City of New York
Department of
Environmental Protection
Bureau of Wastewater Pollution Control

Alternative Wastewater Disinfection Methods

Prepared for
New York - New Jersey Harbor Estuary Program
Pathogen Work Group

September, 1997

City of New York
Department of Environmental Protection
Bureau of Wastewater Pollution Control

and

HydroQual, Inc.
Environmental Engineers and Scientists
December 2, 1997

Mr. Robert Dieterich
US Environmental Protection Agency
Region II
Marine & Wetlands Protection Branch
290 Broadway, 24th Floor
New York, NY 10007

RE: Distribution of Report: Alternative Wastewater Disinfection Methods
Agreement No. CE002873-01-0

Dear Mr. Dieterich:

The attached report was prepared under a USEPA Region II agreement for the NY-NJ Harbor Estuary Program and Bight Restoration Plan. This task had been performed as part of DEP involvement with the HEP Pathogen Work Group. The attached document, together with a previously distributed report Analysis of Pathogen Sources, completes our contractual agreement with EPA.

For further information pertaining to this effort, please feel free to contact Alan I. Stubin, Chief of the Marine Sciences Section, at 212-860-9378.

Sincerely yours,

Robert E. Adamski, P.E.
Deputy Commissioner
Director
Bureau of Wastewater Pollution Control

Attachment

/AIDS

xc: Ausabel (USEPA), Golub (ISC), Suszkowski (HRF), Zambrano (NYSDEC), Downes-Gastrich (NJDEP), Luke (NYCDOH), Dujardin (HydroQual)
ALTERNATIVE WASTEWATER DISINFECTION METHODS

Prepared for

NEW YORK - NEW JERSEY HARBOR
ESTUARY PROGRAM
PATHOGEN WORK GROUP

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION II
Assistance ID No. CE002873-01-0

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EXECUTIVE SUMMARY

Driving the need to improve disinfection methodologies is the goal set forth in the 1972 Clean Water Act to provide waters that are suitable for fishing and swimming. Achieving these goals will require examination of disinfection needs beyond traditional sewage treatment plant point sources. Rain-induced discharges, including non-point source runoff, storm water discharges, and combined sewer overflows must also be considered.

While the success of chlorine disinfection cannot be denied, there is concern that present chlorination practices, while effective for controlling bacteria disease, are inadequate to address viral agents present in municipal effluent and other sewage sources. In addition, concern with regards to the environmental impact of both free and combined chlorine residuals, the product of the most widely used form of disinfection for secondary treatment plants, has prompted both New Jersey and New York to establish protective TRC water quality standards for fresh water streams and estuarine waters. These needs have renewed interest into investigating the development of alternative disinfection techniques.

This study examines the effectiveness of alternative disinfection practices in terms of their current level of application and effectiveness in controlling pathogens via indicators, as well as, their feasibility for use in the NY-NJ Harbor Estuary. Chlorination (and the associated practice of dechlorination), ultraviolet radiation (UV), ozonation, chlorine dioxide and bromine chloride were examined in terms of their advantages and disadvantages, i.e., environmental impact and health issues, expense, and complexity of operation. This effort involved a literature review that focused primarily upon the proceedings of the Water Environmental Federation Disinfection Systems Conference of May, 1993.

Both chlorine and UV are considered highly effective against bacteria pathogens, but are clearly less effective against viruses, protozoan cysts, and spore formers than ozone, chlorine dioxide or bromine-based disinfection; though cost and safety concerns, and the complexity of operation have limited the use of the latter three methods.
Chlorination has and continues to be the dominant method of disinfection. Dechlorination practices may effectively reduce toxic chlorine residuals, but increase operator costs and often substitute other hazardous chemicals. Use of chlorine dioxide or bromine-based disinfection rely upon hazardous chemicals and may also introduce toxic residuals to the aquatic environment. Ozone and UV radiation are the cleanest of the disinfectant methods compared. Use of ozone however, has increased costs associated with safe guarding against potential human health risks. With designs more applicable to low-grade wastewaters, UV systems seem to be a leading alternative to chlorination for treated wastewater applications. A critical limitation to employment of UV is that high turbidity waters necessitate high treatment dosages to ensure adequate disinfection. This in turn translates to increased costs and maintenance needs.

Findings noted herein indicate that overall, disinfection methods are not totally fail safe and typically have some level of environmental consequence. For this reason, application of a single technology (over all others) is not recommended. By far, disinfection technologies that are most actively being considered and applied to wastewaters are chlorination and UV. Ozone has seen very limited application to wastewaters, while chlorine dioxide and bromine-based (bromine chloride) technologies have had virtually no full-scale operating usage with treated wastewaters.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 INTRODUCTION</strong></td>
<td>1-1</td>
</tr>
<tr>
<td>1.1 USE IMPAIRMENT</td>
<td>1-2</td>
</tr>
<tr>
<td>1.2 GOALS</td>
<td>1-2</td>
</tr>
<tr>
<td>1.3 DISINFECTION</td>
<td>1-3</td>
</tr>
<tr>
<td>1.4 NEED FOR FURTHER STUDY</td>
<td>1-4</td>
</tr>
<tr>
<td>1.5 OBJECTIVES OF THIS STUDY</td>
<td>1-5</td>
</tr>
<tr>
<td><strong>2 PATHOGEN INDICATORS AND PATHOGENS</strong></td>
<td>2-1</td>
</tr>
<tr>
<td>2.1 CONTROL OF PATHOGENS/REGULATORY</td>
<td>2-3</td>
</tr>
<tr>
<td>2.2 PATHOGEN INDICATORS IN THE AQUATIC ENVIRONMENT</td>
<td>2-6</td>
</tr>
<tr>
<td>2.3 PATHOGEN CONCEPTUAL BASIS/EPIDEMIOLOGICAL</td>
<td>2-7</td>
</tr>
<tr>
<td>2.4 PATHOGENS OF CONCERN</td>
<td>2-8</td>
</tr>
<tr>
<td><strong>LITERATURE CITED (Sections 1 and 2)</strong></td>
<td>2-10</td>
</tr>
<tr>
<td><strong>3 DISINFECTION TECHNOLOGIES (CURRENT STATUS)</strong></td>
<td>3-1</td>
</tr>
<tr>
<td>3.1 GENERAL OVERVIEW OF DISINFECTION PRACTICES</td>
<td>3-3</td>
</tr>
<tr>
<td>3.2 GENERAL REVIEW OF DISINFECTION TECHNOLOGIES</td>
<td>3-5</td>
</tr>
<tr>
<td>3.2.1 Chlorination and Dechlorination</td>
<td>3-5</td>
</tr>
<tr>
<td>3.2.1.1 Effectiveness</td>
<td>3-9</td>
</tr>
<tr>
<td>3.2.1.2 Process Considerations</td>
<td>3-10</td>
</tr>
<tr>
<td>3.2.1.3 Advantages and Disadvantages of Chlorination - Dechlorination</td>
<td>3-12</td>
</tr>
<tr>
<td>3.2.2 Ultraviolet Irradiation</td>
<td>3-13</td>
</tr>
<tr>
<td>3.2.2.1 Effectiveness</td>
<td>3-16</td>
</tr>
<tr>
<td>3.2.2.2 Process Considerations</td>
<td>3-22</td>
</tr>
<tr>
<td>3.2.2.3 Advantages and Disadvantages of UV Disinfection</td>
<td>3-23</td>
</tr>
<tr>
<td>3.2.3 Ozone Disinfection</td>
<td>3-25</td>
</tr>
<tr>
<td>3.2.3.1 Effectiveness</td>
<td>3-27</td>
</tr>
<tr>
<td>3.2.3.2 Process Considerations</td>
<td>3-27</td>
</tr>
<tr>
<td>3.2.3.3 Advantages and Disadvantages of Ozone Disinfection</td>
<td>3-29</td>
</tr>
<tr>
<td>3.2.4 Chlorine Dioxide Disinfection</td>
<td>3-30</td>
</tr>
<tr>
<td>3.2.5 Bromine Based Disinfection</td>
<td>3-31</td>
</tr>
<tr>
<td><strong>3.3 CONCLUSIONS AND RECOMMENDATIONS</strong></td>
<td>3-32</td>
</tr>
<tr>
<td><strong>LITERATURE CITED (Section 3)</strong></td>
<td>3-36</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

Section

Appendix A: BEACH MONITORING AND CLOSURE CRITERIA FOR NEW YORK AND NEW JERSEY

Appendix B: COMPREHENSIVE LITERATURE REVIEW OF INDICATORS IN MOLLUSCAN SHELLFISH AND THEIR GROWING WATERS - TABLE OF CONTENTS

Appendix C: WATER-BORNE PATHOGENS OF CONCERN

Appendix D.1 COMPARISON OF IDEAL AND ACTUAL CHARACTERISTICS OF COMMONLY USED DISINFECTANTS

Appendix D.2 APPLICABILITY OF ALTERNATIVE DISINFECTION TECHNIQUES
LIST OF FIGURES

ESTIMATED RELATIVE EFFECTIVENESS OF CHLORINE AND UV DISINFECTION FOR REPRESENTATIVE MICROORGANISMS OF CONCERN IN WASTEWATER ...................................................... 3-17

UV DOSAGES REQUIRED TO REACH 35 ENTEROCOCCI/100 ML IN EFFLUENTS, UNDER AVERAGE (AND 95% CONFIDENCE LIMITS FOR) INACTIVATION KINETIC RATES ............................................. 3-18

COMPARISON OF TOTAL ANNUALIZED COSTS FOR UV RADIATION AND CHLORINATION-DECHLORINATION DISINFECTION SYSTEMS ............... 3-20

ADVANTAGES AND DISADVANTAGES OF CHLORINE AND UV DISINFECTION ................................................................. 3-21

EFFECTS OF OZONE DISINFECTION³ ON EFFLUENT QUALITY .......... 3-27

SUMMARY TABLE: COMPARISON OF ALTERNATIVE WASTEWATER DISINFECTANT METHODS ......................................................... 3-33
ALTERNATIVE WASTEWATER DISINFECTION METHODS

SECTION 1
INTRODUCTION

The Estuary Program of the New York/New Jersey Harbor identified releases of pathogens from point and non-point sources as an issue to be addressed through abatement measures of the Comprehensive Conservation and Management Plan (CCMP). This report concerning pathogen disinfection was prepared to serve as a reference for the Pathogens Work Group of the Harbor Estuary Program (HEP). The report is made up of three sections, the first two of which are introductory in nature: Section 1 describes the background and need for this project by primarily citing recent regional reports; and Section 2 summarizes, in brief, regional concerns with the control of pathogens and the use of pathogenic indicators. Section 2 cites numerous publications beyond regional efforts. In both sections, an effort has been made to cite appropriate literature and to provide the reader with background information and sources on the topic for further reading. As such, these sections are not meant to represent an extensive coverage of the subject matter, but to enable the non-technical person to better understand Section 3.

Section 3 provides technical literature references and a synopsis of alternative disinfection methods, focusing on selected research papers from the May 1993 Water Environment Federation Specialty Conference on "Planning, Design and Operations of Effluent Disinfection Systems", held in Whippany, New Jersey.

Throughout this report, we focused on the harbor estuary, i.e., a regional perspective as regards applicability of methodologies and findings. This effort should be useful to HEP in targeting optimal disinfection practices as they relate to the harbor estuary.
1.1 USE IMPAIRMENT

The Comprehensive Conservation and Management Plan (CCMP) (1996) of the New York-New Jersey Harbor Estuary Program (HEP) indicates that a major cause of regional beach closures and unsafe seafood (shellfish) is the presence of pathogens in area waters. Similar findings had also been cited in the Long Island Sound Study (LISS) CCMP (1994), which reported beach and shellfish area closures due to pathogen contamination. An earlier effort, New York Bight (NYB) Restoration Plan Phase II Report: A Review of Closed Shellfish Areas and Bathing Beach Areas in the New York Bight (Pathogens Work Group, 1990), had previously described extensive shellfish bed closure in the Bight Apex and localized coastal areas, as well as, intermittent closure of bathing beaches. As a result of the 1972 Clean Water Act, all dry weather domestic sanitary wastes have been intercepted and provided secondary treatment with disinfection at the many wastewater treatment plants prior to discharge to the harbor/estuary so that combined sewer overflows (CSOs) remain as the dominant source of pathogens to the harbor/estuary. To remedy this problem, it is necessary to reduce loadings of pathogens from Combined Sewer Overflows (CSOs), storm water discharges and non-point sources to levels protective of public health (see pages 28 and 29 of the Summary of the Proposed CCMP (HEP, 1995)). As evident from a series of reports published by the Natural Resources Defense Council (McLain, 1993), pathogen contamination of coastal waters is not unique to the Northeastern United States; rather it is a problem of national concern.

1.2 GOALS

In recognition of use impairments associated with pathogens, the NYB Restoration Plan (now incorporated into the HEP) had upon its outset in 1989 developed and assigned a Pathogen Work Group to:

1) Evaluate the extent of current and historic shell fishing and bathing beach resource impairment;
2) Evaluate levels of pathogens and indicators in the Bight; and
3) Assess the feasibility to reduce these impairments.

Part of their assignment was to incorporate peer review to New Jersey DEP research on an alternative indicator system. To a large extent these assignments have been carried over to the HEP Pathogen Work Group, which has identified three major goals (CCMP 1996):

- Preserve, restore, and maintain human uses of harbor and coastal waters for bathing and shell fishing;
- Ensure protection of human health from waterborne pathogens; and
- Protect marine and coastal resources from adverse pathogenic effects.

To address these goals HEP has developed a number of objectives, one of which is to "optimize disinfection practices". This objective is of importance because those point sources that can incorporate/improve disinfection practices have been identified among the significant sources of pathogens to the Harbor Estuary (HEP, 1996). (See also NY-NJ Harbor Estuary Program Comprehensive Conservation and Management Plan Supporting Document: Pathogen Contamination, (Gastrich 1995)).

1.3 DISINFECTION

As noted by White (1992), the incorporation of standard chlorination disinfection practices in the 20th Century has successfully addressed one of the largest public health issues in the United States. Use of chlorine has virtually eliminated acute waterborne diseases such as typhoid fever and cholera. Early in this century these diseases were endemic and often epidemic, but are now virtually unknown in the United States and other developed countries. Considering where chemical disinfection is practiced, it has been estimated that at least 99 percent of all municipal water supplies and virtually all sewage treatment plants (STPs) practicing disinfection use chlorine or hypochlorite (White, 1992).
Reasons for the widespread acceptance and use of chlorine as a disinfecting agent of choice will be further discussed in detail in Section 3.

Current regulations for the NY-NJ Harbor Estuary, require year round chlorination of sewage effluent to reduce pathogens in shellfish areas. The development, expansion and upgrading of New York and New Jersey sewage treatment plants has considerably improved Harbor Estuary water quality (HEP, 1996). See also Brosnan and O'Shea (1995) New York Harbor Water Quality Survey: 1994, pgs. 7-10, for a brief history of NYC sewage treatment plant development and consequent improvement of estuary water quality, especially as regards fecal and total coliform reduction. Implementation of US EPA interim CSO measures and abatement initiatives will undoubtedly further improve regional water quality. Municipal water pollution abatement initiatives will also address CSO disinfection needs.

1.4 NEED FOR FURTHER STUDY

While the success of chlorine disinfection cannot be denied, there is concern that present chlorination practices, while appropriate for controlling bacterial disease, are inadequate to address viral agents present in municipal effluent (see Characterization of Pathogen Contamination in the NY-NJ Harbor Estuary, (Gastrich et al., 1990)). Importantly, widespread use of bacterial indicators, i.e. coliforms, is inadequate for assessing risks of viral exposure, due primarily to differential die-off in marine waters and increased survival of viruses associated with marine sediments or organic particulates. This difference is further exaggerated following typical chlorination of wastewater (PWG, 1990) and has prompted environmental managers to consider disinfection methods other than chlorination.

Also encouraging environmental managers to consider alternative disinfection methods is increasing concern with regards to forming carcinogenic chlorinated hydrocarbons through the disinfection process. As will be shown in Section 3, a serious disadvantage of chlorination is that chlorinated hydrocarbons do not readily biodegrade and
may bioaccumulate in the food chain. Improvements in analytical laboratory capabilities will likely allow for lower detection levels of these compounds in environmental samples, placing greater demand and scrutiny upon sewage treatment plant (STP) operators. Reflective of these concerns are regulatory changes to NJ and NY STPs, which have added total residual chlorine to the list of parameters for marine water quality standards and reduced the permitted discharge of chlorine in effluents released to fresh water streams containing fish habitats.

Due to the above concerns, the NY Bight Restoration Plan (PWG, 1990) recommended an assessment of both current and alternative disinfection practices for wastewater discharges. This assessment would examine the effectiveness of disinfection in reducing both viral survival and adverse effects on living resources of the aquatic environment. Following up on this earlier recommendation, the HEP Pathogen Work Group called for an assessment of alternative disinfection methods in its final work plan (Task 4.1). This task would:

1) Include a review of available literature on residual and chronic toxic effects of chlorination; and
2) Determine/recommend optimum disinfection method(s), considering cost, efficacy in destroying pathogenic bacteria and viruses, and residual toxicity in ambient waters.

1.5 OBJECTIVES OF THIS STUDY

This report has been prepared to allow managers an overview of alternative disinfection methods in terms of their current level of application, advantages and disadvantages, effectiveness in controlling pathogens via indicators, and ultimately the feasibility of recommended disinfection processes for use in controlling pathogens entering the NY-NJ Harbor Estuary. The current effort to assess alternative waste water disinfection methods represents only an initial step to the fulfillment of Task 4.1 of the HEP CCMP (1996). The charge given to NYC DEP, as described in NY-NJ Estuary/New
York Bight Program, CCMP Supporting Document, Pathogen Contamination, (Gastrich and PWG, 1995), is to "prepare a report summarizing the proceedings of the Water Environment Federation Disinfection Systems Conference held in Whippany, NJ on May 23-25, 1993, and to prepare a base literature survey of the topic".

This effort is also preliminary to Task 4.2 of the same plan, which is to conduct a disinfection monitoring study in order to verify the best methods of wastewater disinfection. To determine whether or not a disinfection monitoring study is warranted, the pathogen work group (PWG) recommended this survey of alternative disinfection methods. As noted in the HEP, CCMP (1996), "HEP supports the use of optimal methods of disinfection and recommends that the states evaluate the results of New York City's investigation, under HEP, of alternative disinfection methods. As appropriate, the states will issue disinfection guidance."
SECTION 2

PATHOGEN INDICATORS AND PATHOGENS

Early sanitary and public health studies, as well as subsequent research and investigations established the water route for transmission of enteric pathogens. However, analytical and technological developments do not as yet allow for direct, simple, routine laboratory qualification and quantitation of the waterborne enteric pathogens. Instead, there has developed a significant, microbiological data base under standardized and modified conditions using surrogate or so-called "Indicator Organisms" to allow for assessment of pathogens. These serve as an index or measure of potential harm or risk, i.e., the greater the quantity of an "Indicator Organism", the greater the index, the greater the chance a given pathogen is present and thereby the greater the potential for disease. Empirically, for most situations this rationale has been upheld.

The coliform bacteria have been the traditional and generally continue to be the indicator organism most often employed. Their use has successfully led to appreciable reductions in risks from fecal-derived pathogens in recreational and shellfish growing waters. However, there are certain well known caveats, exceptions and limitations in using coliform bacteria as an indicator. Consequently, many refinements in techniques and/or choice of genus have been proposed or made. (See Appendix A for a table of beach monitoring and closure criteria, as adapted from an Interstate Sanitation Commission Meeting Summary (Golub, 1994)).

It is worthwhile to develop monitoring techniques more attuned to the presence and concentration of the actual pathogen rather than the presence of *Escherichia coli* and other surrogate indicator organisms. This is duly noted and detailed in *Standard Methods For The Examination of Water and Wastewater* (APHA, 1992) on pages 9-1 to 9-147. See also the New York Bight Restoration Plan Phase II Report (PWG, 1990) for a discussion on the "Use of Indicators" (pages 11 to 14) and "Pathogens of Concern" (pages 4 to 10).
M.D. Pierson and C.R. Hackney, as editors, along with twenty nationally recognized experts primarily from academia, as chapter contributors, prepared an excellent and thorough report,


A copy of their "Table of Contents" chapter titles is provided as Appendix B for the convenience of readers of this report; one can focus on important, specific information on such topics as:

- Microbial and Chemical Indicators;
- Human Enteric Pathogenic Viruses;
- Human Associated Bacterial Pathogens; and
- Epidemiologic Studies.

The above is an excellent and thorough reference source and should be consulted, especially for the extensive "Literature Cited" with each chapter.

White (1992), pages 291 to 324 and 558 to 579, provides another source of background and current information on waterborne pathogens, diseases and indicators. Additionally, a most current and thorough review is given annually in the "Literature Review" June issue of Water Environment Research, a publication of the Water Environment Federation. The June 1994 issue (Vol 66, No 4) has reviews on "Detection and Occurrence of Waterborne Bacterial and Viral Pathogens (pg. 292 to 298), "Disinfection and Antimicrobial Processes" (pg. 361 to 368), and "Health Effects Associated with Wastewater Treatment, Disposal, and Reuse" (pg. 651 to 657). These titles/topics are also covered in prior June issues and are an excellent source for the latest information.
2.1 CONTROL OF PATHOGENS/REGULATORY

The U.S. EPA, through its permit system (National Pollution Discharge Elimination System or NPDES), has transferred their regulatory, administrative, and enforcement requirements concerning surface waters to the States (State Pollution Discharge Elimination System or SPDES). The SPDES permit issued to an authority, municipality or entity allows discharge of wastewaters into receiving waters, with certain qualitative and quantitative conditions/restrictions to prevent receiving water degradation. As stated in the 1972 Clean Water Act, the long term goal for surface waters is to attain water quality suitable for fishing and swimming.

As previously noted, since 1989, due in large part to the efforts of the Interstate Sanitation Commission, all regulated municipal wastewater point discharges into the New York Bight and New York-New Jersey Harbor have been disinfected year-round by chlorination.

Despite certain drawbacks to chlorination (See Section 3), the disinfected effluent from point source discharges is relatively easy to monitor and control as compared to non-point runoff, storm sewer discharges and combined sewer overflows (CSOs). The magnitude of monitoring, evaluating and controlling these sources to the Harbor Estuary is extensive and difficult considering that approximately 60 STPs, 985 municipally owned storm sewer outfalls and 715 combined sewer outfalls (New York and New Jersey) are involved (see Table 3-6 in the NYC DEP/HydroQual 1993 City-Wide Floatables Study). As regards rain-induced discharges, the urban-core area is overwhelmingly hard-surfac ed so that rainfall primarily enters a sewer (storm or combined). These are defined by NYC DEP as a point source discharge. However, there are some non-sewered or natural land areas (most notably in New Jersey south of Raritan Bay) that allow for direct runoff to the Harbor Estuary, thereby compounding the issue of source control.

Examples of regulatory agency efforts to control pathogens to the harbor are the NYSDEC SPDES Permits for NYC and the Citywide CSO Abatement Program, as well as
the New Jersey Infrastructure Improvement Act. Consequently, various disinfection research studies such as those in Jamaica Bay are in progress for controlling and decreasing pathogens in combined sewer overflows (CSO). These include chlorine residuals and the use of other disinfectants such as ultraviolet radiation and ozone.

NYS requires that the CSO abatement program meet water quality standards and that no designated use impairments exist. The conventional disinfection approach would propose chlorination as a final step in the CSO facility. However marine water quality standards for total residual chlorine are not met by the conventional approach. Consequently, NYC DEP is investigating methodologies which might provide a balance to the regulatory requirements. A chlorine residual study is incorporated into the Jamaica Bay CSO abatement project to:

1) Collect data on the chlorine demand of CSO’s;
2) Develop measurement methods for total residual chlorine (TRC) at the chronic and acute μg/L levels set forth in the marine standard (7.5 μg/L for "SA", "SB" and "I" waters which are classified as shell fishing, bathing and fishing respectively, and 13 μg/L for "SD" waters classified as fish survival, e.g., the Kills); and
3) Determine an approach to wet weather discharge dosing and dilution.

As discussed previously, indicator bacteria, i.e., total and fecal coliform bacteria, are most commonly used to indicate the presence of fecal wastes and thereby the potential presence of pathogens in shellfish harvesting waters and primary contact recreation waters.

It should be noted that the only seafood products regulated by microbiological standards for growing water quality are Molluscan shellfish. This is because of:

1) The filter feeding behavior of Molluscan shellfish, wherein microorganisms are concentrated in and on the tissues;
2) The close association of these shellfish with sediments which contain much higher concentrations of pathogens and pollutants as compared to the water column; and

3) The *Molluscan* shellfish tissues are often consumed uncooked.

For the above reasons, NY and NJ rely upon a more stringent total coliform standard of \( \leq 70 \text{ MPN/100 mL} \) for shellfish harvest waters as compared to \( \leq 2400 \text{ MPN/100 mL} \) for NY marine bathing waters, and no single sample shall exceed 200 Fecal Coliforms/100 mL for NJ marine bathing waters. Obviously, marine waters are not likely to be ingested by bathers. For a historical development of shellfish standards and the rationale for establishing growing waters standards, the reader is again directed to the previously cited Pierson and Hackney (1991) literature review of indicators in shellfish and their growing waters.

According to a 1994 Interstate Sanitation Committee meeting on current bathing beach practices (Golub, 1994 and see Appendix A), the New Jersey Department of Environmental Protection (NJ DEP) monitoring program uses a *fecal coliform* standard for bathing beaches of 200/100 mL (10% of FC samples may not exceed 400) with additional conditions, e.g., resampling and sanitary survey for closure and re-opening. The New York City Department of Health (NYC DOH) and Nassau County use closure standards based on the New York State Department of Environmental Conservation (NYS DEC) Water Quality Standards specifying a monthly mean *total coliform* value that is not to exceed 2,400/100 mL or the log mean of five or more *fecal coliform* samples is not to exceed 200/100 mL with certain additional requirements such as frequency of sampling and a sanitary survey. Although not shown in Appendix A, the Connecticut Department of Public Health and Addiction Services uses a running monthly mean *enterococcus* standard of 33/100 mL with a single sample not to exceed 61/100 mL. Other criteria similar to those employed by NY and NJ are also utilized. For additional information on the different indicators used for bathing, see Golub, (1994), McLain (1993), and Kassalow, et.al. (1991).
2.2 PATHOGEN INDICATORS IN THE AQUATIC ENVIRONMENT

Primarily due to the above bathing water indicator standards, there have been few recent, local, reported incidents of bathing water illness. This is largely due to the conservative nature of these standards. Also contributing to this low illness rate are relatively low levels of endemic typhoid fever bacterial pathogens in the general population, little incidental ingestion of saline waters, and continuous wastewater chlorination disinfection. It is however, important to note, that for marine waters receiving chlorinated wastewater effluent, total and fecal bacteria do not adequately indicate the presence of viruses because of their different die-off rates and the increased survival of viruses when associated with sediments and organic particles. Noteworthy, according to the HEP CCMP (1996), is that viruses are now thought to be the most prevalent human disease causing agents in the Harbor. Furthermore, there is a growing interest to identify a reliable human-specific viral indicator as a supplement to existing bacterial water quality indicators.

Viruses are suspect of causing public-health concerns via water contact activities, with a causative relationship established for hepatitis A, Norwalk and Norwalk-like viruses, and rotavirus (Herwaldt, et al., 1991; Hedberg and Osterholm, 1993). This association has been more difficult to develop in assessing shellfish harvest waters and may be the likely reason for many incidents of hepatitis due to consumption of raw shellfish. It is also necessary to understand that currently practiced municipal wastewater chlorination disinfection is not highly effective against viruses. This raises a substantive concern regarding actual and/or potential viral contamination of shellfish growing waters and bathing waters wherein human point pollution sources are present.

Consequently, because of these and other deficiencies, studies seeking alternative indicators of human and warm blooded animal fecal contaminants are underway, including a sweep of potential indicators by the National Indicator Study and more regionally, coliphage (bacterial viruses) by the NJDEP. The latter study has been continuing under the auspices of the HEP. First year results showed F+ RNA coliphage to hold promise as a human specific indicator. These early findings showed coliphage to demonstrate a
relationship with the expected degree of fecal contamination and through stereotyping to have the potential ability to differentiate between human and animal fecal contamination. Continuing studies are expected to strengthen and confirm preliminary correlations and to investigate chlorination effects upon viruses and indicators.

2.3 PATHOGEN CONCEPTUAL BASIS/EPIDEMIOLOGICAL

Considering the popularity of recreational bathing in marine waters, it should be noted that there have been very few definitive epidemiological studies relating gastroenteritis and enterococci density. According to Cabelli, et al. (1983) the first Federal fresh water and marine water quality "criteria for bacteria" were proposed by the National Technical Advisory Committee (NTAC) of the U.S. Department of the Interior in 1968. It was based on Stevenson's 1953 epidemiological studies of fresh water quality and health conducted by the U.S. Public Health Service (PHS) wherein swimmers in water with a median total coliform density of 2300/100 mL had a significantly greater illness rate than the total study population. Additionally, the 1968 NTAC proposed using the fecal coliforms as they are more indicative of human fecal contamination and therefore human health risk.

Stevenson's 1953 US PHS study had shown statistically significant, swimming-associated, gastrointestinal symptoms at 2300 total coliforms/100 mL. Since fecal coliforms were 18% of the total coliforms, i.e., 400/100 mL, the 1968 NTAC proposed: a fecal coliform density not to exceed a log mean of 200/100 mL (half the threshold detectable risk); a minimum of five samples over a 30 day period are to be taken; and during any 30 day period 10% of the samples are not to exceed 400/100 mL. This fecal coliform density represented an "acceptable illness rate" of 19/1000 swimmers.

Researchers questioned the above criteria as to the degree to which coliforms represented the presence of pathogens and whether they actually indicate human health risk. It is obvious why, with such a paucity of epidemiological recreational water information, the U.S. EPA necessarily funded studies on this topic from 1972 to 1978 from
which Cabelli, Dufour, McCabe and Levin provided much information in their publications. Health risks of swimmers and non-swimmers at fresh and marine waters were studied, as were various bacterial indicators, e.g., enterococci and coliforms. From these studies, in 1986 the U.S.EPA (based on an acceptable gastroenteritis rate of 19/1000 swimmers) recommended a dry weather geometric mean of 35 enterococci/100 mL marine recreational waters (minimum five samples over a 30 day period). However, due to much criticism and uncertainty raised with regards to these findings, U.S.EPA has not enforced implementation of its suggested criteria. Rather it has been left to the discretion of individual states to establish their own water quality standards.

A report by the Natural Resources Defense Council (McLain, 1993) indicates that very few states have adopted the U.S.EPA recreational water criteria, most states staying with their fecal and/or total coliform standards, including New Jersey and New York. For fresh and marine waters, Connecticut adopted the enterococci standards.

Obviously local and regional agencies have not opted for the EPA enterococci indicator. In fact, Fleisher (1991) and others have questioned the validity of the methodology and data supporting the U.S.EPA bacteriological water quality criteria for marine recreational waters. Fleisher further questioned the appropriateness of using a single maximum allowable mean enterococci density for all U.S. marine recreational waters. It should be noted that epidemiological studies are complex and confounded in that waterfront users may well be exposed to pathogens through a number of activities other than water immersion, e.g., food consumption.

2.4 PATHOGENS OF CONCERN

Through time and much research, waterborne diseases other than typhoid fever and cholera were recognized, as were their causative organisms. This includes amoebic dysentery, Giardia, bacterial gastroenteritis (Shigellosis, Salmonellosis, toxigenic E. coli, Campylobacter enteritis, Pseudomonas...), Schistosomiasis, Cryptosporidium, Legionella (Legionnaires Disease), worms and viral diseases. Much of this investigative work was
done on potable water supplies rather than wastewater receiving waters, having both recreational and drinking water value. Again, it should be noted, chlorine disinfection is not effective against some life cycle stages of the above pathogens, e.g., Giardia, viruses and Cryptosporidium.

The table in Appendix C is from the New York Bight Report (PWG, 1990) and clearly summarizes the water-borne pathogens of concern in the Harbor Estuary.
LITERATURE CITED (Sections 1 and 2)

Anon., CITY-WIDE FLOATABLES STUDY, NYC Department of Environmental Protection and HydroQual Inc., 1 Lethbridge Plaza, Mahwah, New Jersey 07430. Capital Project WP-112, Final Report, Table 3-6, (September 1993).


SECTION 3
DISINFECTION TECHNOLOGIES (CURRENT STATUS)

The primary literature source which was used for this chapter for information concerning the current status of disinfection technologies was the Proceedings, Water Environment Federation Specialty Conference Series - Planning, Design and Operation of Disinfection Systems (WEF, 1993). Held in Whippany, NJ in May 1993, this conference offered a comprehensive review of current trends in disinfection, including the technologies that are being considered for application to wastewaters.

Two design publications are suggested for a comprehensive analysis of the design, operation and maintenance considerations associated with the alternative disinfection methods. The US EPA Design Manual: Municipal Wastewater Disinfection (US EPA, 1986) remains one of the more detailed design guidance documents for disinfection, and was the first to provide such information for ultraviolet radiation. (In addition, an excellent table comparing the applicability of alternative disinfection methods from this US EPA document has been included in Appendix D of this report.) Water Environment Federation’s (WEF) Manual of Practice for Wastewater Disinfection (WEF, 1986) is a similar document that has been updated and will be published shortly. This latest version (WEF, 1996; in publication) offers an excellent overview of the current status of technologies available for disinfection, including design practice and operation and maintenance considerations applicable to wastewaters.

Three recent publications are recommended that offer detailed discussions of UV, chlorination and potential disinfection applications to CSO-type wastewaters. These are:

1. Comparison of UV Radiation to Chlorination: Guidance for Achieving Ultimate UV Performance (Darby et al., 1995)
2. Disinfection Effectiveness of Combined Sewer Overflows (US EPA, 1995); and

The above documents also provide extensive reference listings and bibliographies.

This section will address several disinfection technologies presented at the 1993 WEF Disinfection Conference, highlighting those techniques that are being used for, and which have practical application to the region’s wastewater sources. These are chlorination (and the associated practice of dechlorination), ultraviolet radiation (UV), ozonation, chlorine dioxide and bromine chloride. By far, the technologies that are actively being considered and applied to wastewaters are chlorination and UV. Ozone has seen very limited application to wastewaters, while chlorine dioxide and bromine-based (bromine chloride) technologies have had virtually no full-scale operating usage with treated wastewaters. Noteworthy, is that nearly half the papers presented at the WEF specialty conference were related to UV, reflecting the increased interest and acceptance of UV systems for treated wastewaters and, more recently, for low-grade waters such as combined sewer overflows (CSOs), sanitary sewer overflows (SSOs) and stormwaters.

In summary, technology currently exists to effectively treat and disinfect such wastewaters as stormwater runoff, CSOs and treatment plant effluents that are discharged to the New York-New Jersey Harbor watershed. This section will review the disinfection technology of chlorination, ultraviolet radiation (UV), ozonation, chlorine dioxide, and bromochlorination as they apply to regional needs. It should be noted, however, that one cannot recommend the universal application of a single disinfection technology over all others. Rather, selection of a specific process/technology will be dictated by the circumstances of the application, i.e., hydraulics, facility requirements, constraints (e.g., neighborhoods, access, space, etc...), wastewater characteristics, local receiving water, and the goals of the treatment/disinfection process. The reader is referred to Appendix D, where these and other characteristics are compared for disinfectant alternatives.

Consequently, from this review it will be apparent that certain technologies are favored over others. Specifically, these are chlorination and ultraviolet radiation.
Chlorination remains dominant in its application to wastewater disinfection and is the "accepted" disinfection process. However, UV is gaining acceptance as an alternative to chlorination and is often selected for new plants. In cases where chlorine use is disallowed for safety and/or environmental reasons, UV is the preferred alternative given the ability of this technology to be easily retrofitted into existing facilities.

3.1 GENERAL OVERVIEW OF DISINFECTION PRACTICES

Disinfection is the practice of reducing the quantity of pathogenic organisms in waters in order to mitigate the risk of transferring waterborne diseases to the general public. It should not be confused with sterilization, in which the goal is the complete elimination of all organisms. Disinfection has been generally practiced with potable waters and with sanitary wastewaters. Potable water disinfection practices are not addressed within the context of this report since its focus is on the control of pathogens in the New York/New Jersey Harbor estuary. Instead, the discussions center on treated discharges from sewage treatment plants (STPs).

Recently, the disinfection of precipitation-induced discharges to natural receiving waters has also been considered, including CSOs, SSOs and urban stormwater runoff. Intermittent in nature, these types of point discharges have generally received little treatment (as opposed to the extensive treatment given to sanitary wastewaters) and can be a significant pathogen load to local surface waters. Current trends have begun to consider the relative impacts of these "non-point" sources. Although "captured" (particularly in urban settings), stormwater runoff will enter a receiving water at multiple points as CSOs, SSOs and as direct storm water sewer discharges. Thus, one is faced with hundreds of discharges instead of the relatively few direct discharges from STPs. These sources provide a substantial challenge to effective treatment, in that they are typically turbid, containing a high level of suspended material and organic enrichment and they display substantial volume fluctuations. Such discharges are receiving heightened interest as "watershed" approaches are being implemented for evaluating disinfection and
other contaminant removal needs, and are being used for setting wasteload allocations on a regional basis.

Contamination of both surface and ground waters is a major concern; however, it was not until promulgation of the Clean Water Act in 1972 that disinfection was mandated for wastewater discharges. This was subsequently modified to a "guidance" at the federal level, and the authority for establishing limits on the basis of technology or water quality standards was delegated to the states. In some cases this has meant that disinfection is not required, often assessed on the basis of the location of the discharge, ambient water quality and the designated receiving water uses. The overwhelming practice, however, is to require some degree of disinfection of wastewater. The analysis for disinfection of wet weather intermittent discharges is not as clear.

Chlorination has and continues to be the dominant method of disinfection. In the 1970s, concerns were raised regarding the formation of carcinogenic chlorine by-products, and with the toxicity of chlorine to local aquatic biota. Public safety issues were also brought to the forefront regarding the transport, storage and handling of liquid chlorine (and sulfur dioxide), particularly in urban areas. These various concerns led to the widespread practice of dechlorinating the effluent prior to discharge, and to a concerted effort to seek alternative approaches to chlorination itself. Much effort was expended through the late 1970s and 1980s to develop and evaluate such technologies as UV, ozonation (a process that was well developed for potable waters), chlorine dioxide and bromine chloride. Several ozone plants were constructed, and remain in operation, while alternative halogen processes were developed primarily on a pilot scale. In contrast, UV systems have been accepted and are being installed for full scale operation at an increasing pace.

Other approaches have been considered, using natural systems. For example, Girts (1993) studied coliform removal in a constructed wetland treatment system. The process was found to be effective for fecal coliform removal, although supplemental disinfection would be needed to meet a limit of 200 FC/100mL. In certain cases, however, such a
system alone may be sufficient to meet water quality goals. Wetlands systems are considered emerging technologies; they have received little consideration in the NY/NJ Harbor drainage area, primarily because of the large area requirements for the wetland treatment and the urbanized characteristics of the drainage basin.

As regulatory agencies have recently advanced the need for disinfection of other discharges (CSO, SSO, and stormwaters), there has been a renewed interest in studying alternatives. In principle, the disinfection of CSO-type wastewaters is directly impacted by the level of pretreatment for solids removal. An excellent review of the status of disinfection of such low-grade wastewaters is to be included in a US EPA report entitled, Evaluation of CSO Disinfection, to be published shortly.

3.2 GENERAL REVIEW OF DISINFECTION TECHNOLOGIES

This section provides a review of the various disinfection technologies that have been mentioned, specifically addressing a description of the technology and its application, its advantages and disadvantages, its efficacy of use/kill, its operation, costs and any current developments noted in recent literature. The review is general in nature, and is directed to giving the reader an overview of the mechanics of the process and its potential applications.

In particular, selected articles from the 1993 WEF Specialty Conference "Planning, Design and Operation of Effluent Disinfection Systems" are cited as they pertain to the individual technologies or to alternative approaches for disinfection. The reader should refer to the design and technology reviews cited earlier for detailed information, and for the extensive reference listings contained in each publication.

3.2.1 Chlorination and Dechlorination

The disinfective qualities of chlorine have been recognized since the early twentieth century. In the United States, chlorine was first used on a large scale in 1908 at the
Jersey City, NJ, water plant (Water Authority Outreach Program, 1991). By 1940, the nearly universal practice of chlorination greatly reduced the threat of certain waterborne diseases in the USA, including typhoid fever and cholera.

Chlorine's disinfecting ability derives from its toxicity at relatively low concentrations. As a powerful oxidant, chlorine undergoes chemical reactions with inorganic and organic substrates. When the organic substrate is part of a living organism, the reaction can produce a change in the organism that may affect the organism's ability to reproduce or metabolize, produce genetic dysfunctions or kill the organism outright. The active agents are hypochlorous acid (HOCl) and hypochlorite ion (OCl\(^-\)) which result from the hydrolysis of chlorine in water.

When there is ammonia present in the water, as is typically the case with conventional domestic wastewaters, intermediary chlorinated amines, or chloramines, are produced. These are primarily in the form of mono- and dichloramines (NH\(_2\)Cl and NHCl\(_2\), respectively), and which are commonly referred to as combined chlorine. If conditions are such that all the ammonia is consumed, and the chloramines are progressively oxidized to free nitrogen and chlorides (a process often referred to as "breakpoint chlorination"), then any additional chlorine that is added will remain as "free" chlorine. This is often the practice in a potable water system, where a free residual is desirable in the distribution system. However, the relatively high concentrations of ammonia in treated and untreated wastewaters makes this uneconomical in traditional wastewater practice. Thus, the active agents in wastewater chlorination are predominantly the chloramines.

Residual free chlorine and chloramines are toxic to fish and other aquatic organisms. In order to protect local biota, dechlorination, or the removal of the residual chlorine, is typically required by most states, particularly for discharges to small streams or to biologically sensitive reaches of a receiving water (e.g., trout fisheries). In such cases, residuals from a discharge are typically limited to levels less than 0.1 mg/L. Although chlorination is typically found to be the more cost-competitive of the disinfection alternatives, adding a dechlorination process will often negate this, making alternatives more economically attractive.
Free and combined chlorine residuals can be effectively removed by sulfur dioxide or by liquid sulfite salts, wherein the sulfite ion (SO$_3^{2-}$) is the active agent. Stoichiometrically, the amount of sulfur dioxide required per part of chlorine removed is 0.9. In actual practice a ratio of 1 to 1.1 is used. Unlike chlorination, which requires contact times between 30 and 60 minutes, dechlorination with sulfite is rapid, requiring only a few minutes reaction time. Granular and powdered carbon can also be used for dechlorination, although, because of their high cost, their application is limited to specific sites or effluents with special discharge requirements. Carbon requirements are usually determined by on-site testing, with doses reported to be typically in the 30 to 40 mg/L range.

When considering the application of chlorination, current analyses will necessarily take into consideration several factors, including the economics of the process and the need for dechlorination. In a case study that is relevant to the NY/NJ Harbor region, Getter, et al. (1993) reported on the disinfection system planning and design conditions for the Deer Island treatment plant under construction in Boston Harbor. In particular, this considered the relevance of dechlorination under circumstances specific to the harbor and discharge locations. In the earlier facilities planning stages, it had been decided to construct a sodium hypochlorite and sodium bisulfite chlorination-dechlorination system. During design, however, the concept of disinfection was reevaluated, based on chlorination experiences at other plants and pilot studies, and considering the ocean outfall location for discharge of the treated effluent.

Getter, et al. (1993) thereby found that seasonal disinfection would be appropriate, given the fact that water quality fecal coliform standards could be met during cold temperature conditions without chlorination. Additionally, dechlorination would not be needed since there was sufficient chlorine demand to consume the residual during the
contact time within the long outfall, and due to the extensive dilution to be achieved with
the new outfall diffusers. Additional work is being done to determine if adequate
disinfection can be accomplished at lower chlorine residuals.

A factor that has influenced the economics and selection of chlorination and
dechlorination has been the safety of the process and the risks associated with the
transport, storage and handling of the chemicals used in the processes. Often, however,
concerns for safety are a perceived problem, without factual basis. White (1993)
addressed the risks and hazards of chlorine leaks when using liquid chlorine (and sulfur
dioxide), generally associated with valve failures in cylinders and tanks. Mohleji and Wong
(1993) cited statistics that showed a very low accident rate with chlorine usage. In 1972
through 1982, for example, there was one accident per 48,000 tons of chlorine
consumed. For perspective, they cited the Greater San Diego Clean Water Program, where
the estimated total chlorine use for all treatment plants is approximately 3,000 tons/year.

Mohleji and Wong (1993) compared the use of hypochlorite versus liquid chlorine,
using costs and nonmonetary factors such as risk potential, reliability, ease of
implementation, traffic and environmental impacts, and the impact of salinity on reclaimed
water. They concluded that liquid chlorine was more appropriate, recognizing the risks in
the transport, handling and storage of the liquid chlorine. The authors noted, however,
that the design and operation of such systems must provide extensive built-in redundancy
of safety equipment and fail-safe systems. The least costly of the hypochlorite
alternatives was still more than twice the cost of the liquid chlorine option, and did not
provide any improvement in effectiveness or process control.

Although cited as a major concern, and often the reason for selecting an alternative
system, safety considerations can be resolved for chlorination and dechlorination
processes. Regulations exist to enforce effective facilities design and emergency response
protocols, including OSHA, Uniform Fire Codes, and SARA Title III requirements. Still, the
increasingly stringent codes (particularly at the local or state levels), are having an effect
on costs and are making alternatives such as UV attractive.
3.2.1.1 Effectiveness

It is well established that chlorine is effective in killing bacterial organisms such as those responsible for typhoid fever, paratyphoid, dysentery, cholera and other related bacterial diseases (WEF, 1996). Species frequently associated with skin, eye and other recreational contact diseases are also controlled by chlorine disinfection.

Although there are many different enteric viruses of public-health concern that may be present in wastewater, direct evidence of transmission by water exists for a lesser number, including: hepatitis A; Norwalk and Norwalk-like viruses; and rotovirus. While there is evidence that chlorine may reduce viral titers by indirect mechanisms such as increased attachment to particles, increased aggregation etc., viral characteristics similar to bacteria (i.e., surface proteins and nucleic acids) may also be potential targets for chlorine's oxidizing activities. It may be that bacteria are more susceptible than viruses to a given chlorine concentration because they are bigger and offer more critical targets for chlorine oxidizing actions, e.g., *E. coli* bacteria may be from 2,000 to 34,000 times larger than viruses, depending on the specific enterovirus it is compared to.

While some viruses, such as those of the Norwalk family, are more resistant to chlorination than others, chlorination may be effective against many enteric viruses. Typically, however, chlorination alone does not provide a reliable barrier for inactivation of residual viruses. At issue is the finding that chloramines, the primary form of chlorine in wastewater disinfection systems (as oppose to potable water treatment) are a weaker disinfectant against microbes than hypochlorite (Sobsey, 1989). The reduced disinfecting power of chloramines makes chlorination an ineffective virucide for the wastewater industry. For viruses not effectively disinfected through standard wastewater chlorination practices, removal has relied primarily upon upstream treatment or pretreatment processes at wastewater plants. For example, conventional activated sludge has been shown to effect a 90 percent reduction in viruses, with further reductions through filtration, if available.
Entamoeba histolytica, Giardia lambia and Cryptosporidium are the primary parasites of concern for disinfection. These have also been the subject of intense investigation with respect to potable water treatment systems. They are very resistant to chemical disinfectants such as chlorine, requiring concentrations and contact times that are well beyond conventional conditions used for bacterial cells (E. coli). Filtration (less than 1 to 3 microns) is currently the recommended primary barrier, or removal mechanism, for cystoidal parasites, though high capital costs associated with filtering large volumes of water makes this less desirable. While there are some indications that a combination of filtration and disinfection is effective for Giardia and possibly Entamoeba, Cryptosporidium is virtually resistant to chlorine.

3.2.1.2 Process Considerations

The principal elements of a successful chlorination system include chemical feeding, injection and mixing, and contacting. Chlorine gas feeders, or chlorinators, are complex but well established technologies.

These are typically contained in a separate room for safety purposes, vaporizing the liquid chlorine and then injecting the chlorine into a small slip-stream of process water that is then mixed with the main wastewater flow. A sulfonator, or sulfur dioxide feeder is similar in design to chlorinators.

In addition to using elemental chlorine (generally stored in liquid form in cylinders or tank cars), chlorine can be introduced in the form of a hypochlorite compound (i.e., salts of hypochlorous acid). Sodium hypochlorite (NaOCl) is the only liquid form in current use. Calcium hypochlorite is the predominant dry form and is used for swimming pools where convenience and safety are more important. In most plants discharging to the harbor, liquid hypochlorite is used. Although the technology exists to generate the hypochlorite on-site (from brackish water or a brine), this is expensive; the hypochlorite is shipped in to the plants in this region, with 5 to 10 day on-site storage capacities. Hypochlorinators are used to feed hypochlorite, relying on simple variable speed metering pumps.
To be effective, chlorine must be rapidly mixed into the wastewater stream. This rapid, high energy mixing enhances the formation of monochloramines and minimizes the formation of organochloramines. The immediate mixing also fosters higher rates of inactivation at the outset, by direct contact with free chlorine and monochloramine, before any extensive loss of the compounds due to decomposition. Modern systems incorporate high energy eductor/mixers at the point of chlorine injection in the contact chamber.

Once mixed, the wastewaters are contacted with the chlorine for a minimum amount of time in order to assure sufficient inactivation of the microorganisms. Generally, this has been on the order of 30 minutes at design flow and 15 minutes at peak flow. It is critical to design for maximum plug-flow hydraulic behavior, often imposed by designing the contact basins in a serpentine arrangement with a length to width ratio of at least 50 to 1. Recent work has shown that these systems can be improved with additional baffling to increase this ratio, and to reduce short-circuiting and dead flow areas.

Critical design elements for chlorination and dechlorination systems have been process control and residual maintenance. Those are important in this day of very restrictive residual limitations. The process control is affected by the variability of the wastestream, both in quantity and quality, temperature, and other environmental factors. Control systems are complex, particularly when incorporating both chlorination and dechlorination, and typically involve both feedback and feed-forward control loops.

Experience has generally been satisfactory, although limitations to the process control capabilities become more evident as one approaches very low residual chlorine requirements (less than 0.03 mg/L).

Strand and White (1993) presented their findings that REDOX control of chlorination can offer benefits over conventional control systems. Experience is limited, but the suggestion is that the technique offers more precise control since it factors out the non-germicidal portion of the total residual chlorine associated with organo-chloramines. This
can result in significant savings in the quantity of chlorine used; as much as 42 percent in the Heightstown, New Jersey STP and 50 percent in the Geneva, New York plant.

Ryder and Faller (1993) reported on a problem that exists when disinfecting partially nitrified secondary effluent, a condition that becomes more relevant as plants move to nutrient removal in the harvest region. When the ammonia concentration is depleted and the nitrite concentration is relatively high, the consumption of chlorine is high. This condition can be diurnally variable, and is particularly evident during early morning hours when organic loadings are lowest. Control is difficult, and experience at operating plants showed that required effluent, MPN fecal coliform limits or 240/100 mL could not be reliably met despite chlorine dosages as high as 25 mg/L.

Another problem that has been observed with chlorination has been regrowth, or "aftergrowth". This has been related to the repair and regrowth of cells that are only injured by the disinfection process. Significant increases in coliform densities are observed downstream of the disinfection compliance monitoring points, particularly if dechlorination is practiced. This has also been ascribed to undercounting of viable cells by conventional microbiological enumeration techniques. Servis and Adams (1993) reported on a method that has been developed for detecting viable but non-culturable cells. This direct viable count (DVC) method was found to give higher counts of viable organisms than did standard plating methods, probably due to the existence of a large number of chlorine injured cells that were in the viable, non-culturable state.

### 3.2.3 Advantages and Disadvantages of Chlorination - Dechlorination

Overall, it is clear that the chlorination and dechlorination processes are well-demonstrated technologies that are easily applied and for which sufficient design information/experience exist. Regulatory demands have imposed more restrictive operational requirements, and will generally require the coupling of the dechlorination process with chlorination. Safety considerations, high-energy mixing systems, and
advanced control systems represent the most recent advances in what can be considered a mature technology. The most often cited advantages to the technology include:

- Chlorine is a potent bactericidal agent;
- As an oxidant, it provides for effective taste and odor control and possible removal of specific organics;
- The process is suitable for poor quality effluents, and for high suspended solids wastewaters;
- The process is responsive to high variability;
- Dechlorination can be easily retrofitted;
- The processes are well demonstrated and have a high degree of reliability; and
- The technologies are cost-effective.

The more-commonly cited disadvantages include the following:

- Restrictions involving the use, storage and transport of hazardous chemicals;
- Sophisticated control requirements when very restrictive residual limitations are imposed;
- Ineffective virucide;
- Ineffective protozoic/cysticidal agent;
- Acute toxicity to receiving water biota;
- Persistent residual, often requiring removal prior to discharge; and
- Generation of chlorinated organics.

3.2.2 Ultraviolet Irradiation

Ultraviolet radiation or UV disinfection is a physical process, relying on the photobiochemical changes brought about by absorption of light energy in the range of 240 to 280 nm. Unlike chemical disinfectants, UV does not "kill" an organism; rather, it damages the nucleic acids, or genetic material of a cell (DNA), such that the cell is unable
to replicate. The UV dose required to accomplish this will vary with the organism, and is generally a function of cell wall thickness and the energy absorption characteristics of the cell material itself. Thus, bacterial cells are affected at relatively low doses, while protected organisms such as viral phage, cysts, spores and cells occluded within solids require much higher dose levels or are not affected at all. Dose is defined as the intensity of the radiation (or rate of delivery) times the exposure time, and is typically expressed as milli-watt seconds/cm².

UV has become the most commonly applied disinfection process next to chlorination. In a matter of 10 years, well over a thousand systems have been installed in the USA, ranging in size from less than 0.1 to greater than 200 mgd (Scheible, 1993). The vast majority of operating wastewater systems, and effectively all of the new or planned systems, utilize the open-channel, modular configuration in which banks of UV lamp modules are arranged in a channel carrying the treated wastewater. The UV lamps are encased in quartz sleeves to protect them and to minimize temperature variations at the lamp surface. This open-channel, modular design is considered state of the art, and offers good hydraulics, easy access for maintenance, and convenient, practical installation requirements. In many plants, existing chlorine contact chambers have been modified with false floors and dividing walls, and retrofitted with UV equipment. Since exposure times in the case of UV range between 5 and 30 seconds, typically the chlorine contact basins generally offer ample space for such retrofits.

The source of UV radiation is the mercury arc lamp. Variations of the lamp exist, primarily related to the lamp's operating pressure. The higher the pressure, the wider the spectrum of light, and the more intense the output. The most efficient of the mercury arc lamps is the "low-pressure" unit. These are typically 0.75 to 1.5 m long, and 15 to 20 cm in diameter. Thirty to forty percent of the input energy is converted to light and nearly 85 percent of this light is monochromatic at approximately 254 nm. This falls within the absorption spectrum for nucleic acids and is near the optimum germicidal wavelength for microorganisms.
The low-pressure lamps are, by far, the predominant UV source used in today's UV disinfection systems, comprising greater than 99 percent of all current installations. The lamps do not have a high intensity, and as such are closely spaced in the wastestream to counteract the absorptive properties of the liquid itself (analogous to the chlorine or ozone demand) and still deliver sufficient germicidal energy. Centerline spacings are typically between 5 and 10 cm. The lamps are sheathed in a quartz sleeve to form an air gap and protect the lamp against temperature swings. The optimum lamp wall temperature is approximately 50°C.

Alternative lamps are still mercury arc type units, but with variations in lamp shape, operating pressure and input power. The driving force in the development of the alternative lamps has been to minimize the number of lamps needed for a given application. Larger plants using the conventional low-pressure lamps require several thousand lamps. For example, the Olympia, WA plant has approximately 2000 lamps for a design peak flow of approximately 55 mgd (Gilbert and Scheible, 1993). Walley and Fries (1993) report nearly 11,000 lamps for the Boonybrook plant in Calgary, Alberta, currently the largest UV installation in North America.

Although the plants are operating very effectively, such large numbers can be cumbersome, particularly for maintenance purposes. A further impetus to employ alternative lamps has been the application of UV to low-grade, turbid waters such as CSO, SSO and storm waters. Low quality water will increase the number of lamps needed, as does the typically high short-term flow rates these waste streams produce.

Medium pressure mercury lamps employ the same basic principles as low pressure lamps, but operate at significantly higher pressures and temperatures (600-800°C). The advantage of the medium pressure lamps is lower capital costs, due to the smaller systems. For example, the typical UV output of a medium pressure lamp is 50 to 60 times higher than that of the low pressure lamp, but the overall light output is polychromatic. Thus, although the input power conversion to light is much the same as the low pressure lamps, only about one quarter of the light is in the germicidal range. This lower efficiency
(5-10 times less than the low-pressure lamps) translates to higher operating costs. However, because of its higher output (intensity), less lamps are needed, with a replacement ratio on the order of 15 conventional lamps to one medium pressure lamp.

A second class of alternative lamps is the high-intensity, low pressure units. These incorporate the advantages of the efficient low-pressure lamp with the high output of the medium pressure lamps. Higher pressures and power inputs are imposed to boost the intensity of the lamp; in some cases the design of the lamp envelop is also modified. WaterGuard uses a folded low pressure, high intensity lamp. Parsons and Scheible (1993) suggested that a single WaterGuard lamp could be used in place of 8 to 10 conventional lamps, based on studies conducted at Winnipeg, Manitoba. Wedeco offers a flattened lamp that is designed to give 2 to 3 times the output of a conventional lamp; several such systems are operating in Europe.

3.2.2.1 Effectiveness

Bench-scale and pilot studies have demonstrated that UV is very effective for the inactivation of bacterial and viral pathogens. Protozoan cysts and spore-formers are more resistant. While only limited information is available concerning the efficacy of kill by UV upon specific pathogens in actual wastewater disinfection systems, the table below, taken from Darby, et al. (1995) shows the relative effectiveness of UV disinfection for selected microorganisms. As they report, because resistance of microorganisms to chlorine and UV varies, a suitable indicator of performance between the two processes is lacking for more resistant forms. In general, however, both disinfectants are highly effective, with UV showing a greater proficiency against viruses, spores, and cysts.
ESTIMATED RELATIVE EFFECTIVENESS OF CHLORINE AND UV DISINFECTION FOR REPRESENTATIVE MICROORGANISMS OF CONCERN IN WASTEWATER

<table>
<thead>
<tr>
<th>Organism</th>
<th>Dosage Relative to Total Coliform Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chlorine</td>
</tr>
<tr>
<td><strong>Bacteria</strong></td>
<td></td>
</tr>
<tr>
<td>Fecal coliform</td>
<td>1.0</td>
</tr>
<tr>
<td><em>Salmonella typhi</em></td>
<td>1.0</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>2.5</td>
</tr>
<tr>
<td>Total coliforms</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Viruses</strong></td>
<td></td>
</tr>
<tr>
<td>Adenovirus</td>
<td>0.5</td>
</tr>
<tr>
<td>Coxsackie A-2</td>
<td>6.0-7.0</td>
</tr>
<tr>
<td>F-specific bacteriophage</td>
<td>5.0-6.0</td>
</tr>
<tr>
<td>Polio 1</td>
<td>6.0-7.0</td>
</tr>
</tbody>
</table>

SOURCE: Replicated from Darby et al. (1995).

A note of caution with regards to such comparisons as made above and as appropriately pointed out by Blatchley et al. (1996), is that due to dependence upon several site specific parameters, which vary independently, meaningful comparisons between performance of disinfection systems can only be made under tightly controlled conditions. Work by these authors, using parallel operating conditions at the West Lafayette, Indiana secondary STP showed UV irradiation to be a reliable disinfection alternative to chlorination and it is more cost-effective in terms of new facility construction.

When considering UV irradiation as a disinfection alternative, of importance is a phenomenon of UV termed photoreactivation. Under certain circumstances, the photo-biochemical damage inflicted on an organism can be repaired. These are enzymatic repair mechanisms, most often catalyzed by exposure to light energy in the visible range. A comprehensive review of this mechanism may be found in Harm (1975). The repair occurs quickly (within minutes to hours from exposure), and can result in a 1 to 2 log increase in the residual density that was present immediately after UV exposure (Scheible, 1987). The phenomenon is limited to bacteria (viruses do not have the necessary enzymes to effect repair). Viruses can only repair if they are allowed to infect host cells immediately after UV treatment. In this case, they utilize host cell enzymes to effect photoreactivation.
The existence of repair mechanisms for UV-induced damage raises several ongoing issues, the primary one being to what extent should photoreactivation be taken into account when designing a system. From an operational perspective, a larger dose would be required to offset any degree of repair, with its consequent increase in the size of the UV system. Darby and Lindenauer (1993) suggest in their analysis that the impact of photoreactivation is relatively insignificant at dose levels greater than 60 to 80 mW-sec/cm$^2$.

Lehrer and Cabelli (1993) pointed out that the etiologic agents of the most common waterborne diseases are Norwalk-like viruses. Many of these viruses will not undergo photoreactivation. Although quantitation of the Norwalk virus is difficult, inactivation of F male-specific bacteriophages (a simulant for the Norwalk virus) by UV was shown by the authors to be quite effective, especially when compared with chlorine-based disinfection processes. This work demonstrated that even considering the least likely inactivation kinetics for enterococci (a mimic for F phage), secondary effluents from two Rhode Island facilities were readily disinfected by low UV doses; whereas UV doses required for primary effluents, under similar conditions, would likely be prohibitive (see Table below).

### UV DOSAGES REQUIRED TO REACH 35 ENTEROCOCCI/100 ML IN EFFLUENTS, UNDER AVERAGE (AND 95% CONFIDENCE LIMITS FOR) INACTIVATION KINETIC RATES

<table>
<thead>
<tr>
<th>Treatment level</th>
<th>Dosages to Reach Target Limit (mW-sec/cm$^2$)</th>
<th>Inactivation Rate$^a$:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Optimal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimal</td>
</tr>
<tr>
<td>Primary Effluent</td>
<td>14.2</td>
<td>57.4</td>
</tr>
<tr>
<td>Secondary Effluent</td>
<td>14.9</td>
<td>17.7</td>
</tr>
</tbody>
</table>

$^a$Conditions based upon ninety-five percent confidence limits for study-derived inactivation parameters.

**SOURCE:** Adapted from Lehrer and Cabelli (1993).

As had been mentioned earlier, nearly half of the papers presented at the 1993 WEF Specialty Conference were directed to UV. These had a large emphasis on water reuse applications on the West Coast, in addition to basic research and case studies of operating
plants. Disinfection of waters for reuse has far more stringent limitations, typically a mean total coliform of 2.2 per 100 mL. This is regarded as an indicator of effective viral inactivation, although additional studies were reported to demonstrate directly the ability of UV to inactivate viruses.

Reuse limits have been found to require filtration and UV doses in the range of 100 to 200 mW-sec/cm$^2$ as opposed to doses of 25 to 40 mW-sec/cm$^2$ typically needed for conventional secondary disinfection. Awad, et al. (1993) demonstrated disinfection on effluents from a rapid infiltration/extraction process and on conventional filtered secondary effluent. Dosages greater than 120 mW-sec/cm$^2$ were found to be adequate for fecal coliform, poliovirus type L.C. and coliphage MS-2 for purposes of water reuse. Oppenheimer, et al., Chen, et al., and Soroushian and DePalma (1993) all reported on the successful application of UV to meet California reuse standards.

Black et al. (1993) presented a case study of the Georgetown plant in Ontario, including the planning considerations leading to UV. They used two primary criteria: suitability of the plant for a retrofit, and applicability to the plant’s waters. Retrofitting to the existing chlorination tankage was found to be readily done, and the secondary effluent was found to be well within the capabilities of the UV process. Similar studies and findings were reported by Blatchley, et al. (1993) and Putnam and Chesler (1993) for plants in Lafayette, IN and Contra Costa, CA, respectively, in which UV was determined to be effective for secondary treatment disinfection and was found to be competitive in costs with chlorination. A more recent publication by Blatchley et al. (1996) reports UV irradiation to be a less expensive alternative than chlorination-dechlorination both in terms of capital and operating costs, for facilities where new construction is required. Where existing, functional chlorination facilities are in place (avoiding construction costs for a new chlorine contact chamber), UV is likely to be a more expensive alternative.

In the one paper that reported on the newer medium pressure lamps, Gehr, et al. (1993) presented their pilot studies on the effluent from a Montreal treatment plant. The effluent was of a low grade and similar to conditions that may be met with pretreated CSO, having an average suspended solids concentration of 40 mg/L, and considerable
ranges of turbidity, transmittance, and dissolved organic carbon. The study showed that the UV system was successful in meeting discharge limits of 2,000 CFU/100 mL. At a dose of 35 mW-sec/cm², a three log unit reduction in fecal coliforms was achieved.

An excellent treatment of the comparative advantages and disadvantages of UV and chlorine may be found in Comparison of UV Radiation to Chlorination Guidance for Achieving Ultimate UV Performance (Darby et al., 1995), a recent Water Environment Research Foundation (WERF) publication. This details the findings of multiple studies supported by WERF on the design and operation of UV systems, their effectiveness and costs as compared to conventional chlorination systems.

A brief table of their UV irradiation and chlorination/dechlorination cost comparisons is replicated below. The report concludes that UV is an effective and cost-competitive alternative to chlorination-dechlorination.

<table>
<thead>
<tr>
<th>Flow Rate</th>
<th>Range in Total Annualized Costs ($1000)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UV Irradiation</td>
</tr>
<tr>
<td>1 mgd</td>
<td>19.6 - 106</td>
</tr>
<tr>
<td>10 mgd</td>
<td>153 - 827</td>
</tr>
<tr>
<td>100 mgd</td>
<td>1,132 - 6,228</td>
</tr>
</tbody>
</table>

¹Costs are planning/reconnaissance level estimates connect with a +50/-30% range of variability in accordance with the American Association of Cost Engineers.

SOURCE: Replicated from Darby et al. (1995).

As depicted by Darby et al. (1995), the table on the following page is a comparison of advantages and disadvantages between UV irradiation and chlorine disinfection. Several papers presented at the 1993 Disinfection Conference relate to work conducted as part of the studies sponsored by WERF. These include Lindenauer and Darby (1993) on the design implications of photoreactivation (a repair mechanism unique to ultraviolet, as explained earlier in Section 3.2.2.1), and Emmerick and Darby (1993) on design models developed for the UV process.
## ADVANTAGES AND DISADVANTAGES OF CHLORINE AND UV DISINFECTION

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chlorine Disinfection</strong></td>
<td>1. At low dosages used for coliform inactivation may not be effective for viruses, spores, cysts.</td>
</tr>
<tr>
<td>1. Well-established technology</td>
<td>2. Residual toxicity or treated effluent must be reduced through dechlorination</td>
</tr>
<tr>
<td>2. Effective disinfectant</td>
<td>3. Formation of trichalomethanes and other chlorinated hydrocarbons</td>
</tr>
<tr>
<td>3. Chlorine residual can be maintained</td>
<td>4. Increased safety regulations</td>
</tr>
<tr>
<td>4. Combine chlorine residual can be provided by adding ammonia</td>
<td>5. Increases effluent total dissolved solids</td>
</tr>
<tr>
<td>5. Germicidal chlorine residual can be maintained in long transmission lines</td>
<td>6. Increases chloride content of wastewater</td>
</tr>
<tr>
<td>6. Traditionally, relatively inexpensive</td>
<td>7. Increases release of volatile organic compounds</td>
</tr>
<tr>
<td></td>
<td>8. Chemical scrubbing facilities may be required</td>
</tr>
<tr>
<td></td>
<td>9. May reduce wastewater pH due to acid generation</td>
</tr>
</tbody>
</table>

| **UV Disinfection**                            | 1. At low dosages used for coliform inactivation may not be effective for viruses, spores, cysts. |
| 1. Effective disinfectant                      | 2. No immediate measure of whether disinfection was effective                  |
| 2. More effective than chlorine in inactivating most viruses, spores, cysts | 3. No residual effect                                                         |
| 3. No residual toxicity                        | 4. Relatively expensive                                                       |
| 4. Improved safety                             |                                                                              |
| 5. Can require less space                      |                                                                              |

**SOURCE:** Adapted from Darby *et al.* (1995).
3.2.2.2 Process Considerations

The two major design and operational factors affecting UV are the intensity and exposure time. Intensity is affected by the output and age of the lamp, the absorptive properties of the water, and the degree of fouling of the quartz sleeve surfaces. Lamps will have a rated output, which will degrade to approximately 60 percent of the rated output through the term of its operating life (10,000 to 15,000 hours). The UV absorbance, or conversely transmittance, of the water will depend on the degree of pretreatment before disinfection. Secondary to tertiary effluents will have transmittances ranging from 50 to 80 percent, while significantly lower levels are observed in CSO-type wastewaters. These two factors are considered in the design sizing of the UV system.

The fouling of the quartz surfaces can severely attenuate the UV intensity and cause the process to fail. A regular cleaning schedule is an integral part of operating a UV system. Most have ex-situ methods, while the recent medium pressure units have been built with in-place automatic cleaning systems.

Exposure time is critical, and the hydraulic design of the system must allow for nearly ideal plug flow. This is a benefit derived from the open-channel configuration, where a high length to width ratio is imposed and approach and exit conditions are fostered to minimize excessive turbulent mixing. The state of knowledge and design in today’s systems appear to recognize these factors and incorporate them successfully into design practice.

A comprehensive review of the design and operating conditions for over thirty operating plants may be found in a recent U.S.EPA publication UV Technology Assessment (US EPA, 1992). Scheible (1993) summarized its findings and reported that all plants were in compliance with their respective permits. The design sizing of the plants fell between 0.5 and 1.7 mgd/UV kW, with an average of about 1.0 mgd/UV kW. The costs ranged between $20,000 and $40,000/UV kW installed and $3,000 to $4,000/kW/year. There are typically 35 conventional lamps per UV kW.
Suspended solids is an important water quality parameter in the design of UV systems. Solids will effect the transmittance of the water, occlude bacteria and generally interfere with the disinfection process to a greater degree than encountered with chemical disinfection systems. This, in effect, establishes the limit of disinfection efficiency that can be accomplished by UV. Certainly one can expect this to vary as a function of the particulates, and their characteristics. In waste waters that have a high degree of inorganic matter or naturally occurring soils solids (CSO and storm waters, for example), the bacterial densities associated with particulate matter may be relatively small. However, in cases of typical municipal wastewaters and biologically treated wastewaters, they can be significant and can account for essentially all residual coliforms in the final effluent. For this reason, a high degree of filtration is required when attempting to achieve very high disinfection levels such as the California reuse standards (2.2 total coliforms per 100 mL).

Scheible (1987) developed correlations of suspended solids to particulate coliforms. This was further developed from additional data bases in the draft EPA report on the impact of solids on CSO disinfection efficiency (US EPA, 1995).

3.2.2.3 Advantages and Disadvantages of UV Disinfection

The principal advantages cited for the UV systems stem from the fact that the technology is generally less complex and does not depend on chemicals or chemical stoichiometry. The technology has potential for application to episodic, high volume flows such as stormwater and combined sewer overflows. Concisely, the advantages are:

- Physical process, no chemical addition required;
- No hazardous chemical handling or storage;
- Easy operation, not affected by temperature or pH;
- Reduced operation/maintenance costs; competitive with chlorination;
- No mechanical equipment or moving parts (except if equipped with wipers);
- Quiet, odor-free operation;
- Rapid disinfection, less space requirement;
• No adverse environmental effects;
• Excellent bacterial and virucidal efficacy; and
• No residual, and no disinfection by-products.

The main disadvantages of this technology generally relate to the need for routine operation and maintenance and the impact of wastewater quality, i.e., potentially high suspended solids and other interfering constituents on efficacy. These concerns may be summarized as follows:

• Down-time for cleaning and replacement of UV elements;
• Better with good-quality effluents, pretreatment may be required to optimize performance:
• Better suited for low/medium sized plants;
• Lack of residual could impact process monitoring and limit applicability of technology for potable water disinfection;
• Possible impact of photoreactivation; and
• Not effective protozoic agent, or (at low dosages) against viruses, spores, or cysts.

Overall, UV disinfection appears to be a growing, viable, successful and cost-effective potential disinfection alternative for many different applications. For most cases, conventional open-channel systems are quite effective in meeting disinfection goals with simple process control and manageable operating and maintenance tasks.

Existing design protocols have been demonstrated to be reliable design aids; however, direct pilot testing is usually the most appropriate avenue to predict adequacy of design and potential performance, particularly with large systems. Research continues to investigate the use of alternative lamps (e.g., high intensity, low pressure; medium pressure, etc.) and continued performance studies on both low quality waste waters in addition to potable sources.
3.2.3 Ozone Disinfection

The discovery of ozone is often credited to the Dutch scientist M. Van Marum in 1793. Werner von Siemens of Germany constructed the first ozonator in 1857, which became the prototype for today’s commercial units. In 1893, drinking water plants were constructed in Oudshoorn, Holland with ozone contractors for disinfection. By the year 1924, there were at least 24 ozone plants in France alone. In the United States, however, chlorine was favored, and ozonation was not generally practiced until the US EPA initiative in the late 1970s and early 1980s encouraged the evaluation and application of alternatives such as ozone.

Ozone is a triatomic allotrope of oxygen which occurs in nature and can be created artificially. It has a pungent odor, and can be detected by smell at levels of about 0.01 ppm, well below concentrations that may be harmful to health. It is an explosive gas at high concentrations (30 percent). Its inherent instability makes it necessary to generate ozone on site.

Ozone is a very strong oxidant. Its decomposition is believed to be catalyzed by the hydroxyl radical. Due to its reactivity, it will readily degrade many organic compounds, yielding a relatively high ozone demand in low-grade waters.

A number of ozone disinfection plants were constructed in the USA, primarily in the late 1970s and early 1980s under the US EPA Innovative and Alternative Technologies initiative. A brief, 1986 report on wastewater disinfection, produced by WEF (then the Water Pollution Control Federation) noted more than 20 operating wastewater ozone facilities in the U.S., with an equal number in various stages of design and construction. These systems were typically associated with plants that had pure oxygen activated sludge facilities, the latter serving as a cost-effective source of oxygen for the generation of ozone. Several plants are still in operation; but few new facilities have been built since or are planned.
The ozone generation process is complex and has generally not been competitive with chlorine-dechlorination or UV in wastewater applications.

Blank, et al. (1993) reported on such a facility in Indianapolis. The city has operated two pure oxygen sludge and ozone disinfection plants for nearly two decades and has provided considerable design and operating experience. In the latest work, studies were conducted to optimize the hydraulic behavior of the contractors. As with standard chlorine contact basins, plug flow is critical. The study reported that improved baffling (converting a four pass chamber to one with seven passes) resulted in more effective disinfection, increasing average log reduction of fecal coliforms/100 mL from 2.24 to 2.42, under comparable ozone dose conditions.

Locally, the Middlesex County Utilities Authority in New Jersey has been investigating the use of ozone for disinfection, and is currently proceeding with conversion of the facility. The pure oxygen activated sludge plant has excess capacity in its cryogenic oxygen production, which could readily be used for a new ozone disinfection system. The plant has been faced with the classic issues regarding its existing chlorination process, i.e., chlorine toxicity and stringent regulatory requirements regarding safety and community emergency response programs.

Alam, et. al. (1993) recently reported on pilot studies at the Middlesex plant. The studies demonstrated that ozonation was very effective, even under variable effluent quality conditions. Fecal coliform limits of 200 MPN/100 mL were consistently met at applied doses between 18 and 28 mg/L for a contact time of 45 minutes. A 25 mg/L transferred ozone dose for the same duration effected a 3 log reduction or a 99.9 percent kill. Additionally, a similar dosage resulted in significant reductions of effluent color, turbidity, solids, and COD; with negligible reductions of BOD$_5$ and NH$_3$-N (see summary below).
### EFFECTS OF OZONE DISINFECTION ON EFFLUENT QUALITY

<table>
<thead>
<tr>
<th>Percent Deductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal Coliform</td>
</tr>
<tr>
<td>99.9</td>
</tr>
</tbody>
</table>

a) Ozonation dosage of 25 mg/L (or less) at ~ 45 minutes contact time.

b) Not effective

**SOURCE:** As reported via a pilot study, Alam et al. (1993)

### 3.2.3.1 Effectiveness

Research has shown ozone to be a highly effective bactericide. Fecal coliforms are inactivated at ozone levels of 2 to 10 mg/L and contact times of less than 10 minutes. Generally, higher concentrations will require low contact times, while longer contact times can yield similar results at low concentrations (Novak, et.al. 1977, and Finch and Smith, 1991).

Ozone is far more effective as a virucide than chlorine or the other halogens. In work with poliovirus (Cain, et. al., 1964; Katzman, et.al., 1974; and Sproul, et. al., 1979) a dose of 0.4 mg/L and a contact time of 4 minutes resulted in a 3-log reduction. Polioviruses are considered more resistant to ozone than other enteroviruses. Recent work with *Giardia* and *Cryptosporidium* have shown ozone to be effective, although at relatively high doses. Data by Finch, et. al.,(1994) suggest that *C. parvum* oocysts are about four times more resistant than *Giardia* under comparable conditions. Ozone has gained attention as possibly the only available, practical, chemical disinfectant that can be used in water treatment for cyst inactivation.

### 3.2.3.2 Process Considerations

Ozone is generated when a high voltage alternating current (6 to 20 kV) is imposed across a dielectric discharge gap that contains an oxygen-bearing gas. It can be generated from air, oxygen-enriched air, or high purity oxygen. When pure oxygen is used as the
carrier gas, ozone levels are 2 to 2.5 times those generated in air, and less power is required. However, if oxygen production costs are included, the use of high purity oxygen is not economical, unless high purity oxygen is required elsewhere in the plant (as in the case of pure oxygen activated sludge plants).

The ozone contactor design is critical to the successful operation of the disinfection process (Darby, 1995). Gas transfer mechanisms play an important role, influenced by the injection method and by the contactor configuration. Typical methods employ diffused bubble (co- and counter-current), positive and negative pressure injection, and mechanical agitators. The more successful configuration, and one that is more widely applied at wastewater plants is the counter-current bubble diffuser. Typical contact times are between 2 and 10 minutes.

Due to its strong oxidizing potential, all materials downstream from the ozone generation point must be resistant (i.e., stainless steel, glass or Teflon), as the presence of organic matter in the aqueous environment will consume ozone in varying amounts. At present a good correlation, relating ozone dose to carbon oxygen demand (COD) or other organic/inorganic demand parameters does not exist. Pilot studies are typically required to estimate ozone demands and dosing requirements; these are then refined during actual operations. Oxidation of organic material, even in potable water, is usually incomplete; reduction in total organic carbon as low as 10-20%, with decreases of COD and biological oxygen demand generally greater (up to 50%) (Dellah, 1975). Mid-1950 studies conducted by the U.S. Army to examine ozone as a wastewater treatment process reported consumption of ozone as high as 100 mg/L (Venosa, 1972). A series of EPA investigations conducted in the 1970s on the use of ozone as a wastewater disinfectant, showed a lesser dosage on the order of 15-20 mg/L met an MPN fecal coliform standard of 200/100 mL (White, 1978).

Off-gas and residual liquid ozone monitors are used with the contactor system to control ozone injection and production rates. The key control parameter for successful operation has been the off-gas monitor (Venosa, 1985; Rakness, et. al., 1984 and 1993).
Contactor off-gas must be treated for ozone removal prior to release. Thermal or catalytic processes are commonly used for this purpose.

3.2.3.3 Advantages and Disadvantages of Ozone Disinfection

Ozonation has not experienced widespread use in wastewater applications. However, the process is finding acceptance as a primary disinfectant in potable water systems, primarily for its oxidative powers and newly demonstrated abilities to disinfect cystoidal organisms. The high ozone demand found even with well treated effluents, the inherent complexity of the process, and its relatively high costs have hindered its application to wastewater treatment. The advantages that are typically cited for ozonation include:

- Excellent virucidal and bactericidal properties, and effective protozoic agent at high dosages;
- Shorter contact times when compared to chlorine, on the order of 10 minutes;
- Less sensitive to pH, temperature and other environmental factors;
- Improvement in receiving water quality due to the high oxygen content of the final effluent; and
- Coincident wastewater quality improvements due to oxidation of residual organics.

The disadvantages relate primarily to economics when compared to the available alternatives:

- Ozonation is two to four times more costly than the alternative technologies;
- Ozone is a health hazard, requiring extensive ventilation and destruction of any off-gas residuals; and
- High ozone demand in typical secondary effluents drive up operating costs.
Since, in large part, the wastewater treatment plants in the NY/NJ harbor area will be secondary or advanced secondary systems, the suitability of the ozonation process is not readily or immediately apparent. This is more the case when one considers management and disinfection of low-grade waters such as CSO, SSO and/or stormwaters.

### 3.2.4 Chlorine Dioxide Disinfection

Chlorine dioxide has been applied primarily to the disinfection of potable waters, and only on a limited basis. It is a particularly effective oxidant, and has found favor when considering taste and odor control or the removal of phenols. It is widely used in industry as a substitute for chlorine as a bleaching agent. Chlorine dioxide is a proven bactericide equal to or greater than chlorine in disinfecting power, and has a higher oxidation potential. The compound has also been shown to be a far more effective virucide than chlorine. It is not prone to generate chlorinated organics, and as such, has a significant advantage over the use of chlorine. It also lacks any reactivity with ammonia.

Despite the above noted strengths, chlorine dioxide has not been received as a viable alternative to chlorine for the disinfection of municipal wastewaters. Although direct laboratory and pilot studies have shown it to be effective and to have certain process advantages, its high costs and need for on-site generation have been a clear hindrance.

Also, in comparison, the overall system is relatively complex to operate and maintain, and one is still committed to having hazardous chemicals on-site, including chlorine. Chlorine dioxide is an extremely unstable and explosive gas and any means of transport is potentially very hazardous. As such, the chemical must be generated on-site. Gaseous chlorine dioxide is normally generated using a process that involves a reaction between sodium chlorite and chlorine. Sodium chlorite is considerably more expensive than liquid chlorine.
Although chlorine dioxide has been applied to the disinfection of potable waters, and has been used extensively in industry, there is no known application to municipal waste waters (US EPA, 1986; WEF, 1996), except for limited pilot studies. There were no papers on the process at the 1993 Specialty Conference, nor is the technology discussed in the draft WEF (1996) manual of practice, a departure from the US EPA and WEF design manuals issued in 1986.

### 3.2.5 Bromine Based Disinfection

The use of bromine chloride for wastewater disinfection is a relatively new and limited practice. Manufactured from bromine and chlorine, it is a hazardous, corrosive chemical requiring special transportation, handling, storage and use precautions. It is shipped in modified chlorine cylinders or tankers, with essentially the same safety and handling procedures as required with chlorine. Although bromine chloride is the most widely used form to date, there are on-site activation methods using sodium bromide to supplement chlorine disinfection processes, as well as, other bromine based disinfection alternatives.

Bromine chloride's water chemistry is analogous to that of chlorine. The chemical hydrolyses to hypobromous acid very rapidly and forms monobromamines and dibromamines upon reacting with excess ammonia, typical of wastewater effluents. This is important to STP operators because wastewater effluents usually contain high concentrations of nitrogen-based compounds which are free for the formation of halomines. These halomines serve as the main disinfection species, achieving the same degree of disinfection as chlorine-based residuals at lower concentrations. In addition, bromamines are much more effective disinfectants than the analogous chlorine species; particularly against resistant microorganisms like viruses or bacterial spores (WPCF, 1986).

Although bromine-based disinfectants are more toxic, the environmental impacts associated with bromine-based residuals are considerably less due to their instability and therefore shorter-lived residuals as compared to chloramines. Rapid dissipation of
bromamines in the wastestream reduces residual toxicity to aquatic life upon release to receiving waters. The greater potency of BrCl further lessens environmental impacts, in that smaller doses of BrCl, relative to chlorine, need be used.

Bromine chloride disinfection facilities are very similar to those used for disinfection with liquid chlorine. Shorter contact times are possible though, resulting in a capital cost saving for the smaller contractor. When compared to chlorine, the advantages to using bromine chloride is its effectiveness against a broader range of microorganisms and a reduction in the potential environmental impacts; although acute toxicity effects and the tendency to form regulated bromination compounds are analogous to the impacts of chlorination. Bromination can result in less capital equipment costs, although operating costs will likely be more. Safety concerns are similar to that of chlorine. Finally, the technology is relatively new, with no established track record.

In all, when one weighs the use of bromine chloride against that of chlorine, there is not a clear advantage to selecting bromination. There has been little recent effort to study or to apply the technology to wastewaters, and the method is not discussed in recent design manuals such as the WEF (1996) manual of practice. No papers were presented on the technology at the 1993 Specialty Conference.

3.3 CONCLUSIONS AND RECOMMENDATIONS

The degree of disinfection and the method of disinfection to be applied to combined sewer overflows and other low-grade, rainfall induced wastewater discharges is under in-depth review at this time by environmental professionals, owners/operators, and regulators alike. Overall, disinfection methods are not totally fail safe and have some level of environmental consequence. An additional obstacle in effectively treating CSOs or stormwater is adapting these various disinfection systems for use on multiple (typically sporadic or discontinuous) point discharges. This report has provided concise discussions of pertinent issues in comparing potentially promising wastewater disinfection technologies. The table below provides a synopsis of these discussions, summarizing the
findings noted herein. Extensive, though not exhaustive literature references have also been provided where appropriate, with considerable attention given to presentations/papers of the 1993 WEF Specialty Conference held in Whippany, New Jersey. Based on this effort, and highlighted in the summary table below, recommendations to the NY/NJ Harbor Estuary Program may be made with regards to several aspects of wastewater disinfection.

**SUMMARY TABLE:**

**COMPARISON OF ALTERNATIVE WASTEWATER DISINFECTANT METHODS**

<table>
<thead>
<tr>
<th>Desirable Disinfectant Attributes</th>
<th>Cl₂</th>
<th>Cl/deCl</th>
<th>UV</th>
<th>O₃</th>
<th>ClO₂</th>
<th>BrCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>The method does not create an environment concern.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>The method is not expensive.</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>The method does not create a safety concern.</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>The method is an effective disinfectant.</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>The method is not complex to operate.</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>The method has an established record of reliable use.</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>The method is applicable for NY/NJ wastewater use.</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: Rating is from 1-5 with 1 being most representative of the statement and 5 being the least.

The recent knowledge on the effects of total residual chlorine (TRC), the product of the most widely used form of disinfection for secondary treatment plants, has prompted both New Jersey and New York to establish protective TRC water quality standards for fresh water streams, estuarian waters. This has prompted the development of alternative disinfection technologies as occurred in the 1970’s with EPA funded programs.

While dechlorination techniques are effective at reducing toxic chlorine residuals, they greatly increase operator costs and often substitute other hazardous chemicals. Use of chlorine dioxide or bromine-based disinfection still rely upon hazardous chemicals, are costlier and more complex processes than chlorination, and may still introduce toxic residuals to the aquatic environment. Ozone and UV radiation are the cleanest of the
disinfectant methods compared, releasing no toxic residual to the effluent stream. Use of ozone however, presents a human health risk and the required ventilation and ozone removal greatly increases associated costs.

The experience to date indicates that ultraviolet radiation disinfection systems have become more common as an alternate in wastewater treatment plants. UV systems have also developed designs more applicable to low-grade wastewaters and seem to be a leading alternative to chlorination for treated wastewater applications. There are now well over 1,000 UV operating plants in the USA, with a definite trend toward replacement of existing chlorination systems with UV technology, and a preference for UV when considering new plant construction. A critical limitation to employment of UV is that high turbidity waters necessitate high treatment dosages to ensure adequate disinfection. This in turn translates to increased costs and maintenance needs.

With regards to the effectiveness or efficacy of kill, chlorination and UV are clearly less effective against viruses, protozoan cysts, and spore formers than ozone, chlorine dioxide or bromine-based disinfection; though cost and safety concerns, and the complexity of operation have limited the use of the latter three methods. Both chlorine and UV are more established methods, considered highly effective against bacteria pathogens, with UV noted to be more proficient at inactivating viruses, spores and cysts at high dosages. Again, high concentrations of suspended solids in wastewaters can reduce UV transmittance, occlude bacteria and weaken the efficacy of UV radiation to a greater degree than likely encountered with chemical disinfection processes. This then establishes the limit of disinfection efficacy that may be accomplished by UV irradiation.

As previously noted, the universal application of a single disinfection technology over all others is not recommended. Therefore along with the efficacy of disinfection it is necessary to evaluate associated use impairments to higher life forms (including humans), considering the specific waterbody and rainfall runoff conditions before performance criteria for disinfection systems are established. Also of consideration in
qualifying potential disinfection methods are general safety concerns, costs associated with use, the complexity of operation, and an established record of reliability.

In the NY/NJ Harbor Estuary region a number of pertinent disinfection projects are ongoing. Site visits by the HEP Pathogens Work Group and technological/data exchanges between NY and NJ water treatment professionals and municipal engineers are recommended, as well as, periodic disinfection seminars to allow for project updates, information sharing, and continued dialogue and communication.
LITERATURE CITED (Section 3)

The following citations (unless otherwise noted) are included in Proceedings, Water Environment Federation Specialty Conference - Planning, Design & Operations of Effluent Disinfection Systems, Whippany, NJ 1993 and are referenced simply as "Proceedings WEF."


Alam, A.M.Z., T. Chien, S. Velicheti, F.H. Kurtz, and M. Rodgers, "Results of Ozone Disinfection Pilot Testing at Middlesex County, NJ Utilities Authority's UNOX Activated Sludge Treatment Plant", Proceedings, WEF.


Awad, J., C. Gerba, and G. Magnuson, "Ultraviolet Disinfection for Water Reuse", Proceedings, WEF.

Bain, R.E., G.A. Romano, Jr., D.P. Drupa, and J.A. Brooks, "A Case Study Do-It-Yourself Chlorination: Beat the Clock and Achieve Substantial Savings", Proceedings, WEF.


Cairns, W.L., "Comparing Disinfection by Ultraviolet Light and Chlorination - The Implications of Mechanism for Practice", Proceedings WEF.

Calmer, J.C., "Chlorine Mixing Energy Requirements for Disinfection of Municipal Effluents", Proceedings WEF.


3-37


Gallagher, Timothy M., "Design and Safety Considerations for Sodium Hypochlorite and Sodium Bisulfite Systems", Proceedings WEF.


Gilardi, R.C., "Chlorine Safety and the Fire Codes from an Industry Perspective", Proceedings WEF.

Gilbert, S. and O.K. Scheible, "Assessment and Design of Ultraviolet Disinfection at the LOTT Wastewater Treatment Plant, Olympia, WA", Proceedings WEF.

Gillette, R, and D. Samuelson, "Effluent Chlorination Control at Sacramento Regional Wastewater Treatment Plant", Proceedings WEF.

Girts, M.A., "Weland Treatment Systems for Disinfection and Dechlorination", Proceedings WEF.

Goddard, L.A., P. Kinshella, and P. Hendricks, "Sodium Bisulfite Dechlorination at the City of Phoenix, AZ 91st Avenue Wastewater Treatment Plant", Proceedings WEF.

Haas, C.N., "What We Think We Know and What We Think We Don’t Know About Chlorination-Dechlorination", Proceedings WEF.

Halm, M.J. and T. Robert, "A First-Order Bacterial Decay Rate Model Used to Determine the Water Quality Effects of Chlorination at the Clinton, Iowa Water Pollution Control Plant", Proceedings WEF.

Hansen, B.E. and K.P. Rademacher, "Disinfection with Calcium Hypochlorite that is Generated On-Site at the Joint Water Pollution Control Plant of the County Sanitation Districts of Los Angeles County, CA", Proceedings WEF.


Haugh, R.S., "Instrumentation and Control of Sulfur Dioxide Dechlorination: an Update on State-of-the-Art", Proceedings WEF.

Huebner, W., "Chlorination/Dechlorination: One System", Proceedings WEF.


Lehrer, A.J., and V.J. Cabelli, "Comparison of Ultraviolet and Chlorine Inactivation of Female-Specific Bacteriophage and Fecal Indicator Bacteria in Sewage Effluents," Proceedings WEF.


Mohleji, S.C. and P. Wong, "Investigation and Comparison of Hypochlorite and Chlorine Disinfection Alternatives", Proceedings WEF.
Neethling, J.B., and D.A. Pivetti, "New Uniform Fire Code Impacts Disinfection Design", Proceedings WEF.


Oppenheimer, J.A., J.E. Hoagland, J.M. Laine, J.G. Jacangelo, and A. Bhamrah, "Microbial Inactivation and Characterization of Toxicity and By-Products Occurring in Reclaimed Wastewater Disinfected with UV Radiation", Proceedings WEF.


Roll, R.R., "Beating the Clock: Time Constraints of Chlorination Control Systems", Proceedings WEF.

Ryder, R.A., and J.A. Faller "Disinfection Challenges with Partially Nitrifying Fixed Film Reactor Effluent", Proceedings WEF.


Solymosi, G.C., "Intelligent, Microprocessor-Based Amperometric Analyzer Enables Part per Billion Chlorine Residual Monitoring and Control", Proceedings WEF.

Soroushian, F., J.L. Newton, and V.B. DePalma, Jr., "Disinfecting Reclaimed Water with Ultraviolet Light", Proceedings WEF.


Strand, R.L and G.C. White, "Managing Biocidal Effectiveness Through Redox Control of Chlorination", Proceedings WEF.


Water Authority Outreach Program, Chlorine is the Preferred Disinfectant, AWWA, Denver, CO, 1991.


White, G.C., "Operator’s Dilemma I-- Risks and Hazards of Chlorine Leaks", Proceedings WEF.


Younkin, C., M.S. Patel, A.S. Sokhey, and M.P. Cook, "Operational Experience with Computer Control of Chlorination/Dechlorination", Proceedings WEF.
APPENDICES

Appendix A: BEACH MONITORING AND CLOSURE CRITERIA FOR NEW YORK AND NEW JERSEY (Golub, 1994)

Appendix B: COMPREHENSIVE LITERATURE REVIEW OF INDICATORS IN MOLLUSCAN SHELLFISH AND THEIR GROWING WATERS, TABLE OF CONTENTS (Pierson and Hackney, 1991)

Appendix C: WATER-BORNE PATHOGENS OF CONCERN (PWG, 1990)

Appendix D1: COMPARISON OF IDEAL AND ACTUAL CHARACTERISTICS OF COMMONLY USED DISINFECTANTS (Darby et al., 1995)

Appendix D2: APPLICABILITY OF ALTERNATIVE DISINFECTION TECHNIQUES (US EPA, 1986)
**APPENDIX A: BEACH MONITORING AND CLOSURE CRITERIA FOR NEW YORK AND NEW JERSEY**

<table>
<thead>
<tr>
<th>DISTRICT</th>
<th>NEW JERSEY</th>
<th>NEW YORK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STATE</strong></td>
<td><strong>NEW JERSEY</strong></td>
<td><strong>NEW YORK</strong></td>
</tr>
<tr>
<td>Testing Frequency</td>
<td>weekly</td>
<td>at discretion of local permitting official</td>
</tr>
<tr>
<td>Indicator Organism</td>
<td>fecal coliform</td>
<td>total -or- fecal coliform</td>
</tr>
<tr>
<td>Test Method</td>
<td>membrane filtration -or- multiple tube fermentation</td>
<td>membrane filtration -or- multiple tube fermentation</td>
</tr>
</tbody>
</table>
| **STANDARD(S)** (Organisms/100 mL) | a. A single sample shall not exceed 200 | a. Total Coliform  
- log mean for 5 or more samples in a 30-day period shall not exceed 2400 -and- 20% of samples in a 30-day period shall not exceed 5000;  
- or-  
b. Fecal Coliform  
- log mean of 5 or more samples in a 30-day period shall not exceed 200 -and- a single sample shall not exceed 1000. |
| Other Criteria | a. sanitary survey  
b. known contamination  
c. aerial surveillance  
d. epidemiological evidence | a. sanitary survey  
b. rainfall/water quality model  
c. floatable debris  
d. medical debris  
e. known contamination |
| Action Required (if bacteriological standard exceeded) | Resample and conduct sanitary survey. A closed beach may be reopened in 24 hrs if survey and resampling results reveal satisfactory conditions. | Resample and conduct sanitary survey. If the resample exceeds the standard or if the survey reveals a hazardous condition, a beach closure is considered. |

**New Jersey:** NJ Departments of Health (DOH) and Environmental Protection (DEP) jointly administer this statewide mandatory beach monitoring program.

**New York:** NYS Dept of Health’s State Sanitary Code states that no bathing beach shall be operated if it constitutes a potential hazard to health. Nassau, Suffolk and Westchester Counties close beaches when standards are exceeded. Westchester County closes Mamaroneck Harbor beaches pre-emptively based on rainfall levels. NYC DOH designates approval of beaches at the beginning of the season, based on the previous year’s water quality data and computer modeling. NYC also has a 12-hour rainfall advisory in effect for certain beaches.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Molluscan Shellfish Industry</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Historical Overview</td>
<td>46</td>
</tr>
<tr>
<td>3</td>
<td>Microbial and Chemical Indicators</td>
<td>106</td>
</tr>
<tr>
<td>4</td>
<td>Human Enteric Pathogenic Viruses</td>
<td>253</td>
</tr>
<tr>
<td>5</td>
<td>Human Associated Bacterial Pathogens</td>
<td>423</td>
</tr>
<tr>
<td>6</td>
<td>Animal and Terrestrial Associated Bacterial Pathogens</td>
<td>470</td>
</tr>
<tr>
<td>7</td>
<td>Association of <em>Vibrio</em> <em>naceae</em>, Natural Toxins and Parasites with Fecal Indicators</td>
<td>567</td>
</tr>
<tr>
<td>8</td>
<td>Methods to Recover Injured Indicators and Pathogens</td>
<td>590</td>
</tr>
<tr>
<td>9</td>
<td>Rapid Methods for Detection and Enumeration of Indicators</td>
<td>618</td>
</tr>
<tr>
<td>10</td>
<td>Detection of Noncultural Indicators and Pathogens</td>
<td>698</td>
</tr>
<tr>
<td>11</td>
<td>Changes in Indicator and Pathogen Populations During Handling of Shellstock</td>
<td>740</td>
</tr>
<tr>
<td>12</td>
<td>Changes in Indicator and Pathogen Populations During Processing and Handling of Shucked Shellfish</td>
<td>763</td>
</tr>
</tbody>
</table>
APPENDIX B (Continued): COMPREHENSIVE LITERATURE REVIEW OF INDICATORS IN MOLLUSCAN SHELLFISH AND THEIR GROWING WATERS

TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Statistical Sampling of Growing Waters and Shellfish Meat</td>
<td>804</td>
</tr>
<tr>
<td>15</td>
<td>Sanitary Surveys of Growing Waters</td>
<td>843</td>
</tr>
<tr>
<td>16</td>
<td>Reported Human Illness from Consumption of Molluscan Shellfish</td>
<td>930</td>
</tr>
<tr>
<td></td>
<td>- US Data for 1973 to 1990</td>
<td></td>
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<tr>
<td>17</td>
<td>Depuration and Relaying of Molluscan Shellfish</td>
<td>955</td>
</tr>
<tr>
<td>18</td>
<td>Using Indicator Information for Managing Risks</td>
<td>1024</td>
</tr>
<tr>
<td>19</td>
<td>Summary</td>
<td>1053</td>
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</table>

**APPENDIX C: WATER-BORNE PATHOGENS OF CONCERN**

<table>
<thead>
<tr>
<th>PATHOGEN:</th>
<th>DISEASE</th>
<th>INFECTIVE DOSE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BACTERIAL:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enteropathogenic <em>E. coli</em></td>
<td>Gastroenteritis</td>
<td>$10^8 - 10^{10}$</td>
<td>Fecal contaminant; Infants more susceptible</td>
</tr>
<tr>
<td><em>Shigella sonnei, S. flexneri,</em></td>
<td>Shigellosis, bacillary dysentery</td>
<td>$10$ viable bacterial cells</td>
<td>Fecal contaminant; does not survive long in aquatic environments</td>
</tr>
<tr>
<td><em>S. dysenteriae, S. boydii</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Vibrio cholerae, V. cholera</em> biotype E1 Tor.</td>
<td>Cholera</td>
<td>$10^8 - 10^9$ viable bacterial cells</td>
<td>Fecal contaminant; associated with raw or inadequately cooked shellfish.</td>
</tr>
<tr>
<td><em>Salmonella typhi</em></td>
<td>Typhoid fever</td>
<td>$&gt;10^3 - 10^7$ viable bacterial cells</td>
<td>Fecal contaminant; associated with raw or inadequately cooked shellfish.</td>
</tr>
<tr>
<td><em>Salmonella enteritidis</em></td>
<td>Paratyphoid fever, salmonellosis</td>
<td>$10^3 - 10^4$ viable bacterial cells</td>
<td></td>
</tr>
<tr>
<td><em>Vibrio species: V. mimicus</em></td>
<td>Skin infection, salmonellosis</td>
<td>$10^5 - 10^7$ viable bacterial cells</td>
<td>Naturally occurring and fecal contaminant.</td>
</tr>
<tr>
<td><em>V. parahaemolyticus</em></td>
<td>swimmer's ear, gastroenteritis</td>
<td></td>
<td>Gastroenteritis associated with consumption of raw shellfish, crustaceans, and fish.</td>
</tr>
<tr>
<td><em>V. alginolyticus, V. vulnificus</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pseudomonas putrefaciens</em></td>
<td>Pneumonia</td>
<td>unknown</td>
<td>Naturally occurring.</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>Gastroenteritis, otitis</td>
<td>unknown</td>
<td>Fecal contaminant. Skin organism.</td>
</tr>
</tbody>
</table>
### APPENDIX C: WATER-BORNE PATHOGENS OF CONCERN (cont)

<table>
<thead>
<tr>
<th>PATHOGEN:</th>
<th>DISEASE</th>
<th>INFECTIVE DOSE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VIRAL:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poliovirus,</td>
<td>Poliomyelitis</td>
<td>2-100 Plaque-forming units (PFU's)</td>
<td>Fecal contaminant</td>
</tr>
<tr>
<td>types 1-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hepatitis A</td>
<td>Infectious hepatitis</td>
<td>unknown</td>
<td>Fecal contaminant; associated with consumption of raw shellfish and contaminated bivalve mollusks, possibly also with swimming.</td>
</tr>
<tr>
<td>Norwalk,</td>
<td>Gastroenteritis</td>
<td>&lt;10 viral particles</td>
<td>Fecal contaminant; possibly associated with swimming</td>
</tr>
<tr>
<td>agent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coxsackieviruses</td>
<td>Aseptic meningitis, pleurodynia, pericarditis, rash, paralysis, respiratory infection</td>
<td>&lt;100 PFU's</td>
<td>Fecal contaminant</td>
</tr>
<tr>
<td>Group B,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>types 1-34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotavirus</td>
<td>Gastroenteritis</td>
<td>&lt;10 viral particles</td>
<td>Fecal contaminant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OTHER:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giardia lamblia</td>
<td>Giardiasis</td>
<td>$10^1 - 10^7$ cysts</td>
<td>Naturally occurring; a cyst in human feces</td>
</tr>
<tr>
<td>Naegleria, Acanthamoeba</td>
<td>Amoebic meningitis</td>
<td>unknown</td>
<td>Naturally occurring.</td>
</tr>
</tbody>
</table>

**SOURCE:** Adapted from Pathogens Work Group (1990).
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Properties/response</th>
<th>Chlorine</th>
<th>Sodium-Hypochlorite</th>
<th>Calcium-Hypochlorite</th>
<th>Chlorine-Dioxide</th>
<th>Ozone</th>
<th>UV Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>Should be available at large quantities at reasonable prices</td>
<td>Low cost</td>
<td>Moderately low cost</td>
<td>Moderately low cost</td>
<td>Moderately low cost</td>
<td>Moderately high cost</td>
<td>Moderately high cost</td>
</tr>
<tr>
<td>Deodorizing ability</td>
<td>Should deodorize while disinfecting</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>na</td>
</tr>
<tr>
<td>Homogeneity</td>
<td>Solution must be uniform in composition</td>
<td>Homogenous</td>
<td>Homogenous</td>
<td>Homogenous</td>
<td>Homogenous</td>
<td>Homogenous</td>
<td>na</td>
</tr>
<tr>
<td>Interaction with extraneous material</td>
<td>Should not be absorbed by organic matter other than bacterial cells</td>
<td>Oxidizes organic matter, also absorbed by organics</td>
<td>Active oxidizer</td>
<td>Active oxidizer</td>
<td>Active oxidizer</td>
<td>Oxidizes organic matter</td>
<td>Absorbed by specific organic compounds</td>
</tr>
<tr>
<td>Noncorrosive and nonstaining</td>
<td>Should not disfigure metals or stain clothing</td>
<td>Highly corrosive</td>
<td>Corrosive</td>
<td>Corrosive</td>
<td>Highly Corrosive</td>
<td>Highly corrosive</td>
<td>na</td>
</tr>
<tr>
<td>Nontoxic to higher forms of life</td>
<td>Should be toxic to microorganisms and nontoxic to humans and animals</td>
<td>Highly toxic to organic matter</td>
<td>Toxic</td>
<td>Toxic</td>
<td>Toxic</td>
<td>Toxic at high dosages</td>
<td>na</td>
</tr>
<tr>
<td>Penetration</td>
<td>Should have the capacity to penetrate bacteria surfaces</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High safety</td>
</tr>
<tr>
<td>Safety/Transportation concerns</td>
<td>Should be safe to transport, store, handle, and use</td>
<td>High risk</td>
<td>Moderate risk</td>
<td>Moderate risk</td>
<td>High risk</td>
<td>Moderate risk</td>
<td>Low risk</td>
</tr>
<tr>
<td>Solubility</td>
<td>Must be soluble in water or cell tissue</td>
<td>Slight</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>na</td>
</tr>
<tr>
<td>Stability</td>
<td>Loss of germicidal action on standing should be low</td>
<td>Stable</td>
<td>Slightly unstable</td>
<td>Relatively unstable</td>
<td>Unstable, must be generated as used</td>
<td>Unstable, must be generated as used</td>
<td>Must be generated as used</td>
</tr>
<tr>
<td>Toxicity to microorganisms</td>
<td>Should be highly toxic at high dilutions</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Toxicity at ambient temperatures</td>
<td>Should be effective in ambient temperature range</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
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Source: Adapted from Darby et al. (1995).  
na = not applicable
### APPENDIX D2: APPLICABILITY OF ALTERNATIVE DISINFECTION TECHNIQUES

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Cl₂</th>
<th>Cl/deCl₂</th>
<th>ClO₂</th>
<th>BrCl</th>
<th>O₃</th>
<th>UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of plant</td>
<td>all sizes</td>
<td>all sizes</td>
<td>all sizes</td>
<td>small to med.</td>
<td>medium to large</td>
<td>small to med.</td>
</tr>
<tr>
<td>Applicable level of treatment prior to disinfection</td>
<td>all levels</td>
<td>all levels</td>
<td>secondary</td>
<td>secondary</td>
<td>secondary</td>
<td>secondary</td>
</tr>
<tr>
<td>Equipment reliability</td>
<td>good</td>
<td>fair to good</td>
<td>?</td>
<td>?</td>
<td>fair to good</td>
<td>fair to good</td>
</tr>
<tr>
<td>Process control</td>
<td>well developed</td>
<td>fairly well developed</td>
<td>problematic</td>
<td>no experience</td>
<td>developing</td>
<td>developing</td>
</tr>
<tr>
<td>Relative complexity of technology</td>
<td>simple to moderate</td>
<td>moderate</td>
<td>moderate</td>
<td>moderate</td>
<td>complex</td>
<td>simple to moderate</td>
</tr>
<tr>
<td>Safety concerns/Transportation on site</td>
<td>yes substantial</td>
<td>yes substantial</td>
<td>yes substantial</td>
<td>yes substantial</td>
<td>no moderate</td>
<td>no minimal</td>
</tr>
<tr>
<td>Bacterial Virucidal</td>
<td>good</td>
<td>poor</td>
<td>good</td>
<td>fair to good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Fish toxicity</td>
<td>toxic</td>
<td>non-toxic</td>
<td>slight to mod.</td>
<td>toxic</td>
<td>none expected</td>
<td>non-toxic</td>
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<tr>
<td>Hazardous by-products</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>none expected</td>
<td>no</td>
</tr>
<tr>
<td>Persistent residual</td>
<td>long</td>
<td>none</td>
<td>short</td>
<td>moderate</td>
<td>none</td>
<td>none</td>
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<tr>
<td>Contact time</td>
<td>long</td>
<td>long</td>
<td>moderate</td>
<td>mod. to long</td>
<td>moderate</td>
<td>short</td>
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<tr>
<td>Contributes dissolved Oxygen</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Reacts with Ammonia</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>yes (high pH only)</td>
<td>no</td>
</tr>
<tr>
<td>Color removal</td>
<td>moderate</td>
<td>moderate</td>
<td>?</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Increased dissolved solids</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>pH Dependent</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>slight (high pH)</td>
<td>no</td>
</tr>
<tr>
<td>O &amp; M sensitive</td>
<td>minimal</td>
<td>moderate</td>
<td>moderate</td>
<td>?</td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>Corrosive</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

**SOURCE:** Replicated from US EPA (1986).