Article 31

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Microbes in Urban Watersheds: Implications for Watershed Managers

When it comes to bacteria, most watershed managers have more questions than answers. Can a beach, shellfish or drinking water use really be maintained in the face of watershed growth? Can water contact recreation uses ever be supported in an urban watershed, and under what flow conditions? What expectations are reasonable for future water uses? What kind of detective work is needed to discover existing bacteria sources? Which bacteria sources are the best targets for management? What watershed practices are most effective in preventing or treating new sources? Eliminating or treating existing sources? What kind of bacteria monitoring is needed to safeguard public health?

Some of the answers to these difficult questions depend on many complex watershed factors, such as the density of development, method of sewage disposal, bacteria sources, actual water uses and weather conditions. Given that watershed managers are increasingly asked to control microbes, this article seeks to present a more coherent framework for how bacteria can be managed in urban watersheds. It begins by describing a conceptual model for managing bacteria in urban watersheds, and then applies the general model to four specific watershed types. The implications for bacteria management in each watershed type are reviewed in detail, with a strong emphasis on the prevention and treatment of new bacteria sources. The last section presents a six-step process to detect existing urban bacteria sources, as well as a review of practices that can eliminate or treat these sources.

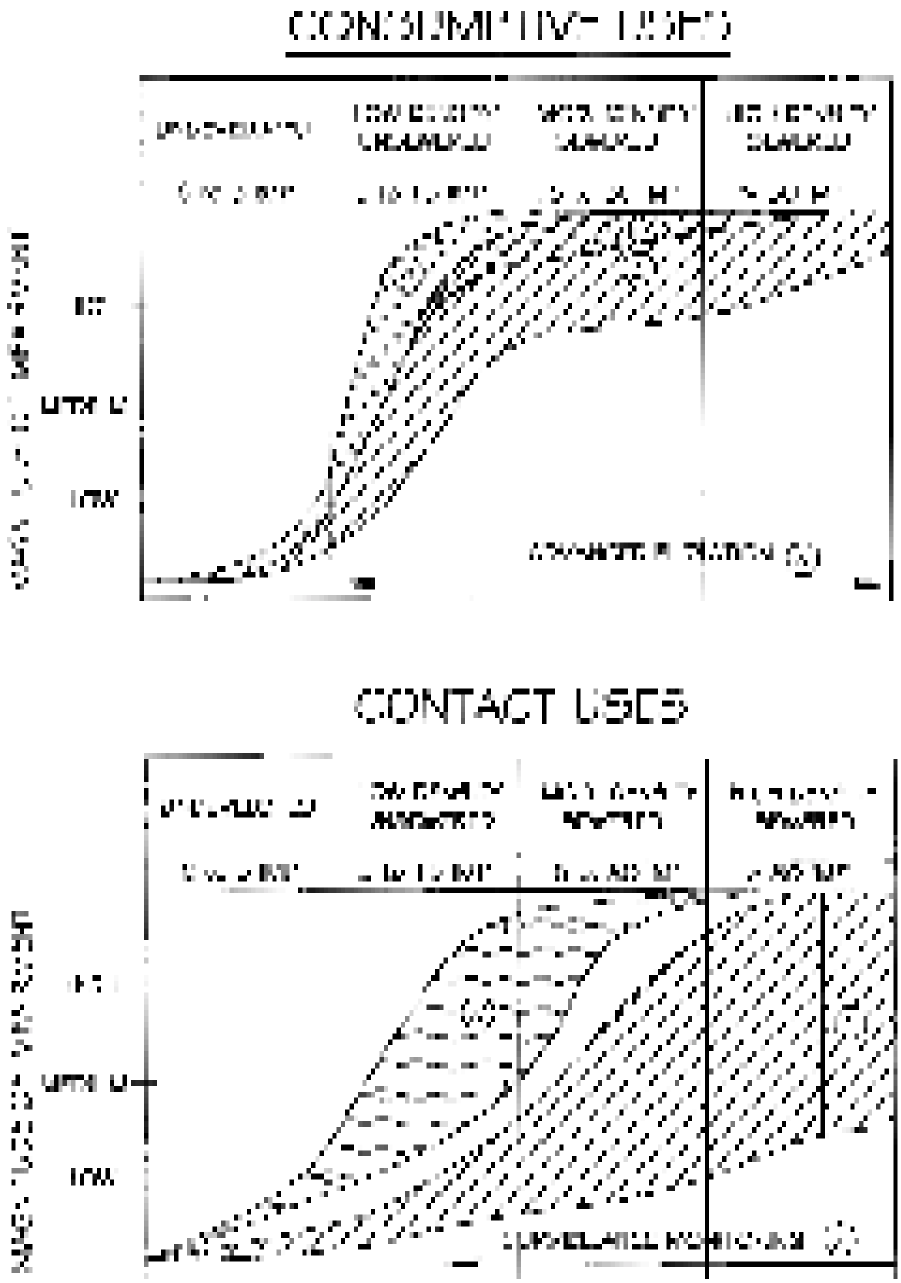
The Bacteria Management Model

Not much is out there to guide watershed managers on how to manage bacteria. To begin to fill this gap, we have developed general bacteria management "model." It is a simple framework that organizes what we know (or think we know) about managing bacteria in different kinds of urban watersheds. The model is a still work in progress, and many of its details need to be confirmed by more research data. It is best regarded as an initial hypothesis rather than a predictive model at this point. Still, it represents a starting point to guide debate on what we can expect to achieve in managing bacteria in urban watersheds (Figure 1).

The bacteria management model distinguishes two broad kinds of human uses: *consumption* as in drinking water and shellfish harvesting, and *contact* such as swimming and other forms of water contact recreation. The model also evaluates use impairments in four kinds of watersheds, based on their density and primary wastewater disposal technique. The watersheds include the following:

- *Very low density watersheds*. These watersheds are essentially undeveloped or rural in character and have less than 5% impervious cover. Septic systems are used for wastewater disposal, but occur at a relatively low density. As a result, livestock and wildlife constitute the primary bacteria sources.
- *Low density watersheds*. While portions of these watersheds remain undeveloped or in rural uses, they are primarily zoned for large lot residential development, which are serviced by individual septic systems. Lot sizes can range from one to five acres. Impervious cover typically ranges from five to 15%, and the density of septic systems frequently exceeds 100 per square mile. Septic systems and stormwater runoff are key sources.
- *Moderate density watersheds*. The land use in these watersheds is primarily suburban in nature. Residential and commercial developments are serviced by sanitary sewers. Impervious cover ranges from 15 to 30%. Stormwater runoff, pets and sanitary sewer overflows are key sources.
- *High density watersheds*. These watersheds are highly urban in character, and wastewater is disposed by a sewer system. Depending on its age and condition, the sanitary sewer system may be a bacteria source, either from combined sewer overflows, sanitary sewer overflows, illicit sewage flows or some combination thereof. Impervious cover in these highly urban watersheds exceeds 30%.

The model projects the frequency of use impairments under dry weather and wet weather flow conditions for each of the four kinds of watersheds, as defined by an exceedance of fecal coliform standards. The impairment curve is expressed as a band, to reflect the variability in watershed sources and the use of management practices which reduce bacteria.



*The bacteria management model "predicts" the degree of use impairment for four kinds of urban watersheds for consumptive uses such as drinking water and shellfish harvesting (**top panel**). Frequent impairment is projected during both wet and dry weather conditions. The wet weather impairment curve (**a**) climbs steeply and is relatively narrow. The dry weather curve (**b**) also climbs steeply, but is much broader, indicating the potential impact of watershed management. Given the high probability of impairment, advanced filtration is recommended to treat drinking water in all but the most lightly developed urban watersheds (**c**).*

*Less impairment is projected for recreational contact uses (bottom panel), with greater impairment noted during wet weather conditions (**d**) than dry weather conditions (**e**). The dry weather impairment curve (e) is very wide, suggesting that watershed management measures can have a strong impact on uses. As the density of development increases, however, communities must institute more intensive surveillance monitoring to protect public health (**f**).*

Figure 1: Conceptual Model for Bacteria Management in Urban Watersheds

In general, the model suggests that very few *consumptive uses* of water can be maintained during wet-weather conditions. The narrow width of the wet weather curve indicates that even when watershed practices are widely implemented (e.g., stormwater treatment, buffers and source controls), frequent impairment of uses can still be expected. While consumptive uses can also be impaired during dry weather, the impairment curve is much wider. The width of the dry weather curve reflects how aggressively human sewage sources are inspected, detected and corrected within a given subwatershed (e.g., septic systems, illicit connections, SSOs and CSOs). The low range of the curve indicates systematic efforts to detect and correct sewage discharges, whereas the high range indicates little or no watershed effort.

The model also indicates that advanced filtration and disinfection are needed to maintain the purity of drinking water in nearly all urban watersheds. Watershed practices are useful in enhancing the effectiveness and reliability of drinking water treatment processes, but cannot, by themselves, protect a water supply in the absence of filtration.

The second panel portrays the impairment curves for *water contact recreation*, such as swimming, wading and boating. Once again, the wet weather impairment curve is very steep, with frequent impairment occurring in moderate and high density watersheds. In this case, the wet weather impairment curve is somewhat wider, suggesting that aggressive implementation of watershed practices can prevent impairment in low density watersheds (e.g., stormwater treatment, buffers, and source controls). The width of the dry weather impairment curve is expected to be much broader, which again suggests aggressive efforts to detect, inspect and correct human sewage discharges within a watershed (e.g., septic systems, illicit connections, SSOs or CSOs) could sharply reduce impairment during dry weather.

From the standpoint of water contact recreation, the model suggests that aggressive efforts to implement watershed practices and eliminate sewage sources can sharply reduce the frequency of bacteria impairments for many kinds of urban watersheds. As watersheds become more urban, however, communities are advised to monitor their waters more frequently, and institute a better notification system to ensure that the public is aware when water uses such as swimming are permitted or prohibited. If routine monitoring is not possible, communities should consider automatic closure of urban waters for water contact recreation during storms and for several days thereafter.

Applying the Model to Real Watersheds

Several bacteria management strategies make sense under all urban watershed conditions. These include the following:

- *Target human sources of pathogens first*. Pathogens from untreated sewage are potentially more dangerous and more controllable than bacteria generated from nonhuman sources delivered in urban stormwater runoff.
- *Attack dry weather bacteria problems next*. The bacteria management model clearly indicates that the greatest range in impairment frequency occurs during dry weather, so that attacking these sources should yield the greatest watershed management benefit. Recreational uses are also more prevalent during dry weather.
- *Adapt bacteria management strategies for unique watershed conditions*. Every watershed has a unique combination of density, impervious cover, sewage disposal methods, bacteria sources and water use, and therefore a single approach to managing bacteria is likely to fail. Four approaches for managing bacteria, based on the four types of watersheds are presented later in this article.
- *Progress from the watershed to the subwatershed to the source*. Watershed managers need to perform watershed detective work to discover existing bacteria sources—to find out exactly where, when and how bacteria are getting into surface waters. A simplified six-step watershed screening process is provided later in this article to help managers track down individual and controllable bacteria sources.
- *Correct existing bacteria sources first*. Existing bacteria sources that are so hard to detect should be the highest priority for correction, particularly since regulatory tools exist to eliminate or treat these sources.
- *Prevent or treat future bacteria sources*. New development creates the potential for new bacteria sources, in the form of stormwater runoff, discharge from failing septic systems or sewers. A key goal in every watershed management plan should be to keep bacteria discharges from new sources as close to zero as current technology and maintenance allows. Guidance on preventing or treating future bacteria sources are provided in Table 1, and is described in greater detail for each of the four watershed types in the next section.

Managing Bacteria in Very Low Density Watersheds

As noted earlier, very low density watersheds are essentially rural watersheds with 5% impervious cover or less. Septic systems are used for wastewater disposal, but because of their very low density, there are very few of them in the watershed. Livestock can be a significant bacteria source if dairies or confined animal feeding operations (CAFOs) are present and are not

Table 1: Practices to Prevent or Treat Future Bacteria Sources

Low density watershed	Moderate to high density watershed
Land use management	New sewer testing
Septic system feasibility criteria	Inspection of new sewer hookups
Septic system technology criteria	SSO monitoring and prevention
Septic system reserve field requirements	Stormwater treatment for new development
Septic system setback requirements	Optimal stormwater outfall location
Minimum lot size for septic system	Engineered stream buffers
Local septage maintenance authority	Pet exclusion
Stream buffers and access restrictions	Waterfowl control/management
Livestock fencing	Public education on pet waste
Wildlife control	Transient sewage disposal
Land application criteria for biosolids	
Stormwater treatment for new development	
Public education	
Recreational sewage pump out facilities	

managed properly. Wildlife can also contribute to background levels of bacteria.

- *Use attainment*. Generally speaking, very lightly developed watersheds can meet most consumption and contact uses most of the time. Occasional standard violations can be expected due to wildlife or livestock sources. Disinfection is needed for drinking water supplies, but it may be possible to avoid advanced filtration if animal production does not occur in the watershed.

- *Preventing future bacteria sources*. Restrictions on land development are a time-honored bacteria prevention strategy. Water utilities have long recognized that land use control is one of the most effective strategies to protect surface drinking water supplies, particularly if they are unfiltered. Numerous water utilities have acquired extensive lands within a contributing watershed and manage them in a forest condition, to reduce the potential for future human bacteria sources due to watershed development. Significant portions of contributing watershed land has been acquired to protect unfiltered water supplies for Boston, New York, Seattle and Portland.

Land acquisition was rated the most effective and reliable tool to protect the quality of surface drinking water supplies, according to a detailed national survey of water utilities and drinking water regulators (Gibbons *et al*., 1991). Nearly a quarter of all water utility companies acquire watershed land as a prevention strategy. The survey respondents ranked land acquisition as the most effective of twenty watershed management tools for protecting waters supplies.

Other highly rated watershed management tools were watershed entry restrictions, prohibition of certain types of development, and restrictions on impervious cover. It is interesting to note that the survey respondents were not very confident about urban stormwater practices as a watershed management tool, ranking them as the 15th most effective management tool.

Other common prevention strategies for very low density watersheds are more stringent septic system requirements (e.g., setbacks, reserve fields and soil suitability criteria) as well as the use of stream or shoreline buffers. Fencing may be advisable if livestock are present and an alternative water supply can be provided. In addition, recreational facilities such as marinas and campgrounds should be designed with sewage pumpout facilities to prevent illegal sewage discharges.

The primary goal of a monitoring program for a very low density watershed is to establish a network of surveillance stations to track trends in fecal coliform over time. These stations can provide watershed managers "early warning" about future bacteria problems.

Managing Bacteria in Low Density Watersheds

While portions of these watersheds remain undeveloped or in rural uses, they are primarily zoned for large lot residential development, which are serviced by individual septic systems. Lot sizes can range from one to five acres. Impervious cover typically ranges from five to 15%, and the density of septic systems frequently is greater than 100 per square mile

- *Use attainment*. While the low density strategy can be an effective form of land use control, it does not necessarily prevent use impairment. The bacteria management model (Figure 1), assumes that low density subwatersheds exhibit a wide potential impairment curve during wet weather. The relatively wide range in the impairment curves indicates that frequent use attainment might be possible if effective watershed practices are widely implemented (e.g., stormwater treatment, buffers and source controls) and if septic systems exhibit a very low failure rate in the subwatershed. If, on the other hand, watershed practices are poorly implemented, or not implemented at all, then routine impairment can be expected during wet weather conditions. Dry weather contact uses, however, can be attained most of the time in low density watersheds. Disinfection and advanced filtration are generally needed to assure the purity of surface drinking water supplies in low density watersheds, primarily due to the risk of *Cryptosporidium* and *Giardia* which can be resistant to traditional forms of water treatment.

- *Preventing new bacteria sources*. The choice to limit development to large lot residential zones in low density watersheds is a form of land use control. Commercial and industrial land uses are excluded from these watersheds since they generally require sewer service to handle their higher wastewater flows. The key prevention strategy in low density watersheds is to prevent residential septic systems from failing (i.e., to maintain the failure rate as close to zero as current technology and management allow). Consequently, communities should consider imposing very stringent controls on new septic systems that cover their design, soil suitability, setbacks, inspection and maintenance provisions.

It is also advisable to set back development a fixed distance from shorelines and streams, to alter drainage patterns to direct runoff to less sensitive outfall locations (i.e., fixed distance from a water intake or beach, or to a zone of greater mixing or dilution) and implement conservation practices on hobby farms. Stormwater practices can also be an important treatment strategy for low density watersheds. Stormwater practices should emphasize those designs that can achieve a high rate of bacteria removal and do not create internal bacteria reservoirs in the drainage system.

The success of a low density strategy stands or falls on the ability to prevent septic system failure. Thus, from a monitoring standpoint, communities should augment their early warning stations at key water use areas with routine monitoring of the performance of new and existing septic systems in the watershed. Several communities have found that a local or regional septic system authority is very helpful in assuring compliance for the thousands of individually owned and operated systems within a watershed. Such an authority has the financial resources to rehabilitate failed systems or connect them to sanitary sewers, particularly at clusters of failed systems located near riparian, lakefront or coastal locations that are closest to water uses.

Managing Bacteria in Moderate Density Watersheds

The land use in these watersheds is primarily suburban in nature. Residential and commercial development are serviced by sanitary sewers. Impervious cover ranges from 15 to 30%. The moderate density strategy seeks to prevent future bacteria sources caused by widespread septic system failure by connecting homes and businesses to a sanitary sewer collection system. This system is managed by a local wastewater authority that has the resources to effectively remove human sewage from the watershed equation, by providing more effective treatment and pumping it to a less sensitive discharge point. Most significantly, the wastewater authority is governed under the NPDES program so that operation and maintenance of the plant and its collection system can be monitored and enforced.

- *Use attainment*. The moderate density strategy supports a greater population density within a watershed, which in turn, increases the amount of impervious cover, pets, urban wildlife, and "improved drainage" that can become new and possibly uncontrollable bacteria sources. Consequently, moderate density often results in frequent impairments during wet weather, which leads to temporary closure of waters for swimming and water contact recreation. As might be expected, surface water supplies located in moderate density watersheds typically require more expensive treatment processes to assure the purity of drinking water. Stormwater outfalls to shellfish beds will inevitably result in permanent closure, unless unusual flushing or dilution are present.

- *Preventing new bacteria sources*. Urban stormwater becomes a major bacteria source in moderate density watersheds. Consequently, stormwater practices, engineered buffers, and source controls should be applied to all new development in order to reduce bacteria concentrations. As previously related, however, these watershed practices are generally not sufficient to meet bacteria standards. Accordingly, in order to meet standards it may be necessary to also require new development to obtain bacteria reductions from existing watershed sources in the form of an offset. The offset could be a stormwater pond retrofit or septic system rehabilitation at an existing development.

Lastly, the local sewer authority needs to be vigilant to prevent overflows and improper connections to any new sewer system that is constructed. This involves initial pressure testing, ongoing field inspection, faster spill response and hotline reporting procedures.

"Early warning" stations in a moderate density watershed will normally pick up violations of bacteria standards during dry-weather. More intensive bacteria monitoring is needed in these watersheds to alert managers when water uses can be reopened during dry weather. An excellent monitoring and public outreach program has been developed in the Charles River in Boston that combines rapid fecal coliform sampling and "red flags" to ensure that the users know when water contact recreation is permitted or prohibited. Other communities have resorted to automatic closure of urban waters during storms and for several days thereafter.

Managing Bacteria in High Density Watersheds

These watersheds are highly urban in character, and wastewater is collected by hundreds of miles of sanitary sewers. The sewer network often becomes a major source of bacteria through episodic discharges from combined sewer overflows, sanitary sewer overflows or illicit sewage flows. In addition, the high levels of impervious cover found in high density watersheds produce stormwater runoff that contains a spectrum of human and nonhuman bacteria sources. The urban drainage network is also very extensive and often contains internal bacteria "reservoirs."

- *Use impairment*. It can be presumed that all human water contact uses will be impaired by bacteria levels during wet and dry weather conditions in high density watersheds, unless very favorable dilution or mixing conditions are present in the receiving water. It is possible, however, to support some water non-contact recreation uses during dry weather, if bacteria sources are adequately managed within the extensive network of sanitary and storm sewers.
- *Preventing bacteria sources*. The primary bacteria management strategy in high density watersheds is to detect, eliminate or treat all potential bacteria sources within the extensive network of sanitary and storm sewers. Considerable detective work is needed to find out exactly where, when and how bacteria are getting into either collection system. In some situations, it may be desirable to construct end-of-pipe disinfection systems at key outfalls near important water uses. Source control is also an essential strategy for high density watersheds, particularly in regard to pet wastes.

It is important to note that even though high density development greatly diminishes water uses, it is a critical element in a regional watershed approach. High density watersheds concentrate growth and related use impairment in a smaller geographic area than any other density strategy. Communities should implement extensive monitoring, posting and watershed education programs to limit the risk to public health in these watersheds.

Detective Work to Find Existing Watershed Sources

The sources and loads of most urban pollutants can be initially estimated for a watershed from a desktop or by a computer, given reasonably accurate land use and discharge permit information, requiring little in the way of additional watershed monitoring. This desktop analysis can be used to compare different pollutant sources, and ultimately be used to target watershed management practices.

In the case of bacteria, however, a desktop analysis is not particularly helpful, since actual bacteria sources must be discovered in the field. Watershed managers need to perform a lot of detective work to isolate existing bacteria sources and find exactly where, when and how bacteria are getting into surface waters. It is a lot like finding a whole bunch of needles in a haystack. Watershed managers must employ a variety of investigative techniques to discover the broken sewer pipe, the failed septic system, the hidden illicit connection, the concentration of wildlife, the overstocked hobby farm or the overflowing manhole.

This search requires at least two phases of watershed detective work. In the first phase, the lengthy list of possible bacteria suspects in each watershed must be whittled down to a manageable size. In the second, field investigations are needed to isolate the exact location of dozens or hundreds of individual bacteria sources so that they can be corrected.

Very few watersheds have been the target of such comprehensive detective work, given the enormous monitoring effort that it would entail. It is possible, however, to take some reasonable shortcuts when it comes to watershed detective work. With this in mind, we suggest a simplified six-step process to track down individual and controllable bacteria sources in a watershed.

Step 1: Re-Analyze Historical Fecal Coliform Data

Re-analyzing historical fecal coliform monitoring data sets is an excellent first step in any bacterial investigation. Historical coliform data from each monitoring station should be carefully segregated into dry and wet weather samples, and geometric means computed for both flow conditions. Samples from cold weather months should be excluded from the analysis.

Likewise, individual monitoring stations should be used to define bacteria conditions for subwatersheds within the watershed. Keep in mind that coliform bacteria data are notoriously variable and very hard to interpret, so at least a dozen samples are needed at each station. Once the geometric means are computed, they can be compared to dry and wet weather bacteria "benchmarks." It is also helpful to derive the 90% confidence intervals.

If fecal coliform samples have never been collected in the watershed, then new monitoring stations should be established at key subwatershed locations. For budgeting purposes, the cost of a year's grab sampling of fecal coliform will run about $1,250 to $2,500 per subwatershed station (Claytor and Brown, 1995).

Step 2: Compare to Urban Watershed Benchmarks

The bacteria benchmarks are not meant to be standards, but rather a comparative gauge to help watershed managers to rank the severity of bacteria problem in different subwatersheds or flow conditions. Subwatersheds that consistently exceed the benchmark are prime candidates for more intensive screening and field investigations. The two suggested bacteria benchmarks for urban watersheds are as follows:

- *Dry weather*: Fecal coliform levels exceed a geometric mean 500 MPN/100 ml in baseflow
- *Wet weather*: Fecal coliform levels exceed a geometric mean of 5,000 MPN/100 during storms.

These benchmarks were derived based on the following rationale. First, bacteria levels below each benchmark are consistently observed in urban streams, and are capable of being solely supported by nonhuman bacteria sources in the watershed (pets, wildlife, waterfowl, or the urban drainage system). Second, the wet weather benchmark generally corresponds to fecal coliform levels that are achieved by current stormwater treatment practices. Third, and most importantly, bacteria concentrations above either benchmark suggest (but do not prove) that *human* sources of bacteria could be present in the watershed, which are always the highest priority for detection and control.

The purpose of the benchmark analysis is to narrow the search to a manageable number of subwatersheds, and to determine whether dry weather and/or wet weather bacteria sources will be targeted.

Step 3: Identify the Types and Locations of Water Uses

In the third step, a watershed manager determines what kind of consumptive or contact uses are present in the subwatershed, and where they are located. While state water quality agencies are required to define permissible water uses for larger water bodies, and must periodically report on their status (i.e., 303(d) lists), they seldom have the monitoring resources to provide detailed information on actual water uses or impairment at the subwatershed level. Therefore, it is important to locate any water intakes, drinking water source areas, shellfish beds, beaches, public water access, or recreation areas that may be present in the watershed. This simple step helps identify the specific use areas that need to be protected in the future, but also existing use impairments in the subwatershed.

Table 2: Characterizing Potential Bacteria Sources in a Watershed

Low density watershed	Moderate and high density watersheds
What is the percentage of impervious cover in the subwatershed?	What is the age, condition and capacity of the sewer system?
How many septic systems are present in the watershed? How old are they?	What is the length of the sewer system?
Under what feasibility, setback, and design standards were they built?	What is percentage of impervious cover for the subwatershed?
What proportion of the watershed is not suitable or marginal for septic treatment?	Have SSOs been reported in the subwatershed?
Are septic systems clustered near receiving waters (along shorelines or streams)?	Are CSOs present in the subwatershed?
Are livestock or hobby farms present?	Are pet densities unusually high?
Are wildlife populations dense in water or riparian areas (beaver, gulls, geese)?	Are urban wildlife populations unusually high or close to receiving waters?
	What is the level of "urban housekeeping" in the watershed?
	Are there any transient sewage sources?

Step 4: Screen Potential Bacteria Sources

If bacteria levels exceed a benchmark, then the next step in the detective work is to get the best leads on the most likely bacterial sources in the watershed, based on its specific characteristics. Table 2 outlines a series of questions to characterize bacteria sources in a watershed depending on whether sewers or septic systems are the predominant method of wastewater disposal. Watershed managers may need to consult many different agencies to fully answer the questions (e.g., wastewater operators, public health authorities, extension agents, animal control and wildlife agencies). It may also be necessary to analyze land use and soil suitability maps, and to verify conditions through a "watershed windshield survey." The outcome of this step is a narrower and more focused list of potential bacteria sources to investigate further.

Step 5: Confirm Bacteria Sources Through Field Investigation

The final step in the detective work involves systematic monitoring to isolate individual bacteria sources in the subwatershed. This can be an expensive and time-consuming step, so the search should be conducted in a sequential manner. The search should focus on specific investigations during dry weather conditions or wet weather conditions, depending on which benchmark has been exceeded in the subwatershed (see Tables 3 and 4). The search is designed to test for human sources first, under the assumption that these sources are potentially more dangerous and controllable than nonhuman sources.

Step 6: Correct Priority Sources

The previous step creates an "inventory" of the location and magnitude of individual bacteria sources in a watershed. In this step, watershed managers choose which strategies to eliminate or treat these existing bacteria sources. Some common watershed practices that can be used to control bacteria are provided in Table 5.

What Do Standard Violations Really Mean?

By now, the astute reader will have noticed that we have avoided the only question that seems to matter to the public and the media: *Is the water really safe or not?* Every watershed manager is eventually asked this question and the answer is vitally important. A negative answer can inflame fears and create negative perceptions about urban waters. A positive answer may create false expectations about public health. The true answer is quite equivocal: water safety depends on how and where we are exposed, whether we are using water for wading, drinking, swimming or harvesting shellfish, the infective dose, incubation period, and our health condition. The specific answer to the safety question will be different for every urban watershed.

Researchers and managers continue to debate the question of the actual health risk from bacterial exposure in urban waters. A full discussion of this important debate is outside the scope of this article. The reader is referred to Pitt (1998), Francy *et al.* (1993), SMBRP (1996), Calderon and Mood (1991), Field and O'Shea (1992) and Seyfried *et al.* (1995) for excellent historical perspectives and/or more recent epidemiological studies. Three points of consensus, however, have emerged over the last few years. First, urban stormwater has been directly associated with symptoms of disease in swimmers near stormwater outfalls (SMBRP, 1996). Second, for a number of reasons, *E. coli* is supplanting fecal coliform as the preferred bacteria indicator by many urban watershed researchers (Nuzzi and Barbarus, 1997; Francy *et al.*, 1993).

Lastly, if *E. coli* or some other indicator is eventually chosen to replace fecal coliform as the primary bacteria indicator, a mammoth research effort will be needed to understand the concentrations, sources and controllability of these new indicators in urban watersheds. It is perhaps because of these massive data gaps that so few states have shown any enthusiasm for switching away from fecal coliform in their water quality standards. As of last year, 44 states and territories still relied on fecal coliform in whole or in part for their recreational water quality standards (USEPA, 1998).

The fact that regulators and scientists can't agree on exactly what fecal coliform violations signify in terms of public health doesn't answer the important safety question. What practical advice can a watershed manager give to those who use urban waters? Several common sense rules are provided below:

- Don't drink urban water unless you are confident that it has been suitably treated.
- Have your vet periodically test stool samples if your dog drinks from urban creeks.
- Don't consume any fish or shellfish that are harvested from urban waters unless you are certain that public health agencies have certified it as meeting standards. Even if the shellfish bed passes muster, it is still advisable to wait several days after storms.
- Wading and boating are usually safe if users take sensible precautions. In general, users should avoid urban streams during and shortly after storms, avoid head immersion, keep cuts and sores covered, wear shoes (to prevent contact with bacteria-rich bottom sediments) and rinse off after activity with an anti-bacterial soap.
- Swimmers should fully understand their watershed before taking the plunge. In particular, swimmers should refrain from swimming within

Table 3: Dry Weather Detective Work for Different Watersheds

Low density watershed	Moderate to high density watershed
Dry weather channel survey *(see Feature Article 5)* Aerial survey of septic systems Conduct visual or tracer tests on suspected failing systems Investigate recreational and seasonal sewage dischargers (e.g., marinas, campgrounds, etc.) Do RNA testing to determine whether FC are of human or nonhuman origin Test ditch or channel sediments to see if they are a bacteria source or reservoir	Dry weather channel survey *(see Feature Article 5)* Test for illicit connections Check integrity of major trunk lines for cracks and leaks Check for historic and unconnected septic systems Do RNA testing to determine whether FC are of human or nonhuman origin Check ponds, lakes and impoundments for waterfowl concentrations

Table 4: Wet Weather Detective Work for Different Watersheds

Low density watershed	Moderate to high density watershed
Inspect septic systems for wet-weather failure Conduct extensive wet-weather monitoring to isolate subwatershed hotspots Do RNA testing to determine whether FC are of human or nonhuman origin Sample runoff from suspected source areas (e.g., hobby farms and livestock areas) Test storm drain or channel sediments to see if they are a bacteria sink or source	Monitor any existing CSOs Check for chronic SSOs at specific manholes and/or pumping stations. Conduct extensive wet-weather monitoring to isolate watershed "hotspots" Do RNA testing to determine whether FC are of human or nonhuman origin Conduct intensive wet-weather monitoring to identify key source areas or subwatersheds

Table 5: Practices for Eliminating or Treating Existing Bacteria Sources

Low density watershed	Moderate to high density watershed
Rehabilitate failing septic systems Connect failing septic systems to sewer Increase septic system cleanouts Retrofit stormwater ponds Retrofit ditches as dry swales Waterfowl management Install recreational sewage pumpouts Implement conservation plans at hobby farms	Eliminate illicit connections to storm sewer Rehabilitate existing sewer system to eliminate SSO's Abate or disinfect CSO's if present Relocate storm outfalls Disinfect at the end-of-pipe Retrofit stormwater ponds Retrofit ditches as dry swales Waterfowl harassment Enforce pet waste disposal

two days of a large storm and avoid swimming near stormwater outfalls. Swimmers should consult a doctor if they experience rashes, ear itches, or gastrointestinal illness after swimming.

—TRS

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