Public-minded citizens came to believe that, since disease always accompanied want, dirt, and pollution, the best and perhaps the only way to improve health was to bring back to the multitudes pure air, pure water, pure food, and pleasant surroundings. ... This point of view relates directly to the problems of disease being created in the modern world by the second Industrial Revolution, and to their control by social improvements.

— Rene Dubos in Man, Medicine, and Environment (1968)

Introduction

Could swimming in Galveston Bay make me sick? Is it risky to eat the seafood from the bay? To the citizens of Texas and the Galveston Bay region, these are compelling questions. News accounts of bay-related health threats get much attention from the media and the public. For example, contamination in Upper Galveston Bay and its tributaries has led to an advisory from the Texas Department of State Health Services (TDSHS) to avoid certain seafood taken from that area. Similarly, large areas of the bay are closed to shellfish harvesting due to potential risk to consumers from pathogenic bacteria.

As we have seen in previous chapters, humans can have a negative impact on Galveston Bay. It is also true that the bay can have a negative impact on humans. There are ways that conditions in the bay can affect the health of people who use it directly for contact recreation or indirectly by consuming seafood captured from the bay.

This chapter summarizes the various types of risk to human health that may be associated with using the bay. Public health risks are placed in three categories: pathogens, such as the bacteria that cause intestinal illness; toxicants, such as dioxins or mercury; and other risks, such as drowning. The discussion of risk factors is followed by a description of the ways in which the responsible agencies address these risks through
management strategies, such as the classification of shellfish harvest areas and the issuance of seafood advisories. The management strategy implemented is based upon the type of human use being managed. For example, human health is threatened when human pathogens or toxic compounds are present in waters used for recreation. This can be addressed by warning the public against engaging in contact recreation in a particular area of the bay. Also, certain types of recreation, such as boating, may be inherently dangerous and justify the implementation of safety regulations. Similarly, concentrations of pathogens and toxic chemicals in fish and shellfish from the bay may be dangerous to consumers of the seafood. This risk can be addressed through seafood risk assessments and seafood advisories.

Human Health Risk Factors

Pathogens in Water and Seafood

The potential presence of human pathogens in bay waters is an important health concern related to human use of Galveston Bay. Exposure to these pathogens could occur through contact (e.g. swimming) and non-contact (e.g. boating) recreation or through the consumption of seafood. Molluscan shellfish, primarily oysters, are especially associated with the risk of infection because they are often consumed raw (Figure 9.2). However, all types of seafood can serve as vectors for some form of disease agent. History provides valid reasons for concern about such diseases as infectious hepatitis, dysentery, and cholera. Thanks to scientific understanding and effective regulation by public health agencies, bacterial outbreaks related to environmental conditions are now rare. However, occasional instances still occur, reminding us that the sources for contamination still exist and that some pathogens occur naturally in the bay ecosystem.

There are four common ways in which bay users are exposed to pathogenic bacteria and become ill: ingestion or inhalation of water, exposure of open wounds to the water, puncture wounds caused by spines on fish, and ingestion of raw or undercooked seafood.

Ingestion of contaminated water is usually associated with swimming in areas polluted by sewage that contains a variety of bacterial pathogens. Gastroenteritis is often the result of such exposure and can be caused by several common types of bacteria, including Streptococci, Enterococci, and Vibrio. Exposure to water with high loads of fecal bacteria can result in respiratory infections and skin pathologies. The incidence of infections from exposure to polluted bay water is difficult to measure because people often do not seek medical attention for such illnesses and few will make the connection between contact with water and intestinal or
respiratory illness. There is also a risk from infection by viruses, but even less is known about the occurrence and effects of viruses found in coastal waters.

Several species of *Vibrio* occur naturally in the waters of Galveston Bay; *V. parahaemolyticus* and *V. cholera* are examples, but it is *V. vulnificus* that appears to have the greatest health impacts. *V. vulnificus* has been identified as the causal agent of septicemia (an infection in the bloodstream, also known as blood poisoning) and necrosis of tissue (often referred to as “flesh-eating bacteria” in the news media) in anglers and boaters, and of gastroenteritis in swimmers. Bacteria related illness can also result from consumption of raw oysters. *V. vulnificus* causes 95 percent of all seafood-related deaths in the United States (Oliver 2005). However, deaths caused by *V. vulnificus* are rare; fatalities are very unlikely unless the patient is immunocompromised. The likelihood of this type of infection increases as water temperature increases (Motes et al. 1998; Oliver 2005) and is not correlated with measures of bacterial pollution.

**Monitoring for Pathogens**

Monitoring of water pollution usually includes determination of the concentration of bacteria in water samples. Monitoring procedures have changed to increase the accuracy and relevance of the measurements. The testing procedure used to determine whether water is safe for contact recreation has changed from fecal coliform bacteria (general bacterial types associated with the mammalian intestine) to *Escherichia coli* in freshwater and *Enterococci* in brackish or salt water (see Chapter 6). The regulatory system does not currently incorporate the importance of *Vibrio* bacteria when determining the safety of consuming raw oysters. However, studies of *Vibrio* are being conducted and they could be included in the regulatory scheme. Many water bodies around Galveston Bay have been declared unsuitable for contact recreation or shellfish harvesting due to contamination of water by fecal bacteria.

The TDSHS determines the status of shellfish harvest areas in Texas estuaries. The status of shellfish harvest areas falls into four categories: prohibited (closed to shellfish harvest), restricted (closed to the harvesting of shellfish for direct marketing), conditionally approved (subject to closure based upon precipitation or water quality conditions), and approved (open to shellfish harvest). In large areas of Galveston Bay, typically near the developed shore, harvesting oysters is restricted. Some areas near the Houston Ship and along developed shorelines are prohibited to shellfish harvest. Areas in which oyster harvest is approved tend to be closer to the Gulf, away from development. Conditionally approved areas usually occur at the boundaries between approved and restricted areas and are change in response to the amount of bacterial loadings from storm water runoff. Figure 9.3 shows the classification of Galveston Bay waters for oyster harvest in 2009.

Fecal coliform bacteria are used in the TDSHS Shellfish Sanitation Program as an indicator of human health risk. Since 1983, fecal coliform most probable number (MPN) data have been used by TDSHS. The Texas Commission on Environmental Quality (TCEQ) does not regulate oyster harvesting, but the Texas Surface Water Quality Standards (TCEQ 2008a) maintain an “oyster waters” designation for protection of oyster reefs. The TCEQ uses the membrane filtration test method to obtain concentration estimates of fecal coliform. The membrane filtration method uses filtration of the water sample to capture bacteria, followed by growth of the filtered bacteria on a selective nutrient medium, and finally, counting of the colonies.
present on the medium (USEPA 1997). The alternate method, *most probable number*, involves inoculating tubes of culture medium with dilutions of the sampled water, followed by incubation of the media for a period of growth, and finally, determination of the amount of bacteria by presence of gas. The differences between the membrane filter and most probable number tests used by these two agencies have prevented their data from being strictly comparable.

Under the TCEQ program, the portions of the bay system designated as “oyster waters” include Upper Galveston Bay, Lower Galveston Bay, Trinity Bay, East Bay, West Bay, Chocolate Bay, Bastrop Bay, Christmas Bay and Drum Bay. Bay segments not meeting water quality standards for the “oyster waters” designation are placed on the Texas 2008 Clean Water Act Section 303(d) List for future assessment by the TCEQ’s Total Maximum Daily Load (TMDL) Program.

Overall, the fecal coliform test used by the TDSHS has been successful in assuring the high quality of Galveston Bay shellfish sold for human consumption. However, the indicator approach has limitations for regulation of oyster harvest. Fecal coliform testing can produce false positive results due to the detection of other organisms in a water sample (Jensen 1992; Pisciotta et al. 2002). Fecal coliforms do not indicate risk from naturally occurring, non-intestinal pathogens such as *Vibrio vulnificus*.

Currently, the bacterial monitoring results from the Galveston Bay watershed document a serious problem that does not appear to respond to current management practices. Most of the monitored water bodies in Harris County and an increasing number in surrounding counties exhibit bacterial concentrations that exceed the regulatory standards for contact recreation. There are regulatory processes in place (e.g., TMDL procedures) to address the high concentrations of fecal bacteria in bay tributaries (including Buffalo

![Figure 9.3. Galveston Bay shellfish harvest areas, 2009. Data source: (TDSHS 2010).](image-url)
Bayou and Dickinson Bayou), which should be suitable for contact recreation. Similarly, a TMDL project for the bay is under way to address high levels of fecal bacteria in waters that should be suitable for shellfish harvest.

**Fecal Coliform Bacteria as Indicator Organisms**

A number of possible metrics indicative of human pathogens in water are available, including fecal coliform bacteria, total coliform bacteria, \textit{E. coli}, fecal \textit{Streptococcus sp}., and \textit{Enterococcus sp}. The TDSHS Shellfish Sanitation Program currently uses fecal coliform bacteria as the indicator, but has used total coliform in the past. The TCEQ incorporated recommendations from the EPA into its standards (TCEQ 2008a) regarding appropriate bacterial indicator measures for tidal and fresh waters. EPA studies indicated that the relationship between gastroenteritis and \textit{E. coli} or \textit{Enterococci} concentrations was significantly stronger than that of the traditional, and more general, fecal coliform bacteria indicator. Therefore, fecal coliform was replaced with \textit{E. coli} for freshwater and \textit{Enterococci} for saltwater. These criteria revisions for contact recreation use were adopted by the TCEQ in 2000.

Fecal coliform bacteria naturally occur in the intestines of mammals and birds. Their fecal material can contain more than one million organisms per gram (Alderisio et al. 1999). Each human produces from 100 to 400 billion coliform organisms per day (Takashi et al. 2007). The primary public health concern in the past has been diseases caused by improper treatment and disposal of human wastes. The absence of coliform organisms indicates that a sample is likely free of disease-producing organisms originating in human waste. Conversely, the presence of fecal coliform indicates contamination that could (but may not) involve human pathogens.

The use of fecal coliform bacteria as an indicator in drinking and recreational waters dates back almost half a century. Before then, total coliform data were used. The use of fecal coliforms as an indicator has its limitations. There are some bacterial pathogens that are unrelated to human wastes. Therefore, they are not detected in the routine tests. For example, \textit{Vibrio vulnificus} is a human pathogen occurring naturally in the waters and biota of Galveston Bay. Conversely, many non-fecal coliforms common in soil and on the surface of plants cannot be distinguished from fecal coliforms by the tests commonly used (Pisciotta et al. 2002). Thus, elevated concentrations of organic materials from a wide range of sources can support bacterial populations that are interpreted as indicative of human health risks. The total and fecal coliform tests need to be interpreted with caution.
Studies suggest that the principal source of fecal coliform bacteria to Galveston Bay is wet weather runoff from upland areas, with urbanized areas acting as a major contributor of bacteria (Jensen 1992). Part of the reason fecal coliform levels are high in urbanized areas is the contribution from sewer leaks and overflows. However, even when the collection systems are not leaking, urban runoff generally has high fecal coliform levels, and runoff occurs in much greater volumes than sewage leaks or overflows.

Neither septic systems along the shoreline nor permitted point source discharges are major contributors of fecal coliform bacteria to the bay as a whole (Jensen 1992). Locally, however, septic systems and permitted discharges can both be important contributors of bacteria. This is especially true for enclosed tributaries, as noted below in the discussion about water conditions in the bay that affect human activities. Runoff from totally undeveloped land also tends to be high in fecal coliform bacteria (TDH 1990), with low incidence of pathogenic organisms.

TCEQ recently completed development of a TMDL for the bacterial contamination of oyster waters in Galveston Bay (TCEQ 2009). Based on the recommendations of the TMDL process, the TCEQ adopted concentration limits for discharges from wastewater treatment facilities and municipal storm water discharges, while prohibiting discharges from ships, boats, and septic systems. Implementation of this load allocation plus incentives to reduce concentrations in unregulated discharges is expected to reduce the concentration of fecal coliform bacteria detected in potential shellfish harvest areas.

**Diseases Transmitted by Seafood**

Two groups of bacteria and two groups of viruses commonly cause illness after ingestion with seafood: *Vibrio* and *Salmonella* bacteria; and *Norovirus* and the hepatitis A virus. Marine toxins, such as brevetoxin, have also occurred in Galveston Bay, resulting in shellfish closures.

**Common Bacterial Pathogens**

Species of the bacterial genus *Vibrio* have been identified as pathogenic for humans with the potential to cause extreme illness and sometimes death. Several *Vibrio* species pose a concern in coastal waters, the most common being *Vibrio vulnificus*, which can cause rapid and devastating disease symptoms in humans. *V. cholerae* and *V. parahaemolyticus* are also commonly present in estuarine waters and do occur in Galveston Bay. *Vibrio* infection is usually associated with eating raw or undercooked shellfish, particularly oysters. The bacteria occur naturally in coastal waters and are most common in warm waters with a temperature range of 10 to 30º Celsius and a salinity range of 5 to 30 practical salinity units (FDA 2004; WHO 2005); conditions representative of Galveston Bay. *Vibrio* species are fast growing, food-borne pathogens of increasing concern for public health. In 2007, in the U.S., there were 549 *Vibrio* illnesses reported to the Centers for Disease Control and Prevention (CDC) and 36 deaths (CDC 2008). Between 1996 and 2004, 50 percent of the reported 549 *Vibrio* infections were caused by *V. parahaemolyticus* and 12 percent by *V. vulnificus* (Qadri et al. 2005).

Fecal coliform testing will not detect these estuarine bacteria, and their occurrence cannot be correlated to concentration of sewage or abundance of coliform bacteria. Therefore, they present a problem for current methods of certifying seafood and regulating harvest areas.
*V. parahaemolyticus* was first identified in Japan in 1950 and was first confirmed in the U.S. in 1971, when it produced an outbreak associated with consumption of steamed crabs. This bacterium causes gastroenteritis and occasionally sepsis with a mortality rate of approximately 1 percent (FDA 2004). One of the largest outbreaks of *Vibrio parahaemolyticus* ever reported, in the summer of 1998, was caused by oysters harvested from Galveston Bay waters (Daniels et al. 2000; DePaola et al. 2000; Myers et al. 2003). Between the end of May and early July 1998, 416 persons in 13 states reported cases of gastroenteritis after eating raw oysters harvested from the bay (Daniels et al. 2000). At the time, oyster beds met bacteriological standards and fecal coliform levels were within acceptable regulatory limits. This suggests that current policies regarding water quality testing associated with oyster harvests may need to be reevaluated.

*V. vulnificus* was first identified by the Center for Disease Control in 1976. In the USA it is the leading cause of death associated with consuming seafood, and has a fatality rate of nearly 40 percent (WHO 2005). Between 2004 and 2007, 23 to 40 percent of the *Vibrio* cases reported to CDC were due to exposure on the Gulf Coast, but all of the cases were sporadic (CDC 2009a). Between 1998 and 2002 about 70 percent of the cases were due to exposure on the Gulf Coast, but again, all of the cases were sporadic. *V. vulnificus* has not been associated with outbreaks, indicated by the stability of the number of exposures over the reporting period.

Sampling of oyster tissue indicates that *V. parahaemolyticus* and *V. vulnificus* are in all oysters harvested from Galveston Bay during the warm weather months (May–October). In order to protect consumers, time-to-refrigeration controls have been imposed upon the Texas oyster industry. Cooling of the oysters quickly after harvest limits the post-harvest growth of these very fast growing pathogens. Additionally, several processors have instituted post-harvest processes such as rapid freezing and storage that reduce *Vibrio* to non-detectable levels. For oyster consumers with compromised immune systems, the best advice is to avoid consuming raw oysters (Personal communication, K. Wiles, 2009, Texas Department of State Health Services).

Consumption of seafood is not the only mode of infection by pathogens in bay waters or on estuarine organisms. On rare occasions, *Vibrio vulnificus* can infect fishermen via puncture wounds from the fins of fish. Similarly, anglers and swimmers can be infected through any open wound exposed to pathogens in water or on the surface of organisms. Cholera and other *Vibrio* infections can also be acquired through ingestion of contaminated water, but this mode of infection appears much less likely in the Galveston Bay region than in less developed areas of the world.

Other types of bacteria are, of course, present in the waters of Galveston Bay. The density of human settlements around the bay (Figure 9.5) and the intensity of human use ensure the entry of human pathogens into the system. Research has shown that pathogenic bacteria, such as fecal *Streptococci*, *Salmonella* and *Clostridium botulinum* are able to survive for some time in estuarine waters (Colwell et al. 1978).

*Salmonella* bacteria are found in over 7 percent of the market oysters in this country. *Salmonella enterica* serotype *typhi* is associated with outbreaks of seafood borne illness and is responsible for the first documented large shellfish outbreak in the U.S. *Salmonella enterica typhi* has been identified in illnesses tied to consumption of oysters from Galveston Bay in 2003 (Gaul 2007). A more common species of *Salmonella*
in oysters is *S. enterica* serotype *newport*, which accounts for 78 percent of the *Salmonella* isolated from market oysters (Brands et al. 2005). The incidence of this major human pathogen does not appear to be related to the prevalence of fecal coliform bacteria.

Studies of the bacterial and viral contamination of the canals in bayside communities from Galveston Bay show that pathogens survive longer in the sediment than in the water column (Gerba et al. 1976; Smith et al. 1978). This suggests that the sediments of Galveston Bay hold a reservoir of an assortment of human pathogens at all times.

**Viruses**

Bacteria are not the only pathogens that should be included in a discussion of human health. Hepatitis A is caused by a virus that comes from the same family of viruses as the polioviruses and rhinoviruses (causal agent for the common cold). The hepatitis virus is excreted in the feces of infected persons and can contaminate water or food products, including shellfish. There is great concern that hepatitis may be contracted by consumption of raw or improperly cooked seafood. Incubation of the virus varies from 10 to 50 days, with the actual disease lasting one to two weeks. Once infected, a person will experience symptoms including fever, malaise, nausea, anorexia and jaundice. Because of the long incubation period, the suspected food is often no longer available for analysis. No satisfactory method is presently available for routine analysis of seafood for the hepatitis virus (USFDA 2009a). However, this mode of infection is very uncommon. For example, in 2006, there were 337 outbreaks of food-borne illness confirmed to have been caused by viruses. Only three of those outbreaks were caused by hepatitis A; 333 cases were caused by norovirus (CDC 2007).

Norwalk viruses, or norovirus, are the most common cause of outbreaks of food-borne illness. The only known reservoir for norovirus is the human intestinal tract, so outbreaks are linked to poor sanitation (CDC 2009b). These viruses can be ingested in a wide variety of raw or undercooked food, not just seafood. They can be accumulated in the gut of oysters, and outbreaks of acute gastroenteritis due to norovirus have been traced to the consumption of raw oysters from Texas. As recently as 2007, oysters from San Antonio Bay were implicated in a norovirus outbreak (News-Medical.Net 2007).
Other viruses that can be traced to raw or partially cooked shellfish include rotaviruses and parvo-like viruses. These can cause viral gastroenteritis resulting in symptoms such as nausea, vomiting, diarrhea, malaise, abdominal pain, headache, and fever (USFDA 2009b).

As in the case of bacteria, consumption of seafood is not the only potential route of viral infection for users of Galveston Bay. Transmission of poliovirus by ingesting water during contact recreation was a public health concern before the polio vaccine became available. Many swimming pools were closed during polio outbreaks. Viruses can attach to other particles and remain viable for days in the water or sediment of the bay (Sage, T. 2000. Personal communication, University of Houston-Clear Lake). This reservoir of viruses has an unknown impact on human health, although it is rare to find illnesses that are the result of ingesting water at estuarine or coastal locations (Yoder et al. 2008). The great majority of waterborne illnesses related to recreational water exposure are associated with swimming pools and lakes.

**Toxic Compounds in Water and Seafood**

Contamination of bay waters by toxic compounds has, thus far, involved mostly human-derived synthetic compounds. This may not be the case in the future, should Galveston Bay host blooms of biotoxic red tide organisms, which have produced health effects in bay users along the Florida and South Atlantic coast. Red tide, caused by the marine dinoflagellate *Karenia brevis* has closed shellfish beds in Galveston Bay.

**Monitoring of Toxics for Water Quality Assessment**

Monitoring of toxics includes sampling for metals and a wide variety of synthetic organic compounds. It is difficult to detect most of these chemicals in the water, so most of the measurements that cause concern are obtained from samples of the sediment where the compounds are likely to accumulate, or from seafood organisms in which some of the compounds bioaccumulate or biomagnify. The compounds that are of greatest concern in Galveston Bay at this time are dioxins, polychlorinated biphenyls (PCBs), and pesticides.

Monitoring of water and sediments suggest that nearly all of Galveston Bay has levels of contamination by toxic metals and synthetic organics that are below levels of health concern. However, there are notable exceptions. The waterbodies found near the center of Houston are surrounded by industrial facilities: lower Buffalo Bayou, lower San Jacinto River, lower Greens Bayou, Patrick Bayou and the Houston Ship Channel. Water samples from the Houston Ship Channel sometimes show concentrations of PCBs or dioxin that exceed the levels considered safe for human exposure. Sediment samples from the Houston Ship Channel (Figure 9.6) contain high levels of such contamination, but there are no health-based standards for sediment contamination (sediment contamination is assessed based on adverse ecological effects), and recreation is not allowed in the Houston Ship Channel due to acute risks presented by the shipping industry.
Human Health Effects from Toxics In Water and Sediment

Chapter 6 documents the degree to which the water and sediment of Galveston Bay are contaminated by toxic compounds. The problem is most acute in the segments of the bay adjacent to industrial and high-density urban development. All of these areas have the potential to be used for contact recreation or shellfish harvest. Thus, it is appropriate to develop plans that would improve management of the waters to reduce contamination and return them to the quality related to those potential uses.

In response to the contamination of seafood by persistent organic pollutants (POPs), a TMDL project was adopted for Buffalo Bayou and the Houston Ship Channel. Intensive studies of dioxins and PCBs in water, sediment, and biota have been performed (Correa et al. 2006; Howell et al. 2008). Sources of dioxin have been identified, and planning is under way to reduce the loadings of dioxin into the Houston Ship Channel to a safe level.

Toxicants in Seafood Organisms

The concentration of toxic compounds in Galveston Bay seafood has become a major issue for management of the bay in recent years. There is no established program to periodically monitor the contamination of seafood in Galveston Bay. However, the Texas Department of State Health Services has performed episodic studies over the last 20 years that have documented the problem and consequently, issued a number of health advisories (Table 9.1). One health advisory was issued a decade ago, and later canceled, for fish and crabs from Clear Creek. This site was being contaminated by leachate from a nearby Superfund site that was eventually contained (TDSHS 1993). In July 2009, TDSHS issued seafood consumption advisory ADV-37 for Clear Creek based on PCB contamination of fish. The contaminant source for this newest advisory on Clear Creek is unknown. Other seafood consumption advisories appear to be the result of contaminant sources that are associated with the Houston Ship Channel or its tributaries. The widespread contamination of seafood, detected by TDSHS and recognized in the bay-wide seafood consumption advisory ADV-35, issued in 2008 (TDSHS 2008b, 2008a), could have contributions from polluted river inflow.

Figure 9.6. The TCEQ regularly collects sediment samples from the Houston Ship Channel. Image courtesy Texas Commission on Environmental Quality.
Table 9.1. Seafood consumption advisories issued by the TDSHS for Galveston Bay since 1990.

<table>
<thead>
<tr>
<th>Year</th>
<th>Area</th>
<th>Species</th>
<th>Contaminant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Houston Ship Channel, Upper Galveston Bay</td>
<td>Catfish and blue crab</td>
<td>Dioxin</td>
</tr>
<tr>
<td>1993</td>
<td>Clear Creek (rescinded)</td>
<td>Catfish and blue crab</td>
<td>Volatile organic compounds (VOCs), chlordane</td>
</tr>
<tr>
<td>2001</td>
<td>Houston Ship Channel (between Lynchburg Ferry and US 90 Bridge)</td>
<td>All species of fish</td>
<td>Organochlorine pesticides, PCBs</td>
</tr>
<tr>
<td>2005</td>
<td>Houston Ship Channel, Upper Galveston Bay</td>
<td>Spotted Seatrout</td>
<td>PCBs</td>
</tr>
<tr>
<td>2008</td>
<td>Galveston Bay</td>
<td>Spotted Seatrout and all catfish species</td>
<td>PCBs, dioxins/furans</td>
</tr>
<tr>
<td>2009</td>
<td>Clear Creek</td>
<td>All species of fish</td>
<td>PCBs</td>
</tr>
</tbody>
</table>

Data on concentrations of toxic chemicals in estuarine organisms are important indicators of ecosystem health and provide critical information on human health risks related to seafood consumption and contact recreation. Thousands of compounds that could affect living organisms in an estuarine environment occur in runoff and effluents. The compounds described below belong to classes of chemicals known to be associated with human health risks. Whereas Chapter 6 characterizes the status and trends of these contaminants in sediments of the Galveston Bay ecosystem, the discussion below delineates the relationship between concentrations of contaminants found in bay seafood and risks to public health.

A very extensive series of health investigations by the TDSHS (TDSHS 1999; TDH 2000b, 2000c, 2000a, 2001a, 2001c, 2001d, 2001b) surveyed finfish and crabs from all regions of the Galveston Bay system for 7 metals, 27 pesticides, 7 PCBs, 92 semivolatile organic compounds, and 72 volatile organic compounds. These studies were followed by a 2004 analysis of contamination of fish and crabs in the Houston Ship Channel and Upper Galveston Bay (TDSHS 2005b). This study added the analysis of dioxins, which were omitted from the earlier analyses of this area. The results of the 2004 study generated serious concern about the levels of PCBs and dioxins in fish and crabs. The health risk documented in the 2004 to 2005 studies prompted further study of more areas of the bay. In 2006 and 2007, the TDSHS collected samples from Trinity Bay, Upper Galveston Bay, and Lower Galveston Bay, which were analyzed for the large suite of potential contaminants used in the 2004 to 2005 studies (TDSHS 2008b, 2008a). A recent study of Clear Creek was performed as part of TMDL implementation (TDSHS 2009). Below we describe the results of all of these studies by contaminant type, with a focus on the spatial and temporal patterns expressed in the fish tissue data.
Reactive Hydrocarbons
Phthalates are used to make plastics pliable. They are contained in many products but are not bonded to the carrier material. Thus, phthalates migrate into the environment from many sources and are now ubiquitous in the air, water, and food of developed countries. In the aquatic environment, they are very toxic to some species. Exposure of humans to phthalates over long time periods can result in damage to liver and testes (Crosby et al. 1998). These compounds have also been attributed to a causal effect on early puberty in girls due to their estrogen-like properties. The body burden of these compounds is related to the consumption of seafood and use of plastic food and drink containers (Chou et al. 2009).

Samples of fish tissue from Upper and Lower Galveston Bay tested positive for three phthalate compounds (TDSHS 1999; TDH 2001b). These were detected in a low percentage of the samples tested and were found at low concentrations. The same low level of contamination by phthalates was found in the TDSHS study of Galveston Bay seafood performed in 2006–07. Seven of 30 tested samples of fish and blue crab showed concentrations of one phthalate compound above the normal detection limit (TDSHS 2008c). This finding indicates that these compounds may not represent a significant risk to human health, according to TDSHS methodology.

Polycyclic Aromatic Hydrocarbons (PAHs)
PAHs are toxic compounds, some of which are carcinogens. They are absorbed by fatty tissues in living organisms and have the potential to bioaccumulate. Aquatic animals with gills are very sensitive to membrane damage from PAH molecules that are activated by the ultraviolet energy in light. Mammals are capable of rapidly oxidizing PAH molecules, but degradation may produce DNA damage and cancer (Brooks et al. 1992). PAHs are related to fossil fuel use. As environmental contaminants, they arise primarily from the discharge or combustion of petroleum products and other organic compounds. Major sources in the coastal environment include drilling operations and petroleum production, transportation activities, riverine inputs, and atmospheric deposition of products from fossil fuel combustion. PAHs are also introduced into the environment from some organic chemical reactions and from fires. Fires can emit PAHs whether the fuel is biomass, as in forest fires, or synthetic materials, as in waste incinerators. Because of the persistent and fat-binding nature of PAHs, it is not surprising that they have been frequently detected as a widespread contaminant in estuarine organisms.
Brooks et al. (1992) conducted a survey of five species of seafood organisms from four locations in the bay. The study analyzed for 24 individual PAHs and revealed total PAH concentrations ranging from non-detectable to 1,253 nanograms per gram (ng/g). Oysters had higher total PAH concentrations than fish and crabs, except at Hanna Reef. Concentrations found in the study were within the range of concentrations reported for Galveston Bay oysters as part of a national study. This study, which looked at oysters throughout the Gulf of Mexico, found that PAHs in Galveston Bay oysters were among the highest 25 percent of sample sites.

The evidence of PAHs in Galveston Bay finfish, however, is quite limited. In the 1999 study of organisms collected from the Houston Ship Channel, there is a single instance of naphthalene detected in a smallmouth buffalo collected in the Turning Basin of the Houston Ship Channel (TDH 2001b). In the 2004 study of the ship channel area, there was only one sample, a smallmouth buffalo fish, with detectable levels of two common PAH compounds: acenaphthalene and phenanthrene (TDSHS 2005b). Based on this evidence, PAHs do not occur in high enough frequency or concentration in Galveston Bay fish to present a public health concern.

**Chlorinated Hydrocarbons**

Most attention to this class of toxic compounds has been focused on pesticides and polychlorinated biphenyls (PCBs). We will treat these categories separately because they are associated with very different health risks at this time.

**Pesticides**

Pesticides studied by TDSHS included DDT and related degradation compounds DDD and DDE; chlordane; aldrin (which degrades to dieldrin); heptachlor (which degrades to heptachlor epoxide); endrin; and lindane. The use of some of these toxic and persistent compounds has been banned or severely restricted in most developed countries because of their tendency to bioconcentrate in food chains and their adverse effects on living organisms.

Health effects of pesticides can include such short-term effects as tremors, convulsions, mental confusion, depression, anemia and even certain types of leukemia (EPA 2001). Long-term effects of human exposure to some forms of synthetic pesticides can include liver and kidney damage, damage to the central nervous system, and cancer. Studies reveal that in spite of the current bans, a variety of organochlorine residues exist in Galveston Bay organisms and sediment (see Table 9.2). Compounds most commonly found included DDT metabolites and occasionally dieldrin and chlordane.

Portions of Clear Creek appeared on the Texas 2000 Clean Water Act Section 303(d) List for elevated levels of chlordane and the volatile organic chemicals dichloroethane, trichloroethane, and carbon disulfide (TCEQ 2000). The TMDL study performed for chlordane in two segments of Clear Creek found that natural attenuation of this banned pesticide should result in decline of concentrations in fish (TCEQ 2010). TMDL implementation plans were completed for the volatile organic pollutants detected in fish from Clear Creek and were approved by TCEQ in 2001. The concentrations of these tissue contaminants in organisms sampled from Clear Creek have, in fact, declined to the extent that the seafood consumption advisory was rescinded in 2001.
The 1999 TDSHS health consultations assayed Galveston Bay seafood for chlorinated hydrocarbons. Concentrations of chlorinated hydrocarbons in tissue of finfish and blue crabs were analyzed from all parts of the bay system. Finfish from the Houston Ship Channel and the Lower San Jacinto River had high concentrations of these chemicals. The concentrations of chlordane were sufficient to justify a seafood consumption advisory (ADV-20) for catfish and crabs in the Houston Ship Channel. Subsequent sampling of the Houston Ship Channel and nearby areas of Upper Galveston Bay in 2004, 2006 and 2007 showed that the pesticide contamination of finfish has declined (see Table 9.2). Sampling of the Houston Ship Channel and nearby areas of Upper Galveston Bay in 2004 showed that the pesticide contamination of finfish has declined (see Table 9.2).

One cause for continuing concern regarding chlorinated hydrocarbons is the wide distribution of these compounds in the bay system. The initial study of tissue contamination of Galveston Bay seafood documented detectable concentrations of several common pesticides (e.g., chlordane and DDT) from multiple regions of the bay, including Christmas Bay (TDSHS 1999; TDH 2000b, 2000c, 2000a, 2001a, 2001c, 2001d, 2001b). The most recent studies of areas of the bay distant from the Ship Channel show that tissue contamination decreases in samples collected in the lower part of the bay system (Table 9.2) (TDSHS 2008b, 2008a).

The TDSHS study of contamination of seafood based on samples of fish and blue crabs collected in 2006 to 2007, from multiple sample locations in the upper and lower bay, is the best source of information about the current condition of seafood in Galveston Bay (TDSHS 2008b, 2008a). Thirty-four pesticides or breakdown products of pesticides were analyzed. In the samples from the upper bay, there were four compounds that occurred at levels above the normal detection level in more than 10 percent of the samples. These were hexachlorobenzene, chlordane, 4,4´ DDD and 4,4´ DDE. In samples from the lower bay sites, three compounds were measured above normal detection limits in more than 10 percent of the cases. These were chlordane, dieldrin and 4,4´ DDE. When the mean values are compared to the health assessment comparison (HAC) values calculated and used by the TDSHS (in Table 9.2), the concentrations are not a significant risk to human health.

Another cause for concern is the continued spraying of pesticides for mosquito control. These pesticides contaminate aquatic habitats that support fish and shellfish. Fish kills in local streams and bayous may be the result of local mosquito control spraying, as was found in streams in Alabama (Young et al. 1951), though no studies in the Galveston Bay watershed have been done. Very low concentrations of pesticides have been shown to kill juvenile shrimp (Chin et al. 1957) and may be reducing the population of this important fishery.
PCBs

PCBs are classified as suspected human carcinogens and known animal carcinogens. The health effects of PCBs include disruption of reproductive function; neurobehavioral deficits, especially in children exposed \textit{in utero}; liver, thyroid, and immune system damage; and increased probability of cancer, especially non-Hodgkin’s lymphoma. In the U.S., the most significant pathway for exposure is consumption of contaminated seafood (Johnson et al. 1999).

Jackson et al. (1998) examined the concentration of PCBs in oysters collected from six sites in the bay, from 1986–94. The study confirmed that PCB concentrations are trending down in Galveston Bay oysters. However, most collection sites showed PCB levels above the median for Gulf of Mexico collection sites. In the same study, DDT showed a general decreasing trend, except at the most polluted site, the Houston Ship Channel, and the least polluted site, Hanna Reef, which exhibited no trend.

Table 9.2. Tissue Contamination Samples from Galveston Bay as compared to the TDSHS HAC values. Data sources: TDSHS Health Consultations and USEPA (2009).

<table>
<thead>
<tr>
<th>Sample Area</th>
<th>Sample Year</th>
<th>No. Detections/No. Samples</th>
<th>Average Concentration (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston Ship Channel (HSC)</td>
<td>1999</td>
<td>4/18</td>
<td>0.010 0.044 0.005 0.763 0.025 0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSC and Upper Galveston Bay</td>
<td>2004</td>
<td>1/35</td>
<td>0.010 0.005 0.000 0.115 0.002 0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trinity Bay and Upper Galveston Bay</td>
<td>2006–07</td>
<td>19/110</td>
<td>0.001 0.005 0.000 0.010 0.000 0.011</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Galveston Bay</td>
<td>2006–07</td>
<td>2/72</td>
<td>0.000 0.002 0.000 0.001 0.001 0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 TDSHS HAC Values (mg/kg)</td>
<td></td>
<td>1.167</td>
<td>1.167 — 1.167 — 1.867</td>
</tr>
</tbody>
</table>

**Table 9.2.** Tissue Contamination Samples from Galveston Bay as compared to the TDSHS HAC values. Data sources: TDSHS Health Consultations and USEPA (2009).
Table 9.3. Mean Concentrations of PCBs Detected in Finfish by Several Studies of Galveston Bay as compared to TDSHS Health Assessment Comparison HAC values (TDH 2001b; TDSHS 2005a; Rifai et al. 2008; TDSHS 2008b, 2008a).

<table>
<thead>
<tr>
<th>Sample Area</th>
<th>Sample Year</th>
<th>No. Detections / # Samples</th>
<th>Mean Concentration of PCBs (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston Ship Channel</td>
<td>1999</td>
<td>3/18</td>
<td>0.045*</td>
</tr>
<tr>
<td>Houston Ship Channel and Upper Galveston Bay</td>
<td>2004</td>
<td>11/35</td>
<td>0.096*</td>
</tr>
<tr>
<td>Trinity Bay and Upper Galveston Bay</td>
<td>2006</td>
<td>110/110</td>
<td>0.051**</td>
</tr>
<tr>
<td>Lower Galveston Bay</td>
<td>2006–07</td>
<td>72/72</td>
<td>0.039**</td>
</tr>
<tr>
<td>Houston Ship Channel (Rifai and Palacheck)</td>
<td>2008</td>
<td>25.6 percent Non-detect</td>
<td>0.137 (catfish)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.285 (seatrout and croaker)</td>
</tr>
<tr>
<td>2008 TDSHS HAC Values (mg/kg)</td>
<td></td>
<td></td>
<td>0.047</td>
</tr>
</tbody>
</table>

*B​ased on analysis of Aroclor mixtures

**B​ased on analysis of PCB congeners

Early studies of PCBs measured the concentrations of aroclor mixtures and detected the contaminant in less than half of the fish sampled (TDH 2001a, 2001c, 2001d, 2001b; TDSHS 2005b). The most recent studies measured the concentrations of single and multiple PCB congeners and detected the compounds in all of the finfish sampled (TDSHS 2008b, 2008a). The change in methodology makes it difficult to determine whether there has been any trend over time. However, results indicate that PCBs may represent a significant health concern for consumers of Galveston Bay seafood. The results of the most recent health consultations resulted in TDSHS issuing a seafood consumption advisory for PCBs, dioxins and furans in catfish and spotted seatrout from all of Galveston Bay, and for all fish from Clear Creek (TDSHS 2009).

**Dioxin and Furans**

Polychlorinated dibenzo-\(p\)-dioxins (referred to herein as dioxins) and polychlorinated dibenzofurans (referred to herein as furans) are toxic, highly stable substances that bind strongly to soil and sediments, making them extremely persistent in the environment. These compounds can occur naturally, but the most significant sources today are incinerators of chlorinated wastes. Dioxins are also by-products of paper bleaching.
Dioxins and furans are capable of affecting health, even when present at very low concentrations. The toxicity response in experimental animals is unusual. After exposure to a lethal dose, the animals stop eating and can die from starvation or toxic effects. Other responses include immunotoxicity and carcinogenicity. Several compounds in this group are probable human carcinogens (Malachowski 1995; ATSDR 1999).

Elevated levels of these compounds in the Houston Ship Channel and nearby waters have resulted in the issuance of a TDSHS seafood advisory and the development of a TMDL. In the recently completed TDSHS health consultation studies performed in 1998 to 2000, dioxins and furans were assayed from finfish and blue crab tissue in Lower Galveston Bay, Christmas and Bastrop Bays, and Clear Lake. Dioxins were detected in all three areas. The most commonly detected dioxin congeners were 2,3,7,8-tetrachlorodibenzofuran (TCDF), 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), and octachlorodibenzo-p-dioxin (OCDD) (TDSHS 1993, 1999; TDH 2000b, 2000c, 2000a, 2001a, 2001c, 2001d, 2001b). The concentrations of all of the detected dioxins and furans were combined in a formula that weighted each of the compounds based on their toxicity relative to TCDD, yielding a TEQ or toxicity equivalent measure. These results led to concerns about the distribution and concentration of dioxins in seafood and to further studies performed from 2004 to 2007 (TDSHS 2005a, 2008b, 2008a).

Table 9.4. Total Dioxin Concentrations Detected in Finfish by Several Studies of Galveston Bay as compared to TDSHS Health Assessment Comparison (HAC) values. Data sources: (Rifai et al. 2005; TDSHS 2005a, 2008b, 2008a).

<table>
<thead>
<tr>
<th>Sample Area</th>
<th>Sample Year</th>
<th>No. Detections / No. Samples</th>
<th>Average PCDF/PCDD in Toxicity Equivalents (pg/g)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston Ship Channel (catfish only)</td>
<td>2004</td>
<td>52/52</td>
<td>6.14</td>
</tr>
<tr>
<td>Houston Ship Channel and Upper Galveston Bay</td>
<td>2004</td>
<td>28/35</td>
<td>1.60</td>
</tr>
<tr>
<td>Trinity Bay and Upper Galveston bays</td>
<td>2006</td>
<td>43/43</td>
<td>1.05</td>
</tr>
<tr>
<td>Lower Galveston Bay</td>
<td>2006–07</td>
<td>11/14</td>
<td>0.75</td>
</tr>
<tr>
<td>2008 TDSHS HAC Values (pg/g)*</td>
<td></td>
<td></td>
<td>2.33</td>
</tr>
</tbody>
</table>

*picograms/gram

The announcement of high levels of dioxin contamination in Galveston Bay seafood was followed by intensive study of the levels and sources of these contaminants for a TMDL (Rifai et al. 2005). This study showed the relationship between dioxin concentrations in water and sediment to the concentrations in...
catfish and crabs. It also showed a spatial relationship between concentration of dioxin in water and the location along the connection between Buffalo Bayou and the Houston Ship Channel. Dioxin levels were highest in a stretch of the channel between Greens Bayou and the San Jacinto River. Subsequently, a major source of dioxins was identified in that area. Once this source has been eliminated, or the release stabilized, dioxin contamination should decline.

Tissue contamination in catfish and crabs was assessed by the TMDL study group in several species of fish and crabs. Ninety-five of 97 samples of crabs and catfish collected for this study exhibited dioxin concentrations in excess of the EPA’s health based standard of 0.47 ng toxicity equivalent (TEQ) per kg of tissue. The average toxicity equivalent level in the catfish samples was 6.14 ng TEQ per kg (Riai et al. 2005). Subsequent testing of seafood organisms for contamination by dioxins and furans in 2006 and 2007 showed detectable levels in all fish species sampled from Trinity Bay and Upper Galveston Bay, and an average concentration only slightly less than that measured from all fish species sampled in the Houston Ship Channel in the 2004 TDSHS study. The mean concentration measured in fish collected from Lower Galveston Bay was lower than that detected in the upper bay, but these contaminants were detected in 79 percent of the fish tested (TDSHS 2008a) (Table 9.5).

**Figure 9.8. Current Seafood Consumption Advisories in Galveston Bay.** Data source: TDSHS.
In 2008 an advisory was issued for spotted seatrout and catfish throughout the bay due to PCB and dioxin contamination. All of the studies of dioxin and PCB pollution suggest that most of these contaminants entered the food chain in, or near, the Houston Ship Channel (Rifai et al. 2005). However, due to the mobility of fish and the connectedness of the food web throughout the bay system, ADV-35 covers Trinity, East, West and Galveston bays. Most recently, ADV-37 has been issued specifically for PCB contamination in Clear Creek (TDSHS 2009). This indicates that dioxin contamination is more limited in scope than PCBs. All of the current seafood consumption advisories are shown in Figure 9.8.

**Trace Metals**

Bivalves are often assayed for concentration of metals in their tissues as a component of water quality studies. Adult bivalves are fixed in place and pass large volumes of water through their shell and over their tissue as they feed. Metal atoms and compounds are ingested with food particles or absorbed. The metals can be deposited in soft tissue or in shell, and their concentrations in tissue or shell serve as short-term or long-term indicators of past water quality. Other organisms, principally finfish and crustaceans, are also used to assess the potential health effects of seafood consumption, but their mobility introduces uncertainty into the relationship between contaminant concentration and sample location.

Those metals found in the tissue of seafood and of greatest health concern for consumers of seafood are mercury, arsenic, lead, and cadmium. Each of the metals has different effects on human development and physiology. Physiological and developmental effects on humans can vary depending upon the person’s age and health condition. Children, pregnant women, the elderly, and those with certain preexisting health conditions are among the most susceptible to metals contamination.

Mercury is known to cause neurological dysfunction and can bind sulphhydryl groups to inhibit respiratory enzymes (Crosby and Crosby 1998). Chronic exposure to cadmium results in liver and kidney damage (Malachowski 1995). Chronic exposure to low levels of arsenic increases the chance of skin and lung cancer. Symptoms of chronic arsenic exposure include gastrointestinal distress, hyperpigmentation, thickening of the skin of the palms and soles, and several neuropathies. Lead contamination is a common environmental problem, especially for children. Chronic exposure to lead can affect the nervous system, cause small increases in blood pressure, and anemia. Exposure to high lead levels can severely damage the brain and kidneys in adults and children and can cause reproductive problems in both women and men. Physiologically, lead can replace calcium in bone tissue and compete with calcium in nerve function. Lead is also able to block the synthesis of heme, which is required to synthesize hemoglobin (Crosby and Crosby 1998).

Brooks et al. (1992) analyzed fish, crabs, and oysters in Galveston Bay for a suite of trace metals. They found concentrations similar to the EPA National Status and Trends findings, with the exception of zinc. Values for zinc were lower in the study by Brooks et al. than in the EPA report, and did not correlate with urban and industrial areas, as determined in the National Status and Trends work. In general, Brooks et al. found no strong relationship between metals in fish tissue and proximity to industrial discharges. The metal concentrations appeared to have no geographical pattern in their distribution.
Toxic metals were included in all of the TDSHS health consultations (TDH 1999, 2000b, 2000c, 2000a, 2001a, 2001c, 2001d, 2001b; TDSHS 2005a, 2008b, 2008a, 2009). The average concentrations for mercury, lead, arsenic and cadmium in some study areas are shown in Table 9.5. Toxic metals were observed in the tissue of seafood from all areas of the bay system and in all years. The distribution of concentrations is approximately what would be expected based on a correlation with industrial and urban inflow. We have omitted from Table 9.5 the early studies of metal concentrations in some areas and selected to focus on the Houston Ship Channel area and Lower Galveston Bay.


<table>
<thead>
<tr>
<th>Sample Area</th>
<th>Year</th>
<th>No. Detections/No. Samples</th>
<th>Finfish Only</th>
<th>Arsenic*</th>
<th>Cadmium</th>
<th>Lead</th>
<th>Mercury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston Ship Channel</td>
<td>1999</td>
<td>4/24 5/24 23/24</td>
<td></td>
<td>0.002</td>
<td>0.005</td>
<td>0.103</td>
<td></td>
</tr>
<tr>
<td>Lower Galveston Bay</td>
<td>1999</td>
<td>30/65 32/65 14/65</td>
<td></td>
<td>0.03</td>
<td>0.011</td>
<td>0.031</td>
<td></td>
</tr>
<tr>
<td>Houston Ship Channel</td>
<td>2004</td>
<td>2/9 0/21 5/21 14/21</td>
<td>0.01</td>
<td>0.00</td>
<td>0.023</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Trinity Bay and Upper Galveston Bay</td>
<td>2007</td>
<td>40/43 0/43 16/43 43/43</td>
<td>0.609</td>
<td>0.00</td>
<td>0.106</td>
<td>0.139</td>
<td></td>
</tr>
<tr>
<td>Lower Galveston Bay</td>
<td>2007</td>
<td>33/33 33/33 33/33 33/33</td>
<td>0.716</td>
<td>0.00</td>
<td>0.025</td>
<td>0.097</td>
<td></td>
</tr>
</tbody>
</table>

2008 TDSHS HAC Values (mg/kg)  
0.07 0.47 0.60 0.70

* Total arsenic; approximately 90 percent is non-toxic organic form
As seen in Table 9.5, arsenic was not tested in the early studies, but it is clearly present in multiple species. Cadmium appears to be a contaminant of the past. It was below detection limits in the most recent samples. Lead levels have not declined as it is a very persistent contaminant, but the levels are too low to be classified as a health risk. Mercury shows a striking increase in concentration between the early and recent studies. Again, the observed values, so far, are too low to be classified as a health risk for consumers of contaminated seafood, but the increase should be cause for concern.

**Marine Biotoxins**

Some species of phytoplankton produce toxins that accumulate in the tissues of shellfish and can, when ingested by humans, cause illness. Several of the most notorious phytoplankton-related pathologies include amnesic shellfish poisoning (ASP), paralytic shellfish poisoning (PSP), ciguatera fish poisoning (CFP), and neurotoxic shellfish poisoning (NSP). The toxins are heat stable and are not destroyed by cooking. Unfortunately, it is difficult to measure the true occurrence of these illnesses as they are frequently misdiagnosed or are not reported at all.

The organism responsible for red tide algal blooms (*Karenia brevis*) (Figure 9.9) produces a substance known as brevetoxin. When this toxin is ingested by humans, NSP can result. Symptoms may include dizziness and nausea and, although not life-threatening, can be debilitating. *K. brevis* can also cause respiratory irritation when the neurotoxin becomes airborne through wave action. During the summer of 2000, a large occurrence of red tide was observed along the Texas coast from Galveston to Padre Island. High concentrations of toxic algae were detected in Lower and Upper Galveston Bay. The Galveston Bay oyster fishery was closed as a result of high brevetoxin concentrations.

The reported frequency of toxic algal blooms has been increasing globally. While no causal factor has been documented, coastal water pollution probably plays a role. Standard water quality parameters indicate the quality of Texas’ coastal waters is improving, but—in a seeming paradox—the frequency, size, and duration of toxic or noxious algal blooms are increasing.

**Drowning**

Pathogens and toxic contaminants are not the only sources of human health risk associated with Galveston Bay. The most acute and lethal impact of Galveston Bay occurs when someone drowns in its waters. Drownings in the bay can be related to boating and fishing accidents, swimming in areas where dangerous currents are present, and flood waters. While there is an inherent risk involved when participating in...
activities on the bay, drownings are actually more common in the surf along the Gulf beaches of the Texas coast and in local swimming pools.

Drownings in Galveston Bay also occur as a result of catastrophes. It is estimated that 6,000 to 8,000 people died in the 1900 hurricane (GCDN 2009);—many of whom were swept off the Bolivar Peninsula and Galveston Island and subsequently drowned in the waters of the bay. More recently, of the 47 deaths caused by Hurricane Ike in September 2008, 18 percent were due to drownings that occurred in and around the bay (Zane et al. 2008).

Managing Risks to Human Health

Records from 1997 through 2001 indicate that Galveston Bay seafood landings account for more than 60 percent of Texas’ white shrimp landings, 36 percent of brown and pink shrimp landings, 28 percent of blue crab landings, and 91 percent of oyster landings (Culbertson et al. 2004). Seafood from Galveston Bay is distributed in a national commercial market. Recreational catch is also consumed by a wide array of people. The number of consumers and the potential for harmful contaminants in seafood are cause for concern due to the risks associated with consumption of contaminated Galveston Bay seafood.

*What is the health risk associated with eating our seafood? Generally, but not always, the health risk is negligible. This is especially true for commercially caught fish and shellfish, which tend not to come from the most contaminated portions of the upper estuary, and which are subject to regulation for health protection. Seafood from some areas of the bay contains generally low but variable concentrations of toxic chemicals that can pose health risks, especially to developing fetuses and children, under certain conditions.*

The responsibility for protecting the health of citizens from the risk factors identified is distributed among several Texas state agencies. The TDSHS is responsible for assessing and managing the risks associated with seafood consumption. The TDSHS classifies shellfish harvest areas and issues seafood advisories. The TCEQ is responsible for classifying water bodies, including sections of the bay and its tributaries, according to their ability to support the traditional uses of contact recreation and fishing. The Texas Parks and Wildlife Department enforces boater safety regulations.

These state agencies are supported in their roles by federal agencies. In 1995, the U.S. Food and Drug Administration passed new seafood safety regulations based on the Hazard Analysis Critical Control Point (HACCP) system. These regulations must be followed by all seafood processors engaged in interstate seafood commerce, which includes all of the wholesalers of Galveston Bay seafood. Rather than focusing on the end-product, HACCP controls are implemented in all stages of processing and shipping. The federal Centers for Disease Control monitor food-borne and waterborne illnesses and work to reduce their occurrence. The EPA supports water quality monitoring projects and the establishment of criteria for quantifying risk from exposure to specific compounds. The Coast Guard cooperates to enforce boater safety regulations.
Seafood Safety in Perspective

By L. James Lester

For most people who manage or use Galveston Bay, health concerns take precedence over concerns about recreational opportunities or conservation. We have described, in detail, the risks to human health associated with the use of Galveston Bay and its resources, but it is important to put these risks in perspective. For example, when considering the risks associated with seafood consumption, it is important to consider the scope of commercial and recreational fishing activities, the quality of the seafood caught, and the management systems that are in place to protect that quality.

Galveston Bay has two major commercial fisheries: shrimping and oystering. The shrimp captured in Galveston Bay have little risk if cooked and handled properly. These animals spend several months as juveniles in the bay and do not accumulate high concentrations of chemical contaminants. Also, they do not filter bacteria and toxic algae from the water, as do oysters. If they live in polluted water, the pathogens would be primarily on their shell, which is discarded before eating. Also, they are consumed after cooking, which normally destroys pathogens.

Oysters have been the cause of disease outbreaks and individual illnesses, mainly because they often are consumed raw. The outbreaks are usually from viral and bacterial pathogens introduced in the shellfish environment from a human source. Management systems are in place to prevent harvest and sale of oysters contaminated by human-derived pathogens. Normally, these systems prevent the harvest of oysters from waters with levels of coliform bacteria that indicate health risks. Also, handling methods are prescribed to minimize the chances of pathogen growth after harvest. Considering the millions of people who contribute wastewater discharges to the tributaries of this bay, it is quite remarkable that it supports a major oyster fishery associated with rare health effects. Some of the health effects caused by consumption of oysters are due to *Vibrio* organisms, which occur naturally, independent of human wastewater. *Vibrio* species can be found on the exterior of fish and in the flesh of oysters. They are not associated with a source that can be regulated. Thus, the presence of *Vibrio* does not represent any failure on the part of management agencies to protect the population of consumers. Persons with compromised immune systems should refrain from consuming raw oysters.

The commercial shrimp fishery and the recreational fishery, as well, also capture substantial quantities of some fish that are marketed for human consumption. There are rules about sale of certain fish species captured in Texas waters, but those are not based on health concerns. Fish are normally consumed after cooking, so there are no pathogens that would represent a health risk. This would be different if the fish were consumed raw. The health problem associated with cooked fish is chemical contamination. Once contamination is demonstrated, regulatory programs are employed to restore water quality to maintain the use of that water body for fishing. While these procedures are in operation, fishing in Galveston Bay is not restricted, although advisory warnings are posted at public access points. In general, risk from consumption of Galveston Bay fish is managed by the consumer, using whatever knowledge he or she has.
Only some species carry high enough body burdens of contaminants to be of concern. Most of the fish in Galveston Bay are considered safe to eat according to the risk assessment from TDSHS. Contaminated fish are not the only route of exposure to the chemical contaminants that resulted in seafood consumption advisories for Galveston Bay seafood. PCBs can be ingested in any animal product with fats, such as meat and dairy. Dioxin is also present in other animal products. Earlier seafood consumption advisories included pesticides. U.S. citizens get most of their exposure to pesticides from consumption of fruits and vegetables, not fish. In contrast, fish and shellfish are the largest sources of mercury exposure (CDC 2005). It is also worth noting that the testing of seafood, while very extensive, does not include all possible chemicals that could have a health risk associated with consumption.

We are just beginning to recognize the effects of pharmaceutical contaminants on aquatic organisms. It is likely that seafood contains low levels of physiologically active drugs, the effects of which are not known.

We will always have issues surrounding the quality of our food supply. Ancient peoples developed dietary taboos to deal with food safety issues. The trend in modern society is to monitor for health risks and regulate the commercial supply chain to minimize risks. This has been as effective as could be expected in Galveston Bay and will be improved in the future. One remaining challenge is to protect people who are consuming seafood from a non-commercial supply chain and who may be difficult to communicate with. Another is to be proactive in monitoring for emerging risks before they are expressed as serious health concerns. We must also determine how contaminants move through the food web of Galveston Bay. Finally, future contamination must be prevented and existing sources of contaminants must be cleaned-up.

To maintain the safety of Galveston Bay seafood, the management system must remain vigilant in protecting water quality from the threats of an ever increasing population. Water quality will ultimately determine whether seafood taken from Galveston Bay is safe for consumption.

—Kirk Wiles, Seafood and Aquatic Life Group, Texas Department of State Health Services
Seafood Consumption

Classification of Shellfish Beds
The consumption of oysters, especially raw, can pose a significant health risk because oysters can concentrate bacterial and viral pathogens in their tissues. The TDSHS Seafood Safety Division is responsible for regulating the harvest of oysters to protect the public from this health risk. Alternatively, the TCEQ is responsible for regulating water quality in areas designated for shellfish harvest via the Texas Surface Water Quality Standards. Harvest areas are classified by the TDSHS based on the observed concentrations of fecal coliforms in the water around the oyster reef. Oyster reefs can be closed on an emergency basis when pathogens or other harmful agents are detected in the water or in the oyster tissue. This type of closure occurred in the summer of 2000 due to red-tide toxins in the oysters, and in the summer of 1998 due to *Vibrio parahaemolyticus* infections in consumers. More recent closures have been due to large inflows of flood waters containing pollutants. For example, oyster harvesting was closed after Hurricane Ike caused oil and chemical spills and pushed large amounts of debris into the bay.

Shellfish Closures

Trends in the Shellfish Harvest Area
The TDSHS periodically produces maps as regulatory tools to designate shellfish harvest area classification in Texas bays. Harvest areas are classified as approved, conditionally approved, restricted, or prohibited. All shellfish harvested in Texas waters must come from approved or conditionally approved areas. Conditionally approved areas remain subject to classification changes based upon meteorological conditions that influence runoff. Oysters may be transplanted from restricted areas to private leases and harvested after a specified depuration period.

Shellfish harvest area maps published by the TDSHS in 2003 and 2009 have been analyzed for spatial changes in the four

Figure 9.11. Change in shellfish harvest classification areas, 2003 versus 2009. Data sources: (TDH 2003; TDSHS 2010).
classifications, as shown in Figure 9.11. The classifications of most potential shellfish harvest areas have remained the same. Changes between the 2003 and 2009 maps of oyster harvest area classifications are summarized in Figure 9.12.

![Figure 9.12. Change in shellfish harvest classifications, by acreage, 2003 versus 2009. Data sources: (TDH 2003; TDSHS 2010).]

Because of high bacteria levels, the Houston Ship Channel remains prohibited to oyster harvests while the northern portion of Trinity Bay, the western shoreline of Galveston Bay, the eastern end of East Bay, and portions of West Bay remain restricted to harvests. Two notable changes have been made in the oyster harvest areas, indicating improved water quality (see Figure 9.11). First, two areas, one north of the Texas City Dike, and one west of the Deer Islands, have changed from restricted to approved. Second, several areas along the eastern fringe of Trinity Bay have been changed from restricted to conditionally approved, as has an area in the upper bay, east of the Houston Ship Channel. These areas were reclassified after a period of drought. Runoff is a major contributor to fecal coliform concentrations in bay waters, so the improvement in oyster waters may not be the result of better management.

Changes indicative of declining water quality can also be found. First, two small areas—one near Smith Point, and the other near Bastrop Bay—have been changed from approved to restricted. Second, an area in the middle portion of Galveston Bay has changed from approved to conditionally approved.
Seafood Risk Assessments

Seafood risk assessments are conducted by sampling a variety of organisms at multiple collection sites. The analytical methods follow standard procedures for the compounds to be screened. The selection of compounds is usually extensive in order to capture unrecognized risks. The array of health assessments performed on Galveston Bay by responsible management agencies has been introduced above.

Brooks et al. (1992) analyzed contaminants in five species of seafood organisms from four sites. Heavy metals, hydrocarbons, pesticides and PCBs were measured in oysters, blue crabs, spotted seatrout, black drum, and southern flounder. They concluded that the risk from consuming oysters taken from Morgan’s Point and fish from Morgan’s and Eagle Points was estimated to be higher than the risk of consuming oysters or fish from other locations. A person who consumed large quantities of seafood would exceed the EPA benchmark risk at all sites examined in that study. This additional risk from consumption of Galveston Bay seafood has been confirmed by subsequent studies. For cancer risk, consumers eating weekly meals of seafood from locations in Galveston Bay are at risk above a benchmark level used by the EPA, according to TDSHS (ADV-3, ADV-20, ADV-28 and ADV-35).

In the first comprehensive TDSHS health consultations (1999 to 2005), several finfish species and blue crab were collected from 35 sample sites in eight areas of the bay system. These tissue samples were tested in the laboratory for metals, pesticides, semivolatile organic compounds, and volatile organic compounds. Samples from some of the locations were also tested for dioxins and furans, as well as organotin compounds. The levels of contamination detected by this testing are described above.

The second comprehensive TDSHS study of potential health effects from Galveston Bay seafood was conducted in 2006 to 2007 for Trinity Bay–Upper Galveston Bay and Lower Galveston Bay. Six sites were sampled for the characterization of Trinity Bay and Upper Galveston Bay, and 10 sites were sampled to characterize Lower Galveston Bay. The study analyzed 110 fish and 12 composite crab samples from the upper bay sites, and 72 fish and 10 crab samples from the lower bay sites. All of the samples were analyzed for pesticides and PCBs, but subsamples were used to study other groups of contaminants. The quantitative results of this testing are discussed above.

Once the concentrations of the various contaminants are known, they can be used to estimate risk from human exposure. This requires assumptions about the number of meals per week or month that would contain Galveston Bay seafood and how much of that seafood would be consumed per meal. Based on EPA recommendations, the TDSHS is conservative in assuming that there are significant numbers of subsistence fishers consuming regular meals of seafood sourced from Galveston Bay.

The TDSHS recently evaluated potential health risks associated with the consumption of fish and crabs from all parts of Galveston Bay (TDSHS 2008b, 2008a). Estimated contaminant exposures from Galveston Bay seafood were compared to health-based assessment comparison values obtained from the EPA and the Agency for Toxic Substances and Disease Registry (ATSDR). The criterion level is the contaminant concentration yielding the highest estimated exposure that is unlikely to cause adverse health effects. All exposure estimations assumed that a person weighing 70 kg was exposed to Galveston Bay seafood at a rate.
of eight ounces per meal, usually once per week. Carcinogenic and non-carcinogenic health effects were assessed. Cancer risks assumed an exposure period of 30 years.

The recent TDSHS health effects characterizations of Galveston Bay seafood concluded that contaminant concentrations detected in organisms sampled from most portions of Galveston Bay did not exceed comparison values, with the exception of contamination of gafftopsail catfish and spotted seatrout from dioxin and PCBs. Thus, non-carcinogenic health effects are not likely to result from an average person consuming one 8-ounce meal of seafood per week. The studies also found that there is a less than one in 10,000 chance of an additional cancer case from consumption of seafood harvested from most areas of Galveston Bay, with the exception of the Houston Ship Channel-San Jacinto River area. The results of the study are described below.

In July 2009, ADV-37 was issued by TDSHS, recommending no consumption of fish from Clear Creek because of high levels of PCBs in fish tissue (TDSHS 2009). The levels in some of these freshwater fish were substantially higher than the comparison levels employed. This problem did not exist, or was not detected, in earlier sampling of this tributary (TDSHS 1993).

**Risk by Toxicant Type**

**Pesticides**

The concentrations of chlordane, DDE, DDD, dieldrin, heptachlor epoxide, and hexachlorobenzene in the Houston Ship Channel and elsewhere, detected by earlier TDSHS health assessments, are cause for concern regarding chronic low exposure level effects. The EPA chronic oral reference dose for chlordane is 0.0005 milligrams per kilogram per day (mg/kg/day) and for dieldrin, 0.00005 mg/kg/day. This is the value used to assess non-cancer health effects from intake of the compound. Only the chlordane concentration measured in fish in the Houston Ship Channel Turning Basin, collected for the 1999 study of health risks, has yielded an exceedance of the reference dose, from weekly consumption of one meal (TDSHS 1999). The estimated risks of non-cancer effects from the other detected pesticides at all other sites sampled in that health study were less than the comparison criteria calculated by the TDSHS.

Using assumptions about the relationship between chronic intake dose and development of cancer, the 2008 TDSHS health assessment (TDSHS 2008b, 2008a) estimated theoretical cancer risks from the consumption
of seafood taken from the Houston Ship Channel, Trinity Bay, Upper Galveston Bay and Lower Galveston Bay. DDE and chlordane are commonly detected in fish from all parts of Galveston Bay. The DDE found in the tissue of fish from Lower Galveston Bay, in the most recent health risk assessment, will increase the lifetime cancer risk, when eating three meals per week, by less than one case in 1 million people. The concentration of chlordane in seafood from the Houston Ship Channel could increase lifetime cancer risk by \(4.9 \times 10^{-5}\), at the same consumption level. The threat of a carcinogen is considered negligible by TDSHS if the increased cancer risk is less than \(1 \times 10^{-4}\).

**Polychlorinated biphenyls (PCBs)**

In early studies by TDSHS (TDH 2001b), the concentration of PCBs in finfish from the region around the confluence of the Houston Ship Channel and San Jacinto River exceeded the comparison value based on the EPA chronic oral reference dose for non-carcinogenic health effects. TDSHS concluded that regular consumption of 1-half meal per week of finfish from this region could cause someone to exceed the reference dose for immunological effects.

The comparison value for cancer risk was not exceeded by the observed concentration of Aroclor 1260. This value was based on the assumptions described above for amount, frequency, and length of consumption. Lifetime cancer risk was estimated to increase by \(2.5 \times 10^{-5}\) from one meal per week of seafood from the Houston Ship Channel and Lower San Jacinto River and did not exceed the criterion of 1 excess cancer in 10,000 people used by TDSHS for public health action (TDH 2001b).

The 2008 health assessments of the Houston Ship Channel and other areas of the bay indicate an increasing risk from contamination by PCBs. The concentrations in Table 9.3 result in the calculation of higher risk levels. The concentrations of PCBs in all fish from all collection sites in Trinity and Upper Galveston Bays exceed the health comparison value (TDSHS 2008c). The calculated hazard quotient (HQ) is 1.09, which suggests adverse health effects are likely from frequent consumption. The samples from the lower bay (TDSHS 2008a) showed a higher HQ of 1.38. However, in none of the species at any of the collection sites did the PCB levels detected result in an estimated increased cancer risk of more than 1 in 10,000. Non-cancer effects are the major cause for concern considering this contaminant alone.

**Dioxins**

The concentrations of all the dioxin congeners detected in tissue from a sampling area were combined, based on their equivalent toxicities, into a toxicity-weighted concentration. These calculated concentrations were compared to criterion levels for cancer and non-cancer risks. In the TDSHS studies completed in 1999 and 2000, the dioxin levels in seafood tissue from the sampled areas of Galveston Bay were well below the comparison values from EPA for cancer and from the ATSDR for chronic, non-cancer pathologies (TDSHS 1999; TDH 2000b, 2000c, 2000a). Dioxin and furans were analyzed for tissue samples from the Houston Ship Channel and the San Jacinto River in 2004.

More recent studies of dioxin levels in fish and crabs from the Galveston Bay system detected levels of these compounds that may be cause for concern. Samples of fish from Trinity and Upper Galveston Bay had detectable levels of dioxins. Gafftop catfish from this area had an HQ of 1.08, indicating the potential for
non-cancer health effects due to high consumption (TDSHS 2008c). Gafftopsail catfish from the collection sites in the lower bay slightly exceeded the health comparison values for dioxins for non-cancer risks (TDSHS 2008a). When contaminant levels were used to estimate increased cancer risks, the results were more problematic. The dioxin levels in gafftopsail sampled from Trinity Bay and Upper Galveston Bay produced an estimated increased cancer risk of 1 extra case in 9,259 consumers. Contamination levels in samples from Lower Galveston Bay yielded estimates of increased cancer incidence of 1 in 24,955 for consumption of gafftopsail catfish and 1 in 35,574 for consumption of spotted seatrout.

Metals
The average concentrations of arsenic, cadmium, and mercury observed in the TDSHS health consultations did not exceed the comparison values for non-cancer risks in any area of the bay, in any year studied (TDH 1999, 2000b, 2000c, 2000a, 2001a, 2001c, 2001d, 2001b; TDSHS 2005a, 2008b, 2008a, 2009). No comparison values were available for lead. However, the values in Table 9.5 show that the observed concentrations of lead in seafood were less than, or approximately equal to, those of mercury, which is a more toxic compound. This implies that lead is not a significant health risk for consumers of Galveston Bay seafood.

Brevetoxin
The National Shellfish Sanitation Program requires that shellfish harvest areas be closed when the concentration of *K. brevis* in the water reaches 5 cells per milliliter. All shellfish harvest areas in Galveston Bay were closed during and for at least six weeks after the red tide event in summer 2000. Harvesting was permitted when brevetoxin was no longer detected in the tissue of oysters. This was the first time that oyster harvest areas have been closed in Galveston Bay due to a toxic algal bloom. No cases of NSP were reported to the TDSHS in association with the toxic algal bloom (Evans et al. 2001). No similar event has occurred since 2000.

Cumulative Risks
Even though individual contaminants may not be present in concentrations representing significant risks to seafood consumers, the consumption of seafood bearing the observed body burden of contamination may result in an additive or multiplicative combination of risks. The TDSHS made cumulative estimates of risk in the Health Consultations published in 2005 for the Houston Ship Channel and adjoining areas, and in
Cumulative non-cancer risks were addressed for all contaminant categories in both areas. The method of assessment employed a hazard index (HI), which is the sum of the ratios of the estimated exposure doses for each contaminant divided by its respective reference dose or minimal risk level. If the hazard index is greater than one, there is a possibility of adverse non-cancer health effects and the responsible agency should act to manage those risks. The ratios of the exposure doses to minimal risk level was quite low for all of the metals, volatile organic compounds (VOCs), and semi-volatile organic compounds for all species collected at all of the sites around the bay in all three studies.

In the 2005 study, the HI was calculated using the hazard ratios for pesticides, PCBs, and dioxins. The sum of the hazard ratios of spotted seatrout from all sites was calculated to be 3.4, equivalent to only 0.3 meals per week to minimize adverse health effects. The hazard index for all other fish species collected at all the sites was 3.0, which is strongly influenced by the concentrations in blue catfish, and the level of contamination in fish collected from the Turning Basin of the ship channel. These hazard indices represent a significant non-cancer health risk. The excess cancer risk calculated for the cumulative effects of pesticides, PCBs and dioxins was greater than 1 in 10,000 for spotted seatrout collected in the Houston Yacht Club marina and for all other fish from all sites. In the former case, the expected increase is 1.5 cases in 10,000, and, for the other fish species consumption of one meal per week is expected to raise the cancer rate by 1.2 cases in 10,000 consumers (TDSHS 2005b).

The 2005 results led to extensive studies of the remainder of the bay. In these subsequent studies, only the hazard quotients for PCBs and dioxins in gafftopsail catfish and spotted seatrout were of sufficient magnitude to be considered for a cumulative effect on systemic toxicity. The HI resulting from addition of the ratios for PCBs and dioxin in gafftopsail catfish exceeded three in both study areas. The addition of risk factors for PCBs and dioxins in spotted seatrout resulted in an HI that exceeded one in both study areas (TDSHS 2008b, 2008a). This is justification for a warning to the public about the risks associated with consumption of these species.

In the most recent health risk assessments, the cumulative risk of cancer from consumption of species tested from Upper Galveston Bay and Trinity Bay was estimated by adding the cancer risks associated with PCBs and dioxins (TDSHS 2008b). All other classes of contaminants were present in concentrations too low to be considered by the TDSHS for cumulative effects. If an average adult consumed one meal (8 ounces) per week of gafftopsail catfish tissue obtained from this area for 30 years, the estimated excess lifetime cancer risk is estimated to be $1.1 \times 10^{-4}$. If this is viewed from a population perspective, it estimates one additional case of cancer among 9,259 people who consume the seafood at the assumed rate. The biggest contributor to cumulative risk in this case is the concentration of PCBs found in these samples. Spotted seatrout from the same area consumed at the same rate could result in an additional cancer case among 20,408 consumers. TDSHS uses one additional case in 10,000 consumers as the critical level for issuance of an advisory based on cancer risk.
A similar estimate of excess cancer risk was performed for PCBs and dioxins in seafood from Lower Galveston Bay. The concentrations of PCBs and dioxins in gafftopsail catfish from this area resulted in estimated cumulative risks of $7.5 \times 10^{-5}$ for the consumption of one meal per week for 30 years. The excess lifetime cancer risk from weekly consumption of spotted seatrout from this area is estimated to be $4.3 \times 10^{-5}$, or one additional case of cancer for every 23,360 people at risk from consumption of this seafood. All other species sampled had considerably lower cumulative risks associated with their consumption (TDSHS 2008a).

**Seafood Advisories**

Seafood consumption advisories are issued by the TDSHS. When indications of a risk to human health are brought to the agency's attention, a risk assessment is conducted. If a risk assessment indicates an imminent health hazard, the affected area is declared “prohibited” for affected species, and taking those species from the area becomes a violation of law. An imminent hazard would exist if just one or a few meals would result in an acute health problem. If a less immediate hazard exists, one created by longer-term consumption habits, a “consumption advisory” will be issued with consumption recommendations for affected populations.

Six seafood advisories have been issued for the Galveston Bay system since 1990 and five of them are in effect: Advisories (ADVs) 3, 20, 28, 35, and 37 (See Figure 9.8). ADV-3 recommends that catfish and blue crabs from the Houston Ship Channel be consumed at one meal per week or not at all if the consumer is a pregnant woman or child. ADV-20 recommends that consumption of any fish from the Houston Ship Channel be limited as described in ADV-3. ADV-28 recommends limited consumption of spotted seatrout from the Houston Ship Channel and the upper portion of Upper Galveston Bay. ADV-35 recommends that spotted seatrout and gafftopsail catfish from any location in Galveston Bay be limited to one meal consumed per week and that pregnant women and children consume none of these fish due to the risk associated with PCB and dioxin-furan levels. ADV-37 recommends that fish from Clear Creek not be consumed at all due to PCB contamination.

A seafood consumption advisory (ADV-3) was issued by the TDSHS in September 1990 for the upper portion of Galveston Bay and segments of the Houston Ship Channel due to elevated levels of dioxin found in catfish and blue crab tissues. The TDSHS advised that no one should consume more than one seafood meal (not to exceed 8 ounces) each month from this area; and that women of child-bearing age and children should not consume any sea catfish or blue crabs from this area. These areas of the bay are now listed on the Texas 2008 Clean Water Act Section 303(d) List due to the elevated levels of dioxin. In 1999, the TCEQ initiated a TMDL project to deal with these elevated dioxin levels. The recommendations of this effort are expected to be issued in the near future.

The second advisory, issued in 1993, was based on three toxic compounds discovered in fish from Clear Creek, one of the principal tributaries on the bay's western shoreline. The three chemicals, all of which are industrial solvents, are dichloroethane and trichloroethane—both of which are believed to cause cancers of the liver and kidneys—and carbon disulfide, which can cause nervous disorders (TDSHS 1993). The contaminated fish were found in the vicinity of the former Brio Refining Company, an EPA Superfund site.
where a cleanup of toxic industrial compounds is under way. More recent samples of fish and blue crabs from Clear Creek, for the contaminants that gave rise to the consumption advisory in 1993, have documented decreased concentrations. This prompted the Texas Commissioner of Health, in October 2001, to rescind the consumption advisory on seafood from Clear Creek (TDSHS 2001).

The 1999–2000 risk assessment for seafood from the Houston Ship Channel found levels of PCBs in finfish from the area around the confluence of the Houston Ship Channel and San Jacinto River, and levels of organochlorine contaminants in finfish from the Turning Basin, that represent potential threats to public health. The estimated risks from consumption of this seafood were sufficient to merit issuance of Advisory 20 from the Texas Commissioner of Health in October 2001. This advisory extended the previous seafood advisory on the Houston Ship Channel and contiguous waters to include all finfish.

TDSHS conducted a risk assessment in 2004 based on samples of seafood from the Houston Ship Channel and Upper Galveston Bay. ADV-28 was issued in January 2005 recommending, to the general population, restricted consumption of spotted seatrout from Upper Galveston Bay and the Houston Ship Channel due to PCB contamination, and no consumption by reproductive women and children (TDSHS 2005b).

The contamination of seafood sampled in 2006–07, described above, resulted in the most recent seafood consumption advisory for Galveston Bay (ADV-35). It is currently recommended that consumption of gafftopsail catfish and spotted seatrout captured anywhere in the major bays of the Galveston Bay system be consumed only in limited amounts—less than 8 ounces per month—due to contamination by PCBs and dioxins. As in previous advisories related to PCBs and dioxins, women of reproductive age and children should not consume these fish at all.

In 2007, freshwater fish in Clear Creek were sampled in a study related to a TMDL program on segments of Clear Creek. Assessment of these fish for contamination by toxic compounds led to the conclusion by TDSHS that a second consumption advisory (ADV-37) should be issued for this water body, the first having been rescinded. The level of contamination by PCBs substantially exceeded the comparison criterion, so the advisory recommends no consumption of fish from these waters. The recommendation of no consumption distinguished this advisory form the others in effect across the bay.

Consumption advisories serve to protect seafood consumers. However, no enforcement is associated with the advisory to ensure that seafood is not taken from the contaminated areas. Nevertheless, more education has followed the most recent advisory than occurred with previous advisories. Warning signs will be posted at public access points to inform people of the risk associated with consumption of particular species from the area they are entering. It is still common to see fishermen and crab traps in the areas of Upper Galveston Bay that are included in the Houston Ship Channel consumption advisory, despite earlier educational efforts. Another shortcoming in the current seafood safety system is the lack of a program that routinely monitors tissue to determine changes in risks associated with Galveston Bay seafood.
Contact Recreation

Although swimming beaches are not widespread along the bay’s shoreline, considerable contact recreation occurs in various portions of the Galveston Bay system. Clear Lake is known for jet skiing and water skiing; Mud Lake for sail boarding; and Taylor Lake for water skiing, and much of the lower bay shoreline offers good wade fishing. The TDSHS does not have a program for regulating contact recreation, nor does it have a public education program regarding contact recreation.

The TCEQ addresses contact recreation by establishing "designated uses" and related water quality standards. These standards, and the TCEQ water quality monitoring data, can be used to determine whether water quality generally supports the use of bay waters for contact recreation. The criterion for this designation was the fecal coliform test. As noted above, TCEQ currently uses Enterococci concentration in salt water and Escherichia coli concentration in freshwater to assess whether a water body supports use for contact recreation. Water bodies that fail to meet the standards for this use have become the focus of Total Maximum Daily Load efforts. An alternative to implementation of a TMDL is to conduct a use attainability analysis that examines the suitability of the water body for contact recreation. Given the trend in the number of water segments impaired due to bacteria, there is growing interest in use attainability analyses.

In general, the open waters of Galveston Bay appear to be safe for contact recreation. Some of the more popular areas for contact recreation in the bay, such as the shallow water around the Texas City Dike and Pelican Island, are currently considered safe for contact recreation. In bay tributaries with poor circulation and numerous sources of contamination, the picture is different.

Many urbanized bayous on the western side of the bay had a TCEQ contact recreation designation, but have been found to exceed the water quality criterion from contact recreation. They are on the Texas 2008 Clean Water Act Section 303(d) List as impaired for this use. These include all or portions of the main stem and tributaries of Spring Creek, Cypress Creek, Cedar Bayou, Buffalo Bayou, White Oak Bayou, Greens Bayou, Brays Bayou, Sims Bayou, Halls Bayou, San Jacinto River below Lake Houston, Clear Creek, and Armand Bayou (TCEQ 2008b).

Bacterial contamination of water bodies in and around the Houston metropolitan area has grown dramatically since 1996, when the first water bodies in the region were listed for bacteria. Multiple TMDLs dealing with the issue of bacterial contamination and contact recreation have been initiated. The bacterial TMDL for Clear Creek was approved by the EPA in March 2009; the bacterial TMDL for Buffalo and White Oak bayous, in June...
2009. There are TMDLs for bacteria in progress for Dickinson Bayou and for five bayous in the Houston metropolitan area. Also, the TCEQ and the H-GAC are working cooperatively on a stakeholder process, with the Bacterial Implementation Group, to plan approaches that would result in reduction of bacterial contamination of 12 metropolitan watersheds. Potential contact recreation risks also exist in the non-urban tributaries of the bay system (e.g., Double Bayou, Dickinson Bayou, Highland Bayou and Oyster Creek). These also have bacterial levels that represent a risk of infection to humans engaged in water-related activities.

The open bay waters generally have low bacterial concentrations. Improvements in sewage treatment over the last several decades have likely helped to reduce overall bacterial contamination. Localized contamination from commercial shipping and pleasure boats can still present problems. Programs have been initiated to reduce the discharge of sewage from ships, boats, and marinas.

Figure 9.16. Kayaking down Buffalo Bayou. Image © iStockphoto.com/Kimberly Smith.
Summary

Maintaining good water quality is important not only to the ecological health of the bay, but also to the public health of bay users. Bay users can come into contact with pathogens and toxics through various activities, including contact recreation and seafood consumption. Fecal coliform indicators have been used to detect pathogens, but with some uncertainty. Some viruses and bacteria can escape detection as experienced in the Vibrio parahaemolyticus outbreak of 1998.

There have been changes both in the classification of shellfish harvesting areas and the regulation of seafood processing. Improved water quality has resulted in the reclassification of some areas near the Texas City Dike and Deer Islands from restricted to approved status. Declining water quality has resulted in the reclassification of two areas, one near Smith Point and the other near Bastrop Bay, from approved to restricted status. In addition to these state actions, the federal government passed the HACCP regulations to further ensure seafood safety.

Health consultations, or risk assessments, conducted by the TDSHS concluded that contaminant concentrations detected in some species sampled from Galveston Bay exceeded comparison values, thus non-cancer health effects are not likely to result from an average person consuming one 8-ounce meal of seafood per week. However, pregnant women and children should not consume the species noted in the consumption advisories. The studies also found that there is a less than 1 in 10,000 chance of an additional cancer occurrence from limited consumption of seafood harvested from most areas of Galveston Bay, but fish from Clear Creek should not be consumed.

Open water portions of Galveston Bay generally conform to Texas water quality criteria for contact recreation. Areas where fecal coliform bacteria levels exceed the state standard are located in the western, developed tributaries of the bay.

In reality, science cannot currently assess all of the risks to bay users or seafood consumers resulting from contamination by bacteria, viruses, or toxic materials. Risk varies among different segments of the population even though some risk estimates are available as guidelines.

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