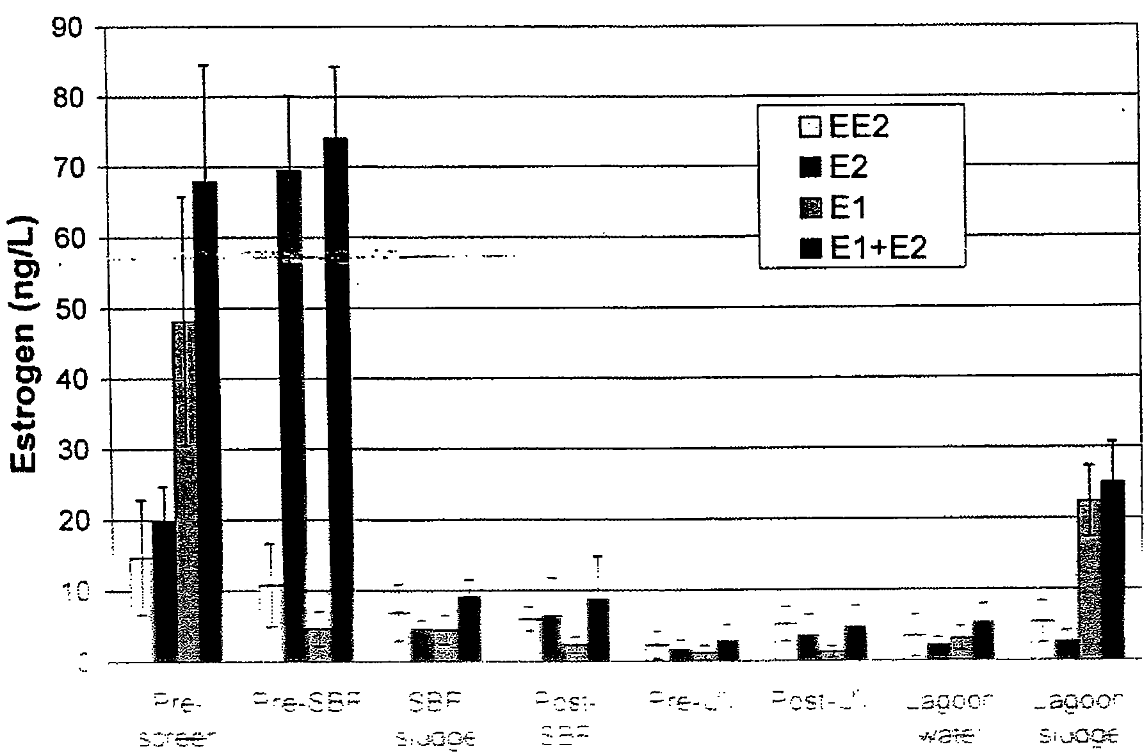


It is also possible to evaluate the overall plant performance in terms of the relative potencies of E1, E2, and EE2. Studies conducted on in-vivo VTG (an egg protein precursor) response in trout established a measure of 17β-estradiol equivalency, which can be used to sum up the overall impact of each endocrine disrupting compound within a sample (Johnson et al., 2001). Using these multipliers, it was determined that the total removal of 17 β -estradiol equivalency within the plant for all three hormones amounted to 77.4 %. Of the total estrogen potency leaving the plant and entering the lagoon prior to the receiving river, the majority (71.4%) was in aqueous form. Considering that previous reports on the impact of E2 and EE2 exposure of fish under laboratory conditions indicate that as low as 2ng/L would induce measurable change in fish reproduction (Snyder et al., 2003), the values reported in this study reaffirm the possibility of adverse effects on wildlife in the immediate vicinity of the outflow. The impact would be amplified during low river flow periods of the year where dilution effects are suppressed.

Fate of Estrogens Within Each Treatment Unit

Soluble phase concentrations of E1, E2, E1+E2, and EE2 throughout the WWTP are presented in Figure 3. EE2 concentrations were consistently lower than E1+E2 throughout the plant, with most variability observed with E1. Although E1+E2 concentrations remained similar between the influent to the fine screen and the influent to the SBR, the reversible transformation of E2 to E1 is apparent in Figure 3.

Figure 3 – Soluble phase concentrations of E1, E2, and EE2 at various sampling points in the WWTP



The activated sludge unit operations, consisting of two parallel sequencing batch reactors (SBRs), were effective in reducing E1+E2, and EE2 in the liquid phase by 88.2% and 44.6%, respectively (Figure 3). Considering the relatively low HRT and SRT of the SBR units the (6 hrs and 1.2 days, respectively), observed removal rates for E1+E2 are close to the higher limit of those previously reported (Lee et al. 2004). The aqueous phases of the waste activated sludge and the SBR effluent appear to be very similar in terms of estrogen distribution, indicating no additional sorption/de-sorption occurring in the sludge.

An equalization basin, which operates at an overall hydraulic retention time of approximately 4 hours, holds the SBR effluent prior to UV disinfection. Some particulate matter settling takes place in this basin which necessitates solids clean-out twice a week. Additional reductions of soluble phase estrogens (68% and 62% for E1+E2 and EE2, respectively) were observed in this basin which could be attributed to additional biological degradation or adsorption/settling. In essence, the equalization basin in this plant behaved similar to a post–secondary clarifier which is still biologically active and provides turbidity removal prior to UV disinfection.

The UV disinfection process in the plant consisted of a medium-pressure, high intensity, flow-through system with an average HRT between 9-12 seconds. Although not statistically significant, the UV process appeared to result in a slight increase in soluble phase estrogens. This could be attributed to UV induced break-down of particulates and consequent release of solid-bound estrogens to the aqueous phase. It is important to note, however, that uncertainties remain with regards to the exact impact of UV treatment on soluble phase estrogens. This was emphasized in reviewed research conducted on the removal E1, E2, and EE2 during lab-scale ultraviolet disinfection studies (Birkett and Lester, 2003). In that study, two separate doses were investigated (32 mWscm^{-2} for 19 seconds and 145 mWscm^{-2} for 20 seconds) with multiple replicates, and in each case some results showed removal occurred while others showed an increase in concentration during the process. Further testing is still required in order to determine the fate of estrogens during UV disinfection processes.

The lagoon process in the plant served several purposes. It acted as the sole treatment process during excess wet weather flow periods, where raw wastewater was directed to the lagoon prior to discharge into the river. When the UV disinfection unit was ineffective due to excess turbidity or not in operation during maintenance and part replacement, the lagoon acted as a final disinfection step prior to river discharge. Finally waste activated sludge was stored in the lagoon prior to bi-annual pumping and application to agricultural land of the sludge sediment (Figure 1). The aqueous phase of the lagoon solids contained higher levels of hormones relative to the lagoon influent. This could be attributed to the possible de-sorption of particulate based hormones from the waste activated sludge while residing in the lagoon. The fact that EE2 did not follow this trend as closely as E1 and E2 supports the de-sorption argument, as this behavior is consistent with the higher affinity of EE2 to organic solids.

One major possible removal process for estrogens in a WWTP is adsorption to particulate matter. The soluble, liquid-phase concentrations of E1, E2, and EE2 were successfully traced within each treatment unit process in the WWTP, but quantification of the solid-phase bound estrogens proved much more difficult. Solids trapped on filters during processing of liquid samples had [illegible] of estrogens [illegible] solids stream: raw wastewater, effluent after the SBR.

effluent after the UV system). Reduction of estrogens in the solid phase within the treatment plant (Figure 2) indicates that biodegradation is probably taking place, and removal of estrogens is not simply due to adsorption. However, no estrogens were detected in the pelleted material from the return activated sludge or the lagoon sludge. Upon further investigation with spiked estrogens, it was discovered that these sludges had a large capacity for adsorption of estrogens, and that the extraction of estrogens from such materials is extremely difficult. This remains one of the main challenges for determining the fate of estrogens in WWTP treatments.

It was not possible to construct a true mass balance of E1, E2, and EE2 in the municipal wastewater treatment plant due to the analytical problems related to sludge analysis. Uncertainties remain with respect to the actual fate of the estrogens within each treatment unit, whether they are being biodegraded or bound to the solid phase. The results suggest that upon land application of the lagoon sludge, one can expect some de-sorption and mobilization of E1. The release and relative effects of estrogens in land applied agricultural wastes and municipal biosolids remain topics of active investigation. Some recent work by Collucci et al. (2001a, 2001b) suggest that in well aerated soils estrogens (E1, E2, EE2) are broken down within several weeks of land application.

CONCLUSIONS

The fate of three selected estrogenic compounds: 17-β-estradiol (E2, natural); estrone (E1, natural, metabolite of E2); and 17-α-ethinylestradiol (EE2, synthetic) were evaluated across each treatment unit within a full-scale municipal wastewater treatment plant. The overall performance of the WWTP compared well with previously reported studies in Canada and elsewhere, as 90.5% removal of E1+E2, and 76.4% removal of EE2 were observed. A larger fraction of EE2 (approximately 52 %) entered the plant in particulate form than E1 and E2 (33% and 25%, respectively). Particulate bound estrogens were as prevalent in the discharged effluent as aqueous phase estrogens. Aerobic sequencing batch reactor units reduced the concentration of E1+E2, and EE2 in the liquid phase by 88.2% and 44.6%, respectively. Additional removal of soluble phase estrogens (68% and 62% for E1+E2 and EE2, respectively) was observed in the equalization basin prior to UV disinfection. The UV treatment process appeared to result in a slight increase in soluble phase estrogens. The aqueous phase of the tertiary lagoon sludge contained higher levels of estrogens compared to the lagoon influent, which was attributed to the possible de-sorption of particulate matter-bound estrogens during storage in the lagoon.

ACKNOWLEDGMENTS

This project was funded by The City of Brandon and the Manitoba Water Services Board. Technical and analytical support was provided by Erin Becker, Cynthia Czajka and Colleen Wilson.

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EDCS IN WASTEWATER: WHAT'S THE NEXT STEP?

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ABSTRACT

The fact that many known and suspected endocrine disrupting chemicals (EDCs) are being found at environmentally significant concentrations in the effluent of wastewater treatment plants (WWTPs) is receiving increasing attention in public and regulatory arenas. The public is concerned about the safety of consuming trace amounts of EDCs in drinking water, though the only confirmed negative effects from EDC exposure have involved wildlife health.

Ample research opportunity exists for the scientific community on this topic: most EDCs have not been identified and/or studied, analytical methods for many identified EDCs have yet to be developed, and the levels of toxicological significance or impact must be established. Additional work must also be done to determine the potential for (1) interactive toxicological effects in EDC mixtures and (2) the formation of undesirable byproducts through treatment. It is likely that the EPA will not consider regulating EDCs until more research has been completed.

Research shows that complete biodegradation of many chemicals of concern can be achieved with adequate SRT and/or HRT in the activated sludge system. When contaminants are persistent or if extremely low effluent concentrations are required, however, higher level removal technology may be needed. Several advanced technologies, such as activated carbon adsorption, ozonation, AOPs, and NF/RO, have successfully removed potential EDCs from water. Most of these technologies, however, are expensive to implement and to operate. Optimization of the activated sludge process could be a less costly option. Issues of by-product formation and EDC additive effects will be important considerations in the design of any treatment strategy.

Long-term facility planning should allow for design flexibility to accommodate possible future EDC regulations. Potential treatment strategies can be incorporated into existing layouts, and room should be left for new equipment. Process selection criteria such as space requirements, byproduct issues, and compatibility with existing facilities must be considered. Planning should favor processes and management strategies that will address not only the concern for EDCs, but other water quality goals as well, so that capital expenditures will cover more than the single, somewhat unclear EDC issue.

Based on current information, it seems logical that a major focus for EDC and PPCP removal should be at the WWTP. Removal of these pollutants from WWTP effluent may solve much of the apparent endocrine disruption problem in the water environment, in addition to providing a cleaner source for drinking water.

KEYWORDS

Wastewater treatment, endocrine disruption, pharmaceuticals, personal care products.

INTRODUCTION

The endocrine system is one of the two main regulatory systems in humans and other organisms. It consists of glands that secrete hormones which are transported in the bloodstream to different parts of the body. These hormones act to control body functions, including reproduction, growth, and development.

Simply stated, an endocrine disrupter is an exogenous substance that changes the function of the endocrine system, affecting the way an organism or its progeny reproduces, grows, or develops. Though most research to date has focused on the disruptive effects on reproduction and development, more recent efforts are examining the effects of disruption on thyroid function and the immune system (McCann, 2004).

Endocrine disrupting chemicals (EDCs) and pharmaceutical and personal care products (PPCPs) are ubiquitous in the environment because of their seemingly endless number of uses and origins in residential, industrial, and agricultural applications. EDCs are derived from both anthropogenic and natural sources; the USEPA is in the process of defining exactly what an EDC is, and those chemicals that meet the toxicity definition will be classified as such in the coming years. The term PPCPs refers to chemicals that enter the environment through use of human and veterinary pharmaceuticals and myriad other products such as antibiotics, analgesics, fragrances, sunscreen, mouthwash, bug spray, and cosmetics. Some PPCPs are suspected of being EDCs, but the terms are not interchangeable and the toxicity concerns associated with the two different groups can be very different. Though the potential hazards associated with some EDCs and PPCPs, such as DDT and DES, have been known for decades, the environmental and health effects of these chemicals in general are only beginning to gain worldwide attention in public and regulatory arenas. Hundreds of compounds are now listed as suspected EDCs; some of these, along with their primary sources, are presented in Figure 1.

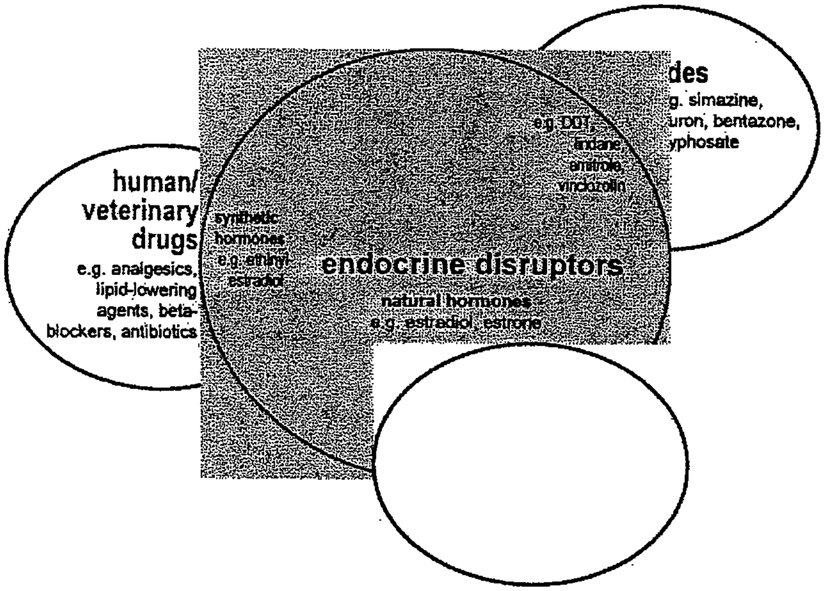

Figure 1. Example of Some EDCs from Various Sources.

There are various pathways by which organisms can be exposed to EDCs and PPCPs; of these, contamination of the water cycle is especially important. EDCs and PPCPs enter the water environment largely through treated wastewater effluent and inputs to water bodies from agricultural or feedlot operations. Agricultural inputs are significant in some areas, and controlling them will be quite a challenge for many reasons. Wastewater treatment plant (WWTP) effluent can be a source for various types and amounts of EDCs and PPCPs, depending on service area characteristics, because most of the WWTPs in service today have not been designed to remove them. Thus, some micropollutants will not be completely degraded or removed through the wastewater treatment process. Aquatic organisms and other wildlife are exposed to EDCs and PPCPs through direct contact in the water environment. Numerous researchers in various countries have reported on the negative effects of WWTP effluent on the reproductive systems of aquatic organisms living in the vicinity of WWTP outfalls. For example, sexual disruption of fish has been linked to estrogenic substances in treated WWTP effluent (Purdom et al., 1994; Jobling et al., 1998; Pickering and Sumpter, 2003). Such effects on wildlife have led to concerns about adverse health consequences in humans, as it is possible that humans can be exposed to EDCs and PPCPs through their drinking water and food.

STATE OF CURRENT EDC KNOWLEDGE BASE

Regulatory and Research Efforts

There is ample research opportunity for the scientific community on the topic of EDCs: most EDCs have not been identified and/or studied, analytical methods for many of the identified EDCs have yet to be developed, and the levels of toxicological significance or impact must be established. Beyond identifying EDCs, additional work must also be done to determine the potential for (1) interactive toxicological effects in EDC mixtures and (2) formation of treatment byproducts that are more dangerous than the parent compounds that were targeted for removal. The U. S. Environmental Protection Agency (EPA) is not likely to consider regulating EDCs until more research has been completed, though long-term facility planning should take into account that some EDCs may be regulated in the future.

Through the Safe Drinking Water Act (SDWA), the EPA currently regulates a number of possible EDCs such as atrazine, chlordane, DDT, dioxin, cadmium, lead, and mercury. But the maximum contaminant levels for these chemicals are defined by their toxic/cancer-causing effects rather than endocrine disruption. EDCs have not been mentioned specifically in U.S. legislation until 1995, when amendments to the SDWA and the Food Quality Protection Act mandated screening of all chemicals and formulations for potential endocrine activity prior to their use or manufacture where they could cause contamination of drinking water or food. To develop a comprehensive screening program, the EPA established the Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC). In its final report in 1998, the EDSTAC recommended consideration of: (1) both human and wildlife effects; (2) examination of estrogen, androgen, and thyroid endpoints; (3) a plan for assessing an estimated 87,000 chemicals; and (4) evaluation of six specific classes of mixtures in addition to discrete chemicals. In 2001, the Endocrine Disruptor Methods Validation Subcommittee (EDMVS) was formed to evaluate and validate methods for standardization of EDC testing. Once this work is completed, we should be able to definitively identify which chemicals are indeed EDCs (Snyder et al., 2003b).

In 1999 and 2000, the United States Geological Survey (USGS) sampled 139 streams across 30 states in the U.S. as the first nationwide reconnaissance of the occurrence of PPCPs and potential EDCs. The survey included sampling for 95 constituents from a wide variety of origins, and found that contamination was generally prevalent and widespread (Koplin et al., 2002). While the authors noted that contaminant concentrations tended to be low and rarely exceeded guidelines for drinking water quality, few federal guidelines or regulations exist concerning EDC or PPCP contamination of our drinking or natural waters. Additional studies must be conducted at relevant concentrations of these substances to identify their toxicologically significant levels and to establish reasonable regulations, if any are required. The state of California is considering regulations for EDCs and PPCPs in indirect potable reuse applications, prompting some practitioners of indirect potable reuse to establish monitoring programs now. Since California is a leader in water reuse, this move may stimulate similar actions in other programs around the world.

The EPA is establishing a reference dose for perchlorate, which may become the first pollutant to be regulated in the U.S. for endocrine disrupting toxicity (Snyder, 2003). Several European countries and Japan, however, already have begun phasing out or limiting the use of a few specific EDCs. Besides the U.S., Europe, and Japan, Australia and Canada also see EDC and PPCP contamination as a priority issue and have research programs in place. Both the European Union (EU) and the United Nations (UN) have launched plans for elimination of priority hazardous substances (European Commission Report, 2001; Stockholm Convention, 2001). The current U.S. administration has pledged support of the UN effort.

In addition, a model has been developed to estimate the concentrations of active pharmaceutical ingredients (API) in U. S. surface waters that result from human consumption. Using a mass balance approach, the P*h*ATE (Pharmaceutical Assessment and Transport Evaluation) model predicted the environmental concentrations of several APIs and the results were compared with measured values at 40 locations. In general, the P*h*ATE model was able to estimate concentrations to within a factor of ten of measured values, indicating that it may have value as a screening tool for estimating the presence of human pharmaceuticals in watersheds nationwide (Anderson et al., 2004).

Human and Wildlife Health Effects

Regarding the effect of EDCs on human health, it has been primarily fear of the unknown rather than fear of the known that has fueled widespread public concern. Excluding specific cases of "high dose response" exposure, results of studies involving population and health trends are inconsistent and do not establish an irrefutable link between low-level exposure to EDCs and adverse consequences to human health. It is the opinion of some scientists, such as Snyder (2003), that the amount of estrogenic chemicals in drinking water is not likely responsible for adverse human health effects because the estrogenic content in water is minute compared with the amount in foods. In addition, exposure to EDCs for humans is completely different from that for fish or other aquatic organisms, so the same response should not be expected. New findings released last year at the ECOHAZARD conference in Germany indicate that it is nearly certain that human exposure to EDCs through drinking water is not significant (McCann, 2004). The scientific community is far from consensus on the topic, though. The issue is far from closed, and scientists, along with environmental and industry groups, are likely to continue to debate it for years to come.

Research into the health effects of EDCs on wildlife is far from exhaustive, but there is more evidence linking EDCs with adverse impacts on wildlife health than on human health. Numerous studies over the past 70 years have demonstrated endocrine disruption in a variety of organisms, including gulls, marine gastropods, frogs, fish, and alligators, as a result of exposure to pesticides, steroids, surfactants, plasticizers, and other synthetic chemicals (Snyder et al., 2003b). New research indicates that there are over 200 species with known or suspected adverse reactions to endocrine disruptors (McCann, 2004).

Identifying the Most Hazardous Chemicals

While debate over what actually defines an EDC is still ongoing, it is generally accepted that the three main classes of endocrine disruption endpoints are estrogenic (natural estrogen blocked or mimicked), androgenic (natural testosterone blocked or mimicked), and thyroidal (thyroid function affected directly or indirectly). The majority of research to date has focused on estrogenic compounds, though disruption of androgen or thyroid function may prove to be of equal or greater importance biologically (Snyder et al., 2003b). Currently, the scientific community is drawing conclusions about the relative hazards of potential EDCs based on collective results of batch, pilot, and full-scale experiments and studies from around the world. In an excellent summary of research involving fate of EDCs and PPCPs in WWTPs, Johnson and Sumpter (2001) conclude that estrone (E1) and estradiol (E2) would be the EDCs of greatest concern based on *in vitro* potency, while ethinylestradiol (EE2) and the alkylphenols OP and NP would be more important based on the more relevant *in vivo* potencies. They state that this latter group could account for as much as 90% of the estrogenicity in a typical WWTP effluent. Discharge concentrations, magnitude of in-stream dilution, and type(s) of species involved are also important factors in considering the impact of the estrogens. It is important to remember, though, that much of the research to date has focused on estrogens, since that is where most wildlife effects have been observed, so conclusions may change as our data base broadens. It is also likely that as research in this area proceeds and analytical technologies advance, scientists will only discover more hazardous chemicals and/or degradation products at even lower concentrations, so this list may prove to be constantly evolving.

Pinpointing the effects of EDC exposure in humans and wildlife is very difficult, since environmental exposure is at very low levels and the perceived effects of endocrine disruption can be subtle and their manifestation may take years. Confusing the matter is the fact that research centers in different countries may use different EDC testing and screening procedures, so they may not agree upon the endocrine disrupting properties of a given substance found in the environment. And without unbiased internationally agreed-upon testing procedures, any unified international response to EDC contamination may be difficult (McCann, 2004).

EFFECT OF WASTEWATER TREATMENT ON EDCS

General

Though WWTPs have been shown to remove substantial amounts of many EDCs from the influent wastewater, low concentrations in the effluent may still lead to in-stream concentrations that are of significance to fish and other aquatic species (Johnson and Sumpter, 2001). Levels of toxicological significance are still being investigated, though research has shown estrogenic effects in rainbow trout at E2 and EE2 concentrations as low as 10 and 0.5 ng/L, respectively (Purdom et al., 1994). The actual concentration seen by aquatic organisms depends on the quantity of water available for dilution in the receiving stream. In population-dense, water-poor areas, high pollutant concentrations in the final effluent are of obvious concern.

Depending on their physicochemical properties, EDCs may be removed through adsorption, biological degradation and transformation, chemical degradation, or volatilization (Birkett and Lester, 2003). Findings reported in the literature indicate that removal efficiency through wastewater treatment varies considerably depending on the type of compound and removal process. The latest research into WWTP reduction capabilities indicates that "endocrine active substances" in the influent from primarily domestic sources were more susceptible to breakdown and removal. With other types of contaminants, very little reduction may occur through the WWTP. If these more intractable chemicals must be removed, application of advanced wastewater treatment technologies like membranes or ozonation may be needed (McCann, 2004). Thus, the technology applied at any given plant must be based on a thorough understanding of wastewater constituents.

Table 1 is an example of general information that can be found in the literature concerning removal of some EDCs and PPCPs through various wastewater treatment processes. It is important to note that the removals are discussed in terms of percentages, since initial concentrations are not provided, it is impossible to know how realistic the removal rates are or what can be expected for effluent quality in a given situation, especially given the fact that some performance studies are done using influent spiked with high contaminant concentrations. This is important, since some compounds may affect the aquatic environment at very low concentrations, and must therefore be reduced to extremely low effluent concentrations through wastewater treatment.

Table 1. Treatment Types and Removal Efficiencies for Selected EDCs*

Compound	Process Type	Removal Efficiency
PCB (polychlorinated biphenyls)	Biofiltration	90%
	Activated sludge	96%
	Biofiltration/activated sludge	99%
NP (nonylphenol)	High loading/non-nitrifying	37%
	Low loading/nitrifying	77%
NP_1EO**	High loading/non-nitrifying	-3% produced as degradation product
	Low loading/nitrifying	31%
NP_2EO**	High loading/non-nitrifying	-5% produced as degradation product
	Low loading/nitrifying	91%
NP_6EO**	High loading/non-nitrifying	78%
	Low loading/nitrifying	98%
17β-estradiol/17α-ethinylestradiol	Filtration – Sand/microfiltration	70%
	Advanced treatment - Reverse osmosis	95%
Organotins	Primary effluent	73%
	Secondary effluent	90%
	Tertiary effluent	98%
Triazines	Conventional two-stage	<40%

*Taken from Birkett and Lester (2003).

**NP_nEO = Nonylphenol ethoxylate, where n = specific number of EO groups

Table 1 indicates that several compounds undergo significant degradation through biological treatment, particularly in nitrifying systems with longer SRTs. While sand filtration or microfiltration appear to remove 17β-estradiol and/or 17α-ethinylestradiol with decent efficiency, removal rates for other contaminants will be higher or lower depending on their association with colloidal or particulate matter. The more advanced membrane treatment option shown, reverse osmosis, provides a significantly higher removal rate, though it is important to realize with this technology that the contaminants removed from the main waste stream are concentrated in a smaller reject stream which may require further treatment and must be disposed of properly.

Depending on the type of contaminant involved, coagulant addition, as is practiced for various reasons at many WWTPs, might help to remove some EDCs and PPCPs, particularly those associated with colloidal or particulate matter. However, many of the EDCs and PPCPs of concern are relatively polar with log K_{ow} values of less than three, so a high degree of removal by partitioning onto particles is not expected. In general, research has not shown that coagulation and flocculation with alum and ferric is particularly effective for removal of PPCPs and pesticides (El-Dib and Aly, 1977; Adams et al., 2002; Yoon et al., 2002). It should also be noted that if a coagulant was used as an adsorbent for a particular EDC or PPCP, the resulting sludge could be hazardous and may require special handling.

Estrogenic Chemicals and Biological Treatment

Though there are many chemicals released into the water environment that are potential EDCs, most work reported to date has focused on xenobiotic estrogens of the alkylphenol group and steroid estrogens, since these two groups of chemicals have demonstrated estrogenic effects in fish. Thus, most of the information presented in this section will pertain to these particular groups of contaminants.

The parent compounds of these two groups, alkylphenol polyethoxylates (APEs) and estrogen conjugates, are not particularly estrogenic; the potentially hazardous estrogenic intermediates are formed because the parent compounds are only partially broken down through wastewater treatment. APEs are nonionic surfactants used in a variety of industrial and household applications, and breakdown into nonlyphenols, octylphenols, and a wide variety of other intermediates during wastewater treatment. Humans excrete natural and synthetic steroid estrogens in inactive forms, which are converted to active hormones, such as estrone (E1), estradiol (E2), ethinylestradiol (EE2), and estriol (E3), in the sewer and through treatment (Johnson and Sumpter, 2001). (EE2 is excreted only when birth control pills are used.)

Many different researchers have reported on the presence of EDCs and/or PPCPs in wastewater and their fate through the biological wastewater treatment process. Studies from research efforts around the world include work by Belfroid et al., 1999; Ternes et al., 1999; Baronti et al, 2000; Korner et al., 2001; Svenson et al., 2002; D'Ascenzo et al., 2002; Lee and Peart, 2002; Andersen et al., 2003; Giger et al., 2003; and Huang, Y., 2003. These authors report a range of removal results for a variety of chemicals, though effluent concentrations of the estrogenic compounds were often found to be in the lower ng/L range, and below detection limits in some cases. In comparing between different studies on the fate of various chemicals through wastewater treatment, it is important to keep several important facts in mind. First, treatment conditions and objectives, such as HRT, SRT, temperature, pH, nitrification, denitrification, and bio-P, are often not sufficiently described by researchers. These factors can have a significant impact on EDC removal rate at any given plant. Second, sampling strategy and analysis can dramatically affect results. Third, spiking the influent to a biological process with high concentrations of contaminant may select for an adapted population of microorganisms that would not normally develop (Johnson and Sumpter, 2001).

This section focuses on the impact of biological treatment design on EDC removal, since that is the key component of a conventional WWTP for EDC/PPCP removal. A recent study in England showed particularly dramatic benefits of adding a biological step. Simply adding a short secondary treatment stage of fine bubble aeration to a domestic WWTP that previously had only primary settlement produced a sudden and sustained reversal in feminization trends in downstream fish (McCann, 2004).

Not all types of biological treatment provide the same degree of benefit. For example, Ternes et al. (1999) and Korner et al. (2001) both observed that trickling filters (TF) were less efficient at reducing the estrogenic content of influent wastewater than activated sludge. More recently, two WWTP in the southwestern U.S. were observed. Both plants have primary clarification and effluent filtration, but the biological process of one plant is a Bardenpho BNR activated sludge system with a solids retention time (SRT) of 10-13 days, and the other is a TF system. Both plants receive primarily domestic influent and operate at an average temperature of about 20 degrees C. A comparison of the effluent concentrations of several potential EDCs and PPCPs, a few of which are the known estrogenic compounds, are shown in Figures 2 and 3.

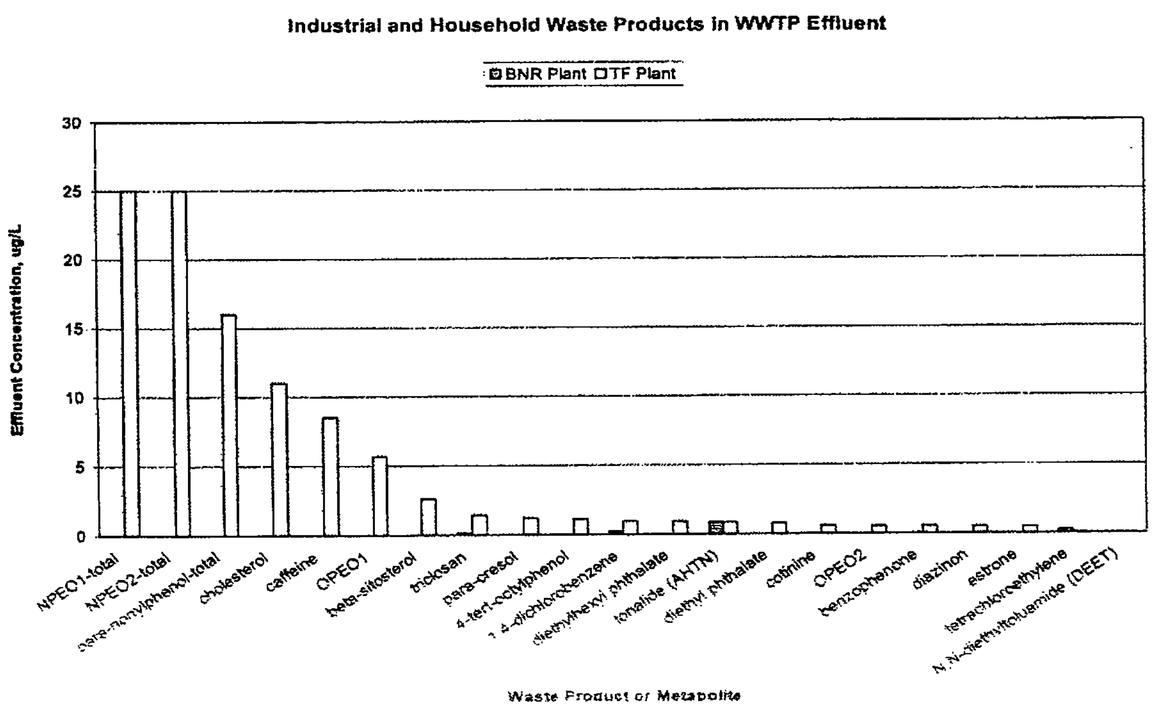

Figure 2. Comparison of Waste Products in BNR and TF WWTP Effluent

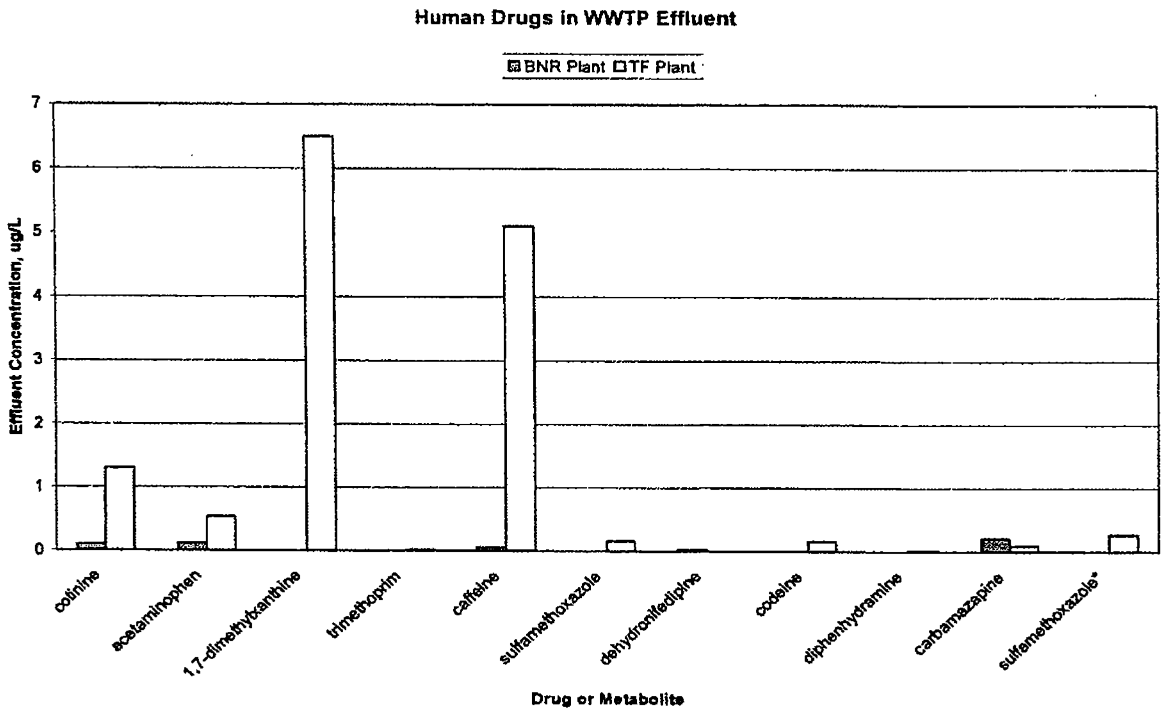

Figure 3. Comparison of Human Drug Concentrations in BNR and TF WWTP Effluent.

From Figures 2 and 3, it can be seen that the activated sludge system does a generally superior job of micropollutant removal as compared to the TF system. Though the more recent studies demonstrate analytical capabilities for measuring EDCs and PPCPs down to the nanogram per liter level, the concentrations shown here in micrograms per liter still provide an excellent comparison of process capability.

In activated sludge systems, hydraulic residence time (HRT) and/or SRT seem to be especially important factors in EDC removal. The longer the HRT, the longer the time available for biodegradation. The HRT of most European activated sludge systems is between 4 and 14 hours (Johnson and Sumpter, 2001), which would explain why this type of treatment would provide better performance than a TF, which might have an HRT of less than one hour. An increase in SRT may enhance the biodegradative and sorptive capacity of the activated sludge. The longer SRT could lead to a more specialized microbial population that can adapt to removal of EDCs and PPCPs. SRT also influences the hydrophobic or hydrophilic properties of the flocs and their ability to act as sorbents.

Several researchers have noted improved EDC removal with increased SRT (Ternes et al., 1999; Holbrook et al., 2002; Andersen et al., 2003). Saino et al. (2004) even specify that SRTs of at least 10 to 12.5 days are required for the organisms that decompose E2 and E1 to grow. In existing WWTP where it may not be possible to adequately increase the SRT because of expense or site constraints, MBR could offer advantages of more flexibility to operate at higher SRTs in a smaller footprint. While microfiltration membranes themselves will not provide an enhanced degree of EDC removal, it has been suggested that EDC adsorption to particulate matter that is retained by the membrane would reduce EDC concentration in the effluent. Ivashechkin et al. (2004) operated conventional activated sludge and MBR pilot units in parallel, operating both for denitrification at two different SRTs (12 and 25 days), and applying the same influent wastewater and sludge loading rate to each system. They did not find an appreciable difference in removal of nonlyphenol (NP), bisphenol A (BPA), and 17α-ethinylestradiol (EE2) between the two systems. The authors determined that EDC removal was due primarily to biodegradation; removed EDCs were not simply sorbed onto sludge particles, nor were they retained in the membrane material or the membrane biofilm. Other researchers, however, have found that microfiltration membranes are able to display some retention of smaller particles or colloidal material onto which EDCs may adsorb (Holbrook et al., 2003; Wintgens et al., 2004). Since pore sizing of membrane material is not uniform between manufacturers, it is possible that a difference in membrane material may explain some of the discrepancies in colloid retention. Differences in limits of detection also likely play a role.

Influent and effluent EDC and PPCP data was also collected from a BNR WWTP in the western U.S. that operates at an average SRT of six days and a temperature of 25 degrees C (Snyder et al., 2003). A pilot MBR was also run in parallel at a much higher SRT. The differences in removal rates for some chemicals are shown in Figure 4. Hormones E1, E2, EE2, E3, progesterone, testosterone, and androstenedione were removed to below detection limits (10-25 ng/L) in both systems. It is likely that the increased removal efficiency of the MBR for some compounds was due to the higher SRT, though it is possible that the filtering action of the membrane contributed.

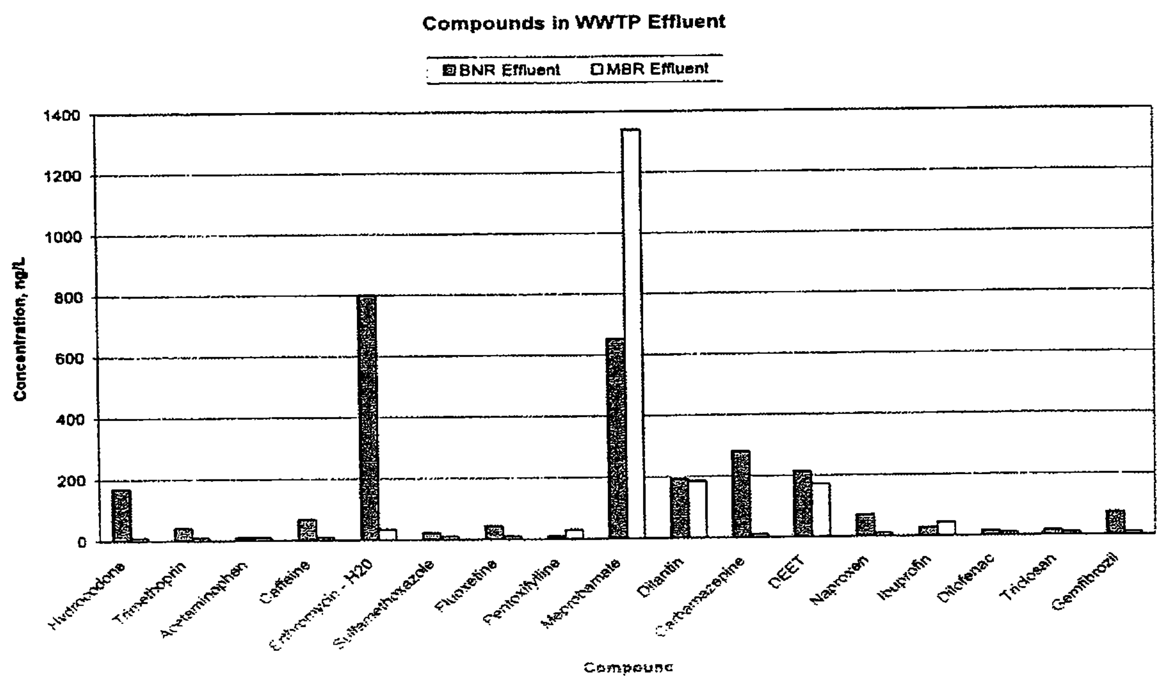

Figure 4. Comparison of Removal Rates Between High SRT MBR System and BNR System

Johnson and Darton (2003) state that E1, E2, EE2, and NP are all "inherently biodegradable and so in theory should not present an intractable problem." A drastic increase in the SRT or HRT of existing WWTPs to allow more complete biodegradation would be both cost and space prohibitive, but application of advanced tertiary treatment technologies for many communities would be far too costly. The alternative approach that they propose is to locally increase the amount of biomass sorbent by providing a carrier material within the activated sludge basin onto which a biofilm can develop. A wide range of mild to strongly hydrophobic organic contaminants would be intercepted by the bacterial surfaces and biodegraded. They propose a fixed surface rather than mobile carrier particles to ensure contact of influent wastewater with the biofilms. The fixed matrices would be located toward the front end of an aeration tank (some degree of plug flow is desired) and would be laid out in several packed zones. Laboratory scale tests have shown that almost all steroid estrogens can be removed by this process at a modest extra cost to existing facilities.

With reference to pollutant adsorption onto activated sludge, many EDCs or PPCPs of concern tend to be hydrophilic, though a few of the estrogenic compounds discussed in this section, like octylphenol and EE2 to some extent, are more hydrophobic (Yoon et al., 2003). Such chemicals can adsorb to and concentrate in activated sludge, and may survive anaerobic digestion. Thus, land application of biosolids is another route of exposure for some EDCs to enter the environment, though the ecotoxicological significance of this is presently unknown (Johnson and Darton, 2003).

In summary, it has been shown that some WWTPs are capable of removing most if not all estrogenic activity, with secondary biological treatment being the key process (Pickering and Sumpter, 2003). These facilities should be studied to determine the reasons behind their success. Where it is not possible to increase SRT and/or HRT at an existing WWTP exhibiting less than optimal performance, addition of advanced tertiary treatment may be the only option if ultra low concentrations of EDCs are eventually required. However, it makes sense that we should first thoroughly research optimization of the activated sludge process as a cost effective treatment process that does not generate additional side streams requiring further treatment and disposal.

Formation of Disinfection By-Products in Wastewater Treatment

All forms of typical wastewater disinfection practiced today will generate disinfection by-products (DBPs) to some degree (White, 1999). The EDSTAC has recommended that DBPs be evaluated for potential endocrine disruptive effects, as it has been suggested that DBPs formed though wastewater disinfection can act as EDCs. The latest research from Japan (Itoh et al, 2004) indicates that chlorination as performed at many WWTPs increases the estrogenic effect of waters containing natural organic matter (NOM). Though chlorination increases the estrogenic effect of NOM and a few other substances, many individual compounds are decomposed by chlorine, drastically decreasing the overall estrogenic effect. For this reason, the authors stress that the *overall* estrogenic effect be evaluated as the sum of increased and decreased activity by chlorination. Because DBPs are suspected to have toxic properties and are generally present in much higher concentrations in WWTP effluent than EDCs or PPCPs, efforts to control EDCs or PPCPs by oxidation may be counterproductive since additional DBPs may be produced (Snyder et al., 2005). The two main ways that DBP production can be controlled are to 1) control the precursors that react with the disinfectant oxidant or 2) allow the DBPs to form and then use a separate process to remove them (Marhaba, 2000). Various strategies are being evaluated to determine the best approach.

RESEARCH INTO ADVANCED TECHNOLOGIES FOR EDC REMOVAL

Biological processes are usually the most cost effective means of removing organics from wastewater, but when these organics are toxic or non-biodegradable, physical and/or chemical methods must be used. These methods include adsorption, chemical oxidation, and membrane processes that have more typically been used for water treatment. Research into advanced EDC/PPCP removal strategies is being conducted worldwide. The following is a sampling of new and traditional technologies that appear to have good potential for full-scale application if ultra low EDC/PPCP concentration limits are imposed. It is not suggested that any of these technologies be incorporated into current upgrade/expansion designs at WWTPs, but rather that the potential for EDC/PPCP regulation be recognized by designing flexibility into any long-range upgrade/ expansion plans.

Activated Carbon Adsorption

Activated carbon has been shown to remove many different types of EDCs and PPCPs to varying degrees. Adsorption will depend on the properties of both the sorbent and the contaminant. Activated carbon efficiently removes hydrophobic organic compounds, but can remove some polar ones as well depending on the strength of polar interactions (Snyder et al., 2003b). NOM also competes for adsorption, so lower NOM content in the water will lead to more efficient use of carbon.

Activated carbon is generally applied in one of two forms: 1) powdered activated carbon (PAC) is added to a sedimentation or contact basin, contacted with water for a few hours, and removed through settling and/or filtration, and 2) granular activated carbon (GAC) is in the form of adsorptive packed beds or filters with continuous flow and short (< 30 minutes) contact times, and can stay in operation for months or years (Snyder et al., 2003b). Adsorbents are very effective for achieving a high degree of removal and low effluent concentrations of contaminant by removing the contaminant from the liquid phase onto the activated carbon. Once exhausted, the adsorbent must be either disposed of or regenerated. The former option merely transfers the pollutant from liquid to solid phase, and the contaminant-rich activated carbon may require further treatment prior to disposal. The latter option can be very costly. Brown et al. (2004) are conducting studies to develop a non-porous adsorbent that can be regenerated in a quick and cost effective manner.

PAC has been shown to achieve over 90 percent removal of E2, EE2, and other potential EDCs from distilled water (Yoon et al, 2002). Wintgens et al. (2004), however, examined use of GAC following MBR treatment of landfill leachate and found that performance was relatively poor for removal of BPA, with only 1.3 g/d of an influent 3.4 g/d being adsorbed. Adams et al. (2002) studied the removal of seven antibiotics from both distilled water and river water using common PAC dosages. They found no statistical difference between the removal results from the two different waters, and concluded that PAC was a viable means of providing treatment for the pharmaceuticals studied. Miltner et al. (1989) also showed that GAC represented a cost effective means of controlling several pesticides. Full-scale information on use of activated carbon for EDC/PPCP removal is not available at this time.

Ozonation

Ozone is a powerful, but selective oxidant. During ozonation, molecular ozone and hydroxyl radicals, to some extent, may transform EDCs and PPCPs (Yoon et al., 2002). While ozone has been commonly used in water treatment, its application for EDC/PPCP removal at WWTP is only now being studied. Wintgens et al. (2004) performed ozonation on a BNR effluent to determine whether trace levels of NP and BPA could be removed. Very low effluent pollutant concentrations were measured for ozone doses of 8, 10, and 15 g O_3/m^3, with no appreciable increase in removal rate with dose. In a German pilot unit, application of ozone to BNR effluent resulted in some removal of over 50 trace organic pollutants that are typically found in wastewater effluent, with removal efficiencies frequently higher than 90% (Ried et al., 2004). Three important EDCs – E1, E2, and EE2 – were effectively oxidized or degraded by ozone, and the authors suggest that they lose most of their estrogenic potency in the process. In addition, antibiotics were no longer detected in the effluent. Ozone was not particularly effective in oxidizing iodinated contrast media compounds, and AOP combinations with ozone did not significantly enhance removal rates.

The nature or concentration of ozonation by-products were not discussed in either study. Formation of DBPs with ozone is an important consideration since some amount of NOM will be present in wastewater effluent. Bromate and brominated organic compounds are of particular concern when waters being treated contain bromide.

Advanced Oxidation Processes (AOPs)

Combinations such as UV plus hydrogen peroxide, ozone plus hydrogen peroxide, and UV plus ozone are powerful oxidation processes that effectively oxidize contaminants. These combinations are designed specifically to increase the concentration of hydroxyl radicals formed, since hydroxyl radicals have less selectivity as oxidants. Substances that are difficult to biodegrade and not removed are oxidized, and the oxidized byproducts may be more amenable to biodegradation. AOPs can be followed by a biological process to further degrade the byproducts, or natural purification processes may be relied upon for treatment, depending on the situation (Ried and Mielcke, 2003). As with ozonation, the hazard potential of the byproducts formed through treatment is also a topic of investigation.

Ried et al. (2004) estimated costs of low pressure UV, ozone, and three AOPs. This information was converted into U.S. units and is presented in Figure 5. As another point of comparison, Ried et al. (2004) reference the total cost for a membrane step at an equivalent of \$1.8 - \$2.2 per thousand gallons.

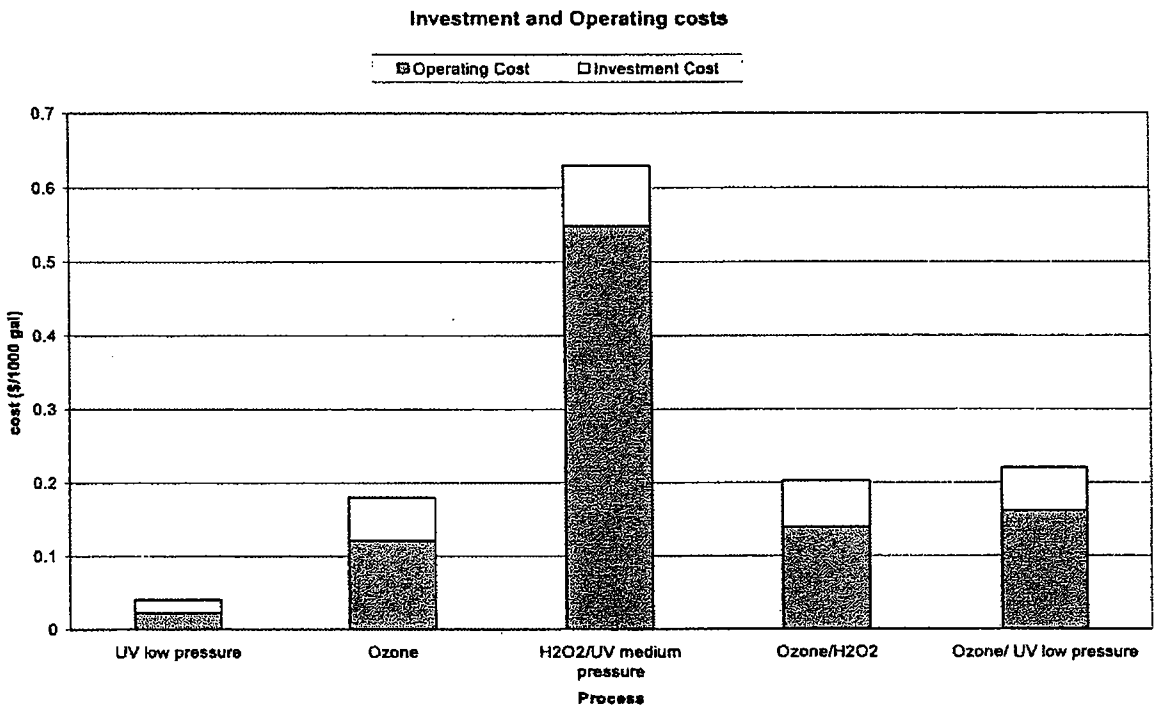

Figure 5. Comparison between UV, Ozone, and AOP Capital and Operating Costs (adapted from Ried et al., 2004).

Reverse Osmosis (RO) and Tight Nanofiltration (NF) Systems

These types of membranes can reliably remove most EDCs and PPCPs, depending on compound size and membrane properties. Microfiltration is required as a primer step. Besides the advantage of effective removal of micropollutants, DBPs are not created in the treatment process. However, RO and NF systems are very expensive and produce a concentrated reject stream that requires further treatment.

Adams et al. (2002) used a low-pressure RO system to remove antibiotics from distilled and river water. Removal rates in both cases were about 90%. With two and three RO units in series, removal rates increased to 99 and 99.9 percent, respectively.

Wintgens et al. (2004) showed that concentrations of E1, E2, and EE2 in MBR effluent could be reduced to very low levels using NF and RO. The effluent hormone concentrations from RO were extremely low, but not zero, and effluent concentrations from NF were slightly higher. Consequently, the hormone concentrations in the reject stream from the membrane processes were extremely high. Depending on the level of hormone concentrations ultimately deemed "insignificant" in the water environment, either NF or RO could be useful as a polishing step, but the concentrated reject stream will pose a new treatment/disposal challenge. RO and NF systems are usually not an economical option at WTPs (Adams et al., 2002), and are therefore not expected to be economical at WWTPs either.

DESIGNING FOR FLEXIBILITY

Future regulatory requirements are unknown at this time, though it is possible that limits on some EDCs may be included in wastewater effluent discharge permits in the future. Several advanced technologies, such as AOPs and RO, have been shown to successfully remove potential EDCs and PPCPs from water. Most of these options, however, involve significant capital and operating expenses that may not be justifiable at this time, since clear regulatory guidance is not available.

In long-range design plans, flexibility should be included to accommodate possible EDC regulations. Potential treatment strategies could be incorporated into existing layouts, and it is important to leave room, both on the site and within the hydraulic profile, for new equipment. The conditions and waste characteristics at every WWTP are unique, so design of the most feasible or cost-effective EDC control strategy will be case-specific. Process selection criteria such as space requirements, byproduct issues, and compatibility with existing facilities must be discussed. Pilot trials will be essential for an optimized design and confirmation that treatment goals can be met. Planning should favor processes and management strategies that will address not only the concern for EDCs, but other water quality goals as well. In this way, capital expenditure will have a broader basis than resolving this one issue that has an unclear outcome.

One option for consideration is the multiple-barrier approach for the protection of public health. This approach includes additional equipment for multiple modes of defense against contaminants (i.e., biological oxidation, physical separation, and chemical oxidation). This could mean the use of activated sludge, filtration, and AOP, or MBR followed by RO and disinfection/oxidation. Incorporation of MBR or integrated fixed film activated sludge into existing biological treatment systems should be considered for enhanced EDC removal where site constraints exist. The higher-level technologies could be added as necessary to meet future treatment requirements. The formation of DBPs can be minimized by strategic positioning of any advanced technologies in the treatment train (e.g., oxidation following filtration).

Though there are several utilities, particularly in the western U.S., that are already considering use of higher-level technologies for EDC or DBP control, it is important to remember that regulations for EDCs and PPCPs are not yet in place. Some utilities are trying to stay ahead of the curve by considering treatment options based on where they think federal or state regulations are headed. In other cases, they may be responding to local demand brought about by public perception of water contamination.

Example and Cost Estimate

The following example describes options that could be considered at a WWTP for enhanced reduction of potential EDCs. The first two options would involve upgrading the existing activated sludge basins to gain a significant amount of SRT; as mentioned previously, many chemicals of concern may be removed by providing adequate SRT. This amount of treatment might be sufficient to meet any new permit requirements. If a higher degree of treatment is required, however, one of several advanced treatment options may be added to suit the situation. Such higher-level tertiary treatment technologies use a powerful oxidation or straining step, and the associated expense is far greater. Table 2 shows a range of the equipment costs and operation and maintenance costs for each of the options, based on Black & Veatch design experience. The costs given for the AOPs do not match those shown on Figure 5, probably because of the differences in chemical and/or energy use and the equipment included. Additional considerations for each option follow Table 2.

Table 2. Equipment and O&M Costs for EDC Removal Options.

Process/Technology	Estimated Equipment Cost(1) ($/gal)	Estimated O&M Cost ($/1000 gal)
MBR	1.00 – 2.50	(2)
IFAS	0.20 – 0.30	(2)
Peroxone	0.40 – 0.80	0.40 -0.80
UV/Peroxide	0.40 -0 .60	0.30 – 0.50
MF/RO	1.65 - 3.74	0.60 - 1.00
MF/RO followed by UV/Peroxide	2.05– 4.34	0.90 – 1.50

(1) Does not include cost of construction.
(2) Separate costs not determined.

MBR and IFAS: These options maximize use of the existing facilities. Both have small footprints and can achieve high SRTs in small tank volumes. The consideration and use of MBR technology around the world is advancing rapidly, driven by the increasing need for high levels of treatment and/or small footprint technologies for both municipalities and industries. Most MBR installations are less than 10 years old; therefore, the design criteria for removing micropollutants using this technology are still evolving. Until recently, only a limited number of manufacturers have been offering this technology. Now, numerous MBR vendors offer systems with significantly different configurations, design approaches, and micropollutant removal efficiencies. In the event that a higher degree of treatment is needed in the future, MBR can also serve as the primer step for RO.

The IFAS process combines fixed-film and suspended activated sludge processes. Fixed film media is available from many manufacturers in the form of plastic elements, string systems, plastic webs, and sponges. Adding this media to existing aeration basins makes it possible to achieve nitrification and removal of micropollutants with less basin volume than would be required for a comparable single-stage activated sludge nitrification process. Further, the added media provides surface area for the growth of nitrifying bacteria without imposing excessive solids loadings on the final clarifiers, because the beneficial microbes remain attached to the media in the aeration basin.

Peroxone: Peroxone, or ozone/peroxide, has been used for a number of years to remove trace pollutants from groundwater. It has also been installed as part of a multiple-barrier approach at numerous potable water treatment facilities. Because of the hydroxyl radicals formed, peroxone has been found to be very effective for removal of DBPs. Costs are site-specific, depending on the flow rate and type of pollutant being removed.

UV/Peroxide: UV/peroxide has been shown to remove trace pollutants such as DBPs, toxic organics, NDMA, EDCs, and 1,4-dioxane. It forms hydroxyl radicals to oxidize the various pollutants. Carbon dioxide and water are the products of complete oxidation of the various pollutants. For some specific trace pollutants, only UV may be needed, though the UV doses would have to be unreasonably high to obtain appreciable removal of most EDCs or PPCPs. Of the AOP options, UV/peroxide may result in the lowest DBP formation. Pilot testing should be conducted to confirm costs Equipment costs for this option are the lowest of the advanced technologies, shown at about \$0.50 per gallon, but to put this in perspective, this means that the equipment cost for a 20 mgd facility may be as high as \$10 million, which does not even include the cost of the building.

MF/RO: Microfiltration followed by reverse osmosis has been used to remove trace pollutants from potable water. Additional research is being conducted to increase the throughput capacity of membrane systems. These types of systems will generally remove DBPs, EDCs, and PPCPs that have a molecular size larger than the molecular cutoff of the membrane system.

MF/RO plus UV/Peroxide: MF/RO followed by UV/peroxide is an example of a multi-barrier approach. Both processes can independently remove a variety of DBPs, EDCs, and PPCPs. Any trace amount that may pass through the membrane process is oxidized by UV/peroxide. As shown in Table 2, UV/peroxide is the most expensive option; however, it is also the most complete barrier for removing pollutants.

Figure 6 provides an example of how these and other options might be designed into an existing wastewater treatment system.

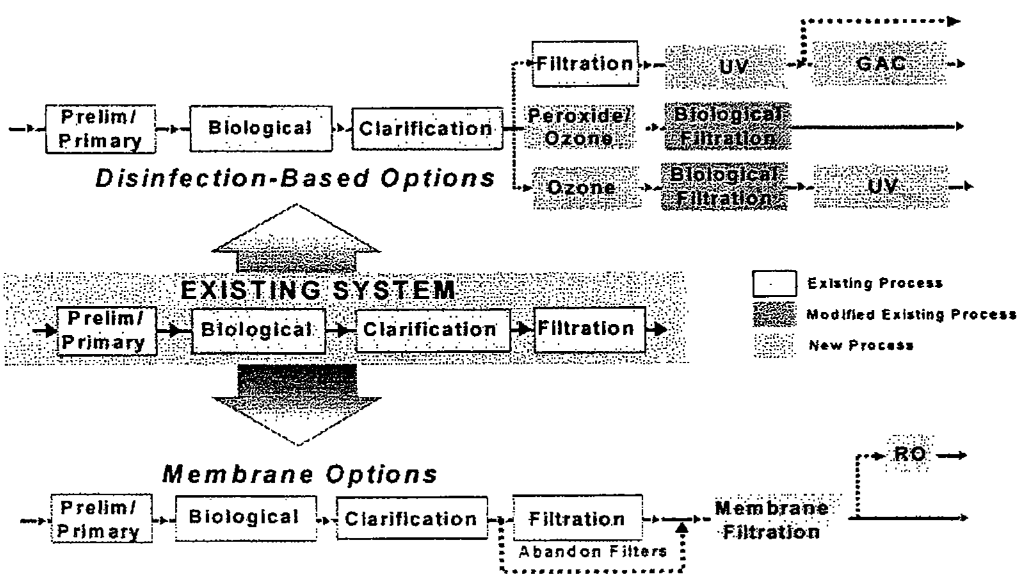

Figure 6. Designing for Flexibility at an Existing WWTP.

WHERE SHOULD TREATMENT EFFORT BE FOCUSED?

Effects of endocrine disruption on wildlife exposed to estrogenic and other chemicals in the water environment have been demonstrated over the past several years. The public has expressed concern about its safety, because the public drinking water sources may contain trace amounts of chemicals that have been shown to cause adverse health effects in fish and other aquatic organisms. Effects on human health cannot be easily extrapolated from effects on aquatic organisms, however, because aquatic organisms are subjected to continuous exposure to these chemicals, whereas human exposure is generally limited to the amount of water consumed. Further, aside from DBP concerns resulting from disinfection, public drinking water supplies have yet to be proven to be causing adverse effects to human health. While it has been shown that high-tech methods such as reverse osmosis and various advanced oxidation processes can remove many suspected EDCs with impressive efficiency, these methods are generally costly and do not solve the problem of environmental pollution if they are installed at the water treatment plant.

It has been demonstrated through many studies, Johnson et al. (2000), Ternes et al. (1999), and Baronti et al. (2000), to name a few, that activated sludge systems have the potential to remove many suspected EDCs to a fairly high degree. The biological process can likely be optimized to achieve an even higher degree of treatment as researchers further study the effects of SRT, HRT, and other parameters. Attempts to achieve a higher level of treatment with activated sludge should be made before resorting to advanced technologies for EDC removal at WWTPs that may be cost-prohibitive for many communities.

This is not to suggest that the current efficiencies of our WTPs be relaxed; the importance of minimizing DBPs and the contaminants that make their way into water sources through runoff, leaching, and other means is recognized. But based on our current knowledge, it seems logical that a major focus of EDC and PPCP removal should be at the WWTP. Removal of these pollutants from WWTP effluent may solve much of the apparent endocrine disruption problem in the water environment, in addition to providing a cleaner source for drinking water. New data may indicate that tighter controls on industry and agriculture/livestock operations should be required as well to make a more significant difference. Once the scientific community has identified "safe" levels of exposure for the affected organisms, any WWTP effluent limits on contaminants of concern can be targeted to support the health of the water environment.

CONCLUSIONS AND RECOMMENDATIONS

Though EDCs are currently not regulated in the U.S., the possibility exists that future regulations will be established for some EDCs in WWTP effluent. Processes are available to remove many, if not all, EDCs and PPCPs from wastewater. Since with adequate retention time, a biological treatment system may achieve complete biodegradation of many chemicals of concern, cost effective options for optimization of the activated sludge process should be explored before investing in advanced treatment technologies with high capital and O&M costs. The issue of by-product formation must be researched further, since chemical or biological oxidation can successfully eliminate a parent compound, only to produce potentially more hazardous breakdown products. The potential additive effects of some EDCs must also be considered in the design of any treatment system.

It is recommended that some degree of flexibility be included in long-term WWTP design to take into account the potential for new regulations on EDCs. Before specific process components can be recommended for treatment of emerging contaminants, however, the scientific community must identify the hazardous contaminants, determine their acceptable concentrations (singly and in combination), and establish standardized analytical methods for their detection. Various conventional and advanced technologies can be assessed for their removal capabilities, and it can be determined whether any additional processes are required at WWTPs to achieve necessary removals.

ACKNOWLEDGEMENTS

The authors would like to thank Lisa Agee for her assistance with the manuscript and figures and Michael Sharp for tracking down the articles, reports, and papers referenced.

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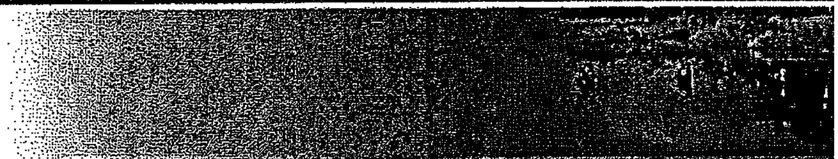
Policy



Policies

Effluent Reuse

Definition

There is no one universal definition as to what effluent reuse comprises but in general it is considered to cover the reuse of wastewater for what ever purpose which may or may not involve treatment.

Wastewater can comprise:

- effluent from municipal sewage works
- waste water from industrial processes
- wastewater from household properties

Reuse should comprise:

- potable water supply
- non potable water supply
- industrial process water
- replenishment of water resources
- irrigation water

Existing Arrangements (UK)

The reuse of effluent to replenish rivers has occurred ever since the introduction of municipal wastewater treatment works. As an indirect consequence of this many lowland storage reservoirs, which rely on abstraction from rivers, will comprise a proportion of effluent. This is often referred to as the indirect use of effluent.

More recently the direct reuse of effluent from industrial processing for further industrial use has been practised. In some circumstances effluent from municipal wastewater treatment works has been used.

There are now examples of wastewater from household use, such as sink and bathrooms (grey water), being re-used as cistern flush water. There has currently been only one example of effluent from all household use (black water) being used for cistern flushing.

Effluent is also used directly and indirectly for the irrigation of crops.

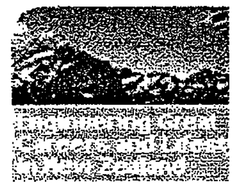
In some areas treated effluent from sewage works is used to replenish groundwaters.

There are cases where wastewater from a municipal sewage works is diverted specifically to replenish flows in watercourses

In one case this has allowed additional abstractions to help refill a reservoir which is used for public water supply. Although specifically engineered for the purpose in practice it is no different to historical arrangements referred to at the beginning of this section

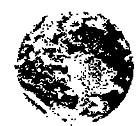
Possible Future Arrangements

search



CIWEM's educatio training initiativ

CIWEM Rivers and Coastal Group



CIWEM Factshee

Sustainable development principles are firmly on the political agenda. This includes the need to minimise the consumptive use of natural resources, such as water, but bearing in mind social, economic and environmental factors.

The EA reference in their regional and national strategies that effluent reuse schemes specifically engineered to enhance water resources could help bridge the gap between supply and demand, especially in the growth regions of the SE of England.

The greatest potential for reuse may be in areas where effluents are discharged to the sea at present, as they could be diverted inland to support river flow and increased abstraction.

Industry is keen to reduce their environmental impact and to reduce costs associated with water supply and effluent discharge. There are many cases, often promoted and reported by Envirowise (DTI/DEFRA), where recycling opportunities have delivered significant savings.

The market for household effluent reuse is growing slowly but green field and new build are ripe for purpose built effluent reuse facilities. Installation of greywater systems on existing individual properties has a long payback period and is not attractive using current technology, particularly for retrofitting existing houses.

Recycling technology is developing and, with membrane technology now well developed, water can be treated for specific reuse purposes.

Issues for Discussion

(a) Although effluent reuse has been practised indirectly for decades through the existing water cycle of abstractions and effluent returns to rivers, there is an underlying concern over schemes directly engineered for that purpose.

(b) The water industry contends that existing standards of effluent consenting (to meet environmental quality standards and Directives) and conventional drinking water treatment is sufficient to protect public health. However there are others who are concerned about the build up of toxins and other "exotics" such as endocrine disrupters through wastewater recycling.

(c) There are also perception issues. Recent anthropological studies have revealed that the general public do not like experiencing other peoples waste and would possibly be concerned if they were aware of even current practices of indirect recycling. As the process of consultation is now widely practised, and will be reinforced through the Water Framework Directive, then not only will new schemes be exposed but concerns may be raised over existing arrangements.

(d) From these concerns the issue of whether or not additional standards for effluent quality that is to be reused for potable water, may need to be considered. There may also be a need for additional treatment reliability to reduce the risk of failure and breakthrough of contaminants.

(e) Changes in the volumes of effluent discharged to rivers could change an environment which has been accustomed to the discharges. There could therefore be an environmental change.

(f) The desire to promote water recycling should be considered in a holistic sustainable way. It is recognised that treatment processes are energy intensive and hence their environmental footprint needs to be considered and compared with more traditional methods of matching demand and supply.

(g) A coherent policy for effluent reuse is needed. This should define the responsibilities of DEFRA, the Environment Agency, and the Water Industry, and establish consistency of view between them. Standards should be realistic and attainable at reasonable cost, while still protecting public health, and protecting against adverse environmental impacts. Good science is needed to see if these ideals can be achieved.

Ed Smith and Derek Giles

L.A. Times Article Reprint
Water Recycling

- "the practice is on the rise ..."
- "projects ... will soon boost usage another 20% ..."
- "independent sewer and water utilities are ... merging."
- "officials estimate that it will cost ..."
- "Outreach to community groups ..."
- "No health problems have been reported ..."
- "to help endangered species ..."
- "a futuristic urban environment ..."

Los Angeles Times

Sunday Final

SUNDAY, AUGUST 17, 1997

Reclaimed Waste Water May Ease State's Thirst

Recycling: Despite 'yuck' factor, the practice is on the rise. San Diego is at cutting edge of what backers see as wave of future sending treated sewage back to the tap.

By JILL LEOVY
TIMES STAFF WRITER

In an effort to help quench California's unending thirst, officials are set to embark on unusual plans to turn treated sewage into drinking water.

San Diego is preparing to pipe water from the local sewage treatment plant directly into the city's second-largest drinking water reservoir.

Communities in the South Bay and Livermore, Calif., have recently joined the Orange County Water District in approving the injection of treated waste water into underground supplies used for tap water.

Water recovered from treated sewage has already become an integral part of the state's water supply. Despite high costs and worries over public squeamishness, the use of "recycled" water has increased about 30% in the last, year.

It is being used to make snow for ski areas, grow hay, make newsprint and concrete, dye carpets, hose down landfills and fill cooling towers in oil refineries.

Critics counter that the process is expensive and may make many public water-drinkers opt for the bottled variety or turn up the noses and say, "Yuck!"

But Paul Gagliardo of San Diego's Metropolitan Wastewater Department believes that his city is about to begin "pioneering a process ... to get people comfortable with the idea of drinking treated sewage."

California spews enough sewage into the ocean to meet a third to half of the state's urban water needs, Gagliardo said.

He is among a small group of zealots who dream of a future in which Californians drink sewage, processed to levels similar to bottled water.

Those views are shared by crusaders such as Santa Rosa organic farmer Lawrence Jaffe, who sells vegetables nourished with recycled water using the slogan "Close the loop," and Bahman Sheikh, a San Francisco consultant who likes to make the poin gulping down a long, cool glass of tertiary effluent.

There is no reason to flush toilets with pure water from Mono Basin," Sheikh said.

Water reclamation in some form has been going on for a long time. Irvine is the granddaddy of reclamation in California, setting a as yet unrealized goal in the early 1960s of recycling all its sewage water for non-potable uses. The Irvine Ranch Water District is still a leader, recently introducing reclaimed water to office air-conditioning systems.

top

WATER: Recycling Seen as Drought-Proof Way to Meet Growing Needs

The surge in water recycling has been propelled by improvements in technology, regulatory changes and a new crop of government subsidies for reclamation systems.

Today, California uses more than 450,000 acre-feet of reclaimed water annually. That is equal to about one-and-a-half Castaic Lakes, or the water consumed by two-thirds of Los Angeles in a year.

Projects now under construction will soon boost usage another 20%, according to the California Water Resources Board.

For all that, reclaimed water is less than 2% of the water used by farms and cities in California.

But advocates predict that will change, and cite models such as Irvine Ranch, where nearly a quarter of the water comes from treated sewage.

"It's like throwing money away if you just let this water go," said Jaffe, who spent his law school student loan to start an organic farm in the shadow of San Jose's treatment plant, where he grows vegetables using local compost and reclaimed water.

People such as Jaffe are fond of pointing out that while the state's reliance on water from the Sierra Nevada and the Colorado River is coming under attack, recycled water is the one source in California that is growing.

It is also drought-proof.

And because reclaimed water is produced locally by cities, it is also largely politics-proof. "No one can take it away from us," said Earle Hartling, water reuse coordinator of the Sanitation Districts of Los Angeles.

As a result, the uses of reclaimed water have multiplied so quickly that health officials have been scrambling to keep up. New regulations should be completed this year, said David Spath, chief of the division of drinking water with the state Department of Health Services.

The rules are expected to soon eliminate one of the ironies of this emerging water supply: its classification as a hazardous wast

Until then, plant workers must fill out lengthy reports when they spill reclaimed water, even if it is drinking water quality.

Despite the regulatory confusion, recycled water is being used in a number of ways

It has been proposed as a source of water to do laundry at San Quentin Prison. It is even being pumped under the sea floor off Long Beach to keep the harbor area from sinking due to oil extraction. The oil companies have used tap water for this purpose--enough to supply 20,000 people with water for a year--but are switching to reclaimed water

top

Throughout the state, independent sewer and water utilities are cooperating, and in the case of San Francisco, merging. Their engineers are taking on dual roles, and converting acre-feet--the conventional measure of sewage

In short, water agencies now see waste water as a resource and incorporate it into long-term supply plans

Once chiefly an issue of handling sewage, reclaimed water is "moving over to the other side of the ledger," said Lou Garcia, director of environmental services for San Jose, which plans to divert nearly 40% of its sewage stream to water supplies in comi years.

The West Basin Municipal Water District, which serves communities from West Hollywood to Palos Verdes Estates, has made water recycling the linchpin of its plan to cut dependence on imported water in half over the next 20 years, largely by converting the region's water-hungry oil refineries to recycled water.

The purest of West Basin's recycled water is being injected into the ground to protect drinking water supplies from seeping seawater. The plan will simultaneously cut sewage discharge into the bay 25%.

San Diego leads the state. Officials decided to covert waste into drinking water after court rulings forced the city to better treat it sewage to protect the ocean. The result is water similar to what most people would consider good for a swimming lake.

Rather than dump that water back into the ocean, San Diego has designed a $150-million system to add another level of treatment, bring the water up to the quality of extra-pure tap water, and pump it to the city's San Vicente drinking water reservoi

The water will be mixed into imported water supplies, comprising up to 10% of the supply by 2001.

"It's a very significant step," said Ken Weinberg, water resources supervisor for the San Diego County Water Authority. "We are creating a new source of water."

WATER: Use of Treated Sewage on Rise in State

The technology for recycled water has developed to where San Diego's water will supposedly be 10 times purer than tap water, Gagliardo said.

State health officials have already approved San Diego's plan, developing a new set of guidelines for the purpose because non exist. The water will be fine to drink, they say. The only worry is breakdowns in the system, so duplicate safeguards have been built in, Spath said.

top

San Diego officials estimate that it will cost about $600 per acre-foot to produce drinking water from waste water, about 30% higher than the cost of purchasing water from the Metropolitan Water District. They acknowledge that figure is fuzzy, however, because it includes federal subsidies and is counted against current sewage treatment costs.

And some San Diegans contend that it would be better spent on developing other water sources: "If you are willing to spend tha kind of money, you could flood the city of San Diego," said Elmer Keen, a retired geographer and critic of the project.

But supporters counter that the cost of recycled water, although expensive, is still far less than the cost of desalinating water or building dams. "It's competitive in my book when compared to other new sources," said Peter MacLaggan executive director of Water Reuse Assn. of California.

San Diego officials are keenly aware of how easily public perception of the project could go awry. "This issue," said one advoc Dr. Rosemarie Marshall Johnson, "gets everybody in a very personal way."

The city conducted focus groups to test monikers for the water, and ultimately chose "repurified" over "recycled," which it seem left too much to the imagination.

top

Outreach to community groups came next, with officials gingerly pointing out that the city's existing water source, drawn from the Colorado River, contains sewage that has been treated and discharged by cities upriver, such as Las Vegas.

"There are some people who find this abhorrent," Gagliardo said. "But we are already drinking discharged waste water. This is ju throwing a lot of technology at it and doing it faster."

Across the state, similar public relations efforts are underway, with water agencies gently seeking to tell the public that they are using a new source of water that's quite close to home.

"All water has gone through countless other organisms before it gets to us," said Hartling. "Dinosaurs, fish, humans–some a lot more recently than we would like to think."

"It's a delicate balance," said Steve Kasower, water recycling specialist with the state Water Resources Board. "It's important the public understands this and doesn't get upset by fear-mongers ... But, dirty or clean, water is just molecules of H_2O with stuff floating between them.

Public acceptance for water recycling is not without precedent.

top

In Northern Virginia, a sewage utility has been treating waste water so that it meets drinking water standards for 20 years and releasing it into the Occoquan Reservoir in an unusual project similar to what San Diego Plans. No health problems have been reported.

At the most advanced sewage treatment facilities today, utilities employ reverse osmosis and microfilter, devices that involve pressing water through microscopic membranes, similar to what is used at bottled water companies such as Arrowhead Water.

Elsewhere in the state, environmental regulation has also spurred new efforts at reclamation.

San Jose is one example. The city is under pressure to reduce the sewage it dumps into South San Francisco Bay, not because the discharge is poisoning anything, but because it is so high quality that it is converting natural saltwater marshes into freshwat ones.

"In effect, the water is too clean," said Steven Ritchie of the San Francisco Public Utilities Commission.

top

With bullrushes springing up in the bay where pickleweed once grew, and pressure mounting to do something to help endangered saltwater species, it was only a matter of time before cities like San Jose came to view their sewage as an enticing supply of freshwater, Ritchie said.

San Jose now has a $140-million reclamation system under construction that will deliver reclaimed water to parks, farms and industries in Silicon Valley, said Garcia, the city's environmental services director.

Some areas are even using reclaimed sewage water to upgrade the purity of their conventional water supplies

Monterey Regional Water Pollution Control Agency will unveil a $75-million project next month that will free farmers from dependence on wells that have grown too salty

More than 12,000 acres will be served, making the project an unprecedented experiment in large-scale use of reclaimed water fo agriculture, said the agency's Keith Israel

Since statewide more than three quarters of urban water is used for things other than drinking, the most optimistic activists predi that someday 20% or even 40% would come from treated waste

top

"Toilet to tap" is the phrase that they use to denote a futuristic urban environment in which treated waste water would be transferred directly to drinking water pipes.

Such a system would require new technology to instantaneously detect germs in treated water. But some reclamation enthusias still see it as inevitable.

The very thought seems to make Spath, of the state health department, uncomfortable. "The time for that is not now, I will tell yc that," he said

Even the strongest advocates sense that the quick turnover of water from sewers to faucets may be a bit to dicey to win wide public acceptance.

"I forbid you to print this," said Orange County reclamation advocate and farmer Charles Peltzer, while expounding ideas for mixing reclaimed water into public drinking water. "The public isn't ready to hear it."

Already, one water recycling plan has run afoul of the public: Three years ago, the Upper San Gabriel Valley Municipal Water District was forced to scale back a plan to replenish ground water with recycled water because Miller Brewing Co. voiced fears that the project might taint its nearby wells.

Other attempts to gauge public reaction have shown conflicting results. A few years ago in Denver, water agency officials conducted focus groups to find out how the public might feel about reusing waste water for drinking. They found to their surprise that many people would rather not think too much about where their water comes from. "They wanted us to just get on with it," said Jane Earle, of Denver Water.

In San Diego, similar consumer studies found that one people were briefed on water supply issues and treatment methods, they usually accepted the idea of recycling readily.

"(But) and initial reaction we hear frequently, 'Yuck,'" said cc consultant Sara M. Katz, who performed the studies.

Still, Jaffe, the Santa Rosa farmer predicts that reclaimed water will follow the same path as compost in the 1980s.

"No one says 'yuck' about compost anymore. It's mainstream. They make jokes about it on sitcoms. That's how reclaimed water should be. Not be exceptional, exciting or controversial. It should be normal."

top

WATER ENVIRONMENT LABORATORY

SOLUTIONS

COVERING ANALYTICAL METHODS AND PRACTICES

Emerging Environmental Contaminants

Drugs and other chemicals are a growing challenge to water quality

Mary E. Sadler and Jane P. Staveley

Environmental chemists are using increasingly sophisticated analytical techniques to investigate the presence of previously undetected contaminants in surface waters. These emerging environmental contaminants (EECs) include thousands of chemical substances that have heretofore been largely outside the scope of monitoring and regulation in ambient waters.

These chemicals are not found on the priority pollutant list. They are, however, constantly being discharged into the aquatic environment from point and nonpoint sources in amounts believed to rival those of fertilizers and agricultural chemicals. Recently, EECs have received significant coverage in scientific journals as well as the popular press, along with speculation about their possible effects on human health and ecological processes.

There is no accepted or defined list of EECs. However, broad subcategories (see Table 1, p. 3) include veterinary and human antibiotics, prescription drugs (codeine, antiasthmatics, and antacids), nonprescription drugs (acetaminophen, ibuprofen, and caffeine), steroids and hormones (cholesterol and synthetic and natural estrogenic compounds), and organic wastewater contaminants (plastics, pesticides, detergents, fragrances, antioxidants, and antimicrobial disinfectants). Some of these chemicals have been recognized as endocrine disruptors. Research suggests that the effects of certain EECs on the endocrine system are elicited at extremely low concentrations, hence the concern for endocrine-active substances in the environment.

The detection of an EEC is not inherently or necessarily equivalent to risk to human health or the natural environment. Both exposure and toxicity are necessary to constitute a risk. In addition, people and aquatic organisms are exposed to a variety of chemical, physical, and biological stressors, making it

continued on p. 2

Synthesize 'Ethics at the Bench'

Most people regard the results of chemical and biological tests as definitive, but environmental lab analysts know that, even with strictly regulated testing, shades of gray are more prevalent than black and white. Judgment calls are routine and necessary in a water and wastewater lab, but that does not make them simple.

To help analysts make appropriate decisions, several organizations offer codes of ethics. Some are simple lists of responsibilities, such as the *Code of Ethics for Water and Wastewater Operators and Laboratory Analysts* published by the Association of Boards of

continued on p. 6

IN THIS ISSUE

WATER ENVIRONMENT LABORATORY SOLUTIONS
COVERING ANALYTICAL METHODS AND PRACTICES

Editor: Steven Spicer
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Water Environment Laboratory Solutions (ISSN 1074-2972) is published 6 times/yr. © 2004 by the Water Environment Federation, 601 Wythe St., Alexandria, VA 22314 USA, 1-703-684-2400.

Subscriptions are $79/yr ($35 WEF members). Single copy price is $7.50. Editorial correspondence should be sent to the Editor. Send change of address (8 weeks advance notice) and claims for missing issues to Manager of Data Management.

difficult to interpret subtle effects and attribute them to a particular chemical detected at parts-per-trillion (ng/L) to parts-per-billion (µg/L) concentrations.

EEC Occurrence

The occurrence of pharmaceutically active compounds in the aquatic environment has been investigated in several studies in Austria, Brazil, Canada, Croatia, England, Germany, Greece, Italy, Spain, Switzerland, the Netherlands, and the United States. A summary of this research concludes that more than 80 compounds from various classes have been detected at concentrations up to the microgram-per-liter level in surface water, groundwater, and wastewater treatment plant effluent. To date, however, only a few instances of trace levels of these compounds have been found in drinking water. Figure 1 (p. 5) illustrates possible sources and pathways of EECs into the environment.

In March 2002, one of the most significant research papers to date on EECs in U.S. waters was published by the U.S. Geological Survey in *Environmental Science and Technology*. The USGS study sampled 139 streams for more than 95 wastewater contaminants during 1999 and 2000. USGS discovered that one or more of the analytes was found in 80% of the 139 sampled streams, 82 of 95 contaminants were detected at least once during the study, and 75% of the streams sampled contained more than one contaminant. A total of 33 of the 95 contaminants are known or suspected to show weak hormonal activity with potential endocrine disrupting properties, and all 33 were detected in at least one stream sample during the study. Measured concentrations of the contaminants were low, with few compounds exceeding drinking water guidelines, health advisories, or aquatic-life criteria where these values existed.

Health and Environmental Effects

Potential exposure pathways to surface water contaminants include direct contact, ingestion of water, and ingestion of food organisms containing the contaminant. If exposure can occur, the question to address is whether the magnitude, frequency, and duration of exposure are sufficient to produce an effect. In other words, is the EEC concentration high enough to cause effects, and do EECs occur often enough over a long enough period of time to produce effects?

One of the concerns about EECs is their potential for continuous input into surface waters. For example, when the general population uses pharmaceuticals, these substances (or their metabolites, which can be more or less biologically active) are then excreted, passing through wastewater treatment and maintaining a constant low level in the receiving water. Similarly, for veterinary products, a compound or its metabolites are excreted, and the resulting manure or slurry is released directly to the environment or applied to land, where the chemicals are subject to runoff or leaching.

Safe Dose?

A low concentration (nanograms per liter to micrograms per liter) of a particular drug in surface water is unlikely to represent a significant risk to humans, as the concentration is many orders of magnitude below the therapeutic dose. For most drugs, the therapeutic dose is based on extensive testing and includes safety factors to protect sensitive subpopulations. Using conservative assumptions, it has been estimated that lifetime consumption of a drug at the low concentrations observed in studies to date, through ingestion of drinking water at 2 L/d (0.5 gal/d), would lead to an exposure equivalent of only one or two therapeutic daily doses.

However, intentional human exposure to pharmaceutical and personal care products is structured. When receiving prescription medication or buying over-the-counter drugs, patients can be informed of [illegible]

Table 1 Emerging environmental contaminant categories	
CATEGORY	**CHEMICAL EXAMPLES**
Human and veterinary antibiotics	Tetracycline, ciprofloxacin
Prescription drugs	Codeine, antiasthmatics, antacids, antidepressants, blood lipid regulators, antiepileptics, diclofenac[1]
Nonprescription drugs	Ibuprofen, acetaminophen, caffeine, aspirin
Steroids and hormones	Estrogenic compounds (estradiol, mestranol, testosterone), cholesterol
Plastics	Bisphenol A[2]
Detergents	Nonylphenol and octylphenol[3]
Antimicrobial disinfectants	Triclosan
Other	Fragrances, antioxidants

[1] Analgesic and anti-inflammatory drug.
[2] Known endocrine disruptor.
[3] Suspected of being hormonally active.

clude the use of certain drugs or be advised of potential drug interactions. Conversely, in surface water EEC contamination, the public is exposed unintentionally to a mix of various unknown contaminants during a long period of time that may potentially include sensitive periods. In addition, sensitive subpopulations — such as people with compromised immune systems or allergies — may be exposed.

While human pharmaceuticals and personal care products tend to undergo centralized wastewater treatment, veterinary products are released into the environment with minimal or no treatment. Thus, although the EEC concentrations in surface water may be extremely low and the potential for risk to human health is probably minimal, additional investigation certainly is warranted.

Ecological Effects

Of more concern is the potential risk to ecological receptors. Much less is known about the effects of EECs on aquatic organisms, but existing data indicate that aquatic life can be quite sensitive at least to some contaminants. While the amount of information required to secure regulatory approval for a new drug is vast, most of this information focuses on effects (both intended and side effects) on the user. The requirements for data on potential ecological effects vary considerably, depending on the relevant regulatory program. This may range from no data at all, to a base set of acute toxicity data on three aquatic species, to more extensive testing. While acute toxicity tests are good screening tools, they are insufficient for identifying subtle effects (on reproduction, growth, development, or hormonal homeostasis) that ultimately and significantly influence the aquatic ecosystem.

For example, hormones affect numerous physiological processes in both vertebrates and invertebrates. Female rainbow trout produce high concentrations of a protein called vitellogenin, a precursor of egg yolk. The occurrence of vitellogenin in male fish is an indicator of exposure to estrogen, and this response has been observed in male rainbow trout exposed to the biodegradation products of alkylphenol polyethoxylates, a major group of nonionic surfactants. Also, antidepressants appear to cause endocrine disruption in fingernail clams that affects reproductive processes. Thus, evidence is accumulating that the basic ecotoxicology tests are not identifying sublethal effects that could occur in aquatic animals.

Even less is known about the effects of EEC combinations that are likely to occur in the environment. The first study to investigate mixtures of pharmaceuticals in aquatic ecosystems found that a mixture of the painkiller ibuprofen, the antidepressant fluoxetine, and the antibiotic ciprofloxacin had significant effects on experimental microcosms. The microcosms, containing bacteria, zooplankton, phytoplankton, plants, and fish, were dosed with low, medium, and high concentrations of the mixture and observed for 35 days. The medium- and high-dose microcosms showed an increased abundance of phytoplankton and zooplankton, but community diversity decreased, and toxicity was observed in duckweed and sunfish. Although the drug concentrations used in the study were orders of magnitude higher than those reported in the environment, the effects were significant.

Wastewater Treatment Effects

Most of the literature available on pharmaceuticals in the environment deals with detection in the aquatic environment and not the environmental fate subsequent to treatment and release. Research data on pharmaceuticals in drinking water, surface water, and wastewater treatment effluent are inconsistent with respect to the removal efficiencies of different contaminants under different treatment schemes. More than 80 pharmaceutical compounds and their metabolites have been detected at very low levels in municipal wastewater treatment effluents and surface waters in Europe. Pharmaceutical compounds also have been detected in groundwater, particularly in areas potentially contaminated by landfill leachate or manufacturing residues. Other research has suggested that ozonation and membrane filtration will remove pharmaceuticals from drinking water, surface water, or wastewater effluent. Table 2 (below) lists several categories of pharmaceutical contaminants and treatments that have been studied extensively in Europe.

Minimal data exist on the removal of pharmaceuticals as a result of primary, secondary, or advanced wastewater treatment. A 1981 study on the ability of 14 wastewater treatment plants to remove endogenous and synthetic estrogens found that 5% to 25% of synthetic estrogens was removed by facilities using primary treatment and 20% to 40% of synthetic estrogen was removed by those using secondary treatment. Between 35% and 55% of natural hormones were removed by primary treatment, and 50% to 70% were removed by secondary treatment. Research at the University of California at Berkeley on estrogen removal found that the removal efficiencies of microfiltration and filtration were nearly the same. Reverse osmosis achieved the highest rate of estrogen removal; however, some estrogens persisted in the effluent. A paper published in 2003 by Snyder et al. (*Environmental Engineering Science*, Vol. 20, No. 5) provides an excellent review of treatment technologies and potential removal efficiencies.

Path to EEC Regulation

In the United States, there are two pri-

Table 2
Summary of European pharmaceutical research

CONTAMINANT	TREATMENT TECHNOLOGY	LOCATION	REMOVAL EFFICIENCY	PRINCIPAL INVESTIGATOR
Salicylic acid	Wastewater effluent	Activated sludge	88% removal	Heberer
Diclofenac (analgesic and anti-inflammatory drug)	Wastewater effluent	Activated sludge	17% removal	Heberer
	Wastewater effluent	Activated sludge	69% removal	Buser et al.
	Drinking water	Bank filtration	Trace amounts in effluent	Verstraeten
	Drinking water	Ozone		Zweiner & Frimmel
	Drinking water	Membrane filtration	Trace amounts in effluent	Heberer; Sedlak
	Wastewater effluent	Membrane filtration	Trace amounts in effluent	Heberer; Sedlak
Ibuprofen	Wastewater effluent	Activated sludge	Significant removal, except for one metabolite	Stumpf et al.
	Wastewater effluent	Activated sludge	Significant removal (96% to 99.9%), includes all metabolites	Buser et al.
Antibiotics	Drinking water	Bank filtration	Significant removal	Heberer et al.
	Surface water	Raw water	Trace amounts in effluent	
	Wastewater effluent	Activated sludge	Trace amounts in effluent	Hirsch et al.
Antiepileptic drugs	Wastewater effluent	Activated sludge	< 10%	
	Drinking water	Bank filtration	No removal	Kuehn & Mueller; Brauch et al.; Heberer et al.
Beta blockers	Wastewater effluent	Activated sludge	Trace amounts in effluent	Hirsch et al.
Blood lipid regulators	Drinking water	Bank filtration	No removal, but metabolites removed	Scheytt et al.
Chemotherapy drugs	Wastewater effluent	Activated sludge	No removal	Kummerere et al.
Contraceptives	Wastewater effluent		Trace amounts in effluent	Desbrow et al.; Belfroid et al.; Spendgler et al.; Ternes et al.; Alder et al.
	Wastewater effluent	Activated sludge	85% removal of estradiol	Baronit et al.
	Wastewater effluent	Activated sludge	No removal of estradiol	Ternes et al.
	Groundwater		Positive detection	Adler et al.
	Drinking water		Positive detection	Adler et al.

[illegible]

mary avenues for the regulation of chemicals in the environment: premarket and postmarket. In premarket regulation, chemicals are evaluated for their potential risk to human and environmental receptors before they are approved for use. In postmarket regulation, chemicals are evaluated after they have been used and released into the environment.

Several EECs already are subject to premarket regulation. The U.S. Environmental Protection Agency (EPA) regulates chemicals that are classified as pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act and other chemicals under the Toxic Substances Control Act. These statutes require the manufacturer to provide information on the fate and effects of chemicals, thereby allowing EPA to perform a risk assessment that determines how a product may be used. Drugs are regulated under the Federal Food, Drug, and Cosmetic Act, administered by the U.S. Food and Drug Administration (FDA). FDA approval of a new drug is considered a major federal action significantly affecting the environment, and thus the provisions of the National Environmental Policy Act are triggered, requiring preparation of an environmental assessment, which evaluates the fate and effect of any new drug to the environment. However, FDA policy includes a provision for a drug's approval without an environmental assessment if the drug concentration is less than 1 µg/L.

The approach differs in Europe, where a tiered environmental risk assessment scheme has been proposed. The first tier consists of deriving a rough estimate of the predicted environmental concentration of a human pharmaceutical, based on predicted amounts used and specific removal rates in wastewater treatment or surface water. If this crude concentration is less than 0.01 µg/L and no environmental concerns are apparent, no further risk assessment is required. A tiered approach also has been developed in the European Union for veterinary medicinal products that considers the predicted environmental concentration in soil, surface water, and groundwater. Recently, Canada has implemented new requirements for ecological assessments of all new products regulated under its Food and Drugs Act.

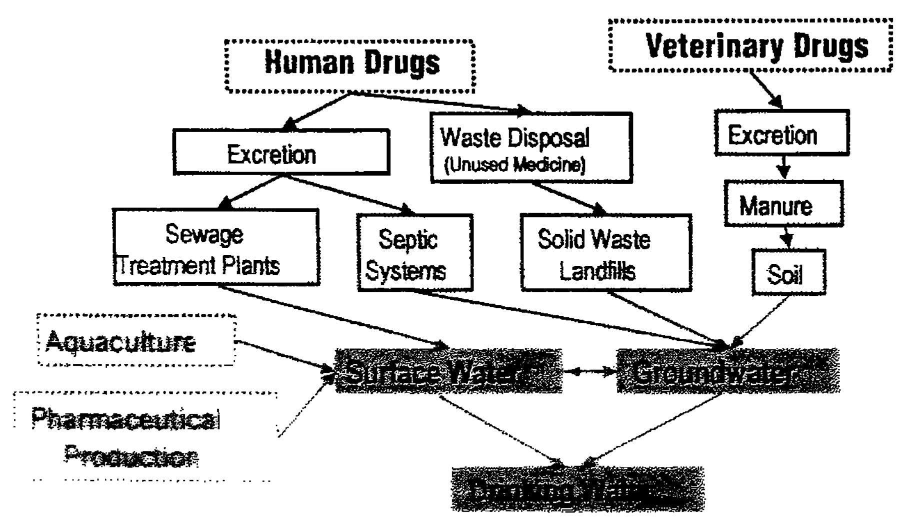
A significant shortcoming of existing approaches to assessing the environmental risks of EECs is that cumulative effects of contaminants affecting similar receptors are not considered. Consideration of cumulative effects is further complicated when chemicals have multiple uses and sources that fall under different regulatory programs. For instance, the antimicrobial compound triclosan is widely used in consumer and personal care products and is regulated by both FDA and EPA. However, at present, each agency evaluates triclosan independently, and thus the totality of sources, uses, and exposures in U.S. surface waters is not being assessed.

The specific provisions of current laws as well as differing agency policies and practices have led to a varying degree of premarket evaluation and regulation of EECs to date. Premarket risk assessments do not account for cumulative exposure and the risks of chemicals regulated by different statutes and agencies. Drugs and other FDA-regulated chemicals may be categorically excluded from an environmental risk assessment but may still contribute to cumulative exposure and risk. And after receiving initial regulatory approval, products receive typically little or no quantitative reassessment of exposure and risk (pesticides are the exception).

Need for More Postmarket Regulation

In the United States, once chemicals are present in surface water or groundwater, they are regulated under the Safe Drinking Water Act (SDWA) and Clean Water Act (CWA). Regulation under SDWA requires sufficient data to demonstrate that a contaminant is known or likely to occur at levels that may adversely affect human health and that regulating the contaminant will provide meaningful improvement to public health. Under CWA, states are required to establish water quality standards based on ambient water quality criteria, or the amount of a chemical that can be present and still allow the waterbody to support its designated

Figure 1
Sources and pathways of emerging environmental contaminants into the environment



uses. EPA has developed such criteria for a list of priority pollutants, but this list does not include most EECs.

Obviously, several regulatory issues must be addressed in the postmarket environment. The first question that should be asked is whether there are risks to human health or aquatic life that should be addressed through SDWA and CWA. There is a strong need for new analytical methods, sensitive ecological effects test methods, and environmental fate data, all of which preclude effective regulation at the present time.

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Ethics at the Bench *continued from p. 1*

Certification (Ames, Iowa). This code states that "water and wastewater operators and analysts must protect the public health and the environment by utilizing their knowledge, skill, and judgment to ensure safe and effective utility operation. To successfully achieve this goal an operator or analyst will:

- Comply with all applicable state, provincial, and federal laws and regulations.
- Upgrade and maintain the knowledge and skills necessary to properly perform the duties of an operator or analyst.
- Conduct all professional duties with integrity and the highest possible ethical standards."

Other ethics codes are more complex. The American Council of Independent Laboratories (ACIL; Washington, D.C.), for example, has developed an Environmental Laboratory Data Integrity Initiative (ELDII) that ACIL literature describes as requiring "a systems approach to ensuring that data is of known and documented quality." ACIL's 16-page policy statement on ELDII calls for such elements as a business ethics and data integrity policy, an ethics and compliance officer, a policy on enforcing business ethics and data integrity through disciplinary action, a mechanism for anonymously reporting alleged misconduct, and a means for internally investigating such reports.

Meanwhile, to help labs establish and maintain the best practices, the U.S. Environmental Protection Agency (EPA) maintains a specialized Web site — www.epa.gov/quality/bestlabs.html — that lists links to references, training, examples, and other online resources on best practices for laboratory quality systems.

Finding the Source

Are ethics codes necessary, or will basic data integrity and data quality guidelines catch most errors?

"There are always a small group of individuals that are bound and determined to cheat," said Jack Farrell, president and CEO of Analytical Excellence Inc. (Altamonte Springs, Fla.), a consulting firm specializing in laboratory ethics. "You know there's not a whole lot you can do about that except put practices in place to spot it early and handle it early."

Data integrity problems arise from several sources, such as management failures, quality system failures, inadequate training, individual laziness or ignorance, and greed — "essentially, cutting corners," Farrell said. Such corner-cutting typically involves data that have been manipulated to bypass a quality control requirement, he said. Manual integration of organics data is probably most notorious, but it happens in all lab areas and types of analyses, he noted.

"You're never going to be able to prevent these types of events from occurring," Farrell said, "but if you put a good, strong data integrity system — which is similar to a quality system — in place that promotes prevention, communication, and ethical decision-making, you have a better chance of minimizing these occurrences." When problems arise, he said, they can be handled by lower-level analysts and supervisors — a process called "ethics at the bench."

Fostering Trust

Part of Farrell's business is teaching classes for lab personnel that combine ethics theory with practical group exercises. For example, a group may be asked to create a statement of organizational values. Defining organizational values clearly and publicly can help an analyst make decisions, Farrell said, because when an ethical dilemma arises, the employee will know which factor — such as honesty or productivity — is most important.

Everyone needs to know how the reporting system works, Farrell said, and "a culture of integrity promotes open communication, has defined procedures, and tends to promote ethics at the bench."

In the absence of such a culture, the reporting system can break down, as may have been the case at the District of Columbia's Water and Sewer Authority (WASA) during the last few years. According to numerous press reports, an analyst allegedly told superiors that lead contamination levels exceeded federal drinking water limits long before the utility district took any remedial action or informed the public. When the analyst allegedly deserted WASA's reporting chain by reporting the elevated lead levels directly to EPA, she was fired and then sued the utility district, press reports said.

WASA [illegible], however, alleged that

United States
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Water Division Region IX - EPA 909-F-98-001

WATER RECYCLING AND REUSE: THE ENVIRONMENTAL BENEFITS

"Water recycling is a critical element for managing our water resources. Through water conservation and water recycling, we can meet environmental needs and still have sustainable development and a viable economy."

—*Felicia Marcus, Regional Administrator*

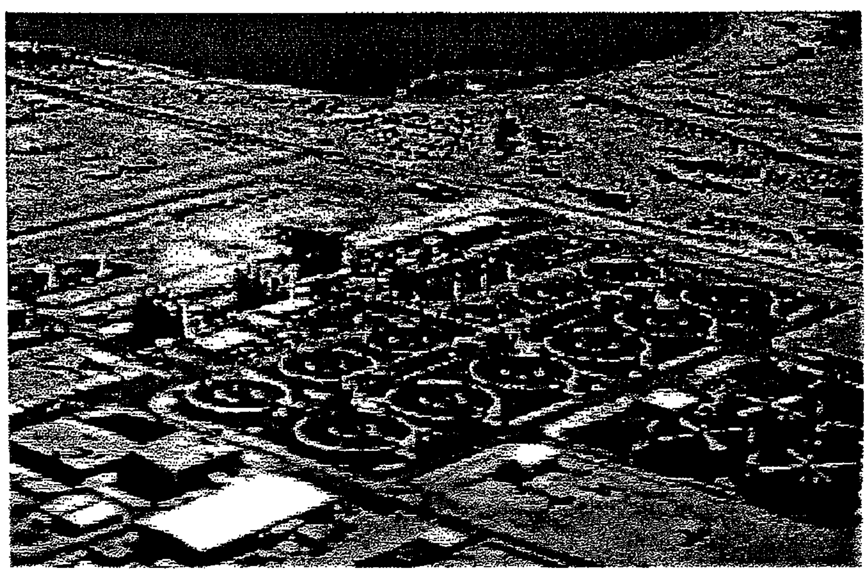
Front Cover—*The Experience at Koele Golf Course,* on the Island of Lanai, has used recycled water for irrigation since 1994. The pond shown is recycled water, as is all the water used to irrigate this world-class golf course in the state of Hawaii.

What Is Water Recycling?

Recycle: verb 1. a. To recover useful materials from garbage or waste.
b. To extract and reuse.

While recycling is a term generally applied to aluminum cans, glass bottles, and newspapers, water can be recycled as well. Water recycling is reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (referred to as ground water recharge). Water is sometimes recycled and reused onsite; for example, when an industrial facility recycles water used for cooling processes. A common type of recycled water is water that has been reclaimed from municipal wastewater, or sewage. The term water recycling is generally used synonymously with water reclamation and water reuse.

Through the natural water cycle, the earth has recycled and reused water for millions of years. Water recycling, though, generally refers to projects that use technology to speed up these natural processes. Water recycling is often characterized as "unplanned" or "planned." A common example of unplanned water recycling occurs when cities draw their water supplies from rivers, such as the Colorado River and the Mississippi River, that receive wastewater discharges upstream from those cities. Water from these rivers has been reused, treated, and piped into the water supply a number of times before the last downstream user withdraws the water. Planned projects are those that are developed with the goal of beneficially reusing a recycled water supply.



The Palo Verde Nuclear Generating Station, located near Phoenix, Arizona, uses recycled water for cooling purposes.

How Can Recycled Water Benefit Us?

Recycled water can satisfy most water demands, as long as it is adequately treated to ensure water quality appropriate for the use. Figure 1 shows types of treatment processes and suggested uses at each level of treatment. In uses where there is a greater chance of human exposure to the water, more treatment is required. As for any water source that is not properly treated, health problems could arise from drinking or being exposed to recycled water if it contains disease-causing organisms or other contaminants.

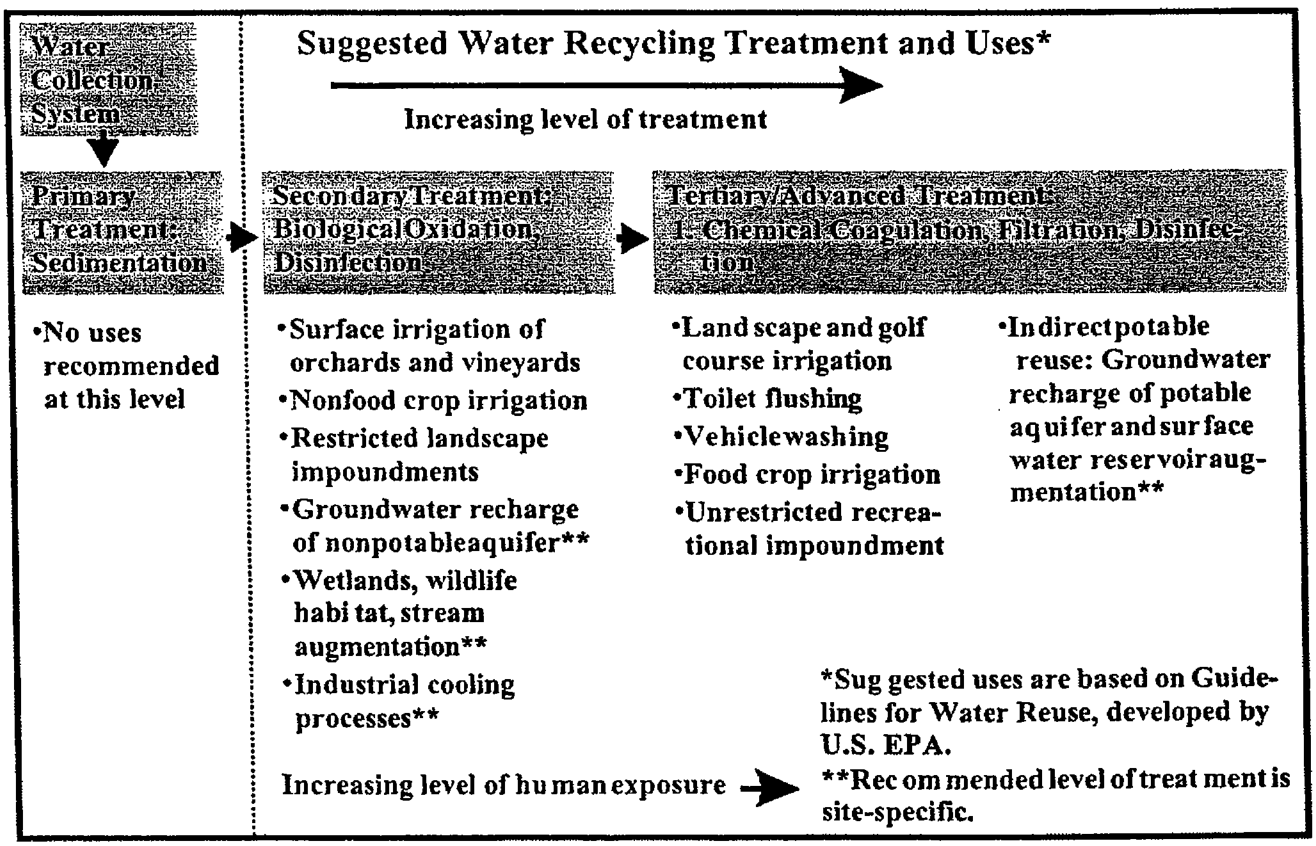
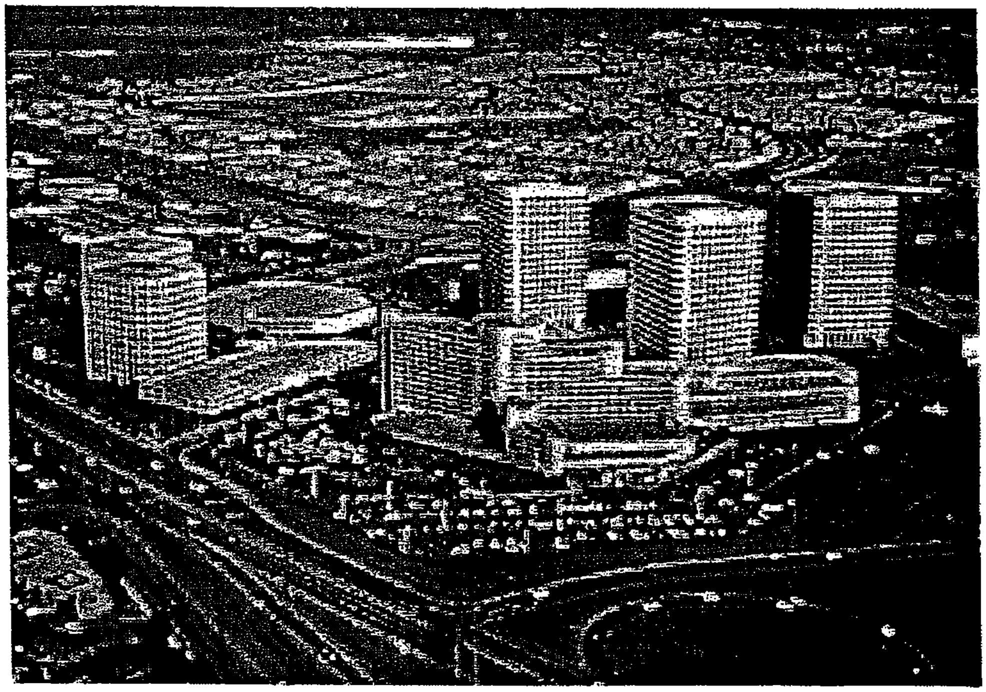


Figure 1: While there are some exceptions, wastewater in the United States is generally required to be treated to the secondary level. Some uses are recommended at this level, but many common uses of recycled water such as landscape irrigation generally require further treatment.

The US Environmental Protection Agency regulates many aspects of wastewater treatment and drinking water quality, and most states have established criteria or guidelines for the beneficial use of recycled water. In addition, in 1992, EPA developed a technical document entitled "Guidelines for Water Reuse," which contains such information as a summary of state requirements, and guidelines for the treatment and uses of recycled water. State and Federal regulatory oversight has successfully provided a framework to ensure the safety of the many water recycling projects that have been developed in the United States.



The Irvine Ranch Water District provides recycled water for toilet flushing in high rise buildings in Irvine, California. For new buildings over seven stories, the additional cost of providing a dual system added only 9% to the cost of plumbing.

Recycled water is most commonly used for nonpotable (not for drinking) purposes, such as agriculture, landscape, public parks, and golf course irrigation. Other nonpotable applications include cooling water for power plants and oil refineries, industrial process water for such facilities as paper mills and carpet dyers, toilet flushing, dust control, construction activities, concrete mixing, and artificial lakes.

Although most water recycling projects have been developed to meet nonpotable water demands, a number of projects use recycled water indirectly[1] for potable purposes. These projects include recharging ground water aquifers and augmenting surface water reservoirs with recycled water. In ground water recharge projects, recycled water can be spread or injected into ground water aquifers to augment ground water supplies, and to prevent salt water intrusion in coastal areas.

[1] *Indirect potable reuse refers to projects that discharge recycled water to a water body before reuse. Direct potable reuse is the use of recycled water for drinking directly after treatment. While direct potable reuse has been safely used in Namibia, Africa, it is not a generally accepted practice in the United States.*

For example, since 1976, the Water Factory 21 Direct Injection Project, located in Orange County, California, has been injecting highly treated recycled water into the aquifer to prevent salt water intrusion, while augmenting the potable ground water supply.

While numerous successful ground water recharge projects have operated for many years, planned augmentation of surface water reservoirs has been less common. However, there are some existing projects and others in the planning stages. For example, since 1978, the upper Occoquan Sewage Authority has been discharging recycled water into a stream above Occoquan Reservoir, a potable water supply source

For over 35 years, in the Montebello Forebay Ground Water Recharge Project, recycled water has been applied to the Rio Hondo spreading grounds to recharge a potable ground water aquifer in south-central Los Angeles County.

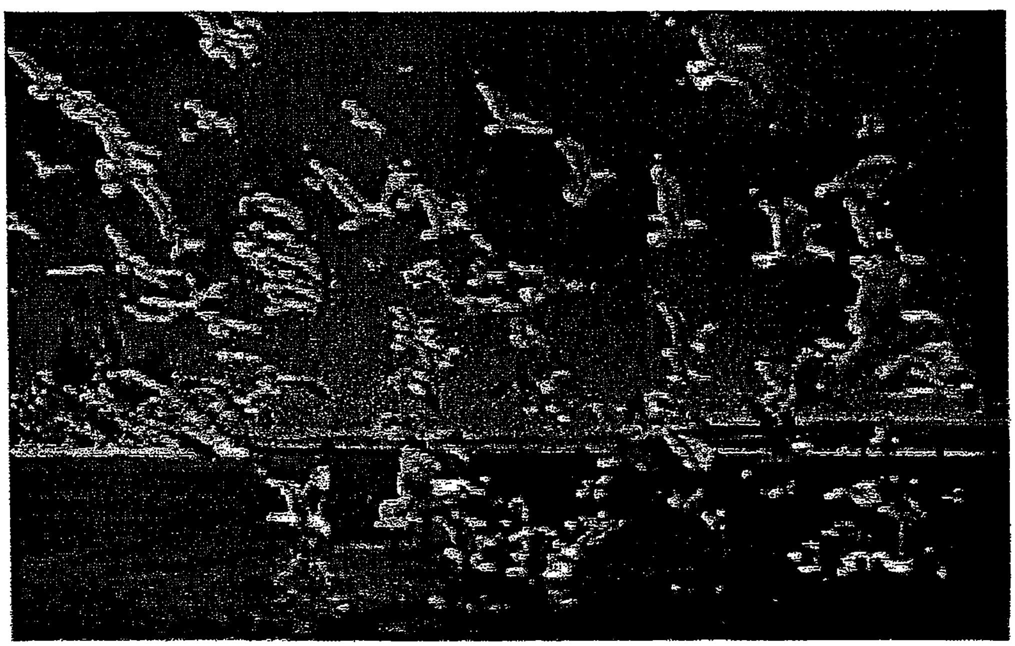
for Fairfax County, Virginia. In San Diego, California, the Water Repurification Project is currently being planned to augment a drinking water reservoir with 20,000 acre-feet per year of advanced treated recycled water.

What are the Environmental Benefits of Water Recycling?

In addition to providing a dependable, locally-controlled water supply, water recycling provides tremendous environmental benefits. By providing an additional source of water, water recycling can help us find ways to decrease the diversion of water from sensitive ecosystems. Other benefits include decreasing wastewater discharges and reducing and preventing pollution. Recycled water can also be used to create or enhance wetlands and riparian habitats.

Water recycling can decrease diversion of freshwater from sensitive ecosystems.

Plants, wildlife, and fish depend on sufficient water flows to their habitats to live and reproduce. The lack of adequate flow, as a result of diversion for agricultural, urban, and industrial purposes, can cause deterioration of water quality and ecosystem health. Water users can supplement their demands by using recycled water, which can free considerable amounts of water for the environment and increase flows to vital ecosystems.



In California, Mono Lake's water quality and natural resources were progressively declining from lack of stream flow. In 1994, the Los Angeles Department of Water and Power was required to stop diverting one-fifth of the water it historically exported from the basin. The development of water recycling projects in Los Angeles has provided a way to partially offset the loss of Mono Basin water and to allow the restoration of Mono Lake to move ahead.

Water recycling decreases discharge to sensitive water bodies.

In some cases, the impetus for water recycling comes not from a water supply need, but from a need to eliminate or decrease wastewater discharge to the ocean, an estuary, or a stream.

For example, high volumes of treated wastewater discharged from the San Jose/Santa Clara Water Pollution Control Plant into the south San Francisco Bay threatened the area's natural salt water marsh. In response, a $140 million recycling project was completed in 1997. The South Bay Water Recycling Program

Incline Village, Nevada, uses a constructed wetland to dispose of wastewater effluent, expand the existing wetland habitat for wildlife, and provide an educational experience for visitors.

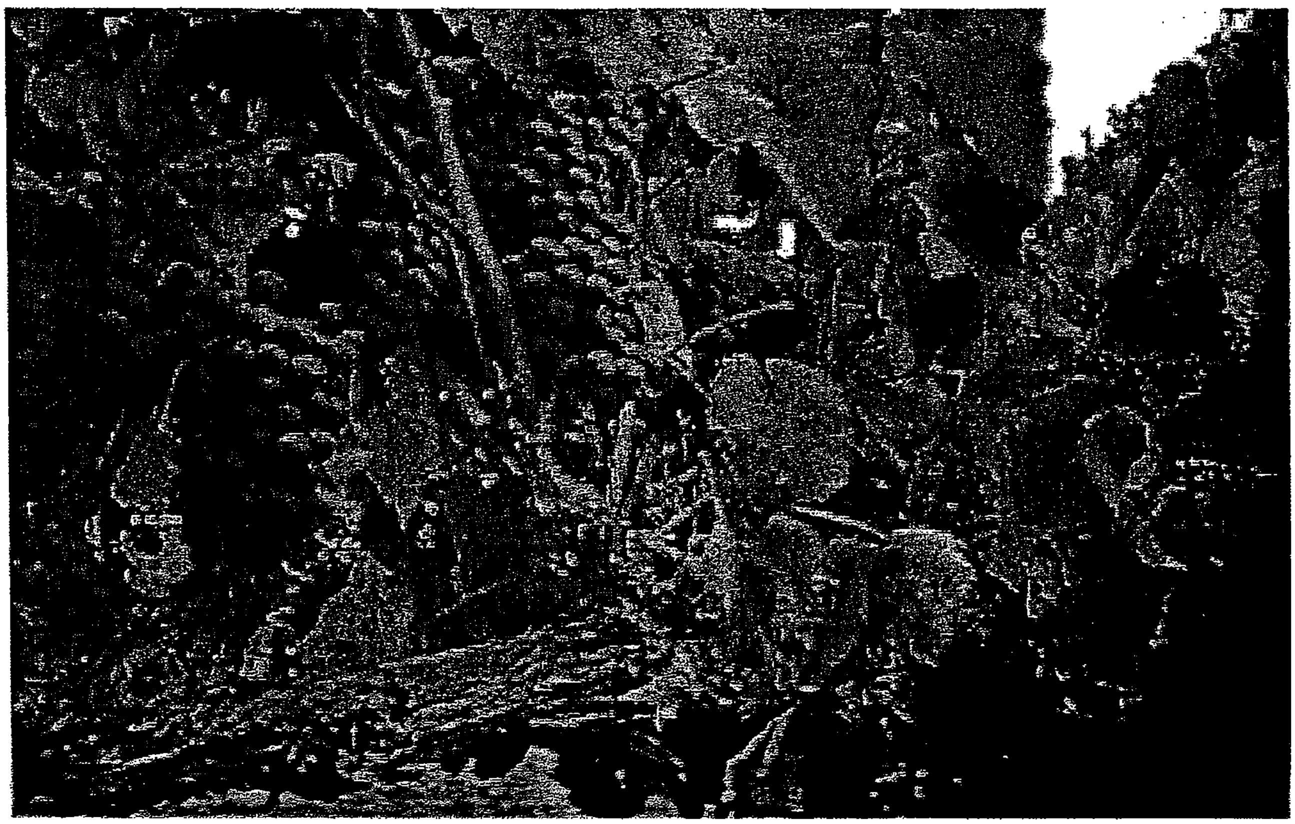
has the capacity to provide 21 million gallons per day of recycled water for use in irrigation and industry. By avoiding the conversion of salt water marsh to brackish marsh, the habitat for two endangered species can be protected.

Recycled water may be used to create or enhance wetlands and riparian (stream) habitats.

Wetlands provide many benefits which include wildlife and wildfowl habitat, water quality improvement, flood diminishment, and fisheries breeding grounds. For streams that have been impaired or dried from water diversion, water flow can be augmented with recycled water to sustain and improve the aquatic and wildlife habitat.

Water recycling can reduce and prevent pollution.

When pollutant discharges to oceans, rivers, and other water bodies are curtailed, the pollutant loadings to these bodies are decreased. Moreover, in some cases, substances that can be pollutants when discharged to a body of water can be beneficially reused for irrigation. For example, recycled water may contain higher levels of nutrients, such as nitrogen, than potable water. Application of recycled water for agricultural and landscape irrigation can provide an additional source of nutrients and lessen the need to apply synthetic fertilizers.



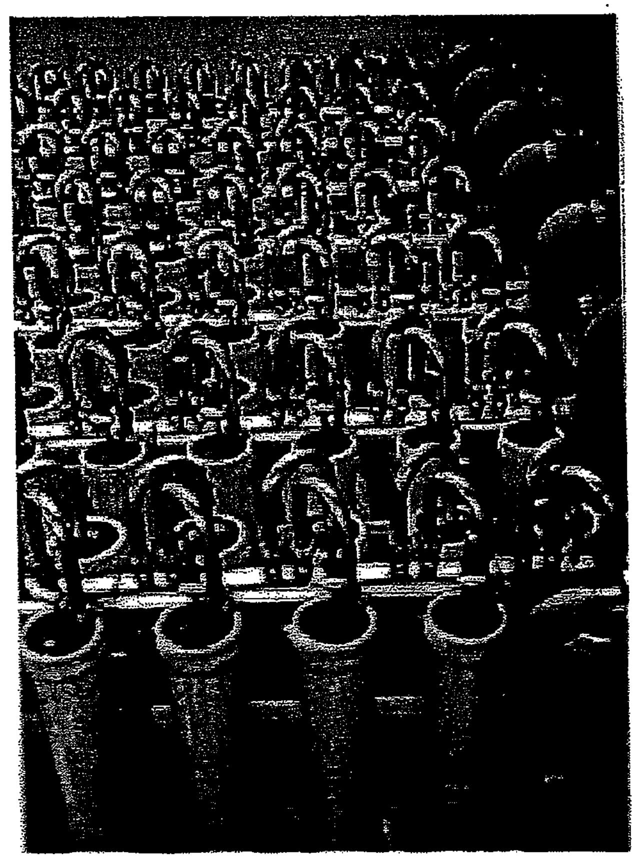
Recycled water has been used for a number of years to irrigate vineyards at California wineries, and this use is growing. Recently, Gallo Wineries and the City of Santa Rosa completed facilities for the irrigation of 350 acres of vineyards with recycled water from the Santa Rosa Subregional Water Reclamation System.

What Is The Future Of Water Recycling?

Water recycling has proven to be effective and successful in creating a new and reliable water supply, while not compromising public health. Nonpotable reuse is a widely accepted practice that will continue to grow. However, in many parts of the United States, the uses of recycled water are expanding in order to accommodate the needs of the environment and growing water supply demands. Advances in wastewater treatment technology and health studies of indirect potable reuse have led many to predict that planned indirect potable reuse will soon become more common.

While water recycling is a sustainable approach and can be cost-effective in the long term, the treatment of wastewater for reuse and the installation of distribution systems can be initially expensive compared to such water supply alternatives as imported water or ground water. Institutional barriers, as well as varying agency priorities, can make it difficult to implement water recycling projects. Finally, early in the planning process, agencies must implement public outreach to address any concerns and to keep the public involved in the planning process.

As water demands and environmental needs grow, water recycling will play a greater role in our overall water supply. By working together to overcome obstacles, water recycling, along with water conservation, can help us to conserve and sustainably manage our vital water resources.



At West Basin Wastewater Treatment Plant in California, reverse osmosis, an advanced treatment process, is used to [illegible]

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EPA Material:

Guidelines for Water Reuse. US EPA Office of Technology Transfer and Regulatory Support. EPA/625/R-92/004. September 1992.

Municipal Wastewater Reuse: Selected Readings on Water Reuse. Office of Water (WH-595) EPA 430/09-91-002. September, 1991.

Other related literature and videos:

Layperson's Guide to Water Recycling and Reuse, published in 1992 by the Water Education Foundation, Sacramento, California.

Video, entitled *Water from Water: Recycling,* produced in 1995 by National Water Research Institute, Fountain Valley, California.

Video, entitled, *Water in an Endless Loop,* produced in 1997 by WateReuse Foundation, Sacramento, California.

IMPLEMENTING SUSTAINABILITY IN WATER RECYCLING

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ABSTRACT

Applying sustainability as one of the decision criteria for evaluating projects is not only the right thing to do for reducing environmental impact, but also for determining long term economic viability. This paper will discuss the tools used for incorporating sustainability into water recycling facilities and will present two case studies, where these tools have been applied: Petaluma, California, and King County, Washington.

KEY WORDS

Sustainability, Water Reuse, Water Recycling, Ecological Footprint, The Natural Step™, LEED™

INTRODUCTION

In planning for wastewater recycling facilities, we have used two tools, The Natural Step Framework and the Ecological Footprint, to evaluate the relative ecological sustainability of various treatment alternatives. The Natural Step™ is a framework for evaluating sustainability. The Ecological Footprint measures the amount of bioproductive space required to produce all materials and energy consumed, and to sequester or absorb all wastes produced, for a given activity or to support a given population. The Ecological Footprint calculation allows easier direct comparison of ~~sustainability criteria using a~~ common unit system (acres).

During the pre-design and design phase, we have used the LEED™ Rating System to help develop environmental goals for projects and identify a multitude of strategies to meet those goals. The Leadership in Energy and Environmental Design (LEED™) Green Building Rating System is a performance-based certification system for buildings that demonstrate significant improvements in environmental performance beyond baseline standards.

DISCUSSION

Case Study 1:
The City of Petaluma, CA has embarked upon a project to replace their existing wastewater plant built in 1938 with a new water recycling facility. Citizens of Petaluma have a strong interest in being environmentally friendly. Consequently, one of the primary goals of the project is to design and build an ecologically and economically sustainable facility. The project team has

incorporated sustainability criteria into the evaluation of alternatives, planning of the facility, and for design and construction. The Natural Step was used to establish project goals for sustainability. The Ecological Footprint was used to evaluated five different treatment trains for the whole plant (see attached figure) and to evaluate individual process decisions such as the use of UV versus chlorine for disinfection. The LEED™ Rating System was used to establish goals for design for the whole plant as well as the occupied buildings.

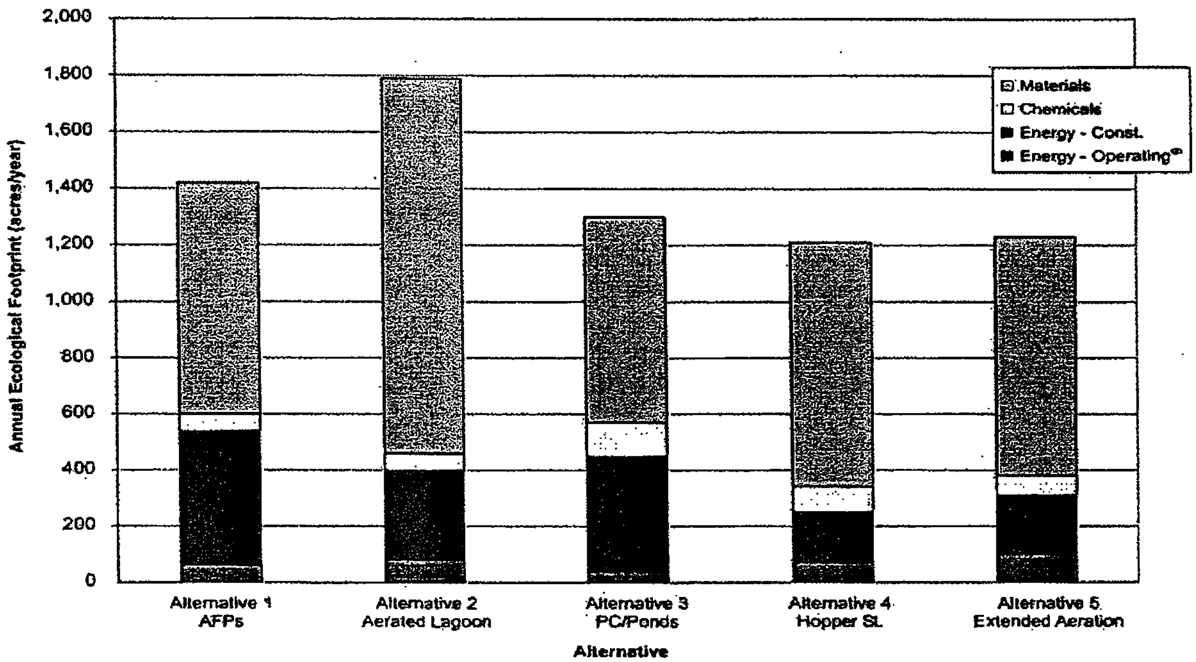
The City of Petaluma is located in California in the northern portion of the San Francisco Bay. The City currently provides wastewater treatment for approximately 55,000 residents. The treatment facilities are located in two places, downtown and east of town, outside the City limits. The City's facilities located downtown at Hopper Street were originally constructed in 1938 and upgraded in the 1950s and 1960s. The City also has 172 acres of oxidation ponds located out of town on Lakeville Highway, built in 1972. The Hopper Street facilities provide primary treatment for up to 6 mgd of flow, and secondary treatment (using two parallel trains, one aeration basins and one rock filters) for up to 4 mgd. Raw wastewater in excess of 6 mgd mixes with the primary and secondary effluent and is pumped out to the oxidation ponds for additional treatment. Final discharge is to the Petaluma River from October 21 - April 30 or to agricultural users from May 1 to October 20 (during non-discharge season). The ponds provide important storage during the non-discharge season, even though they also produce algae, which make meeting TSS requirements difficult at certain times of the year.

The facilities at Hopper Street are nearing the end of their useful life and need to be replaced. The city also wishes to develop recycling facilities for urban reuse which requires filtration and disinfection to meet California Department of Health Services Title 22 unrestricted reuse requirements. Other project goals included developing an economically and ecologically sustainable facility, and developing a facility that would serve as an amenity to the community by providing educational and recreational opportunities.

The City of Petaluma started their project to build a new recycling facility with a planning study to evaluate alternatives for treatment. At the kickoff meeting, The Natural Step framework was reviewed and project goals related to sustainability were established. The next step was to determine the criteria to be used for comparing alternatives. Criteria were grouped into the following categories: costs, neighborhood quality, wastewater treatment, sustainability and environment, and community amenities. Each category had several criteria and no category was given a greater weight than others were. These criteria were developed in part by input from citizens and City council members.

Alternatives were identified and screened in a brainstorming workshop with experts in pond systems, wetland systems, and conventional systems. Five alternatives were selected to be evaluated in further detail. The alternatives ranged from conventional activated sludge to natural/land based systems such as advanced facultative ponds and aerated lagoons. While most of the facilities at Hopper Street need to be abandoned, building new facilities on the Hopper Street site was evaluated as one alternative. All other alternatives considered locating the new facilities at, or adjacent to the existing oxidation ponds at the Lakeville highway site, which would be further from odor receptors. For each alternative the oxidation ponds remained in the treatment train due to their [illegible] importance in providing storage in the non-discharge reuse season. However, since the ponds were included in each alternative, each alternative also included algae removal. The two sub-alternatives for algae removal were either dissolved air flotation (DAFs) or vegetated treatment wetlands. Each alternative also had a sub-alternative of using chlorine or ultraviolet light for disinfection for the unrestricted reuse.

After evaluating the alternatives for all the criteria established, the main difference between alternatives came down to costs and sustainability (as measured by ecological footprint). The ecological footprints for each alternative is shown in the following figure.



(1) Assuming UV Disinfection
(2) Assuming continued use of Calpine power (green power source)

Extended aeration was selected as the preferred alternative. This process actually had the second highest cost, but low environmental impacts (as measured by ecological footprint) and is a reliable process. Vegetated treatment wetlands were selected as the algae removal process following the ponds instead of DAFs, due to low energy use (sustainability). The ecological footprint evaluation for the UV verses chlorine showed that UV is more sustainable, especially when a green power source is used.

After completion of the planning study, design began. The secondary facilities are designed for an annual average flow of 8 mgd. Up to 4 mgd of the secondary effluent can be treated with filtration and UV for urban reuse. The remainder of the flow is sent to the oxidation ponds. Existing plant data shows that the oxidation ponds significantly reduce metals concentrations in the plant effluent. Therefore, all water discharged to the Petaluma River will first go through the existing ponds. The last two oxidation ponds will be converted to vegetated wetlands, totaling approximately [illegible] acres. An additional [illegible] acres of wetlands (open water and dense vegetation) will be created on land adjacent to the oxidation ponds for additional polishing of metals and nutrients. Disinfection for river discharge and the existing agricultural reuse program will continue to be provided by existing hypochlorite facilities located on the pond site.

Sustainable strategies that were evaluated in predesign and being used in final design include use of: high volume fly ash concrete; "green" or vegetated roofs; native plants for landscaping; waterless urinals; high efficiency lighting and appliances; and passive HVAC systems. Other strategies included are: minimizing site work required for construction; optimizing pump station design; and specifying that the contractor recycle construction and demolition debris. The operations and maintenance building is designed to meet LEED™ certification.

Case Study 2:

King County, Washington has plans to construct a new Reclaimed Water Production Facility (RWPF) in the Sammamish Valley. One of the project objectives is that the facility be a model for sustainable design. To help meet this objective, the relative ecological impacts of various treatment options were evaluated, along with a separate study of how the facility affects the sustainability of the overall region. Carollo used the Ecological Footprint to measure the relative ecological impacts of decisions affecting the Sammamish RWPF. The evaluation to answer the question of "Does this recycling project increase the sustainability of the region?" showed that there are multiple benefits of water recycling that are not included in a simple cost analysis. Sustainability allows evaluation of the true costs verses benefits.

In parts of the arid west, water reuse is driven by water supply issues, with not enough potable water to meet all the demands. In the relatively wet areas of the Pacific Northwest, most people would not expect water shortages to be an issue. However, water reuse is becoming more important in these areas because recent drought years have increased the need for maintaining critical water supplies for environmental protection.

Depending upon state regulatory requirements, water reuse may or may not be feasible based purely on cost, as treatment for water reuse (to be protective of public health) is generally required to be at a higher level than is required for river discharge. Due to the higher level of treatment, potable water costs are generally cheaper than the cost to treat wastewater for reuse. So why would an agency implement reuse? The answer lies in evaluating more than just the costs of a project. The benefits of reuse can be numerous and vary depending on the project, but typically include: improved water quality, alternative water supply, environmental enhancement (due to higher quality and increased stream flows), reduced discharge to receiving water bodies, and improved public perception of environmental stewardship. The key for decision makers is understanding community project drivers and including the appropriate benefits when considering a reuse project. The problem with such broad and comprehensive comparisons, of course, is the difficulty associated with making a true "apples to apples" comparison of various options. Placing a monetary value on the benefits of the project and comparing this value to the cost of the project is difficult at best. For a reuse project in the Sammamish Valley, Washington, Carollo Engineers and King County applied a method for comparing costs and benefits called the Ecological Footprint, which allows for an equitable determination of true project value.

In planning the Sammamish Valley Reclamation Facility, Carollo and the County selected the most effective treatment processes to ensure a high quality product for both protection of public health and water quality. The treatment process selected was a membrane bioreactor (nitrification and denitrification in an extended aeration tank followed by microfiltration) and disinfection with ultraviolet light. These processes ensure a product with low nitrogen levels, little or no particles (solids), significant metals reduction, minimal disinfection by-products (DBPs) and full virus and bacteria inactivation.

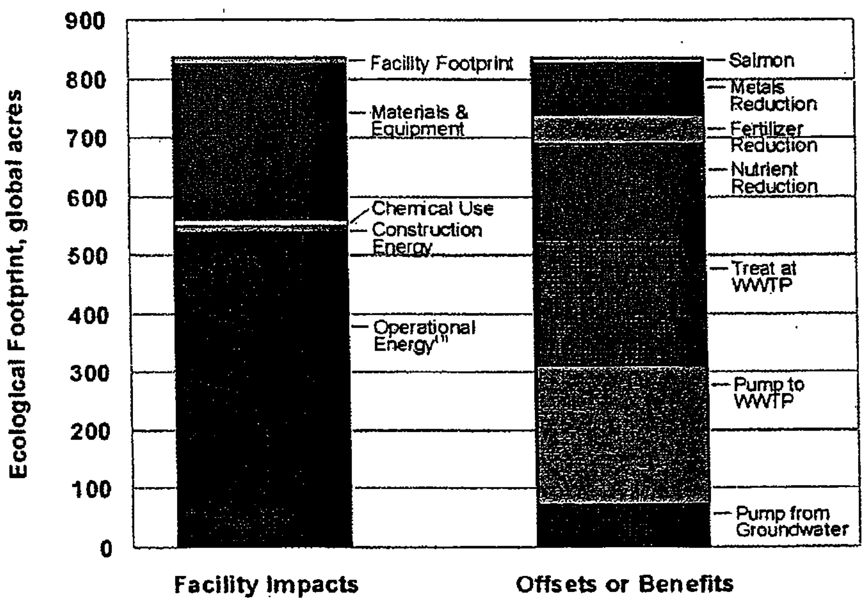
King County has a goal of implementing reuse in satellite locations. The Sammamish Valley was one such ideal location. The Sammamish Valley is a rural area to the east of Seattle, with significant agricultural resources. Water users identified for possible wastewater reuse rely on water pumped from the Sammamish River or from the groundwater. The Sammamish River runs out of Lake Sammamish through the Sammamish Valley and into Lake Washington. The Sammamish River supports important salmon runs of endangered Chinook salmon. Unfortunately, the Sammamish River faces low summer flows and poor dry weather water quality (impairment for dissolved oxygen, temperature and pH), particularly during critical late summer and early fall during the salmon runs. Reuse in the valley would provide water sources to offset groundwater and river pumping, thereby allowing more flow to remain in the river, and enhancing fish runs.

King County had several goals for the Sammamish Valley Reclamation Facility: keep more water in the river to enhance fish runs, preserve the rural character of valley, provide an alternate, reliable supply of high quality water, and provide a facility that serves as a model for sustainable design. To achieve the sustainable design goal, green building techniques were planned and an evaluation of the overall sustainability of the project was initiated. The sustainability was evaluated using the Ecological Footprint method. The Ecological Footprint is a calculation of the amount of land required to produce all the materials consumed in the construction and operation of a facility over its life, plus the land required to sequester or absorb all the wastes produced. It essentially represents the costs of the project in terms of environmental impact. To do an "apples to apples" comparison of the costs versus the benefits of the project, the ecological footprint was calculated for both the costs (construction materials, energy to construct, operating energy, and chemicals to operate) and the benefits.

The benefits of the project were considered as offsets of what the ecological footprint would be if the project were not constructed. Benefits (offsets) include: 1) the energy to pump the groundwater or river water that would be avoided, 2) the energy to pump the wastewater to the regional treatment plant that would be avoided (nearest regional plant over 20 miles away), 3) the energy to treat the wastewater at the regional facility, 4) the water quality improvements of not discharging nutrients to the receiving water (the regional plants do not nitrify), 5) offsetting the need for applied fertilizer to the reuse lands due to the nitrogen in the reuse water, 6) water quality improvement by decreasing metals released to the receiving water, 7) improvements to the salmon run, and 8) preservation of agriculture by providing a reliable water source which may help alleviate development pressures. The ecological footprints of the project costs versus benefits are shown in the attached bar graph.

The results of the evaluation show that the benefits or offsets, not including the agricultural preservation, are approximately equivalent to the ecological footprint of the impacts or costs of building and operating the facility. This assumes that a conventional Washington power mix

(Hydro, natural gas and coal) is used to operate the facility. If King County secures a contract with a green power supplier (from wind or solar), as they expect, the total ecological footprint for the facility drops by over 500 global acres and the benefits then exceed the impacts. Over 300 acres of agriculture would be supplied with reuse water from the facility, in addition to parks, soccer fields, a nursery, a winery and a golf course. Supplying a reliable source of water to the agriculture may help keep these farmers in business and help with the goal of agricultural preservation. When this is placed on top of the other considerations, the benefits of reuse in the Sammamish Valley definitely out weigh the costs.



(1) Assuming conventional WA power mix. King County is interested in pursuing green power supply which drops EF of operational energy to 17 global acres

CONCLUSIONS

In the wastewater and reuse field, the most common decision criteria used to evaluate alternatives in costs. However, to do a fair comparison, other criteria such as environmental impacts, public impacts and benefits and overall sustainability should also be used in the decision making process. The use of sustainability tools such as The Natural Step™, Ecological Footprint, and LEED™ can change the outcome of alternatives evaluation and change the way we think about and develop these projects.

ACKNOWLEGDEMENTS

Acknowledgements to Mathis Wackernagel and Redefining Progress for assistance in developing conversion factors for the Ecological Footprint

ıdirect Potable Reuse

ɔr more than 50 years, California has been a pioneer in water recycling. Advances in technology and new philosophies about eventing the "waste" of water have combined to make water recycling an increasingly important part of water resources anning. The next challenge is to expand the existing uses of recycled water to encompass potable reuse (drinking, cooking, and athing). Direct potable reuse – where the product water is released into a municipal distribution system immediately after eatment – is practiced only in Windhoeck, Namibia at this time and is probably far in the future in the U.S. However, indirect otable reuse is more widely practiced and becoming more accepted. The following paragraphs provide an overview of the rinciples involving indirect potable reuse.

Vhat Is Indirect Potable Reuse?

Vith indirect potable reuse, a highly treated recycled water is returned to the natural environment (groundwater reservoir, storage eservoir, or stream) and mixes with other waters for an extended period of time. Then, the blended water is diverted to a water eatment plant for sedimentation, filtration and disinfection before it is distributed. The mixing and travel time through the natural nvironment provide several benefits: (1) sufficient time to assure that the treatment system has performed as designed, with no ailures, (2) opportunity for additional treatment through natural processes such as sunlight and filtration through soil, and (3) ncreased public confidence that the water source is safe. Unplanned indirect potable reuse is occurring in virtually every major iver system in the United States today.

op

Nhat Technology Is Used to Treat Water for Potable Reuse?

Membrane treatment is the most advanced technology for removal of the tiniest particles – including small ions such as sodium and chloride – from the recycled water. The most common membrane process employed is reverse osmosis (RO). Under elatively high pressure, water is forced across the semi-permeable RO membranes in special vessels to produce nearly pure water. Impurities are collected in a separate brine stream for disposal.

'op

How Proven Is Indirect Potable Reuse?

The Denver Water Board, with assistance from the U.S. Environmental Protection Agency, conducted an intensive study of potable reuse, using a one million gallon per day pilot plant for five years. Several combinations of treatment processes were tested, and potable water was produced and analyzed for nearly all known contaminants. In addition, feeding studies were performed on rats and mice. Over several generations, rats and mice were given recycled water concentrates, while similar control groups were given water concentrates from the snowmelt from the highest peaks of the Rocky Mountains. No significant health differences were found between the two groups.

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What Are Some Examples of Indirect Potable Reuse?

For more than 20 years, the Upper Occoquan Sewage Authority (UOSA) Regional Water Reclamation Plant has been dischargin to the Occoquan Reservoir, a principal water supply source for approximately one million people in northern Virginia. Because of the plant's reliable, state-of-the-art performance and the high-quality water produced, regulatory authorities have endorsed UOSA plant expansion over the years to increase the safe yield of the reservoir. UOSA recycled water is now an integral part of the wate supply plans for the Washington metropolitan area. Other major projects with proven track records are in Los Angeles County an Orange County, California, and in El Paso, Texas.

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What Are the Regulatory Controls for Indirect Potable Reuse?

A basic regulatory structure for water recycling and reuse projects has been in place in California since 1969. However, projects nvolving indirect potable reuse were traditionally evaluated on a case-by-case basis, making it difficult to plan for this type of water recycling application. A breakthrough occurred in January 1996 when a regulatory framework for potable reuse was adopted by a Committee convened jointly by California's Department of Health Services and Department of Water Resources. Eighteen individuals, representing these Departments and major water supply and sanitation organizations, signed the framework The framework establishes six criteria that must be met before a potable reuse project proceeds. With these "ground rules" in place, agencies will find it easier to evaluate the feasibility of implementing an indirect potable reuse project.

top

What Are Multiple Barriers?

One of the most important concepts contributing to the growing acceptance of indirect potable reuse is that of multiple barrier protection. While RO is the heart of a potable reuse process, several other treatment processes are normally added to provide as near a fail-safe system as humanly possible. Primary and secondary treatment, dual media filtration, chemical additions, disinfection, and pretreatment are provided prior to the RO step. Each of these treatment steps removes a certain portion of the initial concentration of microorganisms and pollutants in the water. Additional removal capabilities follow. This combined treatmer capability not only adds up to an impressive cleansing power, but also act as back-ups to one another in case any step in the system fails to perform. Storage is also viewed as an important barrier to contaminants. In addition to multiple-treatment processes, multiple barrier protections also include source control programs (preventing introduction of pollutants at the source) and strict operations and maintenance procedures.

top

ACTON BOARD OF HEALTH

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Town of Acton
Comprehensive Water Resources Management Plan
Citizens Advisory Committee
Indirect Potable Reuse Working Group

Meeting #4
8/18/2005
Acton Wastewater Treatment Plant
20 Adams Street

Call to Order 730pm

I. Introductions

II. Plant Tour

III. Minutes from 6/30/05

IV. Update on Reuse Activities

V. Review of articles from 6/30/05 meeting

VI. Review of new Articles

a. Discussion of the four major topics

1) Emerging contaminants – detection and removal
2) The timing of the implementation of the project and coincidence with regulatory, treatment technology, and political timelines
3) Source reduction efforts for water use and pollutant removal
4) Centralized IPR versus Decentralized IPR

VII. Future meeting dates, sites, and topics

Adjourn by 900pm

Indirect Potable Reuse

For more than 50 years, California has been a pioneer in water recycling. Advances in technology and new philosophies about preventing the "waste" of water have combined to make water recycling an increasingly important part of water resources planning. The next challenge is to expand the existing uses of recycled water to encompass potable reuse (drinking, cooking, and bathing). Direct potable reuse – where the product water is released into a municipal distribution system immediately after treatment – is practiced only in Windhoeck, Namibia at this time and is probably far in the future in the U.S. However, indirect potable reuse is more widely practiced and becoming more accepted. The following paragraphs provide an overview of the principles involving indirect potable reuse.

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top

FACT sheet

WERF

Definitions:

- **Effluent** - treated water leaving a wastewater treatment plant.
- **Endocrine system** - a network of glands that produce hormones which react with receptors to regulate biological processes.
- **Estrogen** - a hormone produced primarily in female sex organs responsible for expression of female characteristics.
- **Hormone** - a "chemical messenger" produced by a gland that travels through the blood to another organ, regulating the activity of that organ.
- **Risk assessment** - a process used to estimate the possible risks to human health or the environment by considering who might be exposed to a compound and what the effects of that exposure might be.

Endocrine Disrupting Compounds and Implications for Wastewater Treatment

What are Endocrine Disrupting Compounds (EDCs)?

Endocrine disrupting compounds (EDCs), sometimes also known as hormonally active agents or endocrine modulating compounds, are substances that can affect the endocrine system in humans or animals, including fish (see definition at left). This fact sheet uses the term endocrine disrupting compound because it is currently the most commonly used term, not necessarily the most scientifically accurate one.

EDCs can be natural or manmade chemicals. Most chemicals are not EDCs. For more information on the endocrine system and hormonally active agents, see http://www.epa.gov/scipoly/oscpendo/edspoverview/primer.htm

Where Do EDCs Come From?

Most common EDCs entering and leaving a wastewater treatment facility are naturally produced by plants and animals. Some are found in products we use. New laboratory methods have enabled us to detect these compounds nearly everywhere.

- Plants and plant products and byproducts are primary sources of these compounds. Products containing soy can contain hormonally active agents.
- Humans and other animals excrete compounds that are hormonally active and can be EDCs. These compounds can occur naturally because our bodies produce them or because they are in the milk, meat or vegetables we eat. They can also be in pharmaceuticals such as birth control pills.
- Plastics, and the manufacture of plastics, can release compounds called plasticizers, some of which are EDCs.
- Some pesticides can be hormonally active.
- Detergents contain compounds called surfactants that improve their cleaning power. Some surfactants can be hormonally active.
- Some other industrial products (or their byproducts) can contain EDCs.

Have EDCs Been Measured In Surface Water?

Researchers have found natural estrogens and other compounds that may be EDCs in the surface water near some wastewater treatment plants. In some instances, the measured concentrations occur at levels that have been found in the laboratory to cause effects on a hormone system in fish.

Are There Environmental Effects from Exposure to EDCs in Wastewater?

In Europe, populations of some fish species near some wastewater treatment plants have shown a range of effects attributed to compounds acting like the hormone estrogen. The specific compounds or conditions causing the effects are not clear. For the most part, researchers found the affected fish near treatment plants where the level of wastewater treatment is more limited than it is in the United States. While much of the research on these effects and their occurrence near wastewater treatment plants began in Europe, similar studies are now underway in the United States and there may be a claim of similar effects in the future. To date, no studies in the United States have effectively linked changes in fish populations to wastewater treatment plant discharges.

Researchers are gathering more data on which chemicals are EDCs, the effects they may have at different concentrations, and their fate in wastewater treatment plants and the environment. While those efforts are underway, it is important to understand that many of the EDCs in treatment plant releases occur naturally. The ecological effects attributed to EDCs in the effluents from wastewater treatment plants may, in fact, be caused by EDCs, but they may also be caused by other conditions, such as temperature.

Should the Public Be Concerned About EDCs In Our Waterways?

When people read or hear reports of possible EDC effects in fish or other aquatic life downstream of a wastewater treatment plant, they may wonder whether they should be concerned about similar effects occurring in humans. Two things are important to remember.

First, no studies to date have effectively linked low concentrations of EDCs in wastewater to adverse health effects in humans. So while concern is an understandable response, no data currently show endocrine disruption in humans as the result of using rivers, lakes, and streams. Large studies have not indicated any association with effects that have sometimes been attributed to environmental exposure to EDCs: Low sperm counts, premature puberty in girls, testicular cancer in young men, and breast cancer in some women.

Second, the effects observed in fish and other aquatic organisms downstream of wastewater treatment plants and attributed to EDCs can also have other causes. Temperature can cause some of these changes. They may also simply represent natural variations in a population. That is not to say that the effects cannot be associated with EDCs in the discharge from a wastewater treatment plant. They might be, but clearly demonstrating a link is difficult.

Are EDCs Treated In the Wastewater Treatment Process?

According to published research, the most commonly used treatment approach can remove over 90% of many of the most common EDCs entering a treatment plant. Engineers design municipal wastewater treatment plants to remove conventional pollutants (solids and biodegradable organic material) from sanitary wastewater. Through their normal operation, those plants will also remove many types of EDCs.

What Are the Implications for Biosolids?

According to Merriam Webster's Collegiate Dictionary, 10th edition, the term "biosolids" refers to "solid organic matter recovered from the sewage treatment process" that is often composted and added to soils as a fertilizer. Biosolids may contain trace amounts of hormonally active compounds that were removed from wastewater during treatment. Detailed studies of the potential effects of other EDCs following land application of biosolids are generally not available yet, and understanding what happens to EDCs in solids is a topic of ongoing research.

What Are the Implications for Recycled Water?

"Recycled water" refers to the practice of using treated wastewater to irrigate areas such as parks, golf courses, or agricultural land. As described above, common forms of treatment will remove most of the mass of the EDCs before the water is recycled. However, more research is needed to understand the environmental consequences, if any, of low levels of EDCs in recycled water.

What Are the Implications for Drinking Water?

Some cities and towns draw their water supplies from surface waters that may contain EDCs from upstream discharges. Researchers have not evaluated the potential risks associated with all of the EDCs that may be in such drinking water supplies. Research on this subject continues. One researcher[1] found that environmental residues of 17-alpha-ethinylestradiol, one of the key and most studied ingredients of birth control pills, present a negligible risk to humans.

Why Do Opinions On EDCs Seem to Contradict One Another?

Laboratory and field studies produce data that can sometimes be difficult to interpret and don't easily translate from lab to field. In addition, it is often difficult to specify exactly which compound is causing an observed effect when there are so many variables, such as water temperature or natural variations in fish populations, that might also cause or contribute to an observed effect. Risk assessment, another common study method that scientists use, may predict results that can't be easily proved or disproved.

Also, it is impossible to prove a negative. When researchers find no effect after an exposure to a suspected EDC, that would suggest the absence of an effect. As more

[1] Christensen, F.M. (1998). Pharmaceuticals in the environment - A human risk? Regulatory Toxicology & Pharmacology, 28, 212-221.

and more researchers fail to find an association between an exposure and an effect, the scientific community becomes more and more confident that the exposure does not cause the effect. But all those negative results would still not prove the absence of an effect. It is always possible that the next experiment will find an association.

What Are the Regulatory Implications?

The U.S. EPA is at the very beginning of the process of determining if additional requirements to control sources of EDCs to the environment are needed. The U.S. EPA's Regulatory Activities Workgroup is reviewing the authorities that U.S. EPA may invoke to require testing, and are exploring considerations for establishing the process that U.S. EPA will use to require the testing. You can find out more about these programs at http://www.epa.gov/scipoly/oscpendo/edspoverview/primer.htm.

References

AMEC Earth and Environmental produced this Fact Sheet for the Water Environment Research Foundation (WERF).

This Fact Sheet serves as a companion piece to *Technical Brief: Endocrine Disrupting Compounds and Implications for Wastewater Treatment* (stock no. 04WEM6).

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USE OF RECYCLED WATER TO AUGMENT POTABLE SUPPLIES: AN ECONOMIC PERSPECTIVE

INDIRECT POTABLE REUSE - THE INTRODUCTION OF RECYCLED WATER INTO A COMMUNITY'S DRINKING WATER SUPPLY – CAN BE A COST-EFFECTIVE MEANS OF SUPPLEMENTING A COMMUNITY'S WATER SUPPLY

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FINAL
September 1999

INTRODUCTION

Maintaining a reliable water supply is one of the most important issues facing California. Many regions of California rely on diverting water from rivers and streams located in other parts of the state or from the Colorado River, a practice that lacks reliability due to droughts and is becoming less acceptable due to our growing awareness of the environmental impacts of these practices.

Recognizing water's importance to the state's economic prosperity and the quality of life enjoyed by its citizens, the California Water Plan focuses on developing a mix of complementary water resources. The state legislature enacted the Water Recycling Act of 1991, acknowledging that recycled water is an integral part of the state's water supply mix and that water recycling should be adopted wherever appropriate. According to the most recent edition of the California Water Plan (Bulletin 160-98), recycled water use in 1995 was 485,000 acre-feet, less than half of the State's goal of 1 million acre-feet per year by 2010.

The majority of municipal wastewater produced statewide continues to be disposed of to the ocean or other saline water body. This untapped resources represents one of the largest potential sources for "new water" in California. Communities throughout the state are planning new or expanded water recycling programs.

Definitions:

Recycled Water – Municipal wastewater that has been subjected to an array of biological, physical, and chemical treatments as necessary depending on the end use.

Indirect Potable Reuse – A particular application where the recycled water (generally having received a substantial degree of treatment) is blended into a community's water supply (via groundwater recharge or surface water augmentation) prior to final treatment and distribution to the customer in the existing water distribution system.

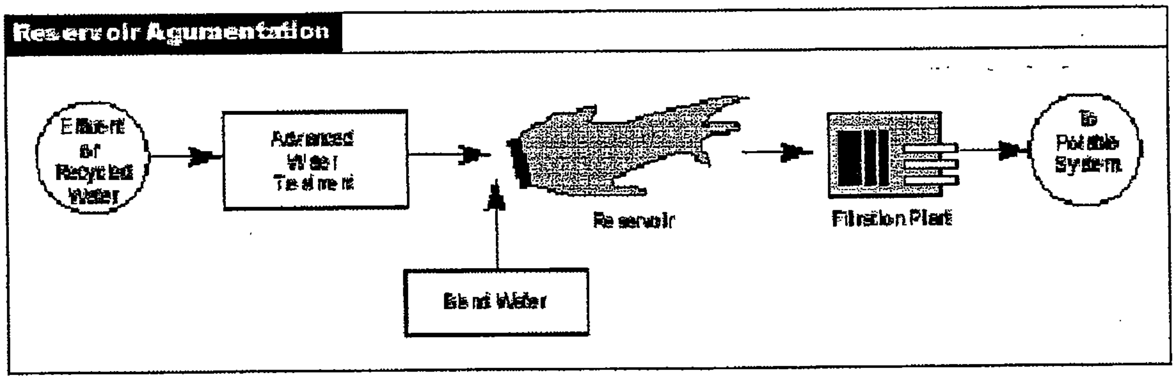
Recycled water is used for a myriad of non potable uses including industrial process, cleaning and cooling water, commercial toilet flushing, aesthetic water features, dust control and fire suppression. Agriculture and landscape irrigation are the predominant non potable uses of recycled water. Urban water recycling projects that rely on landscape irrigation and other non-potable uses often are limited due to the seasonal nature of the demand.

Alternatively, indirect potable reuse – which involves, blending recycled water with other water supplies (groundwater or reservoir) that feed a community's potable water supply system - enables a community to improve recycled water production efficiency and maximize year-around benefits. This use of existing seasonal storage water supply infrastructure enables a community to avoid construction of a separate water storage and delivery system; otherwise needed to provide a customer base and economic viability to a non-potable recycled water project.

Indirect potable reuse projects are in operation in Los Angeles and Orange Counties. And other projects are being considered in the Bay Area and Southern California.

INDIRECT POTABLE REUSE MECHANISMS

Recycled water quality and treatment requirements vary depending on the mechanism used to introduce recycled water into the potable system. Tertiary treated and disinfected (conventional) recycled water is a safe and reliable source for irrigation and industrial applications and some applications that may result in body contact (swimming), but may contain some contaminants that pose a risk to human health if ingested. Conventional tertiary treated recycled water may be used to recharge groundwater supplies if applied via surface spreading and treatment is provided as the water percolates through the soil/aquifer system. To “inject” the recycled water directly into the groundwater basin, or to introduce it directly into a water supply reservoir (upstream of a water treatment plant), additional treatment beyond tertiary is required.



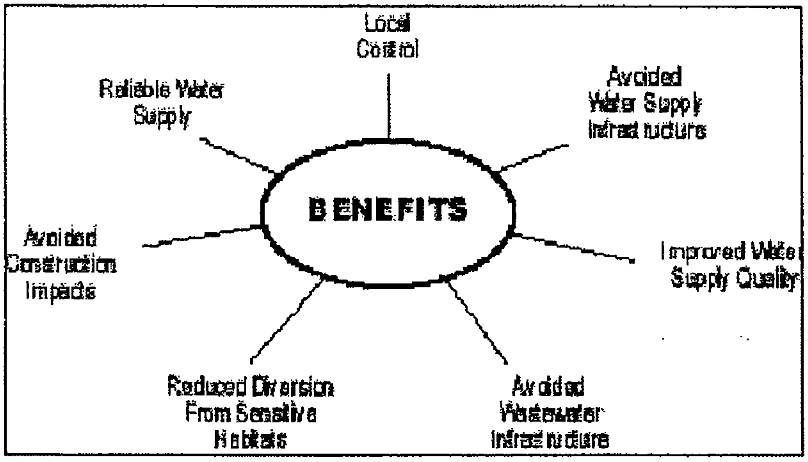
BENEFITS OF INDIRECT POTABLE REUSE

Indirect potable reuse projects provide an array of benefits, some consistent with conventional non-potable applications and others unique to indirect potable applications.

<u>Common Recycled Water Benefits</u>

- Provides a reliable local water supply, which serves a ledge against future droughts and potential uncertainty associated with traditional water supplies.
- Enables some warm suppliers to reduce imports during average and above-average years, and “bank” this imported water for use during dry years.
- Provides economic benefits by retaining businesses, and by attracting new businesses with a reliable water supply, (lower cost?).
- May improve environmental conditions by reducing the need to divert additional supply from sensitive watersheds.
- Reduces the quantity of treated wastewater discharged into the environment.

- May reduce the cost of wastewater treatment and disposal.
- Recycled water projects that include a demineralization step provide a significant enhancement to water quality.
- The yield of indirect potable reuse optimizes a recycled water project through the use of the existing water supply infrastructure, including seasonal storage and distribution facilities.

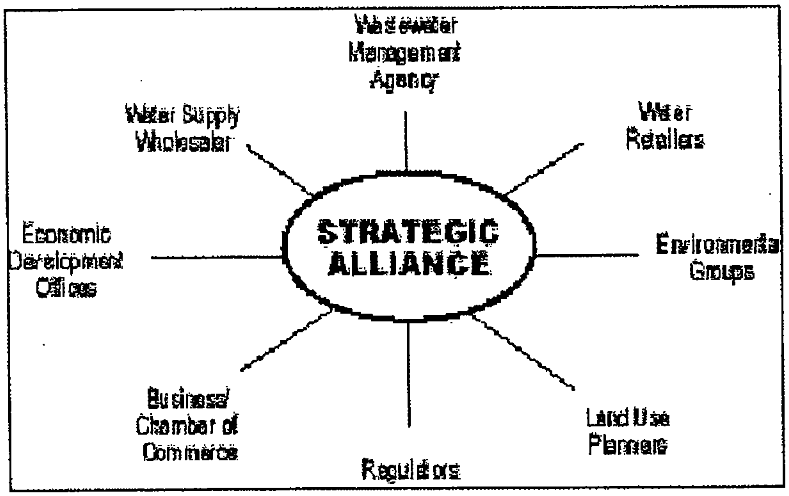


REALIZATION OF ECONOMIC SUCCESS

The economic value of water recycling projects is a function of the potential project benefits and their associated value. A recycled water project is analyzed by comparing the cost of producing and conveying the recycled water to the cost of other new water supply options. Important considerations include reduced or delayed infrastructure costs, improved reliability, savings in treatment costs and environmental benefits. When viewed from this perspective, recycled water projects often are found to provide cost effective new water supplies.

To accurately depict the cost-effectiveness of an indirect potable water recycling project, all potential benefits of the project should be considered. The beneficial effects of a indirect potable reuse project often extend beyond the sponsoring agency, providing regional benefits and in many cases the benefits extend state-wide and beyond. A broad spectrum of stakeholders is needed to provide valuable, consensus-driven input to accurately evaluate indirect potable reuse projects. By venturing outside the sponsoring agency and focusing on institutional relationships, regional and statewide benefits are more likely to be realized. An alliance between the water supply agencies, the wastewater agency, economic development offices, chambers of commerce, environmental interests, state and federal interests such as the CALFED Bay Delta Program, and other stakeholders should be created early in the development of a indirect potable reuse project so that all potential benefits can be considered.

In certain settings, indirect potable reuse projects provide a mechanism for large-scale beneficial use of recycled water with relatively modest additional infrastructure requirements. With a broad spectrum of stakeholders identifying the full array of economic and environmental benefits, indirect potable reuse can provide a cost-effective path for a community to follow in pursuing its recycling ethic.



Three indirect potable reuse projects have been proposed that would exemplify this critical mix of size and breadth of benefits: the East Valley Water Recycling Project, the Orange County Groundwater Replenishment System, and the San Diego Water Repurification Project. These three projects represent varying stages of planning and implementation. The East Valley project is nearing completion of construction. The Orange County project is under design, and the San Diego Repurification project has proceeded to 30% design, but is currently on hold due to unresolved policy and public perception issues.

I. East Valley Water Recycling Project

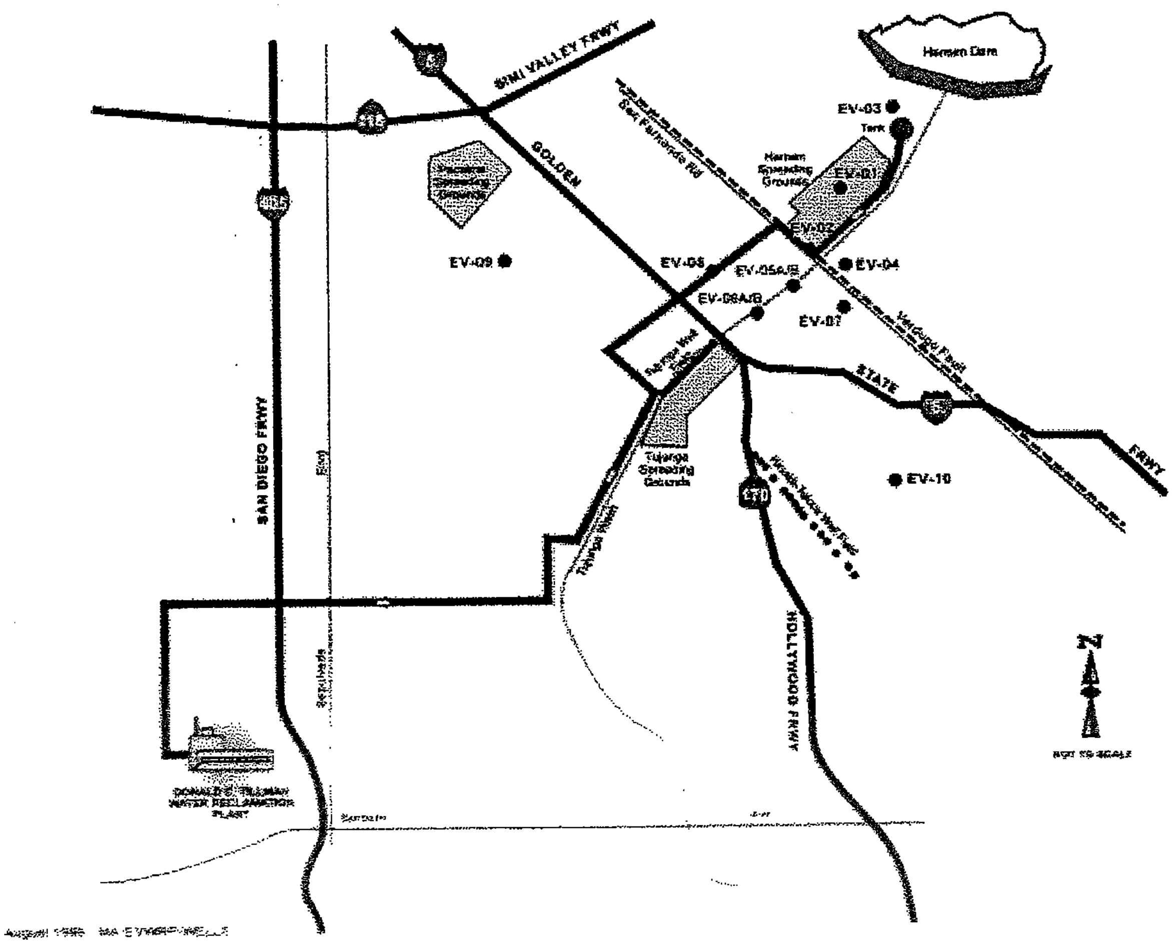
In June 1990, the Los Angeles City Council adopted a goal of reusing about 40% of the City's wastewater by 2010. In response to this goal, the City's Department of Water and Power (DWP) began development of the East Valley Water Recycling Project (EVWRP), which is the cornerstone water recycling project for the City. The EVWRP will ultimately provide up to 35,000 acre feet of recycled water per year for groundwater recharge at the Hansen and Pacoima Spreading Grounds in the San Fernando Valley, and for industrial and irrigation uses along the pipeline route. The EVWRP has received strong local, state, and national political support due to its regional and state importance.

Once completed, the EVWRP will lessen the City's demand on imported water supplies, and will replace a portion of the Mono Basin water no longer available for export. The EVWRP will also reduce the likelihood of severe water conservation measures in the future on residents and businesses in the event of a drought, as the overall reliability of the City's water supply will be improved.

Project Description

Phase IA of the EVWRP includes approximately ten miles of 54-inch diameter pipeline and a pumping station to deliver tertiary treated recycled water from the Donald C. Tillman Water Reclamation Plant to the Hansen Spreading Grounds. Phase IA of the EVWRP also includes an extensive monitoring well network designed to track the recycled water as it travels through the San Fernando Groundwater Basin from the spreading grounds to domestic production wells. Phase IA of the EVWRP will initially deliver up to 10,000 acre feet per year to the Hansen Spreading Grounds. Phase IB of the EVWRP will include construction of additional pipeline to deliver recycled water to the Pacoima Spreading Grounds. Phase II will include construction of additional facilities such as a tank and a booster pump station needed to deliver recycled water to irrigation and industrial customers.

FIGURE 1: EAST VALLEY WATER RECYCLING PROJECT



DWP is the lead agency for the EVWRP. The City's Bureau of Sanitation (Sanitation) and Los Angeles County Department of Public Works (Los Angeles County) have participated in the development of the EVWRP and are identified as responsible parties in the permit for operation of the project. Sanitation owns and operates the Donald C. Tillman Water Reclamation Plant which is the source of the recycled water for the EVWRP. Los Angeles County owns and operates the Hansen and Pacoima Spreading Grounds and will spread recycled water delivered by the EVWRP.

DWP staff worked closely with staff from the Regional Water Quality Control Board (Regional Board) and the State Department of Health Services (Health Department) to evaluate the EVWRP and develop appropriate operational and monitoring criteria. After review of the Groundwater Recharge Engineering Report by the Regional Board and the Health Department, Water Reclamation Requirements (permit) were issued on September 18, 1995. This permit allows for groundwater recharge of up to 10,000 acre feet per year at the Hansen Spreading Grounds for a three-year demonstration period. Groundwater modeling results, as well as the geologic and hydrogeologic features in the groundwater basin, indicate that this project is very conservative when evaluated using the proposed regulations for groundwater recharge upon which the approval for the EVWRP was based. An extensive groundwater monitoring and modeling program will track actual changes in water quality and recycled water movement within the groundwater basin, which will provide data for determining appropriate future project operations. The monitoring well system will also provide additional safeguards to the water supply by serving as an early warning system.

Economics

Phase IA of the EVWRP, which is scheduled to begin operation in 1999, has cost approximately $52-million. Up to 25% of this cost is being funded by the federal government through the Federal Reclamation Projects Authorization and Adjustment Act of 1992. Up to 50% of the total cost is being funded by the State of California through the Environmental Water Act of 1989. The remaining 25% of the total cost is being funded by ratepayers through special conservation and reclamation rate adjustments.

ESTIMATED CAPITAL AND OPERATION AND MAINTENANCE COSTS FOR PHAS IA

Without federal and state reimbursement

Capital Costs	$52.000.000
Amortized annual cost (6% interest for 30 years)	$3.777,743

Operation & Maintenance cost per acre-foot (AF)	$100
Annual delivery	10,000 AF
Cost of delivered water	**$478 per acre-foot**

With 25% federal and 50% state reimbursement

Capital Costs	$52,000,000
State Reimbursement (50%)	$26,000,000
Federal Reimbursement (25%)	$13,000,000
Net DWP capital expenditure	$13,000,000
Amortized net capital expenditure (6% interest for 30 years)	$944,436
Operation & Maintenance cost per acre-foot (AF)	$100
Annual delivery	10,000 AF
Cost of delivered water	**$194 per acre-foot**

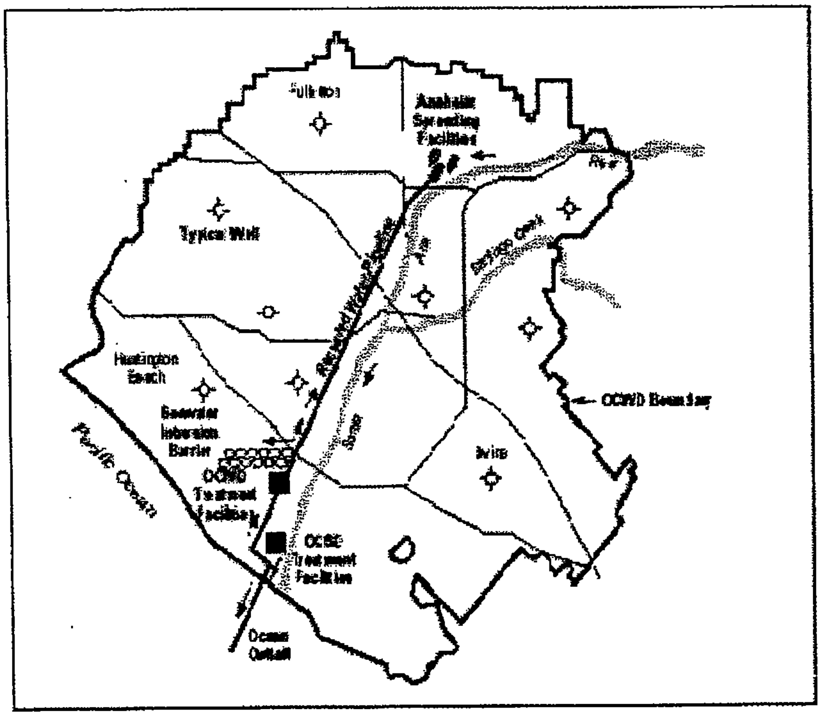
Phase IA of the EVWRP will provide water at an estimated cost of approximately $478 per acre-foot, with a net cost to DWP of approximately $194 per acre-foot when state and federal funding is considered. Even if state or federal funding had not been available, the EVWRP would still provide a new reliable source of water at a cost comparable to other water supplies, and significantly less expensive than other new supply options. According to the City Of Los Angeles Department of Water and Power Urban Water Management Plan Fiscal Year 1997-1998 Annual Update, seawater might be desalinated using new technology which has produced desalted ocean water at a cost of about $800 per acre-foot in pilot tests, or approximately $2000 using current technology. Furthermore, the EVWRP has other benefits which have not been quantified such as the reduction of water imported from the Mono Basin, and improved water system reliability resulting from a new local supply of water.

II. Groundwater Replenishment System

The Groundwater Replenishment System is being developed jointly by the Orange County Water District (OCWD) and the Orange County Sanitation District

(OCSD). After five years of planning and analysis, the Groundwater Replenishment System was determined to be the most economical and feasible new water supply for the region.

With OCSD secondary treated effluent as its source, the Groundwater Replenishment System would provide additional treatment including reverse osmosis and ultraviolet disinfection. The advanced treated recycled water would then be pumped to either: 1) existing spreading basins where it would percolate into and replenish the groundwater supply or 2) a series of injection wells that act as a seawater intrusion control barrier. The Groundwater Replenishment System would be implemented in three phases, providing roughly 68,000 afy of new water by the year 2003, 95,000 afy by 2010, and up to 120,000 afy by 2020.



Capital and Operation and Maintenance Costs

The cost of the water produced by the Groundwater Replenishment System is dependent on many factors including regulatory permit requirements, equipment and construction costs, power costs, operation and maintenance costs, system on-line reliability requirements, interest rates, and grants received from outside agencies. The following is a conservative preliminary estimate of the costs for the most probable alternative for Phase I of the Groundwater Replenishment System.

Capital Costs	$267 Million

Operation & Maintenance	$17.3 Million/year
Grant Receipts	$25 Million
Interest	6% amortized over 25 years
Power Cost	$0.06/kwh
Capacity Utilization	100% Barrier; 82% Spreading
Cost of Product Water	**$565/AF**

The utilization factor – the percentage of time that the system produces recycled water – significantly affects product water cost. It is anticipated that recycled water would be produced continuously for both the barrier and the spreading basins, with the exception of approximately 70 days during the winter months when the basins may not be able to accept water due to peak storm flows.

The estimated annual cost of the Phase I Groundwater Replenishment System, including capital amortization, operation, and maintenance totals approximately $38.2 million per year.

Value of Project Benefits

An explanation of project benefits and their economic values (avoided costs) are described below.

1. ***Alternative Water Supply***

If the Groundwater Replenishment System is not implemented, one of a variety of alternatives would need to be implemented to make up the anticipated water supply shortfall. OCWD conducted an analysis of three alternatives to meet the Groundwater Replenishment System production capacity. Each alternative would rely on continued imported water availability at non-interruptible rates, and two of the three alternatives would include some level of expansion or modification of Water Factory 21, OCWD's existing advanced recycled water treatment system. Based on the analysis, the following alternative represents the least-cost alternative to the Groundwater Replenishment Project.

Water Factory 21 would be expanded to provide all the water needed for seawater intrusion control via groundwater injection. Additional water needed for spreading would be purchased from the Metropolitan Water District of Southern California (MWD) and would require the construction of a pipeline from MWD's Diemer by-pass pipeline to the spreading facilities located in Anaheim. OCWD would avoid $ 27.4 million in annual costs, including expansion of existing treatment facilities, reduction in operation and maintenance costs, pipeline construction, and imported water costs, by implementing the Groundwater Replenishment System instead of this alternative water supply. Provided that imported water is available, the equivalent unit cost to implement this alternative would be $695/AF.

2. ***Salinity Management***

The Groundwater Replenishment System service area receives water from the Santa Ana River and imported water from the Colorado River Aqueduct and the State Water Project. The first two of these sources have relatively high salinity levels, potentially causing both agricultural and urban customers economic impacts. Agricultural water users suffer economic damage through reduced crop yields, added irrigation labor management costs, and added drainage requirements. Urban customers may incur additional costs due to more frequent replacement of plumbing and water using appliances. Estimated normalized costs for these replacements range from $100 to $150 per household each year.

The reverse osmosis-treated product from the Groundwater Replenishment System would lower the overall TDS content of the groundwater basin by at least 12.5 percent, saving the average household approximately $12.50 per year (or $25/AF). Industries and other large water users also could realize significant savings. With an average projected water use of approximately 675,000 AFY over the next 25 years, this provides an annual benefit of $16.9 million.

3. ***Reliability***

Allocations from imported water supplies are already overextended. Drought worsens the situation. And the population in north and central Orange County is increasing. It is currently projected that approximately 186,000 AFY of additional water would be required by the year 2020 to satisfy OCWD's service area demands.

The water supplied from the Groundwater Replenishment System would be available during times of drought, relieving the region of its dependence on imported water supplies. In addition, the Groundwater Replenishment System would protect the existing groundwater from further seawater intrusion and contamination. The value of this benefit is dependent on both drought frequency as well as other factors and is difficult to assess. No attempt to quantify the value of this benefit has been made.

4. ***Delay/Avoid Ocean Outfall Construction***

Implementation of the Groundwater Replenishment System would divert up to 100 million gallons per day (mgd) during Phase I from the Sanitation Districts Ocean Outfall Disposal System. During peak wet weather events, peak discharges of about 750 mgd are projected while the ocean disposal system capacity is approximately 480 mgd. To make up for this shortfall, OCSD is considering a variety of options including use of existing standby disposal facilities, retarding flows (peak shaving), and inflow reduction techniques to delay the near term cost of constructing a second ocean outfall. The most significant and economical way to reduce the peak is the diversion of 100 mgd through the Groundwater Replenishment System.

The estimated $150 million cost of a new ocean outfall can be delayed at least ten years by application of several peak reduction methods including this project. Assuming that half of this delay is due to the Groundwater Replenishment System (5 years) the savings at 6% interest spread over 25 years yields a $5 million per year benefit.

5. ***Section 301 (h) Waiver***

OCSD currently has a waiver under Section 301 (h) of the Clean Water Act from the requirement to discharge strictly secondary treated effluent thanks to a comprehensive source control program (in the wastewater collection system) and the relatively good quality of their effluent. OCSD's waiver is the largest granted by the United States Environmental Protection Agency (EPA) and in 1989 was estimated to save over $50 million per year in capital, operation, and maintenance costs. Protection of this waiver is OCSD's highest priority, and commitment to water reclamation could complement future waiver requests. However, the degree to which waiver savings can be attributed to the Groundwater Replenishment System is difficult to assess. If for example, the Groundwater Replenishment System accounted for 20% of the savings, the project could be credited with $10 million per year in cost avoidance. However, no credit was taken for this project benefit.

6. ***Revised Discharge Permit***

OCSD's 1998 ocean discharge permit allows a discharge of 20,000 metric tons per year of suspended solids and, thanks to a condition in the permit, would be re-opened if the Groundwater Replenishment System were built. The Regional Water Quality Control board could then consider an increase in solids loading discharge to 25,000 metric tons per year, potentially delaying construction of new secondary facilities (10 years). The savings in operation and maintenance (including solids disposal), amortized at 6% interest over 25 years, is $9.9 million per year. However, these savings were not included in the evaluation of this project.

Economic Summary

The annual cost to implement the Groundwater Replenishment System including capital, operation and maintenance, engineering, administration, and contingencies, at 6% interest and amortized over a 25-year period, would be approximately $38.2 million. Totaling the avoided costs presented above, including Alternative 2 as the next lowest cost water supply solution, the total annual benefits are as follows:

Item	Total Annual Cost Avoidance (Millions $)
OCWD Cost Avoidance	$27.4
Salinity Management	$16.9
Reliability	Not Counted
OCSD, Delay in outfall	$4.9
OCSD, Waiver Support	Not Counted
OCSD, Secondary Savings	Not Counted
TOTAL BENEFITS	**$49.2**

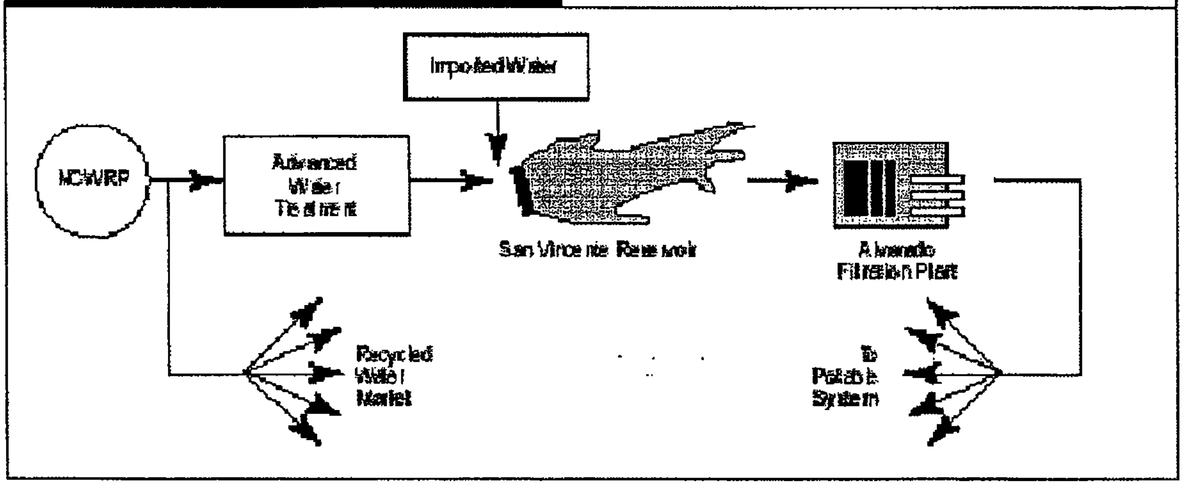
This results in a maximum Benefit to Cost Ratio of 1.288 ($49.2/$38.2), not including estimates for reliability, waiver support, and secondary treatment savings. Based on this analysis, OCWD and OCSD have decided to move forward with the implementation of this project.

III. San Diego Water Repurification Project

The City of San Diego, in conjunction with the San Diego County Water Authority (SDCWA), the Metropolitan Water District of Southern California (MWD), and the U.S. Bureau of Reclamation, has proposed a surface water augmentation project to achieve indirect potable reuse of reclaimed water from the City's North City Water Reclamation Plant (NCWRP). The Water Repurification Project would provide a renewable, reliable, local source of raw water that would expand the City's total available raw water supply under its direct control. In a region in which 90% of its water supply is imported from the Colorado River and northern California, this project is not only resource-efficient, but it also improves the cost-effectiveness of the NCWRP.

The proposed project, designed to produce between 15-20,000 AFY of repurified water, consists of a 20 million gallon per day (MGD) advanced water treatment plant (co-located with the NCWRP) and a 23-mile pipeline to deliver the repurified water to the City's San Vicente water supply reservoir in eastern San Diego County. The advanced treatment plant (AWTP) would treat tertiary effluent from the NCWRP using a treatment process train including microfiltration, reverse osmosis, ion exchange, and ozonation. The repurified water would be introduced into San Vicente Reservoir, where it would blend with imported water. Raw water from San Vicente Reservoir would be pumped to the Alvarado Filtration Plant prior to being introduced into San Diego's potable water distribution system.

San Diego Repurification Schematic



The City has been conducting research into the advanced treatment and ultimate use of repurified water as a supplement to potable supplies since the early 1980's. Since 1993, the City has worked closely with the California Department of Health Services (DHS) to develop a project that meets the department's strict standards for public health and reliability, while maintaining its cost-effectiveness. DHS has approved the project for design, which commenced in early 1997 but was put on hold in late 1998 due to policy and public perception issues.

Capital and Operation and Maintenance Costs

The following is a preliminary estimate of the costs for the San Diego Water Repurification project.

Capital Costs	$168 Million
Operation & Maintenance	$4.1 Million/year
Interest	5.75% amortized over 30 years
Power Cost	$0.05/kwh
Capacity Utilization	83%
Gross Cost of Product Water	**$1060/AF**

Title IX Funding	($38/AF)
SRF Loan (0%, 30 yrs)	($94/AF)
MWDSC Incentive	($250/AF)
SDCWA Incentive	($100/AF)
Cost of Product Water	**<u>$578/AF</u>**

The above unit cost is based on 1) estimated repurified water production of 15,000 AFY, grant funding of $8 million, and a State Revolving Fund $50 million zero interest loan, with $7 million (13%) contributed by City.

Value of Project Benefits

An explanation of project benefits and their economic values are described below.

1. ***Alternative Recycled Water Supply***

The City and the SDCWA have committed to incorporating water recycling into the water supply mix. At a production capacity of 30,000 AFY, NCWRP is the largest water recycling plant in the region, and provides the best opportunity for large-scale reuse. A recycled water distribution system currently serves roughly 5,000 AFY of NCWRP product to local non potable customers. If the water repurification project is not built, the City would expand the non potable distribution system to serve an additional 5,900 AFY.

The value of the Water Repurification project includes the avoidance of construction and operation of this expanded distribution system. The estimated capital cost of this distribution system expansion is $83 million. Estimated annual operations and maintenance costs to distribute the additional 5,900 AFY are $450,000.

2. ***Additional Avoided Wastewater Costs***

Wastewater flows that are not treated at NCWRP and beneficially reused must be conveyed to the Point Loma Wastewater Treatment Plant. These unused flows would cause increased operation of the City's collection system Pump Station No. 2, and would undergo re-treatment at the Point Loma plant. The City has estimated that annual operations and maintenance costs associated with accommodating this 5,900 AFY are $236,000 at Pump Station No. 2 and $855,000 at Point Loma.

Economic Summary

The City commissioned an independent study of the cost-effectiveness of the Water Repurification project. Considering the estimated construction and operations and maintenance costs of the project, and considering the avoided costs as discussed above, San Diego expects this project to fully recover 100% of its capital costs, debt service and operation and maintenance costs within fifteen years after it commences operations.

CONCLUSIONS

Recycled water represents a safe and reliable new water supply that provides insurance against future droughts or shortages of imported water supplies, and provides a stable foundation for maintaining and improving California's economic prosperity and quality of life.

The East Valley Water Recycling Project, Groundwater Replenishment System, and San Diego Water Repurification Project exemplify how indirect potable reuse projects, when compared to other water supply and wastewater management options, can offer the greatest benefits for the least cost. The ultimate success of these projects would be attributable to project sponsors reaching out and forming alliances with the full array of beneficiaries. Public involvement and education also would be instrumental in successful project development.

ACTON BOARD OF HEALTH

Douglas Halley
Health Director

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Acton, MA 01720

Telephone 978-264-9634
Fax 978-264-9630

Town of Acton
Comprehensive Water Resources Management Plan
Citizens Advisory Committee
Indirect Potable Reuse Working Group

Meeting #5
10/25/2005
Acton Town Hall
Room 126

Call to Order 730pm

I. Introductions

II. Discussion of Draft Final Report

Adjourn by 900pm

INDIRECT POTABLE REUSE WORKING GROUP

Acton Board of Health - Telephone (978) 264-9634

FINAL REPORT

OF THE

ACTON INDIRECT POTABLE REUSE

WORKING GROUP

NOVEMBER 15, 2005

Background

The Acton Indirect Potable Reuse Working Group was formed in May, 2005, as a sub-group of the Citizens Advisory Committee (CAC) for the Comprehensive Water Resources Management Plan (CWRMP). The Group was tasked with the evaluation of the concept of Indirect Potable Reuse, prior to any consideration of its implementation within Acton. The Group performed its duties under the following mission statement:

> "To evaluate the potential feasibility of the implementation of Indirect Potable Reuse of highly treated Wastewater Treatment Plant effluent through a discharge to a wellfield; the group will examine the issue from the "human" perspective, looking at the political and public relations impacts of any proposal. Those impacts can then be used to determine whether this concept is feasible as a discharge option within Acton."

The Group members are:

Art Gagne' –	Member of the CAC
Eric Hilfer –	ACES representative and member of the CAC
Joanne Bissetta –	Member of the Acton Board of Health
Greta Eckhardt –	Acton Resident
Pat Cumings –	Member of the CAC

Observers who attended meetings:

Dr. Peter Shanahan –	MIT Professor and Co-Founder of Hydroanalysis Inc.
James Gagliard –	Acton Wastewater Treatment Facility Manager
Mary Michelman –	President of Acton Citizens for Environmental Safety (ACES)

Indirect Potable Reuse – The Concept

Indirect Potable Reuse, which is groundwater recharge via surface or subsurface disposal in order to augment a potable aquifer, has been in practice across the United States for many years in both planned and unplanned fashions. In Massachusetts, according to the Reclaimed Water regulations now under review, Indirect Potable Reuse would be defined as a discharge of highly treated wastewater treatment plant effluent into an aquifer, with no less than a one year travel time from the point of discharge to the point of intake of the well(s).

Indirect Potable Reuse is only one facet of the larger concept of reclaimed water use. This holistic approach to preservation of the local hydrologic cycle includes reuse options for irrigation – residential, commercial, and agricultural; industrial cooling systems; process water in manufacturing facilities; toilet flushing; snowmaking; and fire protection systems. As greater awareness is achieved in regards to the growing scarcity of water resources, water reclamation practices, like Indirect Potable Reuse, are growing in popularity.

Acton CWRMP

The Acton Comprehensive Water Resources Management Plan (CWRMP) was undertaken as part of the acceptance of the Middle Fort Pond Brook Sewer Project by the Massachusetts Department of Environmental Protection (DEP); to determine the wastewater disposal needs for the entire Town, along with the integrated planning necessary to protect Acton's vital liquid resources for the next 20 years.

The CWRMP is guided by two groups working jointly to develop a cohesive plan. The Project Team – consisting of Acton Health Department staff and Woodard and Curran, Inc. engineers and scientists; and the Citizens Advisory Committee – a group of local stakeholders appointed by the Acton Board of Selectmen to represent the broadest possible range of views in regards to Acton's water resources.

As part of the project, wastewater disposal options were evaluated for centralized and decentralized sewer projects of varying sizes. As Acton is both regulatorily and environmentally limited for surface discharge locations, subsurface discharge must be the primary option examined. Subsurface disposal of treated wastewater requires soils with high permeability in order to efficiently dispose of the effluent from both a cost and footprint perspective. As Acton is solely reliant on groundwater aquifers for its public water supply and those aquifers are located in the most permeable soils, the concept of Indirect Potable Reuse was a concept that could not be ignored as a part of a 20 year water resources management plan.

Indirect Potable Reuse Working Group

A sub-group of the Citizens Advisory Committee was formed in May of 2005 to further examine the issues surrounding Indirect Potable Reuse. As explained earlier, the group was established to represent important viewpoints, and to also solicit comment from stakeholders who had positive, negative, and non-existent opinions on the concept.

The group received information packets, consisting of published educational journal articles, copies of government-produced information, and newspaper articles all directly related to Indirect Potable Reuse. Copies of these packets are included in Appendix A of this report. The group met throughout the summer of 2005, to discuss the issues related to Indirect Potable Reuse in accordance with the group's mission statement.

Discussion

After a thorough review of the academic and professional research presented, the group delineated four major areas of concern, each containing topics requiring further research.

These four major areas of concern are:

1) Detection and removal of multiple classes of emerging contaminants
2) Timing of implementation in regards to technological, regulatory, and political timelines
3) Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields
4) Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

Detection and removal of multiple classes of emerging contaminants

Current research by multiple educational and governmental institutions have identified new classes of emerging contaminants in wastewaters, drinking waters, groundwaters, and surface waters. While research into the possible health effects of these categories of contaminants is ongoing, the absence of concrete toxicological and medical data cannot be ignored. These new classes of contaminants include pharmaceuticals, personal care products, their metabolites and their by-products.

Studies in Europe, Australia, and the United States are in varying stages of completion in regards to the prevalence of these compounds in wastewater treatment plant influent and effluent. The Town of Acton is participating in one of these studies, sponsored by the Johns Hopkins Bloomberg School of Public Health. This study will report the prevalence and concentration of many of the most common classes of these emerging contaminants, allowing the Town to develop a baseline against which to measure future treatment and disposal options. Separate studies are evaluating the capacity of different wastewater treatment technologies and processes to reduce or eliminate these compounds from the waste stream. Initial results of both sets of studies are presented in some of the articles attached to this report in Appendix A.

Timing of implementation in regards to technological, regulatory, and political timelines

If the Town chooses to further consider Indirect Potable Reuse as a reclaimed water practice, it will be impacted by the progression of the acceptance of this practice on a local, regional, and national scale.

At the local level, a significant public participation and education campaign must be successfully mounted, and this campaign should be spearheaded by an elected or appointed Town official, not a staff member. It is important that the residents of Acton sufficiently understand the concept of Indirect Potable Reuse so that they may both collectively and individually accept or reject the proposal. This local acceptance must also fit into the Town's broader water resources management strategy in regards to the treatment and disposal capacity necessary to provide a solution to the designated needs areas.

Developments on the regulatory front may have the greatest impact on the possibilities for implementation of Indirect Potable Reuse in Acton. The Commonwealth of Massachusetts is currently developing a new set of Reclaimed Water Regulations, which will govern the reuse of highly treated wastewater in a variety of modalities. Indirect Potable Reuse will, of course, be included as a component of these regulations. These regulations will govern the effluent quality required for an Indirect Potable Reuse discharge, and the economic implications of the level of treatment may be the ultimate determining factor in implementation.

From a technological standpoint, the field of wastewater treatment advances each day in its ability to reduce various compounds to increasingly lower concentrations in treatment plant effluent for reuse projects. While it is impossible to predict what effluent limitations would be placed on any proposed Indirect Potable Reuse project in Acton sometime in the future, it can be expected that proven technologies will be available to meet those limits. The current wastewater treatment plant on Adams Street is discharging potable water according to EPA/EHA primary and secondary standards, and a grab sample collected from the effluent channel. A caveat to this section would be the inclusion of any classes of emerging contaminants in effluent limitations. As stated previously, studies are still underway to determine which treatment process will most efficiently remove which classes of compounds. Further study would be required, possibly at the local level, in order to determine the best course of action in this case.

<u>Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields</u>

The Town of Acton receives 95% of its drinking water from the five Acton Water District wellfields located across the community (see figure 1). As the implementation of Indirect Potable Reuse is evaluated against the needs areas identified in the Comprehensive Water Resources Management Plan, the possibility of lesser discharges spread across multiple wellfields should also be considered. This could allow for broader basin-wide recharge, which could be a benefit to stream flow; and it could also allow for greater proliferation of offsite wastewater disposal solutions for needs areas from north to south Acton.

<u>Coupling implementation with increased water conservation and emerging contaminant source reduction efforts</u>

The implementation of an Indirect Potable Reuse project in Acton, and the public participation and education campaign that will proceed such a project, will offer a unique outreach opportunity for the Town and the Water District to further encourage conservation, and to discourage the waterborne disposal or decrease in usage of those products which, along with their metabolites and by-products, make up the classes of emerging contaminants mentioned previously.

Recommendations

Indirect Potable Reuse is a concept which may serve a purpose in the future water resources management efforts in the Town of Acton. Through its work, the group determined that four major areas of concern existed, and under each of those areas, many questions still remain unanswered. Those four areas are, again:

1) Detection and removal of multiple classes of emerging contaminants
2) Timing of implementation in regards to technological, regulatory, and political timelines
3) Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields
4) Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

As the Town completes the Comprehensive Water Resources Plan development process and moves forward with bringing wastewater management solutions to needs areas, no concept, including Indirect Potable Reuse, should be discarded prior to an intensive, citizen-driven, review process.

Should the Town choose to further explore implementation of Indirect Potable Reuse, a permanent committee, similar to the Sewer Action Committee, should be appointed by the Board of Selectmen to further evaluate implementation options. This committee should be chaired by an elected or appointed town official who is also a resident of the community. It should include representation from, at least, the following stakeholders:

- Acton Board of Health
- Acton Citizens for Environmental Safety
- Acton Planning Board
- Acton Water District
- Acton Conservation Commission
- The current incarnation of the Wastewater Citizens Advisory Committee
- Residents from those areas who will benefit from the additional disposal capacity
- Acton residents-at-large

This committee should work with the Town's consultants to cultivate a public participation and education plan devoted to Indirect Potable Reuse, and if the response is positive, should work to bring the project to fruition.

Indirect Potable Reuse, as a concept, holds much promise, not only for the Town of Acton, but for many other communities across New England, as the true nature of the scarcity of our liquid reserves becomes readily apparent.

APPENDIX B

INFORMATION ON JOHNS HOPKINS STUDY

JOHNS HOPKINS
BLOOMBERG
SCHOOL of PUBLIC HEALTH

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Phone: (410) 955-2609; Fax: (443) 287-3560

November 29, 2004

Dear Collaborators:

Thank you for waiting so patiently on news from us. We are happy to report that a large number of collaborators have come forward to participate in our study. An overview of the current coverage of the U.S. is provided in the attached map that shows volunteers from municipal water treatment utilities (blue) as well as volunteers from the Groundwater Foundation (green). For updates and maps showing complete coverage, visit Dr. Halden's personal webpage. (http://www.jhsph.edu/dept/ehs/faculty/halden/home/Nationwide%20Study.htm), accessible through his faculty webpage (http://www.jhsph.edu/Dept/EHS/Halden) by clicking on the link: "For more information visit my personal web page." On the map you will notice that we have excellent coverage in the East and West but still need volunteers in the South and Midwest. If you have colleagues in these areas of poor coverage, please forward our information to them.

On August 25, our research group presented some of our data from our local WWTP at the 228th National Meeting of the American Chemical Society, which included the Second National Symposium on the Environmental Chemistry of Pharmaceuticals and Personal Care Products. The seminar was taped and is available on the Internet at: http://www.tntech.edu/wrc/PPCPWebcast/Heidler/Heidler.html. Additional coverage of our research can be found at: http://www.jhsph.edu/dept/ehs/faculty/halden/Different_Studies.htm and http://www.scienceupdate.com/index.cfm (archived under "September 30, 2004").

We are now asking for your assistance in the first phase of our nationwide survey of surface waters and wastewater treatment systems. Please confirm your availability during the months of December to February by email (jheidler@jhsph.edu) and we will send you the required sampling materials, including a trip blank, gloves and bottles, and a pre-paid FedEx air bill for returning the samples. In the package, you will find instructions for the collection samples. Essentially, we would like you to provide us with the following:

1. Raw wastewater (after mechanical screening but prior to settling)

2 x 250 mL 24-hour composite sample (ideal) **OR**
2 x 250 mL grab samples, ideally taken during high-flow and low-flow situations.

2. Treated wastewater (effluent)

2 x 500 mL 24-hour composite sample (ideal) **OR**
2 x 500 mL grab sample

3. Biosolids

1 x 250 ml primary sludge **AND**
1 x 250 mL excess (wasted) activated sludge **AND**
1 x 250mL pre-digested sludge (primary/activated mix) **AND**
1 x 250 mL digested, dewatered sludge (processed sludge)

4. Effluent-receiving streams

a. 2 x 500 mL of effluent-receiving stream upstream of effluent input
b. 2 x 500 mL of effluent-receiving stream downstream of effluent input
(Taken ~0.5 miles downstream of WWTP inputs to allow for mixing)

Please record the sampling day, time and location, including the names of the streets at the nearest intersection. If you have access to a global position system (GPS) unit, please log in the sampling locations and forward the information to us. Additionally please provide us with the following information on the plant:

- Description of plant (activated sludge, secondary, tertiary, or trickling filter, etc)
- Capacity (MGD)
- B.O.D. for influent and effluent
- Amount of suspended solids for sampling days
- Flow data for the sampling days

Thank you very much for your support of the JHU Center for Water and Health Nationwide Survey of Pharmaceuticals and Personal Care Products (PPCPs) in U.S. water resources.

Sincerely,

Jochen Heidler and Rolf Halden

Network of collaborators to date

Brent Reagor

From: Jochen Heidler [jheidler@jhsph.edu]
Sent: Monday, November 29, 2004 10:03 AM
To: Jochen Heidler
Subject: Johns Hopkins PPCP Study Update

Dear Collaborators,

thank you very much for your interest in participating at the Johns Hopkins University (JHU) research project on the fate and transport of pharmaceuticals and personal care products (PPCPs) in the environment.

Attached you will find information about the status of our project and detailed sampling instruction.

Please confirm your participation in order to send you the sampling materials.

Again, thank you very much.

Sincerely,

Jochen Heidler and Rolf Halden

Jochen Heidler
Ph.D. Student
Johns Hopkins University
Bloomberg School of Public Health
Department of Environmental Health Sciences
615 N. Wolfe Street / W6704
Baltimore, MD 21205
410-955-8692
jheidler@jhsph.edu

Brent Reagor

From: Jochen Heidler [jheidler@jhsph.edu]

Sent: Tuesday, June 07, 2005 9:49 AM

To: Brent Reagor

Subject: Johns Hopkins Sampling Materials

Dear Mr. Reagor,
I'm finally ready to send your sampling kit by the end of this week.
Again, I apologize for the delay in our study.
Please confirm your availability in order to receive your sampling kit.

Best regards,

Jochen Heidler

Jochen Heidler
Ph.D. Student
Johns Hopkins University
Bloomberg School of Public Health
Department of Environmental Health Sciences
615 N. Wolfe Street / W6704
Baltimore, MD 21205
410-502-2620
jheidler@jhsph.edu

Brent Reagor

From: Jochen Heidler [jheidler@jhsph.edu]
Sent: Friday, June 24, 2005 3:44 PM
To: Brent Reagor
Subject: RE: JSPH Study Samples

Your samples arrived today.
We will inform you as soon as we will have some data from our analysis of your samples.

Thanks for providing these samples for us.

Best regards,

Jochen Heidler

Jochen Heidler
Ph.D. Student
Johns Hopkins University
Bloomberg School of Public Health
Department of Environmental Health Sciences
615 N. Wolfe Street / W6704
Baltimore, MD 21205
410-502-2620
jheidler@jhsph.edu

From: Brent Reagor [mailto:breagor@acton-ma.gov]
Sent: Thu 6/23/2005 12:40 PM
To: Jochen Heidler
Subject: JSPH Study Samples

The samples left my office this afternoon. Tracking numbers:

844998071876 -- influent and biosolids
851851586510 -- effluent and receiving waters

If there are any problems, please let me know.

--Brent

Brent L. Reagor, R.S.
Acton Board of Health
472 Main Street
Acton, MA 01720
P -- (978) 264-9634
F -- (978) 264-9630

Sampling kit for

Raw wastewater (influent)

And

Biosolids.

Dear Collaborator,
Enclosed in your sampling kit you will find 6 x 250 ml sample bottles, biohazard bags, gloves, stickers for labeling, gel packs (for cooling) of the bottles and a prepaid FedEx air bill.

Detailed sampling instructions:
Raw wastewater (influent):

1. Sampling should be done at a location after mechanical screening but prior to settling. (If no such location is accessible, sample prior to the screen.)

2. Please provide us with the following: 2 x 250 mL 24-hour composite influent sample (ideal) **OR** 2 x 250 mL grab influent samples.
Important: Do not overfill the bottles to avoid rupture during subsequent freezing.

3. Collect the grab samples on two consecutive weekdays (e.g., Mo&Tu or Th&Fr).

4. Wear gloves during sampling to avoid both contact with bacteria and contamination of your samples with personal care products.

5. Please record on the bottles using the provided stickers the day, time, flowrate, your name and the location.

6. Make sure that the bottle lid is screwed on tightly

7. Freeze the bottles overnight together with the gel packs.

8. Put bottles into the biohazard plastic bags.

9. Pack the bottles into the same box they arrived in, add the biosolids samples.

10. Remove the paper on the side of the shipping box that covers the "diagnostic specimen" sticker.

11. Send the box back to us using the pre-paid FedEx air bill.

Biosolids:

Please provide us with the following:
1 x 250 ml primary sludge **AND**
1 x 250 mL excess (wasted) activated sludge **AND**
1 x 250mL pre-digested sludge (primary/activated mix) **AND**
1 x 250 mL digested, dewatered sludge (processed sludge)
Important: Do not overfill the bottles to avoid rupture during subsequent freezing.

1. Wear gloves during sampling to avoid both contact with bacteria and contamination of your samples with personal care products.

2. Please record on the bottles using the provided stickers the day, time, your name, the location, and the average mass of suspended solids produced per month if available.

3. Make sure that the bottle lid is screwed on tightly

4. Freeze the bottles overnight together with the gel packs.

5. Put the bottles into the biohazard plastic bags.

6. Pack the bottles into the same box they arrived in with the influent samples

7. Remove the paper on the side of the shipping box that covers the "diagnostic specimen" sticker

8. Send the box back to us using the pre-paid FedEx air bill.

Thank you very much,

Jochen Heidler and Rolf Halden

Sampling kit for

Treated wastewater (effluent)

And

Effluent-receiving stream samples

Dear Collaborator,
Enclosed in your sampling kit you will find 6 x 500 ml sample bottles, one trip blank as our control, gloves, stickers for labeling of the bottles and a prepaid FedEx air bill.

Detailed sampling instructions:
Treated wastewater (effluent):

1. Sampling should be done at a location directly prior to the discharge of the effluent into surface waters.

2. Please provide us with 2 x 500 mL 24-hour composite effluent samples (ideal)
   OR
   2 x 500 mL grab effluent samples from two consecutive days.

3. Collect the grab samples on two consecutive weekdays (e.g., Mo&Tu or Th&Fr).

4. Wear gloves during sampling to avoid both contact with bacteria and contamination of your samples with personal care products.

5. Using the provided stickers, please record on the bottles the day, time, flow rate, your name and the location.

6. Make sure that the bottle lid is screwed on tightly.

7. Pack the bottles into the same box they arrived in together with the stream samples and send it back to us using the pre-paid FedEx air bill.

Effluent-receiving stream samples:

1. Sampling should be done at normal river height. Don't sample after heavy rain to avoid dilution effects and data bias.

2. Please provide us with the following: **2 x 500 ml water samples from upstream** of your local wastewater treatment plant, and **2 x 500 ml from downstream** of your local wastewater treatment plant (~500-1000 ft downstream of discharge location; record approximate location).

3. Wear gloves during sampling to avoid contact with bacteria and contaminations of your samples with personal care products.

4. Collect duplicate samples upstream and downstream from the riverbanks where the flow velocity is similar to that of the stream. Avoid slow-moving and stagnant water.

5. Please record on the bottles using the provided stickers the day, time and sampling location in relation to the wastewater discharge pipe. Please include the names of the streets at the nearest intersection.

6. Make sure that the bottle lid is screwed on tightly

7. If you have access to a global position system (GPS) unit, please log in the sampling locations and forward the information to us.

8. Pack the bottles into the same box they arrived in with the effluent samples and send it back to us using the pre-paid FedEx air bill.

Thank you very much,

Jochen Heidler and Rolf Halden