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VIRAL AND BACTERIAL CONTAMINATION OF BEACHES

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Introduction

Interest in the contamination of beaches by microbes is driven by concern for human health. The agents of concern are human pathogens, microorganisms capable of causing disease. Most are derived from human feces; therefore disposal of excreta and water-borne sewage are of particular importance in their control. Pathogens derived from animal feces may also be significant in some circumstances. The human population of concern constitutes primarily the recreational users, whether local residents, visitors, or tourists. Recreational use of natural waters (including coastal waters) is common worldwide and the associated tourism may be an important component of local and/or national economy.

Scientific underpinning and insight into public health concern for fecal pollution of beaches developed rapidly from around 1980. Approaches to regulation and control (including monitoring) have yet to respond to the increased body of knowledge, although some insights into potential approaches are available.

This article draws heavily on two recent substantial publications: the World Health Organization *Guidelines for Safe Recreational Water Environment*, released as a 'draft for consultation' in 1998, and *Monitoring Bathing Waters* by Bartram and Rees, published in 2000.

Public Health Basis for Concern

Recreational waters typically contain a mixture of pathogenic (i.e., disease-causing) and nonpathogenic microbes derived from multiple sources. These sources include sewage effluents, non-sewage excreta disposals (such as septic tanks), the recreational user population (through defecation and/or shedding), industrial processes (including food processing, for example), farming activities (especially feed lots and animal husbandry), and wildlife, in addition to the indigenous aquatic microflora. Exposure to pathogens in recreational waters may lead to adverse health effects if a suitable quantity (infectious dose) of a pathogen is ingested and colonizes (infects) a suitable site in the body and leads to disease.

What constitutes an infectious dose varies with the agent (pathogen) concerned, the form in which it is encountered, the conditions (route) of exposure, and host susceptibility and immune status. For some viruses and protozoa, this may be very few viable infectious particles (conceptually one). The infectious dose for bacteria varies widely from few particles (e.g., some *Shigella* spp., the cause of bacillary dysentery) to large numbers (e.g. 10^8 for *Vibrio cholerae*, the cause of cholera). In all cases it is important to recall that microorganisms rarely exist as homogeneous dispersions in water and are often aggregated on particles, where they may be partially protected from environmental stresses and as a result of which the probability of ingestion of an infectious dose is increased.

Transmission of disease through recreational water use is biologically plausible and is supported by a generalized dose–response model and the overall body of evidence. For infectious disease acquired through recreational water use, most attention has been paid to diseases transmitted by the fecal–oral route, in which pathogens are excreted in feces, are ingested by mouth, and establish infection in the alimentary canal.

Other routes of infectious disease transmission may also be significant as a result of exposure though recreational water use. Surface exposure can lead to ear infections and inhalation exposure may result in respiratory infections.

Sewage-polluted waters typically contain a range of pathogens and both individuals and recreational user populations are rarely limited to exposure to a single encounter with a single pathogen. The effects of multiple and simultaneous or consecutive exposure to pathogens remain poorly understood.

Water is not a natural ambient medium for the human body, and use of water (whether contaminated or not) for recreational purposes may compromise the body's natural defenses. The most obvious example of this concerns the eye. Epidemiological studies support the logical inference that recreational water use involving repeated immersion will increase the likelihood of eye infection through compromising natural resistance mechanisms, regardless of the quality of the water.

On the basis of a review of all identified and accessible publications concerning epidemiological studies on health outcomes associated with recreational water exposure, the WHO has recently concluded the following:

- The rate of occurrence of certain symptoms or symptom groups is significantly related to the count of fecal indicator bacteria. An increase in outcome rate with increasing indicator count is reported in most studies.
- Mainly gastrointestinal symptoms (including 'highly credible' or 'objective' gastrointestinal symptoms) are associated with fecal indicator bacteria such as enterococci, fecal streptococci, thermotolerant coliforms and *Escherichia coli.*
- Overall relative risks for gastroenteric symptoms of exposure to relatively clean water lie between 1.0 and 2.5.
- Overall relative risks of swimming in relatively polluted water versus swimming in clean water vary between 0.4 and 3.
- Many studies suggest continuously increasing risk models with thresholds for various indicator organisms and health outcomes. Most of the suggested threshold values are low in comparison with the water qualities often encountered in coastal waters used for recreation.
- The indicator organisms that correlate best with health outcome are enterococci/fecal streptococci for marine and freshwater, and *E. coli* for freshwater. Other indicators showing correlation are fecal coliforms and staphylococci. The latter may correlate with density of bathers and were

Table 1 Criteria for causation in environmental studies (according to Bradford Hill, 1965). Application to bathing water quality and gastrointestinal symptoms

Criterion	*Explanation*	*Fulfillment*
1. Strength of association	Difference in illness rate between exposed and nonexposed groups, measured as a ratio	Yes Significant associations have been found; the ratios are relatively low (usually < 3)
2. Consistency	Has it been observed by different people at different places?	Yes In several countries and by various authors
3. Specificity of association	A particular type of exposure is linked with a particular site of infection or a particular disease	No
4. Temporality	Does the exposure precede the disease rather than following it?	Yes Most studies indicate temporal relationship
5. Biological gradient	A dose–response curve can be detected	Yes Most of the selected studies show significant exposure–response relationships
6. Plausibility	Does the present relationship seem likely in terms of present knowledge?	Yes For example, the results are in line with findings on ingestion of infective doses of pathogens
7. Coherence	Cause-and-effect interpretation of the data should not conflict with knowledge of natural history and biology of the disease	Yes
8. Experiment	Did preventive actions change the disease frequency?	Preventive actions have not yet been described in the studies
9. Analogy	Are similar agents known to cause similar diseases in similar circumstances?	Yes Similar to ingestion of recreational water, gastrointestinal symptoms are known to be caused by fecally polluted drinking water

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reported to be significantly associated with ear, skin, respiratory, and enteric diseases.

In assessing the adequacy of the overall body of evidence for the association of bathing water quality and gastrointestinal symptoms, WHO referred to Bradford Hill's criteria for causation in environmental studies (**Table 1**). Seven of the nine criteria were fulfilled. The criterion on specificity of association was considered inapplicable because the etiological agents were suspected to be numerous and relatively outcome-nonspecific. Results of experiments on the impact of preventive actions on health outcome frequency have not been reported. This degree of fulfillment suggests that the association is causal.

Because of the study areas used, especially for the available randomized controlled trials, the results are primarily indicated for adult populations in temperate climates. Greater susceptibility among younger age groups has been shown and the overall roles of endemicity and immunity in relation to exposure and response are inadequately understood.

The overall conclusions of the work of WHO concerning fecal contamination of recreational waters and the different potential adverse health outcomes among user groups were as follows:

- The overall body of evidence suggests a casual relationship between increasing exposure to fecal contamination and frequency of gastroenteritis. Limited information concerning the dose–response relationships narrows the ability to apply cost–benefit approaches to control. Misclassification of exposure is likely to produce artificially low threshold values in observational studies. The one randomized trial indicated a higher threshold of 33 fecal streptococci per 100 ml for gastrointestinal symptoms.
- A cause–effect relationship between fecal pollution or bather-derived pollution and acute febrile respiratory illness is biologically plausible since associations have been reported and a significant exposure–response relationship with a threshold of 59 fecal streptococci per 100 ml was reported.
- Associations between ear infections and microbiological indicators of fecal pollution and bather load have been reported. A significant dose–response effect has been reported in one study. A cause–effect relationship between fecal or bather derived pollution and ear infection is biologically plausible.
- Increased rates of eye symptoms have been reported among bathers and evidence suggests that bathing, regardless of water quality, compromises the eye's immune defenses. Despite biological plausibility, no credible evidence is available for increased rates of eye ailments associated with water pollution.
- No credible evidence is available for an association of skin disease with either water exposure or microbiological water quality.
- Most investigations have either not addressed severe health outcomes such as hepatitis, enteric fever, or poliomyelitis or have not been undertaken in areas of low or zero endemicity. By inference, transmission of enteric hepatitis viruses and of poliomyelitis – should exposure of susceptible persons occur – is biologically plausible, and one study reported enteric fever (typhoid) causation.

The WHO work of 1998 led to the derivation of draft guideline values as summarized in **Table 2**.

Sources and Control

The principal sources of fecal pollution are sewage (and industrial) discharges, combined sewer overflows, urban runoff, and agriculture. These may lead to pollution remote from their source or point of discharge because of transport in rivers or through currents in coastal areas or lakes. The public health significance of any of these sources may be modified by a number of factors, some of which provide management opportunities for controlling human health risk.

With regard to public health, most attention has, logically, been paid to sewage as the source of fecal pollution. Pollution abatement measures for sewage may be grouped into three disposal alternatives, although there is some variation within and overlap between these: treatment, dispersion through sea outfalls, and discharge not to surface water bodies (e.g., to agriculture or ground water injection).

Where significant attention has been paid to sewage management, it has often been found that other sources of fecal contamination are also significant. Most important among these are combined sewer overflows (and 'sanitary sewer' overflows) and riverine discharges to coastal areas and lakes. Combined sewer overflows (CSOs) generally operate as a result of rainfall. Their effect is rapid and discharge may be directly to areas used for recreation. Riverine discharge may derive from agriculture, from upstream sewage discharges (treated or otherwise), and from upstream CSOs. The effect may be continuous (e.g., from upstream sewage treatment) or rainfall-related (agricultural runoff, urban runoff, CSOs). Where it is rainfall-related, the effect on downstream recreational water use areas may

Table 2 Draft guideline values for microbiological quality of marine recreational waters (fecal streptococci per 100 ml)

95th centile value of fecal streptococci per 100 ml	*Basis of derivation*	*Estimated disease burden*
10	This value is below the no-observed-adverse-effect level (NOAEL) in most epidemiological studies that have attempted to define a NOAEL	Using the indicator level/burden of disease relationship it corresponds to the 95th centile value that is associated with less than a single excess incidence of enteric symptoms for a family of four healthy adult bathers having 80 exposures per bathing season (rounded value), over a 5-year period, making a total of 400 exposures
50	This value is above the threshold and lowest-observed-adverse-effect level (LOAEL) for gastroenteritis in most epidemiological studies that have attempted to define a LOAEL	Using the indicator level/burden of disease relationship it corresponds to the 95th centile value that is associated with a single excess incidence of enteric symptoms for a family of four healthy adult bathers having 80 exposures per bathing season (rounded value)
200	This value is above the threshold and lowest-observed-adverse-effect level for all adverse health outcomes in most epidemiological studies	Using the indicator level/burden of disease relationship it corresponds to the 95th centile value that is associated with a single excess incidence of enteric symptoms for a healthy adult bather having 20 exposures per bathing season (rounded value)
1000	Derived from limited evidence regarding transmission of typhoid fever in areas of low-level typhoid endemicity and of paratyphoid. These are used in this context as indicators of severe health outcome	The exceedence of this level should be considered a public health risk leading to immediate investigation by the competent authorities. Such an interpretation should generally be supported by evidence of human fecal contamination (e.g., a sewage outfall)

Notes
1. This table would produce protection of 'healthy adult bathers' exposed to marine waters in temperate north European waters.
2. It does not relate to children, the elderly, or the immunocompromised who would have lower immunity and might require a greater degree of protection. There are no available data with which to quantify this and no correction factors are therefore applied.
3. Epidemiological data on fresh waters or exposure other than bathing (e.g., high exposures activities such as surfing or whitewater canoeing) are currently inadequate to present a parallel analysis for defined reference risks. Thus a single guideline value is proposed, at this time, for all recreational uses of water because insufficient evidence exists at present to do otherwise. However, it is recommended that the severity and frequency of exposure encountered by special-interest groups (such as body-, board-, and wind-surfers, subaqua divers, canoeists, and dinghy sailors) be taken into account.
4. Where disinfection is used to reduce the density of indicator bacteria in effluents and discharges, the presumed relationship between fecal streptococci (as indicators of fecal contamination) and pathogen presence may be altered. This alteration is, at present, poorly understood. In water receiving such effluents and discharges, fecal streptococci counts may not provide an accurate estimate of the risk of suffering from mild gastrointestinal symptoms.
5. The values calculated here assume that the probability on each exposure is additive.

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persist for several days. In river systems the decrease in microbiological concentrations downstream of a source (conventionally termed 'die-off') largely reflects sedimentation. After settlement in riverbed sediments, survival times are significantly increased and re-suspension will occur when river flow increases. Because of this and the increased inputs from sources such as CSOs and urban and agricultural runoff during rainfall events, rivers may demonstrate a close correlation between flow and bacterial indicator concentration.

The efficiency of removal of major groups of microorganisms of concern in various types of treatment processes is described in **Table 3**.

Advanced sewage treatment (for instance based upon ultrafiltration or nanofiltration) can also be effective in removal of viruses and other pathogens. The role and efficiency of ultraviolet light, ozone, and other disinfectants are being critically re-evaluated. Treatment in oxidation ponds may remove significant numbers of pathogens, especially the larger protozoan cysts and helminth ova. However, short-circuiting due to poor design, thermal gradients, or hydraulic overload may reduce residence time from the typical design range of 30–90 days. During detention in oxidation ponds, pathogens are removed or inactivated by sedimentation, sunlight, temperature, predation, and time.

Table 3 Pathogen removal during sewage treatment

Treatment	*Enterococci* (cfu l^{-1})[a]	*Enteric viruses*	*Salmonella*	*C. perfringens*[b]
Raw sewage (l^{-1})	2 800 000	100 000–1 000 000	5000–80 000	100 000
Primary treatment[c]				
Percentage removal	32	50–98.3	95.5–99.8	30
Number remaining (l^{-1})	1 900 000	1700–500 000	10–3600	70 000
Secondary treatment[d]				
Percentage removal	96	53–99.92	98.65–99.996	98
Number remaining (l^{-1})	110 000	80–470 000	< 1–1080	2000
Tertiary treatment[e]				
Percentage removal	99.6	99.983–99.999 9998	99.99–99.999 995	99.9
Numbers remaining (l^{-1})	11 000	< 1–170	< 1–8	100

[a]Miescier JJ and Cabelli VJ (1982) Enterococci and other microbial indicators in municipal wastewater effluents, *Journal of Water Pollution Control Federation* 54: 1599–1606.
[b]Long and Ashbolt (1994) *Microbiological Quality of Sewage Treatment Plant Effluents*, AWT-Science and Environmental Report No. 94/123, Water Board, Sydney.
[c]Secondary = primary sedimentation, trickling filter/activated sludge and disinfection.
[d]Tertiary = primary sedimentation, trickling filter/activated sludge, disinfection, coagulation–sand filtration, and disinfection; note that tertiary does not involve coagulation–sand filtration and second disinfection steps for *C. perfringens*.
[e]Primary = physical sedimentation.
Adapted from Yates and Gerba (1998) *Microbial Considerations in Wastewater Reclamation and Reuse*. Vol. 10, Water Quality Management Library, Technomic Publishing Co., Inc. Lancaster, PA, pp. 437–488.

Disposal of sewage through properly designed long-sea outfalls provides a high degree of protection for human health, minimizing the risk that bathers will come into contact with sewage. In addition, long-sea outfalls reduce demand on land area in comparison with treatment systems, but they may be considered to have unacceptable environmental impacts (for instance, nutrient discharge into areas where dilution or flushing is limited). They tend to have high capital costs, although these are comparable to those of land-based treatment systems depending on the degree of treatment, whereas recurrent costs are relatively much lower. Ludwig (1988) has presented a comparison of costs and ecological impacts of long-sea outfalls versus treatment levels. Diffuser length, depth, and orientation, as well as the area and spacing of ports are key design considerations. Pathogens are diluted and dispersed and suffer die-off in the marine environment. These are major considerations in length of outfall and outfall locations. Pretreatment by screening removes large particulates and 'floatables'. Grease and oil removal are also often undertaken.

Re-use of wastewater and groundwater recharge are two methods of sewage disposal that have minimal impact upon recreational waters. Especially in arid areas, sewage can be a safe and important resource (of water and nutrients) used for agricultural purposes such as crop irrigation. Direct injection or infiltration of sewage for ground water recharge generally presents very low risk for human health through recreational water use.

Control of human health hazards associated with recreational use of the water environment may be achieved through control of the hazard itself (that is, pollution control) or through control of exposure. Fecal pollution of recreational waters may be subject to substantial variability whether temporally (e.g., time-limited changes in response to rainfall) or spatially (e.g., because, as a result of the effects of discharge and currents, one part of a beach may be highly contaminated while another part is of good quality). This temporal and spatial variability provides opportunities to reduce human exposure while pollution control is planned or implemented or in areas where pollution control cannot or will not be implemented for reasons such as cost. The measures used may include public education, control/limitation of access, or posting of advisory notices; they are often relatively affordable and can be implemented relatively rapidly.

Monitoring, Assessment and Regulation

Present regulatory schemes for the microbiological quality of recreational water are primarily or exclusively based upon percentage compliance with fecal indicator counts (**Table 4**).

These regulations and standards have had some success in driving cleanup, increasing public awareness, and contributing to improved personal choice. Notwithstanding these successes, a number

Table 4 Microbiological quality of water guidelines/standards per 100 ml

Country	*Primary contact recreation*			*References*
	TC[a]	*FC*[b]	*Other*	
Brazil	80% < 5000[c]	80% < 1000[c]		Brazil, Ministerio del Interior (1976)
Colombia	1000	200		Colombia, Ministerio de Salud (1979)
Cuba	1000[d]	200[d] 90% < 400		Cuba, Ministerio de Salud (1986)
EEC[e], Europe	80% < 500[f] 95% < 10 000[g]	80% < 100[f] 95% < 2000[g]	Fecal streptococci 100[f] Salmonella 0 l^{-1}[g] Enteroviruses 0 pfu l^{-1} Enterococci 90% < 100	EEC (1976) CEPPOL (1991)
Ecuador	1000	200		Ecuador, Ministerio de Salud Publica (1987)
France	< 2000	< 500	Fecal streptococci < 100	WHO (1977)
Israel	80% < 1000[h]			Argentina, INCYTH (1984)
Japan	1000			Japan, Environmental Agency (1981)
Mexico	80% < 1000[j] 100% < 10 000[k]			Mexico, SEDUE (1983)
Peru	80% < 5000[j]	80% < 1000[j]		Peru, Ministerio de Salud (1983)
Poland			*E. coli* < 1000	WHO (1975)
Puerto Rico		200[l] 80% < 400		Puerto Rico, JCA (1983)
California	80% < 1000[m,n] 100% < 10 000[k]	200[d,n] 90% < 400[o]		California State Water Resources Board (no date)
United States, USEPA			Enterococci 35[d] (marine), 33[d] (fresh) *E. coli* 126[d] (fresh)	USEPA (1986)
Former USSR			*E. coli* < 100	WHO (1977)
UNEP/WHO		50% < 100[p] 90% < 1000[p]		WHO/UNEP (1978)
Uruguay		< 500[f] < 1000[q]		Uruguay, DINAMA (1998)
Venezuela	90% < 1000 100% < 5000	90% < 200 100% < 400		Venezuela (1978)
Yugoslavia	2000			Argentina, INCYTH (1984)

[a]Total coliforms.
[b]Fecal or thermotolerant coliforms.
[c]'Satisfactory' waters, samples obtained in each of the preceding 5 weeks.
[d]Logarithmic average for a period of 30 days of at least five samples.
[e]Minimum sampling frequency – fortnightly.
[f]Guide.
[g]Mandatory.
[h]Minimum 10 samples per month.
[i]Monthly average.
[j]At least 5 samples per month.
[k]Not a sample taken during the verification period of 48 hours should exceed 10 000/100 ml.
[l]At least 5 samples taken sequentially from the waters in a given instance.
[m]Period of 30 days.
[n]Within a zone bounded by the shoreline and a distance of 1000 feet from the shoreline or the 30-foot depth contour, whichever is further from the shoreline.
[o]Period of 60 days.
[p]Geometric mean of at least 5 samples.
[q]Not to be exceeded in at least 5 samples.

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Salas H (1998) History and application of microbiological water quality standards in the marine environment. Pan-American Center for Sanitary Engineering and Environmental Sciences (CEPIS)/Pan-American Health Organization, Lima, Peru.

of constraints are evident in established approaches to regulation and standard setting:

- Management actions are retrospective and can only be deployed after human exposure to the hazard.
- The risk to human health is primarily from human feces, the traditional indicators of which may also derive from other sources.
- There is poor interlaboratory and international comparability of microbiological analytical data.
- While beaches are classified as 'safe' or 'unsafe', there is a gradient of increasing frequency and variety of adverse health effects with increasing fecal pollution and it is desirable to promote incremental improvements by prioritizing 'worst failures'.

The present form of regulation also tends to focus attention upon sewage, treatment, and outfall management as the principal or only effective solutions. Owing to high costs of these measures, local authorities may be effectively disenfranchised and few options for effective local intervention in securing bather safety appear to be available.

A modified approach to regulation of recreational water quality could provide for improved protection of public health, possibly with reduced monitoring effort and greater scope for interventions, especially within the scope for local authority intervention. This was discussed in detail at an international meeting of experts in 1998 leading to the development of the 'Annapolis Protocol'.

The 'Annapolis Protocol' requires field-testing and improvement based upon the experience gained before application. Its application leads to a classification scheme through which a beach may be assigned to a class related to health risk. By enabling local management to respond to sporadic or limited areas of pollution (and thereby to upgrade the classification of a beach), it provides significant incentive for local management action as well as for pollution abatement. The protocol recognizes that a large number of factors can influence the safety of a given beach. In order to better reflect risk to public health, the classification scheme takes account of three aspects:

1. Counts of fecal indicator bacteria in samples collected from the water adjoining the beach.
2. An inspection-based assessment of the susceptibility of the area to direct influence from human fecal contamination.
3. Assessment of the effectiveness of management interventions if they are deployed to reduce human exposure at times or in places of increased risk.

The process of beach classification is undertaken in two phases:

1. Initial classification based upon the combination of inspection-based assessment and the results of microbiological monitoring.
2. Taking account of the management interventions.

Inspection-based assessment takes account of the three most important sources of human fecal contamination for public health: sewage (including CSO and storm water discharges); riverine

Table 5 Risk potential to human health through exposure to sewage

Treatment	*Discharge type*		
	Directly on beach	*Short outfall*[a]	*Effective outfall*[b]
None[c]	Very high	High	NA
Preliminary	Very high	High	Low
Primary (including septic tanks)	Very high	High	Low
Secondary	High	High	Low
Secondary plus disinfection	Medium	Medium	Very Low
Tertiary	Medium	Medium	Very Low
Tertiary plus disinfection	Very Low	Very Low	Very Low
Lagoons	High	High	Low

[a]The relative risk is modified by population size. Relative risk is increased for discharges from large populations and decreased for discharges from small populations.
[b]This assumes that the design capacity has not been exceeded and that climatic and oceanic extreme conditions are considered in the design objective (i.e., no sewage on the beach zone).
[c]Includes combined sewer overflows.
NA, not applicable.
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Table 6 Risk potential to human health through exposure to sewage through riverine flow and discharge

Dilution effect[a,b]	*Treatment level*				
	None	*Primary*	*Secondary*	*Secondary plus disinfection*	*Lagoon*
High population with low river flow	Very high	Very high	High	Low	Medium
Low population with low river flow	Very high	High	Medium	Very low	Medium
Medium population with medium river flow	High	Medium	Low	Very low	Low
High population with high river flow	High	Medium	Low	Very low	Low
Low population with high river flow	High	Medium	Very low	Very low	Very low

[a]The population factor includes all the population upstream from the beach to be classified and assumes no instream reduction in hazard factor used to classify the beach.
[b]Stream flow is the 10% flow during the period of active beach use. Stream flow assumes no dispersion plug flow conditions to the beach.
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discharges where the river is receiving water from sewage discharges and is used either directly for recreation or discharges near a coastal or lake area used for recreation; and bather-derived contamination. The result of assessment is an estimate of relative risk potential in bands as outlined in **Tables 5, 6** and 7.

Use of microbial and nonmicrobial indicators of fecal pollution requires an understanding of their characteristics and properties and their applicability for different purposes. Some very basic indicators such as sanitary plastics and grease in marine environments may be used for some purposes under some circumstances. Some newer indicators are under extensive study, but conventional fecal indicator bacteria remain those of greatest importance. Indicators of fecal contamination and their principal uses are summarized in **Table 8**.

By combining the results of microbiological testing with those of inspection, it is possible to derive a primary beach classification using a simple lookup table of the type outlined in **Table 9**. This primary classification may be modified to take account of management interventions that reduce or prevent exposure at times when or in areas where pollution is unusually high. Such 'reclassification' requires a database adequate to describe the times or locations of elevated contamination and demonstration that management action is effective. Since this 'reclassification' may have significant economic importance, independent audit and verification may be appropriate.

Table 7 Risk potential to human health through exposure to sewage from bathers

Bather shedding	*Category*
High bather density, high dilution[a]	Low
Low bather density, high dilution	Very low
High bather density, low dilution[a,b]	Medium
Low bather density, low dilution[b]	Low

[a]Move to next higher category if no sanitary facilities are available at beach site.
[b]If no water movement.
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Implementation of a monitoring and assessment scheme of the type envisaged in the Annapolis Protocol would be likely to have a significant impact upon the nature and cost of monitoring activities. In comparison with established practice, it would typically involve a greater emphasis on inspection and relatively less on sampling and analysis than is presently commonplace. At the level of an administrative area with a number of diverse beaches, it would imply an increased short-term monitoring effort when beginning monitoring, but a decreased overall workload in the medium to longterm.

Recreational use of the water environment provides benefits as well as potential dangers for human health and well-being. It may also create economic benefits but can add to competing local demands upon a finite and sometimes already over-exploited local environment. Regulation, monitoring, and assessment of areas of coastal recreational water use should be seen or undertaken not in isolation but within this broader context. Integrated approaches to management that take account of overlapping, competing, and sometimes incompatible uses of the coastal environment have been increasingly developed and applied in recent years. Extensive guidance concerning integrated coastal management is now available. However, recreational use of coastal areas is also significantly affected by river discharge and therefore upstream discharge and land use practice. While the need to integrate management around the water cycle is recognized, no substantial experience has yet accrued and tools for its implementation remain unavailable.

Table 8 Possible sewage contamination indicators and their functions

Indicator/use	*Function*	
	Pros	*Cons*
Fecal streptococci/ enterococci	Marine and potentially freshwater human health indicator More persistent in water and sediments than coliforms Fecal streptococci may be cheaper than enterococci to assay	May not be valid for tropical waters, due to potential growth in soils
Thermotolerant coliforms	Indicator of recent fecal contamination	Possibly not suitable for tropical waters owing to growth in soils and waters Confounded by non-sewage sources (e.g., *Klebsiella* spp. in pulp and paper wastewaters)
E. coli	Potentially a freshwater human health indicator. Indicator of recent fecal contamination. Potential for typing *E. coli* to aid identifying sources of fecal contamination. Rapid identification possible if defined as β-glucuronidase-producing bacteria	Possibly not suitable for tropical waters owing to growth in soils and waters
Sanitary plastics	Immediate assessment can be made for each bathing day Can be categorized Little training of staff required	May reflect old sewage contamination and be of little health significance Subjective and prone to variable description
Rainfall in preceding 12, 24, 48 or 72 h	Simple regressions may account for 30–60% of the variation in microbial indicators for a particular beach	Each beach catchment may need to have its rainfall response assessed Response may depend on the period before the event
Sulfite-reducing clostridia/*Clostridium perfringens*	Always in sewage impacted waters Possibly correlated with enteric viruses and parasitic protozoa Inexpensive assay with H_2S production	May also come from dog feces May be too conservative an indicator Enumeration requires anaerobic culture
Somatic coliphages	Standard method well established Similar physical behavior to human enteric viruses	Not specific to sewage May not be as persistent as human enteric viruses Host may grow in the environment
F-specific RNA phages	Standard ISO method available More persistent than some coliphages Host does not grow in environmental waters below 30°C	Not specific to sewage WG49 host may lose plasmid (although F-amp is more stable) Not as persistent in marine waters
Bacteroides fragilis phages	Appear to be specific to sewage ISO method recently published More resistant than other phages in the environment and similar to hardy human enteric viruses	Requires anaerobic culture Numbers in sewage are lower than other phages, and many humans do not excrete this phage (hence no value for small populations)
Fecals sterols	Coprostanol largely specific to sewage Coprostanol degradation in water similar to die-off of thermotolerant coliforms Ratio of $5\beta/5\alpha$ stanols >0.5 is indicative of fecal contamination; i.e., coprostanol/5α-cholestanol >0.5 indicates human fecal contamination; while C_{29} 5β (24-ethylcoprostanol)/5α stanol ratio >0.5 indicates herbivore feces Ratio of coprostanol/24-ethylcoprostanol can be used to indicate the proportion of human fecal contamination, which can be further supported by ratios with fecal indicator bacteria	Requires gas-chromatographic analysis and is expensive (about $100/sample) Requires up to 10 litres of sample to be filtered through a glass fiber filter (Whatman) to concentrate particulate stanols

Table 8 *Continued*

Indicator/use	*Function*	
	Pros	*Cons*
Caffeine	May be specific to sewage, but unproven to date Could be developed into a dipstick assay	Yet to be proven as a reliable method
Detergents (calcufluors)	Relatively routine methods available	May not be related to sewage (e.g., industrial pollution)
Turbidity	Simple, direct, and inexpensive assay available in the field	May not be related to sewage; correlation must be shown for each site type
Cryptosporidium (animal source pathogens)	Required for potential zoonoses, such as *Cryptosporidium* spp., where fecal indicator bacteria may have died out, or are not present	Expensive and specialized assay (e.g., Method 1622, USEPA) Human/animal speciation of serotypes not currently defined

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Table 9 Primary classification matrix

Sanitary inspection category (susceptibility to fecal influence)	*Microbiological assessment category* (indicator counts)				
	A	*B*	*C*	*D*	*E*
Very low	Excellent	Excellent	Good	Good (+)	Fair (+)
Low	Excellent	Good	Good	Fair	Fair (+)
Moderate	Good[a]	Good	Fair	Fair	Poor
High	Good[a]	Fair[a]	Fair	Poor	Very poor
Very high	Fair[a]	Fair[a]	Poor[a]	Very poor	Very poor

[a]Unexpected result requiring verification.
(+) implies non-sewage sources of fecal indicators (e.g., livestock) and this should be verified.
Reproduced with permission from Bartram and Rees (2000).

See also

Pollution Control. Sandy Beaches, Biology of.

Further Reading

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VOLCANIC HELIUM

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Introduction

Volcanic activity along the global mid-ocean ridge system and at active seamounts introduces a helium-rich signal into the ocean basins that can be