5-16-03

Hilary Hauser
HEAL THE OCEAN
P.O. Box 90106
Santa Barbara, California 93190

Dear Hilary:

Appended is a brief report identifying issues of concern related to the discharge of secondary and even tertiary treated sewage into shallow coastal waters used for recreational purposes. I hope this report meets your expectations and will be useful in HEAL THE OCEAN's continuing efforts to involve people and improve coastal water quality.

Sincerely,

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Title: Concerns and risk factors associated with discharges of secondary treated sewage into very shallow coastal waters.

Introduction

Worldwide, domestic wastewater discharges represent one of the most significant threats to the coastal oceans. The majority of the world's populations live along the coasts where sewage is discharged untreated. From a public health perspective, continued emphasis on better treatment of sewage for discharge into estuarine and marine environments remains a costly but essential societal obligation.

Domestic sewage contains pathogenic microorganisms that can cause serious human diseases. Sewage contamination of fresh and marine waters is a means whereby disease causing microorganisms can be transmitted to people engaged in recreational activities or through consumption of edible filter-feeding shellfish. The United States is among those nations whose coastal waters do not generally receive untreated municipal sewage discharges.

Although sewage treatment in the United States has significantly eliminated many debilitating waterborne diseases (e.g., cholera, typhoid fever), sewage also contains a myriad of chemical toxicants including heavy metals, a variety of household organic chemicals including pesticides and petroleum hydrocarbons, and other chemicals contained in soaps, cosmetic preparations, as well as common everyday pharmaceuticals (pharmaceuticals and personal care products or PPCPs) whose effects on marine life are not well understood and until recently unrecognized (National Research Council 1999). Many of these chemicals pass through sewage treatment facilities unscathed and are known to be endocrine disrupters of aquatic animals. Compounds of concern include the nonylphenols, extremely pervasive compounds found in plastics, pesticides, and other industrial and domestic detergents. Natural and synthetic human estrogens (birth control pills) excreted in human urine may interfere with the developmental physiology and reproduction of aquatic marine organisms. As we learn more about these compounds, it is very likely that the costs of their disposal will be very high indeed.

Sewage also contains antibiotics (Halling-Sorensen et al. 1998) which can select for antibiotic resistant bacteria in the environment and bacterial viruses that carry antibiotic resistance and toxin genes (Miller 1998, Muniesa and Jofre 2000). Concerns relate to disease causing naturally-occurring marine bacteria which incorporate these elements and become unresponsive to antibiotic therapy.

Protection of public health and the indigenous coastal biota are essential and recognized reasons to justify improved discharge quality or to minimize effects, effluent relocation to achieve greater dilution. Treatment to reduce nutrient loading to coastal waters is a second important benefit to prevent the occurrence of undesirable species and harmful algal blooms.

Pathogens. The introduction of human pathogens into marine/estuarine environments is a concern on both local and global scales. Enteric pathogens continue to pose significant risks to fishing, recreational bathing and shellfish-consuming populations (Henrickson et al. 2001, Griffin et al. 2003). Important disease causing waterborne pathogens include bacterial pathogens such as *Vibrio cholerae*, the shigellae and salmonellae, enteric viruses such as the caliciviruses (e. g., Norwalk agent) and hepatitis A, and protists such as *Cryptosporidium.* Many of these microorganisms have been responsible in recent years for disease outbreaks associated with exposure to marine and fresh waters.

The microbiological quality of coastal waters is directly affected by point sources such as sewage treatment plants, riverine discharge, storm derived runoff and possibly, contaminated ground water flow. The feces of marine mammals have been implicated in certain situations on the northwest coast of the United States as sources of indicator organisms. In recent years microbiological studies have demonstrated greater persistence of certain enteric pathogens in marine waters than previously recognized. Nutrient enrichment of coastal waters and sediment may provide conditions that prolong pathogen survival.

Many countries in the world discharge untreated or inadequately treated sewage into coastal waters. Population growth, landuse alterations, changes in animal populations, intensive agricultural practices, use of waste stabilization ponds, soil transport, and medical therapeutics are some factors which influence the kinds and properties of pathogenic enteric microorganisms transported to marine waters and their fates. Understanding relationships between landuse and the occurrence of fecal indicators and pathogens is an important goal for remediation of coastal waters.

Risk of disease at coastal bathing beaches. There is considerable evidence that exposure to polluted marine bathing waters results in an increased frequency of human disease symptoms (Henrickson et al. 2001). Numerous prospective epidemiologic studies have been conducted to quantify risk associated with exposure to recreational bathing (e. g., Cabelli et al. 1982, 1983; Kay et al. 1994) and to derive quantitative relationships with indicator microorganisms (Cabelli et al. 1983). The latter study is the basis for current EPA recreational water microbiological indicator criterion. Most epidemiologic studies confirm that swimmers have an increased risk of disease compared with nonswimmers (Cabelli et al. 1983, Griffin et al. 2003). Disease symptoms include eye-ear, respiratory, gastrointestinal disorders and infrequently more serious conditions. Pathogens associated with outbreaks attributed to marine recreational waters have generally not been identified but are assumed to be viruses. There is also some evidence to suggest certain pathogens associated with exposure to bathing waters may be passed from person to person. Illnesses associated with recreational waters of nonenteric etiology have been attributed to the staphylococci (Favero 1985: Charoenca and Fujioka 1991, 1995) and *Pseudomonas aeruginosa* (Seyfried and Cook 1984). Evidence presented suggests that sediments can be a reservoir for staphylococci and routine monitoring for this group has been proposed for recreational marine waters (Charoenca and Fujioka 1991). Monitoring for this group is not required and the presence or absence of staphylococci would not be reflected by the fecal coliform indicator.

Submerged swimmers can also be exposed to sewage-derived chemicals which can enter through the mouth, eyes, ears and nose. Recent studies using artificial skin have shown that toxic and other sewage-derived chemicals in the water can possibly enter the body through a process known as dermal adsorption (Moody and Chu 1995). Chronic exposure to chemicals through this mechanism could affect the immune system.

Factors which must be considered with regard to discharge of sewage into shallow coastal waters used for recreational purposes. Even in developed countries such as the United States, significant health risks have been attributed to beach exposure and the frequency of beach closures appears to have accelerated in recent years ((Henrickson et al. 2001)). The National Resources Defense Council (2001) reported a doubling of beach closings (fresh and marine) from 1999 to 2000. Causes of increased frequencies of beach closures are complex and may be related to population increases, beach usage, degree of sewage treatment, increased volumes of sewage discharge, changes in coastal water quality, runoff, climate changes and improved surveillance.

Dispersion of the sewage discharge plume. An obvious concern with coastal discharges is that they be situated in well characterized waters where the chance of pathogen transport (hence disease risk) into beach waters is minimized. The dispersal dynamics of a sewage plume are complex and subject to many hydrographic factors including dilution volume, stratification, surface and bottom currents, their seasonal directions, internal waves, seasonal and short-term wind directions, bottom topography, density and volume of effluent, and climate. These factors should be evaluated over the range of seasonal and climatic conditions which are normal to coastal environments. Adequate seasonal coverage is not only important because of environmental factors, but because some pathogens such as hepatitis A show seasonal patterns of occurrence. It is not unreasonable to assume that under certain conditions shallow water discharges such as those into Santa Barbara waters would move in the direction of bathing areas.

Published studies have shown that differences in density between the effluent and its constituents and surrounding waters will affect effluent fate and transport. Particle-associated viruses and bacteria would behave differently than buoyant components and could be deposited in sediment and later transported inshore by wave action. If the dispersion and dilution characteristics of the plume and the concentration of viruses in the effluent are known, predictions of viral concentrations bracketing a range of release efficiencies could be calculated, Dye or isotopic methods have been used to trace discharge plumes for modeling purposes. Biological (bacteria or virus) or chemical (fecal sterols) indicators can be used to study transport of microorganisms and to evaluate the influence of weather and wind patterns.

Effectiveness of sewage treatment and disinfection against some enteric viruses. Secondary sewage treatment utilizes microorganisms within the treatment plant to biochemically digest under favorable oxygen regimes settled sewage solids from the primary sedimentation step. Secondary treatment is expected to reduce biological oxygen demand (BOD) and suspended solids by 85-90%, and to remove 90-99% of coliform bacteria. This process generally can reduce the pathogenic bacterial and viral load by values which may range from 99 to 90%, respectively. Actual values vary and depend on a variety of factors such as plant design, processing time within the plant, loading, and disinfection contact times.

Treatment of sewage is not a stoichiometric process because the characteristics and composition of the material received varies, the volume, hence the holding time may be affected by weather conditions (i. e., significant precipitation events), environmental temperatures affect sewage treatment processes, and therefore the efficiency of pathogen removal may also be expected to vary. Departures from ideal conditions do occur and the quality of the effluent can fluctuate. Importantly, there is always a range of treatment efficiency with regard to bacterial and viral removal. Although laboratory studies with cell-culture adapted strains of hepatitis A can demonstrate effective removal through disinfection, similar studies have not been done with wild-type hepatitis viruses in actual effluents because of analytical limitations.

Secondary sewage treatment effluents are generally disinfected, usually with chlorine or UV light. One study has shown that ozone is an effective disinfectant for hepatitis A in the laboratory (Vaughn et al. 1990). There is considerable evidence that enteric viruses are differentially affected by disinfection (Seyfried et al. 1984, IAWPRC 1991). Viruses especially resistant to chlorine disinfection and UV include hepatitis A and norvoviruses such as Norwalk agent. Studies to evaluate a bacterial virus known as a male-specific bacteriophage, (which is similar in gross structure and size to hepatitis A virus) as a viral indicator show it present at comparatively high levels in secondary effluents after chlorination. By comparison, bacterial indicator concentrations were reduced to counts on the order of one magnitude or undetectable. Because the minimal infectious dose of viruses is assumed to be very low, disinfected effluent free of indicator bacteria provides a false sense of safety because the effluent can still contain infectious virus at comparatively high levels.

Tertiary treatment is a laudable goal for all ocean discharges because it raises the standard of effluent quality to a higher level than secondary treatment. Tertiary treatments can be focused on nutrient removal, such as reductions in phosphate and nitrogen levels or employ additional disinfection through UV or microfiltration.

Inadequacy of bacterial indicators and standards to reflect health risk. The basic rationale of the indicator concept is that it should reflect the presence of pathogens. When this concept was conceived in the early 1900’s first applied to marine waters in the United States viral pathogens were not considered. In the years that followed bacterial standards were pressed into action by extension to also predict viral presence. Standardized methods for routine detection of viral pathogens in marine waters do not exist and viral presence is highly variable. A variety of “indicator” viruses have been studied as alternative indicators (IAWPRC 1991) but none thus far have been formally adopted for marine or recreational waters.

Numerous reports in the technical literature have shown that bacterial indicators such as the fecal coliform or the enterococci are poor or inappropriate predictors of viral pathogens (e. g., Jiang et al. 2001, Noble and Fuhrman 2001) owing to the protracted persistence of the latter and their resistance to disinfection. Many investigators have reported the presence of enteric viruses in waters meeting the more stringent water quality criterion for shellfish growing waters (Richards 1985). Recent studies using new molecular techniques to detect some enteric viruses support older studies showing that bacterial indicator densities are not predictive of viral presence (Griffin et al. 2003). Jiang et al. (2001) detected enteric adenoviruses in Southern California beach waters which at times did not exceed the water quality standard. Detection of adenovirus in southern California nearshore waters implies that other equally or more resistant enteric viruses are likely to persist in coastal waters. Adenoviruses can be ingested orally and are known to cause sore throat, diarrhea, fever and nausea. An approved routine laboratory test to detect hepatitis A virus is still unavailable. Monitoring STP effluents based on conventional bacterial indicators must therefore be used with caution to assess effluent quality as this provides no information on viral water quality.

The derivation and validity of the current federal water quality criterion used to assess and regulate the sanitary quality of marine recreational waters has been questioned (Fleisher 1991). The fact that the EPA criterion for marine waters is to apply universally to all US coastal waters seems a poor assumption given the observation that environmental conditions which influence pathogen and indicator persistence differ markedly by region. In general, the research community has shown that waters meeting coliform bacterial standards do not adequately reflect the health risks.

Other studies suggest that some bacterial indicators and pathogens when exposed to seawater enter a kind of dormant state but still remain viable and capable of causing disease (Roszak et al. 1984, Pommepuy et al. 1996, Caro et al. 1999). Microorganisms in this state are called viable-but-nonculturable (VBNC), meaning that they will not be detected using culture-based methods such as the approved total and fecal coliform MPN tests. An assessment of sanitary water quality populated with indicator bacteria in the VBNC state will lead to an underestimation of the health risk.

Persistence of pathogens in sediments. Given that a secondary or even tertiary effluent can contain disinfection-resistant viral pathogens, we have very little data on their persistence in natural marine waters. Aside from many reports demonstrating that certain viruses can survive under in vitro conditions much longer than bacterial pathogens (months as opposed to days), field experiments to understand the effects of salinity, seasonal temperature, sunlight, and sediment on viral pathogen persistence remain to be conducted. As noted, the lack of routine detection methods for pathogenic viruses limits survival studies of any type. The older literature shows increased survival when viruses are associated with sediment and organic particles (Richards 1985). Shiaris et al. (1987) observed a protective effect of intertidal sediments on indicator bacteria. Discharge of effluent at shallow depth may provide conditions more favorable for association of pathogens with sediment. Not only is the vertical path length shorter, but near shore sediments with high suspended particulates may provide conditions more conducive to pathogen survival and resuspension than deeper discharge areas.

There is a comparatively small body of literature suggesting that sediment resuspension will facilitate transport of bacteria and viruses into the water column. Sediment resuspension processes on beaches can be caused by waves or by actions of the bathers themselves could be expected to result in increased exposure to pathogens.

Surveillance frequency. The ability to detect fluctuations in indicator and perhaps pathogen densities is affected by sampling frequency. Given the very dynamic nature of beach environments sampling frequencies ideally should be continuous and integrative and adjusted in response to usage, storm events, or shifts in hydrographic parameters that might be anticipated to lead to adverse discharge quality and increased potential health risk. Unfortunately continuous integrative samplers are not yet available for any pathogen. Sampling and processing costs will usually present practical limits to high frequency discrete or grab sampling with extended spatial coverage. Thus, it is unlikely that all contamination events at beaches will be detected using minimal sampling regimens now followed. Results from a World Health Organization (WHO) workshop on recreational waters (November, 1998) showed that densities of indicator organisms in coastal beach waters varied greatly over time with little predictability, within and between days and locations. Overall, it is very unlikely given the current state of monitoring that exceedances of indicator densities and pathogen presence, hence disease risk, will be detected for a proportion of the time.

Dissemination of antibiotic resistance elements into coastal waters. As previously noted widespread and permissive use of antibiotics in agriculture and for human therapeutic use where antibiotics are ineffective have resulted in a explosion of drug resistance among environmental bacterial species (e. g., Rice et al. 1995). Genetic elements conferring such resistance can be found in bacteria (Al-Jebouri 1985) and bacterial viruses discharged in sewage. Considerable evidence now exists that genetic information coding for antibiotic resistance is commonly transferred between microorganisms organisms through common mechanisms such as transduction and conjugation, whereby genetic elements conferring resistance to antibiotics and toxics can be exchanged in the environment (Boyd and Hartl 1997, Davison, J. 1999). Genetic exchanges can occur in sediment or for example within the gastrointestinal tracts of animals. While the effect of discharged genetic elements may not present an immediate health concern owing to exposure to disinfected effluents, it does provide a source of antibiotic resistance or other virulence elements to bacteria indigenous to the marine environment. Such bacteria may include bacterial genera capable of causing opportunistic infections in humans exposed to coastal waters, e. g., *Vibrio* spp. and the nontuberculous mycobacteria, thereby rendering treatment potentially more difficult, protracted and costly.

Conclusions

Pearson (1975) describes various scenarios associated with the location of sewage discharge outfalls into coastal waters and considers reciprocal relationships between discharge quality and distance of outfall dispersion system from shore. He concludes that longer outfall dispersion systems are more effective, providing more dilution of nonconservative elements and more "decay" time for removal of coliform microorganisms. He suggests that moving discharge outfalls inshore based on improved levels of treatment will not provide an appropriate level of effluent dilution nor will it reduce adverse environmental impacts. Based on his comments desirable goals to improve coastal beach water quality in the Santa Barbara area would therefore be (a) to locate discharges as far offshore as possible and (b) to apply advanced tertiary treatment to the discharge for the effective removal of viral pathogens, nutrients and harmful or ecologically disruptive chemicals. Goal (b) will require development of sampling approaches and routine methods to detect and verify the effectiveness of viral removal.

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