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# REPORT OF THE EXPERTS SCIENTIFIC WORKSHOP ON CRITICAL RESEARCH NEEDS FOR THE DEVELOPMENT OF NEW OR REVISED RECREATIONAL WATER QUALITY CRITERIA

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# CHAPTER 4
# COMPARING RISK (TO HUMANS) FROM DIFFERENT SOURCES

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## 4.1 Introduction

Fresh and marine recreational waters and beaches may be impacted by human and/or animal feces from point and non-point sources. Studies have recently been completed by EPA on assessing rapid water quality indicators and their ability to predict swimming-associated illness at freshwater beaches impacted by publicly (and privately) owned (sewage/wastewater) treatment works (POTW) systems. Similar EPA studies are currently planned (starting summer of 2007) to assess the risk of illness for people who swim in marine recreational waters impacted by POTW systems (point sources of fecal contamination). Thus, in the near future additional information should be available on risk of illness for bathers at marine beaches largely impacted by human sewage. Plans are also underway by the Southern California Coastal Water Research Project to assess swimming risks at least one marine beach that is impacted by non-point source sewage that likely contains a mixture of human and animal feces. However, there remains a paucity of data on the risk of illness for swimmers at beaches exclusively (or primarily) impacted by feces from animals. The absence of such data makes it difficult to interpret the health significance of the frequent and persistent elevated fecal indicator levels in such waters that have been attributed to animals in many locations throughout the United States.

It is widely believed that human feces pose a larger health risk than animal feces to swimmers and other primary contact recreational water users. This belief derives from the basic concept that virtually all enteric pathogens of humans are infectious to other humans, while relatively few of the enteric pathogens of animals are infectious to humans. Possible exceptions are bird flu virus and swine hepatitis E virus (HEV). Workgroup members regarded the evidence for swine HEV transmission by water to be very weak and felt that it could disregarded in terms of risk assessments during the next 2 to 3 year EPA planning period. Bird flu was discounted as a major concern for swimmers because it was felt that if an outbreak of bird flu was recognized in birds or humans in the United States, early public health recommendations would include directives for people not to swim in waters that might be impacted by bird or human feces, including chlorinated public pools.

Counterbalancing the concept that animal feces may pose a lower risk is recognition that animals do harbor many bacterial and protozoan pathogens that pose a human health hazard and that some of these pathogens, such as enterohemorrhagic *E. coli* (EHEC), can cause serious, potentially life-threatening illness in humans. In addition, animal feces are often directly deposited in freshwater that receives no treatment before reaching bathing areas. The concentration of both feces and pathogens may be sufficiently high at beach locations at various times to pose a significant health risk to swimmers.

The bottom line is that there are few data to demonstrate whether animal feces pose a lower, greater, or equivalent health risk to bathers than human feces. If there is a difference, it would be helpful to know the magnitude of that difference in order for EPA to make appropriate public health recommendations. The only way to get a better sense of the health risk for swimmers posed by animal feces is to conduct targeted studies. Some types of studies (epidemiological and quantitative microbial risk assessment [QMRA] studies) would produce quantitative estimates of risks while others (fate and transport, pathogen loads in water, etc.) would provide supporting information or stand alone qualitative information about risk.

It is recognized that there are many different types of animals and that the pathogen risks posed by feces from these animals are different. These differences, as well as the different pathways (point, non-point, fecal deposition on land versus in water, etc.) that feces reach bathing areas, have to be taken into account in weighing risk. Workgroup members approached the issue by developing Table 5 in order to rank the likely risks from different sources of fecal contamination and to help prioritize which bather/animal-fecal-risk interface studies should be undertaken first.

The initial workgroup member discussion focused on assessing the universe of pathogen sources of interest to recreational waters. Workgroup members developed a table (Table 5) in which the major sources of fecal contamination categories are in rows. The major rows are wildlife, agricultural animals, domestic animals (pets), human/sewage, and what the workgroup termed "secondary environments" (i.e., soil, sand, and sediments). The wildlife row is subdivided into aquatic birds and all others. The agricultural animals are divided into poultry and other (largely comprised of domestic livestock such as cattle, sheep, and pigs). The human/sewage is divided

**Table 5. Comparing Risks (to Humans) from Different Pathogen Sources.[a]**

| Source | Viruses | Protozoa | Bacteria | |
|---|---|---|---|---|
| **Wildlife** | | | | |
| Aquatic birds | N | L | L-M | |
| Other (e.g., deer) | N | M | M | #2 priority |
| **Agricultural animals** | | | | |
| Poultry | N | N | M-H | |
| Other (e.g., cattle, sheep) | N | M | M-H | #1 priority |
| **Domestic animals** | | | | |
| Pets (e.g., dogs, cats) | N | L | L | |
| **Fecal shedding by bathers** | | | | #3 priority |
| Adults | L | L | L | |
| Children | H | H | H | |
| **Sewage** | | | | |
| No treatment (combined sewer overflows) | H | H | H | |
| No treatment (separate storm sewer overflows) | ?* | ?* | ?* | |
| Secondary treatment** | H | H | M | |
| Plus chlorine** | H | H | L | |
| Plus UV | M-H (L with increased energy) | | L | |
| **Secondary environments***** | L | L | M | |

[a] Does not have an explicit fate and transport component
* Risk largely depends on amount of human feces present
** Focus of most (U.S.) recreational water epidemiological studies
*** Sediment suspension and contact with beach sand

N = estimated no or negligible risk, L = estimated low risk, M = estimated medium risk, H = estimated high risk into untreated sewage, secondary treatment sewage, chlorinated sewage, and UV-treated sewage. Fecal shedding by bathers (adults and children) is considered separately.

The columns are defined by broad microorganism groups of viruses, protozoan and bacteria. By an expert opinion process (within the workgroup) each cell of the table was given a risk estimate of no (zero) or negligible risk (N), low, medium, and high (L, M, H). The types of characteristics discussed included infectious dose, numbers of pathogens per gram of stool from infected animals, implication of source in waterborne disease (extended discussion on foodborne disease and vector-borne disease), persistence and survival in the environment and finally an assumption that sources are in close proximity to a primary contact recreational area. The N, L, M, H risk designations in the table cells represent the workgroup's "best guesses" and assumed that animal feces was deposited in freshwater relatively closed to bathing sites. The workgroup did not specifically address pathogen "die-off" associated with fecal deposition on land (spring/summer temperatures resulting in pathogen drying, transport from soil to water affects on viability, etc.). It was felt that many of these types of data are available and that the table could be updated with real data at a later date as a separate project. It was recognized that updating the table with published data might change the values in one or more risk rankings of the table cells.

With rare exception, viruses are species-specific. Essentially, all enteric oral/fecally transmitted viruses that infect humans are of human origin. For all of the animal viral sources of pollution, the viral cells were given a zero or negligible risk (indicated by "N" entries in Table 5). All the human sources were given a high risk estimate with the exception of UV-treated sewage. UV-treated sewage at current levels has up to a 0.5-log reduction of viruses and hence this cell was assigned a medium risk. More energy intensive UV irradiation may provide up to a 4-log viral reduction and result in a low risk ranking. Sentinel viruses for this group include enteroviruses, hepatitis A virus, norovirus, rotovirus, and adenoviruses. The major protozoan pathogens of concern are *Giardia* and *Cryptosporidium*. Given the current knowledge of infectious dose, the long survival in the environment, many of the animal cells within the table were given a low, low-to-medium, or medium risk level. As with the viruses, all the human cells within the table were given a high risk rating with the exception of UV-treated sewage. The bacteria had similar ratings to the protozoa ranging from low-to-medium and again, the human sources were all assigned a high ranking with exception of chlorine- and UV-treated sewage that received a low risk ranking.

Bather density was divided into adults and children (recognizing that children could be divided into specific age groups) with the assumption that hygiene and accidental fecal discharges were much more likely to occur in children than adults. Thus, for adults, a low risk ranking was assigned across the columns and a high risk ranking was assigned for children.

Based on the few studies done on secondary environments, viruses and protozoa were given a low risk rating, while bacteria were given a medium rating.

In developing Table 5, workgroup members noted the following discussion points:

1. Current epidemiological literature suggests that the symptomatic profile of swimming-associated illnesses indicates primarily viral illnesses.
2. Certain pathogens such as EHEC have a low probability of occurrence but are associated with severe a health outcome.
3. Information available to the workgroup suggested that nonhuman fecal sources impacted freshwater sources more than marine water sources.
4. Combined sewer overflows (CSOs) were considered as untreated sewage.
5. Separate storm sewer overflows initially were put in the domestic animal row but subsequent discussion of recent studies suggested that they could have a human component in many communities.

In discussing the future research needs related to the development of new or revised recreational water quality criteria, the workgroup members defined the ultimate goal to be a determined quantitative risk estimate for each fecal source (row). The benchmark by which risks should be compared is the secondary and chlorine treated sewage row that is currently the focus of recently completed EPA National Epidemiological and Environmental Assessment of Recreational (NEEAR) epidemiological studies for freshwater and the planned marine water studies. The following research projects were suggested to meet that objective of determining a sound and defensible risk estimate for each row of Table 5.

## 4.2 Summary of Workgroup Discussions and Reflections on Workgroup-specific Charge and Questions

The charge to the workgroup was to consider the impact of waterborne pathogens from various sources, both human and nonhuman, on the health risk resulting from exposure to fecal contamination in recreational waters. Workgroup members considered the impact of the issue on beach monitoring and notification and the classification of waterways as impaired. The discussions were wide-ranging. Discussions began with the consideration of the relationship of likelihood of illness due to nonhuman sources to likelihood of illness predicted by the use of epidemiological data from human exposure to POTW-impacted waters using fecal indicators. Possible approaches to modifying the application of regulatory approach using considerations of infectivity to pathogens among species were debated. The location of fecal sources relative to the site of monitoring and the potential of animals to move off-site were also discussed. These topics are all reflected in the potential research activities proposed and discussed in this chapter.

Six charge questions were provided to the workgroup (see Appendix A) to help stimulate discussion, and to identify key issues for consideration. A brief synopsis of responses to the questions is presented below.

- *Question 1: Is setting criteria based on a treated human point source such as a POTW protective, under-protective or overprotective of other potential sources of human pathogen? Why or why not? Are there data to support this conclusion?*

Whether the criteria are protective would depend on the effectiveness of treatment in reducing the levels of pathogens and the relative reduction in indicator organisms. Secondary wastewater treatment with chlorination could provide a false sense of security for protozoa and viruses. This reflects the higher degree of effectiveness of chlorine in killing/deactivating bacteria relative to viruses and protozoa. Given that current indicators are bacteria and would be reduced to a greater extent than viruses and protozoa, low indicator levels might suggest that waters impacted by POTWs were relatively pathogen-free when they still contained a significant virus and protozoan load. Data are available to characterize the relative effectiveness of disinfection techniques across classes of waterborne pathogens and indicator organisms.

- *Question 2: Based on the "state of the science," what conclusions or assumptions are reasonable to make about risks to humans exposed to human fecal contamination, non-point source contamination from animal sources, and mixed sources (e.g., combined sewer overflows [CSOs] and (separate) storm sewer overflows)?*[6]

Workgroup members felt that it is reasonable to assume that exposure to fecal contamination from untreated human waste posed the highest risk. Treated sewage was judged to be of lower concern, although it was more similar in risk to untreated human waste than to nonhuman sources. In general, treated and untreated sewage should be treated similarly for the purposes of evaluating risk. Discussion of CSOs led to the conclusion that they should be considered similarly to untreated sewage in terms of public health concern. Although separate storm sewer overflows were initially considered to be similar to animal waste in nature, there was a recollection of data in the literature (Haile et al., 1999) noting the occurrence of a significant occurrence of human pathogenic viruses in stormwater effluent and associated health effects merits further investigation. Aquatic avian sources were considered to be of low public health concern. Other wildlife and agricultural animal (including poultry) feces were deemed to be of moderate concern.

- *Question 3: To what extent is it reasonable to apply risk estimates from POTW-influenced beaches to non-POTW beaches? Do we understand scientifically whether this would lead to overprotection? What science would be important to understanding this?*

A portion of the answer to this question is reflected in the responses to Questions 1 and 2 above. The propensity to over- or under-protect would depend upon the source of the waste impacting the site. Non-point sources that largely reflect nonhuman sources of fecal contamination would probably be overprotected by studies in POTW-impacted locations. Mixed sources or untreated human sources may be inappropriately characterized by the POTW-dominated data. The workgroup's generalizations are reflected in Table 5. Addressing the public health significance of CSOs and separate storm sewer overflows are problematic because of the site-specific nature of the extent to which they vary by site characteristics. Although the importance of dilution of pathogens and indicator organisms in runoff events was discussed, no conclusion was reached about its significance.

[6] It is important to note that the workgroup was specifically charged (see Appendix A) to address (separate) storm sewer overflows and not sanitary sewer overflows, the latter of which are often discussed in conjunction with CSOs and commonly using the acronym "SSO." For this reason, workgroup members decided to not use the acronym SSO anywhere in the chapter.

- *Question 4: Assess whether there is a possibility of overprotection due to a compounding of risks from multiple factors (such as the current definition of gastrointestinal [GI] illness [i.e., no fever]; more sensitive molecular-based methods; assuming that POTW risks = nonhuman fecal contamination source risks, etc.).*

This question was referred to the Acceptable Risk workgroup (see Chapter 5).

- *Question 5: How should EPA evaluate risk that may have a low probability of occurrence but a significant risk, if it occurs?*

This question was considered by workgroup members to be unlikely to be adequately represented by completed epidemiological studies due to the low incidence (or detection) of pathogens that are associated with severe health outcomes. However, this important public health issue might be addressed using quantitative microbial risk assessment (QMRA) methods or by using large-volume filtration in future epidemiological studies.

- *Question 6: What are the key data gaps and uncertainties needed to support criteria development in the near term?*

The research needs and their prioritization are presented in a separate section (4.4). Epidemiological studies were given a high priority, with QMRA as an important adjunct. Additional epidemiological studies were encouraged by workgroup members because the data produced directly measure outcomes of interest (e.g., GI illness) and the data produced are more directly comparable to data being obtained for human health risks at marine beaches largely impacted by human sewage. Thus, epidemiological studies were preferred to the extent that they were possible and were viewed as an anchor for QMRA studies. However, it was recognized that it may be difficult to find freshwater recreational sites with sufficient bather activity to provide adequate sample sizes for an epidemiological study. If suitable sites cannot be found, then modeling the risk using QMRA techniques based on available epidemiological information would provide quantitative risk estimates that could help with short-term decision making on health risks. Similarly, if pathogen-source combinations in Table 5 cannot be conducted, it may be possible to use QMRA to provide quantitative risk estimates.

## 4.3 Options for Approaches and Implementation Considerations

The considerations in the followings section are not applicable to the current U.S. approach (i.e., US EPA, 1986; see also Chapter 1) because there is no way to take into consideration the charge to this workgroup on comparing risk to humans of fecal contamination from different sources. The following considerations are applicable to both the European Union (EP/CEU, 2006) and WHO (2003) approaches to criteria development. The sanitary investigations are important for the topics discussed by this workgroup. Simultaneous use of multiple indicator organisms or a tiered approach may be necessary.

### 4.4 Research Needs

1. Prioritize the next generation of studies. The purpose of these studies is to (1) revisit the ratings using a more through literature review and (2) gain as much information as currently exists on the magnitude of the fecal pathogen source problem across the United States.
    a. Quantify the magnitude of difference in the risk of illness from different exposure sources (see Table 5) to see if they are different from POTW-impacted waters.
        i. Initial estimate of risk – populate the table with infectious dose data and likely number of organisms excreted in stool per gram to characterize fecal source rank.
        ii. Magnitude across the United States
            1. Number of impaired waters
            2. Number of beaches affected by the sources (number of affected bathers if available)
        iii. Identify potential fresh and marine recreational sites for each of the fecal pathogen sources (rows) for future epidemiological studies. Priority should be given to freshwater sites.
2. Identify and characterize potential sites for future epidemiological studies using the following sources of information:
    a. National Pollution Discharge Elimination System (NPDES) – provides location of all point source dischargers and their levels of discharge
    b. CWA §303(d) list and §305(b) reports
    c. Sanitary investigations and microbial source tracking to confirm site characterization
    d. Compile information (via literature review and/or site-specific) about pathogen loads in non-point source water impacted by all sources of fecal contamination (human and animal), characterizing with respect to pathogens and indicators in freshwater versus marine water.

#### 4.4.1 Epidemiological Studies

Workgroup members agreed that epidemiological studies are the most desirable approach to define and quantify health risks to humans swimming in fecally contaminated waters. Although many epidemiological studies have been previously conducted at point source-impacted beaches, very few such studies have been published on non-point source-impacted recreational waters. The relationship between current water quality indicators and health outcomes that is currently used in regulating beaches was developed from studies at point source-impacted beaches where water quality indicator levels correlated with swimming-associated illness (US EPA, 1986). It is plausible that the relationship between water quality indicators and health is different at non-point source-impacted sites since indicator levels may be high due to animal (e.g., birds, other wildlife) or other sources that do not increase the risk of human illness. Some workgroup members felt that it is appropriate to conduct epidemiological studies at non-point source-impacted sites to better define risk and guide future regulations.

Some workgroup members noted that epidemiological studies cannot be performed in all of the various types of non-point source-impacted waters for which there is a need to know risk. In many of these types of sites, other techniques (such as QMRA) will necessarily have to be used (see Section 4.4.2). The choice of the specific sites (beaches, rivers, lakes) in which to conduct epidemiological studies could be guided by the risk rankings developed in Table 5. These rankings include the types and concentrations of pathogens present, the number of affected waters across the United States, the number of people who are exposed to such sites, and the number of sites affected by regulatory restrictions under the CWA §303(d) guidelines.

Two principal study designs have been used in prior beach epidemiological studies—the randomized controlled trial (RCT) and the prospective observational cohort. The RCT has been primarily used in European studies and the observational cohort in many countries. Workshop participants discussed the relative strengths and limitations of each study design. With respect to the issue of health risks in non-point source-impacted waters, the workgroup members actively discussed the advantages of each design and felt that each had merit. Because of the required sample size (i.e., number of swimmers) is much less for an RCT, workgroup members could envision situations in which an RCT could be employed in future non-point source epidemiological studies. Workgroup members did note that in the United States it would be more likely for such an epidemiological study to receive human subjects approval if the enrollment scheme were altered from the RCT that has been used in several European studies. In Europe, subjects are typically recruited and enrolled in the studies at sites distant from the beach and then brought to the study sites. Workgroup members discussed an alternate design for consideration in the United States; specifically, enrolling willing persons who are about to enter the water and randomizing them to either swim or not swim that day. As in all epidemiological studies, aggressive exposure measurements of the water ingested and measures of water quality (e.g., indicators of fecal pollution) to which the swimmer is exposed would be critical. In non-point source sites where adequate numbers of swimmers could be enrolled, the prospective cohort design could be used for epidemiological studies. Workgroup members felt that it would be very helpful at some point to use both study designs simultaneously on one beach. This would allow for a direct comparison of the results and help guide future epidemiological studies.

1. Epidemiological studies (**highest priority is to conduct studies at beaches impacted by different types of non-point sources of fecal contamination [see Table 5]**)
    a. Randomized control trials (for consideration at beaches with low numbers of bathers)
        i. European design should be modified for use in the United States (suggestion – randomize people about to swim into groups that will swim or not swim)
        ii. Potential problem – identifying appropriate numbers of participants may be more difficult for inland (predominantly fresh) recreational waters than marine waters
        iii. Estimated necessary sample size – 1,500 people/site
    b. Prospective observational cohort study
        i. Potential problem – identifying sufficient numbers of participants may be more difficult for inland recreational waters than marine waters

ii. Estimated necessary sample size – 5,000 to 10,000 people/site (200 to 400 people/day)
iii. Wide range of exposures needed

### 4.4.2 Quantitative Microbial Risk Assessment

Several workgroup members advocated for QMRA studies in developing new or revised recreational ambient water quality criteria (AWQC). In part because QMRA can be used to rank the relative risks of different situations, such as sites impacted by animal versus human fecal wastes, and where no direct epidemiological information is available. QMRA studies can also be instructive in recreational areas where such studies have already been completed.

QMRA is increasingly used to characterize risk to humans from exposure to contaminated water when engaging in "contact recreation," especially swimming, but also other forms of water contact such as water skiing. It translates the environmental occurrence of pathogens and the volume of water that individuals are exposed to into a probability of infection or illness. Inputs with known variability are described by statistical distributions from which many random samples are taken, often using a "Monte Carlo" calculation procedure, to derive a risk profile.[7]

The following four step process is used: (1) identifying the important pathogens ("hazards"); (2) determining human exposures to contaminated water, via ingestion or inhalation; (3) characterizing dose-response, using data available from clinical trials, illness surveillance, and outbreak data; and (4) mathematically characterizing the risks and communicating risks and attendant uncertainties.

For step 1, a suite of sentinel pathogenic microorganisms should be considered for each situation as they are considered to cover the range of illnesses that could arise in the United States, such as the following:

- viruses – norovirus, Hepatitis A virus, caliciviruses, enteroviruses, rotavirus, adenoviruses;
- bacteria – EHEC, *Campylobacter* spp., *Salmonella* spp., *Shigella* spp.; and
- protozoa – *Giardia* cysts, *Cryptosporidium* oocysts.

The setting for each site of interest will dictate which of these pathogens should be used. For example, a recreational site impacted only by animal wastes should not need to include viruses. Adenoviruses will need to be included where aerosols may be inhaled (e.g., by water skiers).

For step 2, information on water ingestion and exposure rates, along with duration of the recreational activity, are combined with the concentration of pathogens in the water to obtain a

[7] EPA's Office of Water has developed a "complete draft" of a Protocol for Microbial Risk Assessment based on the EPA-ILSI (ILSI, 2000) *Revised Framework for Microbial Risk Assessment* (http://www.ilsi.org/file/mrabook.pdf) and which is consistent with the chemical risk assessment paradigm. The Agency has initiated a review to insure it meets risk assessment needs for all water-based media. Contact Stephen Schaub, EPA Office of Water (see Appendix B), for information on the Protocol for Microbial Risk Assessment.

dose—all these variables being described by statistical distributions. Information on the origin, quantity, and fate and transport of wastes deposited on a land surface and into waterways is of prime importance in determining the distributions of pathogens in the water that is subsequently ingested or inhaled.

For step 3, several dose-response analyses have been reported and may be used, albeit with caution. In particular, the form of the "dose" used in a clinical trial needs to be made consistent with the form used to describe the dose ingested or inhaled.[8] Also, uncertainty in the dose-response equation, in the form of credible intervals, can be captured by the calculation process.

In step 4, risk profiles may be derived, in the form of a cumulative distribution function—this will be particularly useful for examining the risks associated with rare but highly significant illness (e.g., EHEC). This also enables uncertainty measures to be calculated. Comparing relative risks for different sites should be done by comparing risk profiles, rather than by comparing single risk "numbers."

1. QMRA provides a range of possible illnesses or risks, allows comparisons across all fecal pathogen sources (see Table 5), and number of illnesses by a modeling approach (**highest priority is to conduct assessments at beaches impacted by different types of non-point sources [see Table 5]**). There was discussion among workgroup members regarding the strengths and limitations of conducting QMRA versus epidemiological studies (see Eisenberg et al., 2006); QMRA:
    a. Is a potential alternative, adjunct, or precursor to epidemiological studies
    b. Can evaluate infection and illness
    c. Could evaluate sentinel (index) pathogens such as:
        i. Bacteria (EHEC, *Campylobacter*, *Salmonella*, *Shigell*a)
        ii. Protozoa (*Giardia*, *Cryptosporidium*)
        iii. Viruses (norovirus, Hepatitis A, caliciviruses, enteroviruses, rotavirus, adenoviruses)
    d. Can consider inhalation as an additional route of exposure if data are available
        iv. Adenoviruses
2. QMRA is a good way to compile information (via literature review and/or site-specific) about pathogen loads in source waters impacted only by animal sources (with an emphasis on freshwater) and to characterize pathogens and indicators.

### 4.4.3 Etiologic Agents

Workgroup members felt it important to emphasize that there is a glaring lack of knowledge about the incidence with which specific pathogens cause swimmer-associated illnesses at both non-point source- and point source-impacted beaches. Identification of such pathogens as the actual cause of illness in swimmers would provide important information for developing new or

[8] For example, a rotavirus clinical trial will report dose as FFU (focus forming units); there may be many virus particles for each FFU.

revised recreational AWQC (or State Water Quality Standards) to enhance the protection of public health. In order to go forward with currently available technologies, the diagnosis of viruses could be made by exclusion of bacterial and protozoan pathogens causes of illness. Additionally, such information would be essential inputs into QMRA models to be used at recreational sites (or types of sites) where epidemiological studies cannot be conducted due to expense or insufficient numbers of swimmers. Because advances in modern techniques in microbiology now make a more complete identification of specific pathogens possible, workgroup members felt that the epidemiological studies currently underway and planned provide a unique opportunity to collect specimens (stool, saliva, and/or blood) from swimmers (and non-swimmers as controls) with which to identify the responsible waterborne pathogens. Such data would be complementary to the data collected in studies of pathogen occurrence in water that are presented elsewhere in this chapter and these proceedings. Workgroup members suggested that both types of pathogen occurrence information (in humans, in water) be collected during future epidemiological studies in order to minimize cost and maximize the utility of the information.

1. Identify etiologic agents of swimming-associated illness.
2. Pilot approaches for identifying etiologic agents in planned and ongoing epidemiological studies.
3. Classify etiologic agents in ill swimmers by broad groupings (i.e., viral, bacterial, protozoan).
4. Develop and evaluate sample collection techniques (stool, salivary antibodies, blood).

All of the above could be done as an adjunct to epidemiological studies.

### 4.4.4 Fate and Transport

Because direct pathogen detection is not feasible on an ongoing basis, a surrogate measure relating water quality conditions to human health risk is required. When developing the appropriate indicator(s) to use in this approach, knowledge of the fate and transport characteristics of the pathogens and indicator(s), both individually and as they relate to each other is critical.

Individually, fate and transport is significant because only those pathogens that are present and viable in a given waterbody pose a potential public health risk. These pathogens are typically divided into the following three major categories: viruses, bacteria, and protozoa. Because the microbiological characteristics of each of these groups are significantly different, it is not unreasonable to assume that their fate and transport characteristics will vary (perhaps significantly) as well.

The most simplistic route of pathogen transport is direct deposition. Once the pathogen(s) (assumed to be carried in the feces of warm blooded mammals) is excreted over or in the water, the question is twofold—how long will the pathogen be viable and available (i.e., persist in the water column).

Indirect deposition of feces introduces a more complex situation. First, the fecal properties of different mammals can vary substantially. One of the primary differences (aside from pathogen and indicator density) is moisture content. That is, very "wet" feces is more likely than "dry" feces to introduce pathogens into the aquatic environment. After defecation, the distance of the feces from surface water plays an important role as well. Driven by precipitation and transported primarily via surface runoff, the pathogens are typically washed into the surface water either by sheet flow or are collected and discharged through a storm water collection system. During this transport, they are subjected to a variety of environmental factors—including, but not limited to, UV disinfection, predation, temperature—that affect the proportion that will ultimately end up in surface water in which people are recreating.

Another category of indirect deposition includes point source discharges, such as POTWs, CSOs, concentrated animal feeding operations (CAFOs), and other NPDES permitees. In addition to the issues identified above, the effect of the treatment processes that these effluents are subjected to plays a role in fate and transport of the pathogens.

Resuspension from sand, soil, or sediment (i.e., secondary environments) can also play an important role in pathogen fate and transport. There may be a reservoir of indicator(s) and/or pathogens that could be reintroduced into the water column. Additionally, regrowth of either the indicator(s) or pathogens could represent a source and/or confound the risk assessment/prediction.

Ideally, the indicator(s) chosen as the surrogate for the pathogens will have the same fate and transport characteristics of the pathogens themselves. However, since this is unlikely, it is important to know and relate the characteristics that are specific to the indicator(s) and the pathogens so that the measurement of the indicator can be correlated to the concentration of the viable pathogens in the water and ultimately to public health risk.

A number of studies have been published on the fate and transport of many waterborne pathogens and current indicator organisms. Therefore, a literature review to identify any data gaps so that additional studies may be designed and also to inform QMRA studies would also be useful.

1. Conduct fate and transport studies for indicators and sentinel (index) pathogens.
2. Conduct literature review to identify data gaps and to inform QMRA.
3. Identify indicators that have the similar fate and transport characteristics as pathogens.
4. Should include assessment of risk of pathogens and indicators being resuspended from sand, soil, and sediments (secondary environments).

### 4.4.5 Determine the Occurrence of Pathogens in Impacted Recreational Waters

The pathogen occurrence and pathogen concentrations in water impaired by animal feces in one or more non-point study site(s) (e.g., beach impacted by [non-CAFO] agricultural animal runoff; Table 5, priority #1) could be compared with pathogen load in planned POTW-impacted marine epidemiological studies. It is also proposed that investigators consider using high-volume, tangential-flow water filtration methods that were recently developed for assessing bioterrorism threats to drinking water. This technology was designed to simultaneously capture very low concentrations of viruses, bacteria, and parasites in 10 to 100 L of water using a single collection apparatus (filter and pump). Although the equipment and pathogen recovery methods were initially designed to work on finished drinking water, there has been additional research to adapt the process for use on raw water supplies. The raw water application of this technology may be sufficiently understood for its employment in current or planned studies within the next 2 to 3 years. If the methods have not yet been adequately evaluated for this purpose, EPA may wish to encourage fast tracking their development for use in recreational water epidemiological and related field studies. Use of the large volume filtration tools might also be helpful to assess risks associated with low probability events that have serious health consequences (e.g., EHEC).

1. Determine the occurrence of pathogens in affected waters using the high volume filtration currently being developed for counter bioterrorism purposes.

### 4.4.6 Bather Studies

Bathers themselves can be a source of both indicator organism and pathogens in recreational waters (Elmir et al., 2007). Workgroup members suggested the following studies to determine the magnitude of this problem and/or the conditions at recreational sites in which this would be a problem.

1. Conduct additional studies on the impact of bathers on levels of indicator organisms and as a source of infectious pathogens for other bathers.
2. Develop better tools for assessing bather density.
3. Incorporate bather density into the study design and analysis of future recreational water epidemiological studies.
4. Conduct additional studies on human shedding in a controlled setting with a focus on young children.
5. Incorporate bather contribution to indicators and pathogens in QMRA studies.

### 4.4.7 Additional Research (Either Short- or Long-term Depending on EPA Priority-setting)

The following research would also enhance many of the ongoing and future efforts described in this chapter and elsewhere in these proceedings.

1. Include epidemiological data in predictive modeling efforts. This would broaden the use of both epidemiologic and modeling data. Many recreational epidemiological studies collect an extensive set of environmental data. Whether this is sufficient to accomplish environmental modeling is unknown. Both modelers and epidemiologists should discuss the feasibility of this effort.
2. Develop a method for accurate exposure assessment among swimmers. Exposure assessment in terms of water contact and quantity of water swallowed or inhaled is an area of potential misclassification in observational epidemiologic studies. The following would improve exposure assessment in epidemiologic studies:

a. Develop individual sampling devices.
b. Develop methods and conduct studies to determine the quantity of water ingested and inhaled in recreational settings. Consider studying secondary recreational contact for potential comparison.

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