WADING IN WASTE

Thanks to unchecked development along America's coasts, disease-causing microbes are increasingly fouling beaches and shellfish beds

By Michael A. Mallin

America's stunning, sinuous coastlines have long exerted an almost mystical pull on the imaginations of the country's citizens. The irresistible attraction is perhaps best described by Herman Melville in the opening pages of *Moby Dick:* "Nothing will content them but the extremest limit of the land.... They must get just as nigh the water as they possibly can without falling in." In recent years, millions of Americans have moved to coastal areas, particularly in the Southeast, to take advantage of their balmy climate, recreational opportunities and natural beauty. Unfortunately, rapid and poorly planned development is spoiling this beauty in a shocking way: a growing number of beaches and shellfish beds along the coast have been contaminated by disease-causing microorganisms coming from animal and human wastes.

According to a recent report by the Natural Resources Defense Council, in 2004 coastal states ordered 19,950 days of closures and pollution advisories affecting 1,234 ocean and freshwater beaches, or about one third of all the beaches regularly monitored by health officials. The total number of beach days covered by the regulatory actions was 9 percent higher than the total for 2003 (which, in turn, was 50 percent higher than the 2002 total, although that jump was partly caused by changes in federal monitoring rules). The reason for 85 percent of the closures and advisories was the detection of excessive counts of fecal bacteria in the beach waters.

Moving downstream with animal feces in storm water runoff or with human waste in sewage overflows and septic-tank leaks, the waterborne microbes can cause liver disease, respiratory infections and potentially fatal gastrointestinal disorders. Such illnesses are common in Third World countries with poor sanitation, but in the U.S. the problem stems from unwise growth, not poverty. The construction of so many homes, roads, shopping centers and parking lots has disrupted the natural drainage systems in coastal areas, and wastes that were once filtered by forests or wetlands are now regularly fouling marinas and beaches.

How can coastal states and communities reduce microbial pollution? The issue has led to conflicts pitting developers and pro-growth politicians against regulatory authorities, commercial and recreational shellfishers, surfers, swimmers, divers and conservationists. Fortunately, some innovative solutions are available. "Smart growth" strategies can restore polluted coastlines and pro-

vide economic benefits as well. Because frequent beach closures can dampen tourism and depress real estate values, the adoption of reasonable controls on coastal development would safeguard the shoreline economy as much as it would protect the public's health.

The Coastal Boom

IN ITS 2004 Coastal Trends Report, the National Oceanic and Atmospheric Administration noted that 153 million Americans—or 53 percent of the country's population—lived in the counties bordering the seacoasts and the Great Lakes, which make up only 17 percent of the continental U.S. land area [*see box on page 57*]. What is more, another seven million people are expected to join the coastal population by 2008, and the total is seasonally expanded by hordes of vacationers. Large areas that used to be forests or farmland are being turned into resorts, residential subdivisions, strip malls, restaurants, office complexes and industrial parks. In the process, construction companies are draining wetlands and covering formerly vegetated soils with asphalt, concrete and housing materials.

The resulting landscape is dominated by impervious surfaces—parking lots, roads, sidewalks, rooftops and construction sites compacted by heavy equipment—that do not let water soak through. When it rains, the water flows over these surfaces, picking up animal feces and other pollutants and washing them into drainage ditches or storm drains, many of which lead directly to urban lakes, coastal creeks or beach areas. Whereas sewage treatment plants remove harmful bacteria and other contaminants from their effluent, storm water runoff is usually untreated. Because this runoff emanates from a wide area rather than a single source, it is classified as nonpoint source pollution. The Environmental Protection Agency has stated that this type of pollution is the leading remaining cause of water-quality problems in the U.S.

Storm water runoff carries fertilizers, pesticides, heavy metals and petrochemicals, but it is the disease-causing microbes—the bacteria, viruses and protozoa derived from feces—that pose the principal threat to human health. A single gram of dog feces, for example, contains an estimated 2.3 million bacteria. (And for certain particularly hazardous bacteria, as few as 10 organisms can cause an infection.) Urban and suburban watersheds receive a steady influx of manure from domestic animals such as dogs and cats and from wildlife such as raccoons and squirrels. In vegetated areas, rainwater and runoff trickle through the soil, which cleanses the water of fecal bacteria and viruses, as well as many other pollutants. In contrast, impervious surfaces accumulate pollutants during dry periods and funnel high concentrations of the contaminants downstream when it rains.

The problem is particularly worrisome along the coast because the microbes pollute shellfish beds and areas used for recreation. Shellfish are primarily filter feeders, meaning that they strain large volumes of seawater through their bodies to concentrate food material such as microscopic algae. But they also concentrate the potentially harmful organisms that are present in the water. If humans consume raw or poorly cooked shellfish from waters contaminated with fecal microbes, they run the risk of contracting gastroenteritis (a disease characterized by vomiting, diarrhea and stomachache) as well as more severe, life-threatening illnesses.

To protect shellfish consumers, state agencies are required to post signs in polluted shellfish beds notifying the public that harvesting clams, mussels or oysters there is illegal. The U.S. Public Health Service has set a nationwide safety standard for shellfish beds using measurements of fecal coliform bacteria, a broad category of microorganisms found in the intestines of humans and animals. Shellfish cannot be harvested from the area if the geometric mean of the bacterial counts in 30 sets of samples is higher than 14 colony-forming units (CFU) per 100 milliliters of seawater. (A geometric mean is a type of average that minimizes the effects of outlying values.) In 1995, which was the last time NOAA compiled a national shellfish register, harvesting was restricted or prohibited in 31 percent of the country's shellfish-growing areas. The agency reported that urban runoff was the most commonly cited source of the pollution invading shellfish beds.

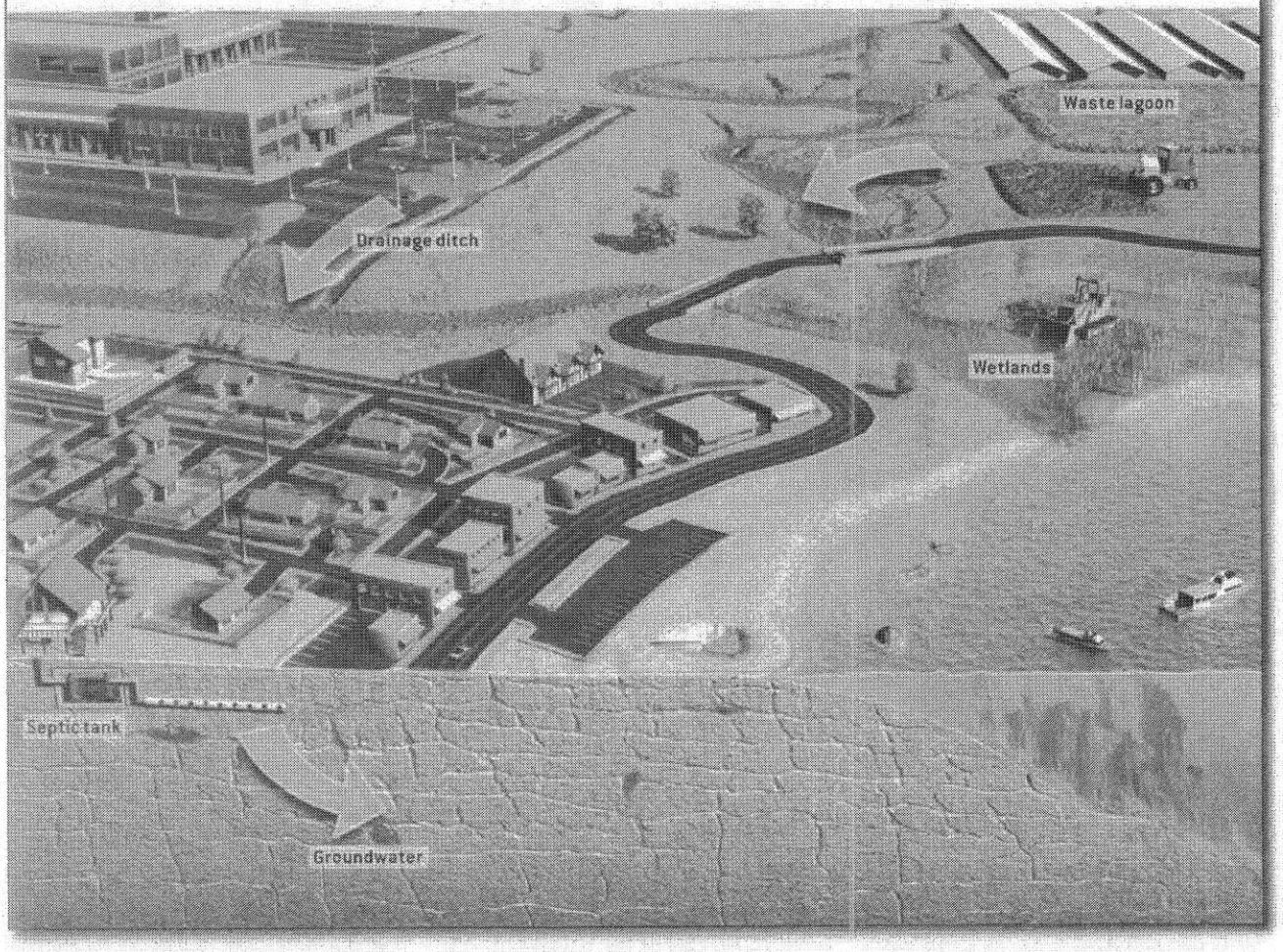
The reason for 85 percent of BEACH CLOSURES and advisories is the detection of excessive fecal bacteria.

Overview/*Microbial Pollution*

- Because of booming growth in U.S. coastal regions, much of the area near the shoreline is covered with impervious surfaces such as parking lots, roads and sidewalks. When it rains, storm water runoff from these surfaces can carry animal feces and their accompanying microbes into drainage ditches that lead directly to lakes, streams and beaches.
- Contamination by fecal bacteria is the leading cause of beach closures and advisories, which now affect one third of the country's monitored beaches. Hazardous microbes also plague marinas, tidal creeks and shellfish beds.
- To fight microbial pollution, coastal communities can encourage the preservation of green spaces, install filters in storm drains and prevent the placement of septic tanks in areas with porous soils.

FECAL MICROBES ON THE MOVE

Poorly planned development is the primary cause of microbial pollution in coastal areas. Most shopping centers, for example, are surrounded by enormous parking lots that funnel waste-laden runoff to drainage ditches. In many coastal residential developments, the effluent from septic tanks flows into fissured limestone or sandy soils that allow fecal microbes to seep into the groundwater. Industrial-style livestock operations typically spread their manure over fields or store it in lagoons; heavy rains can wash the wastes into nearby streams. And new construction often destroys the wetlands that filter disease-causing organisms from the water before they can reach beaches and shellfish beds.



DAVID FIERSTEIN

More recently, my laboratory at the University of North Carolina, Wilmington, analyzed data from five coastal North Carolina counties and found a strong correlation between human population growth and the closure of shellfish beds. In 1984, when 352,125 people lived in the five counties, 35,275 acres of shellfish waters were closed; by 2003, the combined population had risen to 501,596 and the closed acreage had grown to 42,304.

Microbial pollution also poses a serious danger to people involved in common recreational activities such as swimming, surfing, wading, diving, snorkeling, waterskiing and boating. If fecal organisms contaminate a lake, stream or seashore, anyone in the water risks infection by microbes entering through the mouth, nose, eyes or open wounds. Some of the illnesses caused by water contact include gastroenteritis, conjunctivitis (eye infections), cellulitis (skin irritations such as swimmer's itch), ear infections, respiratory infections and more serious diseases such as hepatitis and Guillain-Barré syndrome, an inflammatory disorder of the peripheral nerves that can induce paralysis. Some of the waterborne bacteria that can cause these health problems are *Escherichia coli*, *Clostridium perfringens* and various species of *Enterococcus*, *Aeromonas*, *Campylobacter*, *Salmonella*, *Shigella* and *Yersinia*. Among the many waterborne disease-causing viruses are hepatitis A and Norwalk; the pathogenic protozoa include *Cryptosporidium*, *Entamoeba* and *Giardia*.

Don't Drink the Water

IN RECENT YEARS, several of these microbes have triggered severe disease outbreaks in the U.S. and Canada. In

1993 *Cryptosporidium* protozoa infected the Milwaukee drinking water system, leading to more than 100 deaths and 400,000 illnesses. In 1999 an outbreak of *Escherichia coli* and *Campylobacter* resulted in two deaths and 116 illnesses among fairgoers in New York's Washington County after they drank water contaminated by runoff from a cattle barn. In 2000 residents of Walkerton, Ontario, fell victim to infections by *E. coli* and *Campylobacter* that caused 2,300 illnesses and seven deaths, mostly among the elderly and infants.

Fecal microbes from SEPTIC SYSTEMS in the Florida Keys can enter coastal waters within hours.

Again, the contamination was traced to microbe-laden runoff from a cattle feedlot that entered the town's water supply.

Health officials measure the concentrations of various indicator bacteria to assess the danger from waterborne pathogens, especially along beaches. When the bacterial counts get too high, the authorities issue polluted-water advisories or close beaches to swimming and other recreational activities. The EPA recommends that states use *Enterococcus* bacteria as the safety indicator for ocean and bay water. Under the EPA's standards, seawater is considered unsafe if the geometric mean of five *Enterococcus* samples collected within 30 days is greater than 35 CFU per 100 milliliters or if any individual sample is above 104 CFU per 100 milliliters. In freshwater, the EPA limits on mean concentrations are 33 CFU per 100 milliliters for *Enterococcus* and 126 CFU per 100 milliliters for *E. coli*. These standards, however, may be too lax. The EPA has estimated that swimming in seawater with the maximum acceptable counts will cause 2 percent of bathers to fall ill.

Up the Creek

RESEARCHERS HAVE BEEN studying the environmental damage caused by impervious surface coverage since the late 1980s, but my laboratory was the first to examine the effects on fecal bacterial counts. We focused on New Hanover County, a rapidly growing area in North Carolina. From 1990 to 2000 the county's population increased by 25 percent, and it is expected to rise another 31 percent by 2020. My research team has studied the water quality of six urbanizing tidal creeks in the county for the past decade. We collected and analyzed more than 1,000 samples of fecal coliform bacteria and *E. coli* taken throughout the creeks and looked for correlations between the bacterial counts and various demographic and landscape attributes of the creek watersheds.

We found that the average fecal coliform counts were generally higher in the creeks with more people and with a larger percentage of developed land in their watersheds. But the bacterial counts were most strongly correlated with the prevalence of impervious surfaces. In Futch Creek—where impervious surfaces covered only 7 percent of the surrounding land—the average coliform count was 12 CFU per 100 milliliters, but in Bradley Creek—where asphalt and concrete blanketed 22 percent of the watershed—the count was more than seven times higher [*see box on page 58*]. The correlation between *E. coli* abundance and the percentage of impervious surface in the watershed was also very strong. Ours was not an isolated finding: A. Fred Holland, Denise M. Sanger and their colleagues at the South Carolina Department of Natural Resources later reported a significant correlation between fecal coliform counts and impervious surface coverage in the watersheds of 22 tidal creeks in the Charleston metropolitan area.

The results suggest that storm water runoff from developed areas may have a multiplier effect on bacterial concentrations downstream. The abnormally high flows coming from large parking lots or subdivisions may erode the drainage ditches and stream banks, bringing suspended sediments into the water. These sediments are also readily washed off construction sites where the soils have been stripped of vegetation. The suspended sediments and other particles cloud the receiving waters. (The degree of cloudiness is called turbidity.) What is more, the sediments, particularly clays, can physically and chemically bind with pollutants such as ammonium, phosphate, metals, and fecal bacteria and viruses.

Binding to soils protects bacteria from ultraviolet radiation that would normally kill the organisms. Bacteria can also obtain carbon, nitrogen and phosphorus nutrients from the soil particles, and the microbes can hitch long-distance rides as they travel downstream with the sediments. In our study of the tidal creeks in New Hanover County, we found a highly significant correlation between turbidity and the abundance of fecal coliform bacteria. Other studies performed in the Chesapeake Bay, western Florida, the Mediterranean coast and Australia have yielded similar findings.

The sediments lying at the bottom of shallow coastal waters are also a reservoir for fecal bacteria and other microbes. A research team led by Lawrence B. Cahoon, my collaborator at U.N.C. Wilmington, has found high concentrations of disease-causing organisms—including fecal coliform bacteria, enterococci and streptococci—in tidal creek sediments. The microbes can

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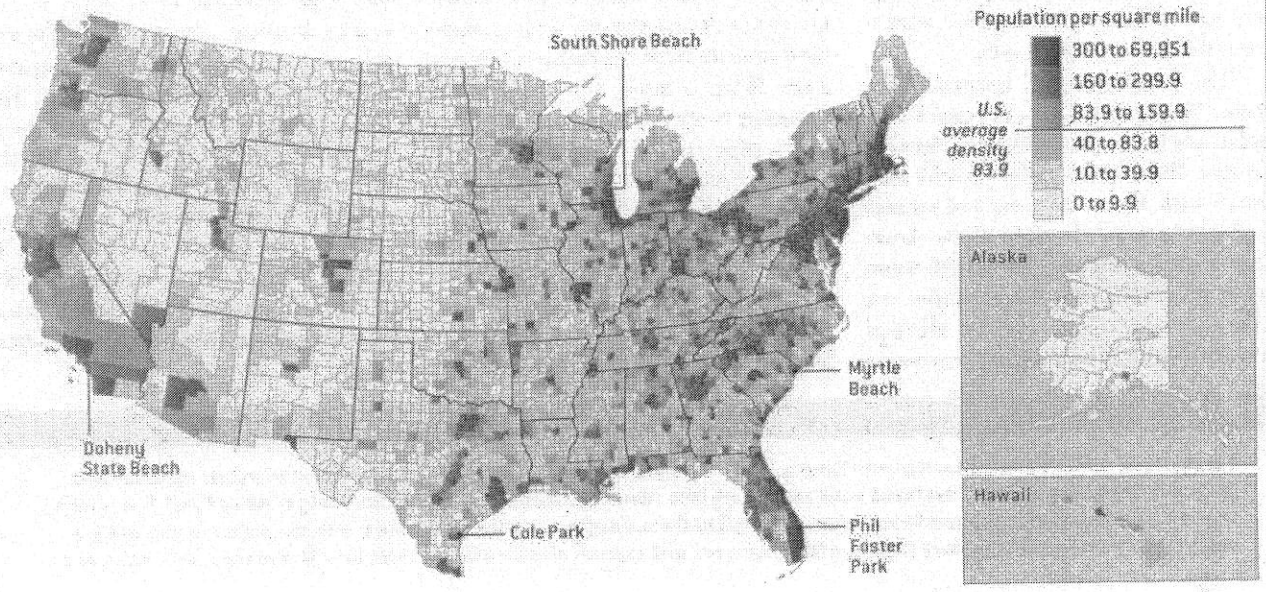
AMERICA'S SULLIED BEACHES

The most polluted beaches and bays in the U.S. are generally located in densely populated coastal counties. Bacterial contamination prompted the closures and advisories at the areas listed below in 2004 (the last year for which nationwide records are available). The highest counts measured at each beach were far above the safety standards for individual samples of *Enterococcus* and *Escherichia coli*, 104 and 235 colony-forming units (CFU) per 100 milliliters, respectively.



BEACH LOCATION	TYPE OF BACTERIA MEASURED	HIGHEST COUNT (CFU PER 100 MILLILITERS)	NUMBER OF CLOSURE OR ADVISORY DAYS IN 2004
Doheny State Beach Orange County, California	*Enterococcus*	38,800	312
Phil Foster Park Palm Beach County, Florida	*Enterococcus*	600	108
South Shore Beach Milwaukee County, Wisconsin	*Escherichia coli*	2,419	72
Myrtle Beach Horry County, South Carolina	*Enterococcus*	1,130	54
Cole Park Nueces County, Texas	*Enterococcus*	14,400	53

SOURCES: U.S. CENSUS BUREAU (map); U.S. ENVIRONMENTAL PROTECTION AGENCY, NATURAL RESOURCES DEFENSE COUNCIL, ORANGE COUNTY OCEAN WATER PROTECTION PROGRAM, WISCONSIN BEACH HEALTH AND TEXAS GENERAL LAND OFFICE (table)

survive for extended periods in the sediments because they are protected from ultraviolet radiation and have ready access to nutrients. And because the tidal creeks are generally shallow, agitating the sediments at the bottom can suspend enough bacteria in the water to exceed the safety standards for human contact. Windy conditions or wading children and pets can easily pollute the water just by kicking up the creek's muddy bottom. Furthermore, our students have found high concentrations of fecal microbes in the sediments near several public boat ramps; such ramps are ubiquitous and heavily used in the coastal regions of the Southeast.

Sand and Sewage Don't Mix

POORLY DESIGNED sanitation systems in coastal regions can also contribute to microbial pollution. In communities where storm drains feed into sewer pipes, heavy rains can cause overflows that dump untreated human waste into rivers, lakes and bays. Many municipalities are now tackling this problem by separating their sewer and storm water systems. A new dilemma is emerging, however, in coastal areas where residents do not have sewage hookups and must put their wastes in septic tanks instead.

One such area is the Florida Keys, which is home to more than 25,000 septic systems. The predominant terrain in the Keys is karst topography—the underlying soils consist primarily of limestone, with many cracks and sinkholes caused by erosion. This geologic forma-

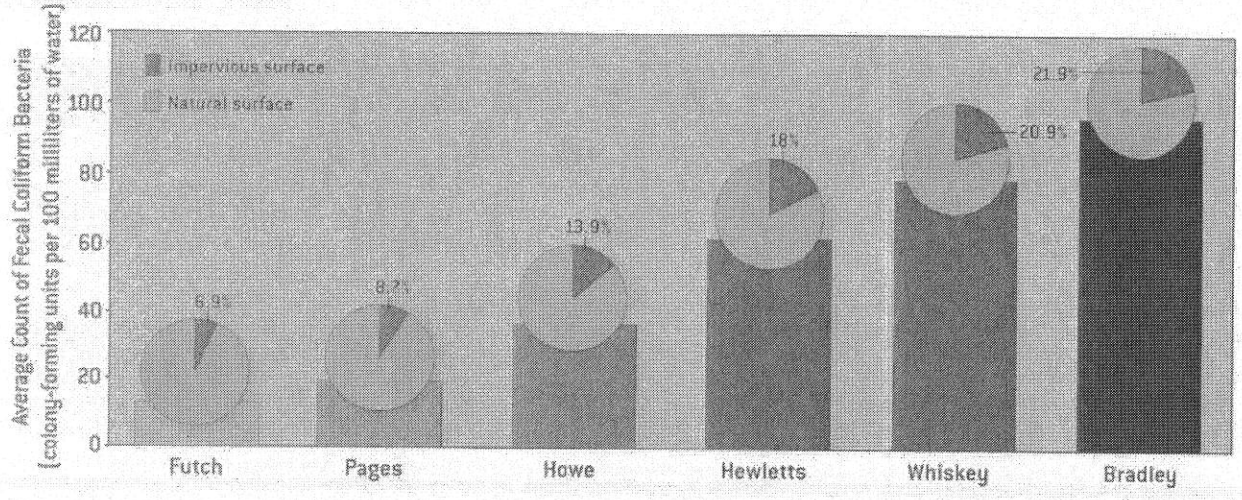
tion is very porous and hence cannot effectively filter the bacteria-rich effluent from septic tanks. In 1995 a research team led by John H. Paul and Joan B. Rose of the University of South Florida found that fecal microbes from septic systems in the Keys readily pass through the soil and can enter coastal waters near the shore within hours.

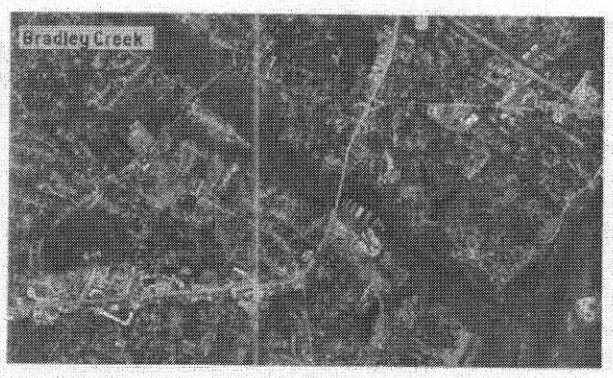
The problem is not limited to the Keys. Sandy soils along the coast have relatively large spaces between the sand grains. When these soils become saturated with water, bacteria and viruses can easily move through them. Areas containing sandy soils and a high water table are thus unsuitable for septic systems, yet poor planning has allowed their presence in many rapidly growing coastal regions, including some of the sandy barrier islands along the Atlantic and Gulf coasts. In a study of water quality in Brunswick County, North Carolina, which has many septic tanks in the sandy soil (up to 20 per hectare), Cahoon found high fecal coliform counts in the freshwater and seawater downstream from the dense residential sites. What is more, the ditching and drainage systems serving the developed areas appeared to facilitate the discharge of fecal bacteria into nearby waters, including shellfish beds.

Other investigators have identified distinctive patterns in the severity of microbial pollution. Erin K. Lipp, now at the University of Georgia, and her colleagues determined that in Florida Gulf Coast communities such as Charlotte Harbor and Sarasota Bay, fecal bacteria counts in bays and tributaries increase sharply with the outgoing tide. The microbes move readily through the sandy, saturated soils surrounding the crowded fields of septic tanks into nearby creeks draining into the bays. The pattern not only is tidal but varies according to weather conditions as well. The researchers discovered that in wet years corresponding to El Niño events, the water in Tampa Bay is significantly more polluted by fecal bacteria and viruses than it is in dry years. This effect is again the result of increased runoff and subsurface movement through saturated soils around improperly sited septic tanks.

THE EFFECTS OF CONCRETE AND ASPHALT

A study of six tidal creeks in New Hanover County, North Carolina, found a strong correlation between microbial pollution and the prevalence of impervious surfaces such as parking lots, roads and sidewalks. In the relatively pristine Futch Creek (*left*), where impervious surfaces covered less than 7 percent of the watershed, the average counts of fecal coliform bacteria were much lower than in Bradley Creek (*right*), where concrete and asphalt blanketed more than one fifth of the surrounding area.





LUCY READING-IKKANDA; MICHAEL A. MALLIN (*left*); NEW HANOVER COUNTY PLANNING DEPARTMENT (*right*)

In southern California, where large amounts of urban runoff flow into the Pacific Ocean, Rachel Noble of U.N.C. Chapel Hill and her colleagues found that the extent of shoreline water that failed to meet safety standards was 10 times greater following rainfall than it was during dry periods. Nationwide, many shellfish beds are automatically closed for a few days or weeks after a rainfall, because these areas are subject to bacterial pollution from storm water runoff.

But urban runoff and septic seepage are not always the main culprits behind microbial pollution. In coastal streams draining rural areas, the driving factor is often the waste from livestock farms. On the coastal plain that extends from Maryland to Florida and in certain Gulf Coast areas as well, traditional livestock farms have been largely supplanted by giant, industrial-style facilities where huge numbers of swine, poultry and cattle are raised in close confinement. The facilities dispose of the vast amounts of manure by either spraying it as a liquid or spreading it as litter on nearby fields. If the spraying or spreading occurs shortly before or during a rainstorm, fecal microbes from the waste can enter nearby streams via overland runoff.

A Cleaner Future

TO PROTECT America's coastal waters, developers and builders clearly need to move away from their current destructive practices—including clear-cutting, wetlands drainage and extensive use of pavement—and switch to smart-growth strategies. When planning new resorts, shopping centers, office complexes and residential subdivisions, the designers must minimize the use of impervious surfaces and maximize the amount of vegetated areas. A site with plenty of green spaces among the paved areas will have less runoff, and percolation through the soil will remove many of the contaminants swept from the asphalt and concrete.

In particular, wetlands need to be preserved and, if possible, enlarged to maintain the natural filtering of storm water runoff. In a study of 11 streams in the coastal plain of eastern North Carolina, my laboratory found that in the watersheds where the wetland coverage was relatively large—in this case, greater than 13.5 percent—periods of rainfall did not substantially increase the fecal coliform bacteria counts. The results indicate that preserving wetlands (and presumably expanding them) is an effective way to guard downstream waters from suspended sediments and microbial pollution. Builders can help the effort by curtailing the runoff of sediments from construction sites.

Developers should take advantage of new technologies that can reduce the amount of storm water runoff and even treat it on-site. For example, parking lots can now be paved with porous concrete, a semipervious substance that allows water to pass into the soil below and yet provides enough structural support for automobiles. And new collection systems can funnel storm water runoff from parking lots to filters that use layers of absorbent minerals and organic material to cleanse the polluted water. (Large parking lots can also be downsized, because most were built to accommodate holiday shopping rather than day-to-day traffic.) These technologies could be applied to existing developments as well as new ones. If a community wishes to reduce runoff pollution to revitalize its beaches or save the local shellfish industry, it can install filters in all its parking lots, create vegetated buffer zones along streams and ditches, and reconstruct wetlands in selected locations.

The poor performance of septic systems in sandy soils and in areas of karst topography is a clear indication that coastal regions require more advanced sewage treatment systems. Some conservation groups have pointed out, however, that the construction of centralized sewage systems will lead to even denser development and more water pollution. Thus, when coastal communities build sewage systems, the municipal authorities should put restrictions on impervious surface coverage in new developments, limiting it to, say, 10 to 15 percent of the total area (especially near shellfish beds).

America's coasts can be a wonderful destination, both for vacation travel and for relocating homes and businesses. But without careful planning and the political will to protect coastal resources, the gorgeous beaches, sparkling bays and tranquil tidal creeks will become nothing but hazardous receptacles of our waste. We must ensure that unchecked development does not ruin the very qualities that brought people to the coast in the first place.

PRESERVING WETLANDS is an effective way to guard downstream waters from microbial pollution.

MORE TO EXPLORE

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More information can be found online at www.nrdc.org/water/oceans/gttw.asp and www.epa.gov/beaches/