Chapter 9

Implications of Sea Level Rise for Hazardous Waste Sites in Coastal Floodplains

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INTRODUCTION

On the night of July 20, 1977, 30 cm (1 ft) of rain fell on Johnstown, Pennsylvania, in a period of six hours. As a result, the Connmar River, which runs through the heart of the city's industrial district, overflowed its banks. Cylinders containing compressed gases, drums containing toxic chemicals, oil-soaked debris, and other hazardous materials were washed downstream and deposited on recreational and residential properties when the floodwaters receded.

Recognizing the potential threat to public health and the environment, the federal and Pennsylvania state governments immediately set up a joint task force to address this threat. At considerable cost, the clean-up team surveyed the area, collected the containers, analyzed their contents, and returned them to their owners or safely disposed of them. Although it would have been infeasible to locate and identify every container that washed away, about 500 cyclinders and 500 drums were collected in this effort.

Although there are 1,100 active[1] hazardous waste sites within 100-year floodplains in the United States (DPRA, 1982) and possibly as many closed or abandoned sites, flooding disasters such as the Johnstown incident have been infrequent in the past. However, a rise in sea level could significantly increase the probability of flooding for many of these sites and bring more sites into floodplains. Furthermore, erosion and salt intrusion that would result from a rise in sea level could become additional threats, even to those waste sites that are adequately protected against flooding.

This chapter first discusses the hazards associated with waste sites in floodplains and federal regulations to mitigate those hazards. It then discusses the potential impacts of sea level rise on specific types of hazardous waste sites and illustrates how sites in the Charleston and Galveston areas would become vulnerable to flooding. Finally, it presents the authors' conclusion that compliance with existing regulations could prevent serious problems with operating sites but not with closed or abandoned sites.

BACKGROUND

This section provides general information on the federal regulations and guidelines for the siting of hazardous waste facilities, particularly as they apply to floodplains. Then, the method of delineating the 100-year flood boundary and the general characteristics of floods are discussed.

Regulations for Siting Hazardous Waste Facilities

The Resource Conservation and Recovery Act (RCRA) created a legal mechanism for the management of hazardous wastes. EPA implemented RCRA through a series of regulations and guidelines; a significant part of the regulations restrict waste disposal in environmentally sensitive areas. The following RCRA regulations pertain to hazardous waste facilities in floodplains:

> *Floodplains:* [B 264.18(b)] Hazardous waste surface impoundments, waste, piles, land treatment units, and landfills preferably should not be located in a 100-year floodplain. Facilities so located must be designed, constructed, operated, and maintained to prevent washout of any hazardous waste by a 1 00-year flood. However, in accordance with ?264.18(b)(1)(i) if the owner or operator demonstrates that, in the event of a flood, the waste would be removed to a safe area before flood waters reached the facility, special design and operating procedures to prevent washout are not required. This option may not be viable for many existing surface impoundments, waste piles, land treatment units, and landfills. Accordingly, the Agency is promulgating a second exemption, defining narrow circumstances in which existing facilities, not designed and operated to prevent washout, may be located in a 100 year floodplain without the owner or operator making the demonstration cited above in ?264.18(b)(l)ii). These circumstances are where the owner or operator demonstrates that a washout would cause no adverse effects on human health or development. (CFR, 1982, *Federal Register,* vol. 47(143): 32290-32291.)

EPA did not prohibit the operation of facilities in the 100-year floodplain, both because of the potential economic impacts of such a requirement and because of the availability of techniques to protect the facilities from floods.

EPA has adopted the Flood Insurance Administration's (FIA) minimum requirements for new construction and substantial improvements of any nonresidential structure in 100-year floodplains. The requirements specify that the lowest floor of a building, including the basement, must either be elevated to the 100-year flood elevation or be flood-proofed so that the structure is watertight and capable of withstanding the forces exerted by floodwaters during a 100-year storm. The standard specifies the same operational and design standards for new and existing facilities.

Methods of Delineating the 100-Year Flood Boundary

The FIA prepares flood insurance maps for communities subject to periodic flooding. Approximately 17,000 communities and counties are in the flood insurance program; however, the mapping coverage varies (FEMA, 1978). A community applying to enter the program is initially placed in the "Emergency Program" until certain requirements are fulfilled and then it enters the "Regular Program."

Flood hazard boundary maps (FHBM) are prepared for communities in the Emergency Program and have been prepared for nearly all floodprone communities in the United States (FEMA, 1978). These maps show the areas within the community that are vulnerable to a 100-year flood. The floodplain boundaries are only approximate on these initial maps, and surge elevations are not provided. Owners or operators of waste sites may appeal the boundaries of the 100-year floodplain on a FHBM by submitting conclusive scientific evidence that the boundary is incorrect.

While a community is in the Emergency Program, flood insurance studies involving detailed field engineering surveys are conducted. The information obtained from these studies is used to prepare a flood insurance rate map (FIRM) and a flood boundary and floodway map. Because the FIRM delineates precise boundaries of the 100-year floodplain, it is the final determination of whether the facility is located within the 100-year floodplain.

Flood Characteristics

The most important flood characteristics are depth, velocity, duration, and fall. The depth of floodwater around a structure is the most critical element in planning and designing flood control measures to meet strength and stability requirements. The velocity of floodwaters during overbank/ inland flow conditions has important implications for scouring, sediment transport, debris loading, and dynamic loading on structures and obstructions. The flood's duration determines the extent of saturation of soils and building materials, seepage, and water pressure in soils and under foundations. The rate of rise and fall of a flood to and from its crest affects the size of flooding and the required drainage provisions.

Advance warning from flood forecasting is important, particularly where flood control plans require time for wastes to be removed before floodwaters reach the facility. Floating debris can cause increased loads against structures, resulting in damage. Wave action caused by coastal storm surge can also result in significant hydrodynamic loads on structures in the flood zone. All these aspects of floods should be evaluated and their probable effects considered when siting and designing a hazardous waste facility in a floodplain.

HAZARDOUS WASTE FACILITIES IN FLOODPLAINS

EPA is preparing a regulatory impact analysis (RIA) for operating hazardous waste facilities located in or proposed for location in floodplains. Included in the preparation of the RIA are visits to hazardous waste facilities. This section discusses the preliminary findings of Walesh and Raasch (1983), who visited approximately 10 hazardous waste facilities during 1982 and 1983 as a part of EPA's assessment of the impact of the regulations discussed in the previous section. By including a wide range of waste management technologies and flood mitigation measures, the site visits provided a wealth of field-based ideas, information, and a representative view of the current situation. Site-specific field data combined with the flood mitigation and hazardous waste facility experience of the project team were the basis for the following observations. Although these observations do not represent a scientific sample, they do represent perhaps the only available systematic review of the flood mitigation experience of hazardous waste facilities.

Hazardous Waste Management Technologies and Flood Mitigation Options

Walesh and Raasch observed several waste management technologies, the most common being surface impoundments, containers (primarily 55 gal drums), and above-ground tanks. Most above-ground tanks were used to store hazardous wastes temporarily, and some were used to pretreat wastes using processes such as solids settling and acid neutralization. The wastes handled by these sites included acids, alkalis, solvents, heavy metals, grease and oils, paint waste, and PCBS.

Flood mitigation options for hazardous waste facilities can be divided into two categories: flood protection (not allowing floodwaters to reach the facility) and floodproofing (allowing floodwaters to come into contact with structures but preventing any damage). The structural components of facilities such as tanks, containers, incinerators, and structures used in thermal, chemical, physical, and biological treatment can be floodproofed EPA, December 30, 1980). Landfills, surface impoundments, land treatment, and waste piles require flood protection. The flood mitigation measures commonly being applied to hazardous waste facilities are the same as those commonly used to flood-protect or floodproof facilities and structures that do not handle hazardous wastes.

Because new facilities have more flood mitigation options available than existing facilities, the cost of achieving RCRA floodplain standards for them is generally less. Risks for new facilities (particularly those susceptible to inundation and severe wave action) can be reduced by considering not only the direction of the shore but also the orientation of the units in light of the probability of flooding from various directions. The proper orientation of structures may reduce impacts from receding floodwaters as well. Floodwater elevations and velocities associated with the 100-year storm must be identified at the facility's location to ensure the design of adequate flood control measures. Existing facilities located in 100-year floodplains must either modify management units at the facility, divert or prevent the entry of floodwater (e.g., levees), or relocate.

Flood Protection. Levees, generally earth mounds with trapezoidal cross-sections, are the most common means of flood protection. Walesh and Raasch observed an earth levee along the entire bay boundary of a large sanitary landfill on San Francisco Bay that contained a hazardous waste site. The portion of this levee exposed to wave action was armored with riprap. Another example was an earth levee along the San Joaquin River in California that both contained and flood-protected a series of surface impoundments constructed on a riverine floodplain at a chemical manufacturing plant.

Floodwalls, usually constructed of concrete or sheet steel and functioning like earth levees, are used where wave attack is significant or space is limited. However, they are not used as much as levees, probably because of their higher costs and the general availability of the larger space required for levees.

Hazardous waste facilities in coastal floodplains are often traversed by small creeks or drainage ways. The stormwater runoff these streams carry may significantly exacerbate the flooding from storm surge alone. Safely and economically accommodating this drainage is a major problem at some facilities. The owners of a large landfill in California, for example, plan to increase the capacity of two existing drainage ways so as to divert drainage around their hazardous waste management areas. To prevent interference with operations, street improvements and a large stormwater detention facility were recently constructed at the naval base in Charleston to capture and temporarily store drainage from higher land outside of the floodplain with subsequent slow release to the river. The owner of a manufacturing plant along the Thunton River in Massachusetts installed a floodproofing gate on an entrance to his plant. When floods are expected, the gate is closed to prevent drainage from entering the plant.

Floodproofing. The most commonly used methods of floodproofing are grading, fencing, and upgrading the structural integrity of containers; elevating containers and/or facilities above flood levels; and emergency plans to evacuate wastes. The elevation of storage units, incinerators, and treatment facilities on earth fill above flood levels is often effective, provided that the fill does not easily erode. The selection and placement of fill should be based on the effects of saturation from floodwaters, slope stability, scour potential, and on whether settlement is uniform or differential. Column piers or walls can also be used, provided they do not restrict the flow of floodwaters and are protected against scour.

Grading of landfills and land treatment areas is used to establish a slope for runoff. The slopes are generally greater than 2 percent to provide adequate drainage and prevent wastes from leaching but less than 5 percent to reduce flow velocities and minimize erosion (U.S. EPA, September 1980). Fencing that does not impede the flow of floodwaters has been installed around facilities to restrict flotation of containers and reduce structural damage from flood debris impact. The structural integrity of treatment units, storage facilities, and incinerators should be designed to withstand hydrostatic and hydrodynamic forces associated with the 100-year flood (Department of the Army, 1972).

A commonly used floodproofing measure is placing hazardous waste containers in locations above the flood level. Examples include a fenced drum storage area at a chemical manufacturing plant positioned near, but outside and above, the floodplain. Another observed example was a manufacturing plant located entirely within the Taunton River floodplain, with a hazardous waste drum and storage area on an upper floor of the building well above flood stage. The naval facility in Charleston plans to floodproof its new hazardous waste management storage building, which will be in a coastal floodplain, by constructing the entire facility on fill so as to elevate it above flood level.

Another common means of floodproofing is the development of a formal contingency plan or emergency action plan. A plan prepared by the naval facility includes preparation for emergency situations such as forecast hurricanes. A large chemical company in New Jersey and a manufacturing plant in Massachusetts also have plans that include temporarily removing drums of hazardous waste from flood-prone storage areas.

Flood Protection and Floodproofing Design. Professional engineers are responsible for the design and construction of the flood mitigation measures at hazardous waste sites. These measures are similar to those for other private and publicly owned structures and facilities located on floodplains.

Although there is general agreement that flood impact mitigation is an element of proper management at hazardous waste sites, there is no common approach used to select the design flood, which can be attributed primarily to two factors. First, there are widely differing perceptions of the flood threat and its economic, public health, and safety consequences relative to the cost of flood mitigation at facilities. For example, some facility managers view the 100-year recurrence interval flood as such a remote event that the cannot justify protecting facilities against it. However, protection designed against the 100-year storm is becoming the norm in most areas. Second, some existing facilities were built many years prior to the institution of hazardous waste management regulations or even state and federal floodplain management regulations. Therefore, facility designers used the design flood criterion they considered most economic and otherwise appropriate. For example, a chemical manufacturing facility in California used the largest flood on record to design berms to flood protect surface lagoons located on the San Joaquin River floodplain.

Nor has the concept of freeboard (extra height in a facility as a safety factor) been universally accepted and applied. In some cases, no freeboard is provided. When freeboard is incorporated in the design of flood mitigation measures, it is generally 1 m or less (2-3 ft).

Many operators of existing hazardous waste facilities would resist retrofitting existing facilities to provide flood mitigation for 100-year floods because they do not believe the costs are justified. Particularly in the case of older, congested facilities, flood mitigation retrofitting measurer, could be extremely disruptive and very costly.

The managers of new facilities appear much more likely to design for a 100-year flood. They would generally accept designing flood mitigation measures for the 100-year or similar flood, including a sea level rise increment, as a condition of occupancy of the floodplain or they may even accept simply staying out of the floodplain. For example, one operator, after strongly stating his opposition to imposing 100-year recurrence interval flood mitigation criteria on his company's existing hazardous waste and related facilities, told Walesh and Raasch that if his company were constructing a new manufacturing facility with its attendant hazardous waste generating, treating, and storage components, it would simply stay out of the floodplain.

Flood mitigation practices do not generally include secondary measures (redundancy) to offset the possibility of structural failure. For example, when a levee is used to protect a riverine community from flooding, buildings are not normally floodproofed to provide protection in the event that the levee fails. However, a variation on this concept is occurring at some hazardous waste sites in the form of written contingency plans or emergency action plans in the event that a levee, floodwall, or other structural flood mitigation measure appeared to be in danger of failure. These plans typically include evacuation of employees and temporary transport of hazardous materials to safe locations.

One of the coastal sites Walesh and Raasch visited provided a rare example of structural redundancy. A surface lagoon containing hazardous wastes at this privately owned landfill was encircled by a berm. The next level of protection was a berm containing a cut-off wall with the bottom of the cut-off wall keyed into relatively impermeable subsoil. Although the primary purpose of this combination was to contain liquid hazardous wastes that may discharge from the lagoon into the surrounding soil, the berm/cut-off wall combination could also serve as a flood protection measure. Beyond the berm/cut-off wall, the entire outer perimeter of the hazardous waste area, plus the adjacent landfill, was protected from high water and waves with a levee.

Implementing Flood Protection and Floodproofing Measures

In many cases, the primary motivation for the implementation of flood mitigation measures is to permit the continuous and safe operation of the entire facility as well as the protection of the public from toxic wastes. For example, the management of a large, privately owned and operated landfill with a hazardous waste area explained that they could not afford to have all or a portion of the facility temporarily closed by flooding. Other examples Walesh and Raasch identified included a manufacturing plant and a naval facility that generated hazardous wastes as part of their overall operations, with treatment and temporary storage of hazardous wastes being secondary activities. The managers of these two facilities explained that flood protecting and floodproofing the hazardous waste handling areas, as well as other vulnerable portions of their physical plants, were necessary so that flooding would not endanger employees and interrupt their major functions.

Rarely do facility managers indicate that local, state, or federal regulations were the primary motivation for instituting flood mitigation measures. However, the degree of protection provided is driven primarily by regulations. Although facility managers generally agree that flood mitigation measures are good business and management practices, they do not necessarily agree that protection should be provided for flood events as rare as the 100-year recurrence interval flood required by EPA regulations.

Costs of Flood Protection and Floodproofing Measures

The costs of hazardous material management (including, but not limited to, flood mitigation measures) can be high, particularly for retrofitting existing facilities. For example, a government facility Walesh and Raasch visited plans to construct a $1 million hazardous waste facility with only approximately 5-10 percent of the cost being used for floodproofing, that is, elevation of the facility on fill so that it will be above flood levels. However, it is usually difficult, if not impossible, for an operator to separate the flood mitigation costs of an existing or proposed facility from the other hazardous waste or even hazardous material handling costs. For example, a berm or wall constructed around a hazardous waste storage tank located in a floodplain may contain the wastes, as well as provide floodproofing for them.

Inspection and Maintenance of Flood Mitigation Measures

Inspection of flood mitigation measures at hazardous waste facilities is usually part of routine production operations. Inspection procedures were found to include daily inspection by hazardous waste personnel of all storage locations on a naval facility, periodic monitoring of impoundment embankments and groundwater quality by engineers, and essentially continuous inspection of drum storage areas by the personnel consolidating wastes and sealing drums. Maintenance of flood mitigation works is provided on an as-needed basis at most sites.

How Facility Operators ViewEnvironmental Protection

Most owners and operators of hazardous waste sites generally view treating, storing and disposing of hazardous wastes as a secondary activity - part of the cost of running their business. Examples are provided by the several manufacturing firms visited during the project as well as by government facilities that handle hazardous wastes. The most important exceptions are sanitary landfills that treat hazardous wastes, where the treatment, storage, and disposal of hazardous waste is one of the primary activities.

Although hazardous waste management is widely viewed as part of the cost of doing business, most operators believe that controls and their attendant costs are required to protect the environment, provided that the controls and costs are reasonable. According to one manager, his firm has significantly changed its attitude toward environmental matters in recent years and now openly and positively accepts its environmental responsibilities.

GENERAL IMPACTS OF SEA LEVEL RISE ON HAZARDOUS WASTE SITES

The impacts of sea level rise on hazardous waste sites can be classified into increased storm damage, shoreline retreat, and changes in water tables. Increased risk from storms is likely to be the most important factor. A rise in sea level would bring new sites into floodplains and result in more severe flood levels for those already in floodplains. Furthermore, the risks from damaging storm waves would increase as deeper water allowed these waves to penetrate further inland.

Shoreline retreat could also threaten hazardous waste sites. As Chapters 1, 4, and 5 explain, a sea level rise results in both inundation and erosion; a rise of 1ft could result in shoreline retreat from a few feet along rocky coasts to several miles along low-lying marshland. Significant shoreline retreat might leave a waste site under water or in the surf zone subject to constant wave attack. Operators of existing sites, especially factories for which the waste site is a small portion of the entire operation, would generally protect their operation from an encroaching shoreline. Abandoned sites, however, would not be guaranteed the same protection.

Finally, changing water tables could threaten wastes stored in surface impoundments and landfills. Higher water tables could threaten containment vessels by exerting additional hydrostatic pressure. Furthermore, saltwater can permeate clay liners that are impervious to freshwater. As a result, the risk of wastes leaching through the liners would increase.

Although existing EPA regulations do not address changing water tables, the regulations would protect the public from risks associated with shoreline retreat and flooding for existing sites, provided that flood maps were redrawn in a timely fashion. However, if sea level rise is not anticipated and these sites then undertake the necessary mitigation actions to comply with EPA regulations, additional outlays that could have been avoided may be required to ensure protection against such a rise in sea level. Some facilities would have to redesign and rebuild their flood protection works to withstand the greater risks from sea level rise. Furthermore, other sites might have chosen to locate farther inland had they realized that their chosen site would someday be in a floodplain.

IMPACTS ON SPECIFIC TYPES OF HAZARDOUS WASTE SITES

Information on the potential impacts of coastal flooding on hazardous waste facilities is limited.[6] On the basis of this limited information, this section briefly describes the types of impact that sea level rise could have on landfills, land treatment areas, surface impoundments, waste piles, storage facilities, and incinerators.

The impacts of sea level rise on landfills are inundation, waste solution migration, physical erosion, and saltwater intrusion.

Inundation of a landfill can result if flood waters are high enough. A ponding effect will cause increased leachate production by adding water to the volume of wastes in the landfill and causing varying degrees of saturation (which may affect structural stability).

Waste solution due to floodwater may result in increased leachate production and the potential migration of these wastes onto neighboring properties. Active sites that are not capped are particularly vulnerable.

Waves can cause extensive erosion of any loose cover material. The degree of impact would relate directly to the amount of wave action resulting from a coastal flood. Erosion is particularly significant at landfills constructed so that the waste is above ground level.

Salt intrusion from sea level rise may affect landfills with clay caps and/or liners. In coastal areas, where the extent of saltwater intrusion inland may be significant, it is common to have shallow unconfined aquifers with depths that respond rapidly to fluctuations in sea level. A rise in sea level would result in a rise in the water table. The liner of a landfill may become inundated as the shallow water table rises, thus building up increased hydrostatic pressure on the liner. If the aquifer contaminated with saltwater, there may be significant clay-salt interaction, which can result in increased permeability of the clay liner and potential migration of leachate from the facility. Recent research efforts have shown that increased salt concentrations may cause a decrease in the shear strength of clay, thus weakening its structural stability. Sodium chloride may cause clay to dehydrate, resulting in a decrease in permeability but an increase in porosity (Evans, 1981). Other salts may have different effects.

A rise in sea level could have two effects on land treatment areas. First, wastes could dissolve or be suspended in the nearby soil. Also, increased leachate production and migration are possible. Second, physical erosion caused by coastal wave action might result in a total washout or removal of the soil layer and the incorporated wastes.

Three primary effects on surface impoundments could be anticipated as a result of sea level rise. First, waste solution or the suspension of settled dry wastes from the bottom of the impoundment could persist after floodwaters recede. Second, physical erosion resulting from coastal wave action could cause the structural failure of the sides of the impoundment, resulting in the release of wastes. Finally, inundation could result in the migration of wastes from the facility, receding floodwaters could cause the failure of the impoundment structure because of pressure differentials and saturated soil conditions, and contact of saltwater with a clay liner could result in increased leachate movement.

A sea level rise could have three primary effects on waste piles, which employ biological decomposition in the treatment and disposal of waste. First, waste solution or suspension could occur. Second, physical erosion could occur because of high-velocity flooding, which would cause complete washout of the pile. The waste pile may remain saturated after floodwaters have receded, allowing waste to continue leaching out. Last, saturation of the pile could cause structural weakening and result in a collapse of the pile and potential washout.

Storage facilities would have the options of either developing emergency plans to remove wastes prior to flooding or incorporating structural engineering solutions. But if these measures failed, the consequences could be serious. Tanks could overflow, containers could float or spill if not properly secured, structural damage to above-ground or partially above-ground tanks could be caused by floating debris or by increased hydrostatic pressure, and saltwater could corrode tanks and containers.

Municipal waste incinerators could experience three types of damage due to a sea level rise. First, waste solution or suspension in the storage and operating components of the facility could occur. Second, structural damage, caused by hydrodynamic loads due to wave action or hydrostatic loads due to inundation could be realized. as could structural damage from floating debris in a high velocity flood. Finally, increased salt content could corrode components.

EFFECTS OF SEA LEVEL RISE ON HAZARDOUS WASTE SITES IN THE CHARLESTON AND GALVESTON STUDY AREAS

Both active and inactive hazardous waste facilities were identified and mapped for the study areas. The facilities were identified by study area zip code using the RCRA Part A database for locating active sites and the CERCLA ERRIS file (a data base including abandoned hazardous waste facilities) for locating inactive sites. The locations of these facilities were estimated using street maps for the two study areas. The accuracy of facility location was reduced by the difficulty in plotting on the street maps, which were of very small scale. Consequently, the uncertainty in exact location must be considered, especially with regard to the analysis of facilities within the 100-year floodplain.

A characterization of hazardous wastes found at the active facilities was made using the RCRA Part A data base. Information on wastes contained at inactive sites was not available. The risk from waste types can be inferred from the presence of carcinogens and ecotoxins found at the facilities. This section discusses the changes in the vulnerability of these sites, in light of the results from Chapters 4 and 5.

Charleston, South Carolina

As a result of Charleston's industrial concentration, all of its 11 hazardous waste facilities are located in the northern and central sections of the Charleston peninsula. Figure 9-1 shows the locations of these facilities and the 10-year and 100-year floodplains. All 7 of the active sites were identified as storage and/or treatment facilities, including tanks, containers, and waste piles. The wastes associated with these facilities are listed as follows:

xylene	cadmium[a]
toluene	arsenic[a]
ethyl benzene	benzene[a]
phenol	beryllium[a]
tetrachloroethylene	chromium VI[a]
mercury	nickel[a]
cyanide	vinyl chloride[a]

nitrobenzene	dichlorobenzene
lead	iron ferro (IC) cyanide

[a]known carcinogens of greatest concern to human health

Figure 9-1. Map of Charleston study area showing the locations of hazardous waste facilities relative to the 10- and 100-year floodplains for 1980. C = active hazardous waste management facility; ●= inactive hazardous waste management facility.

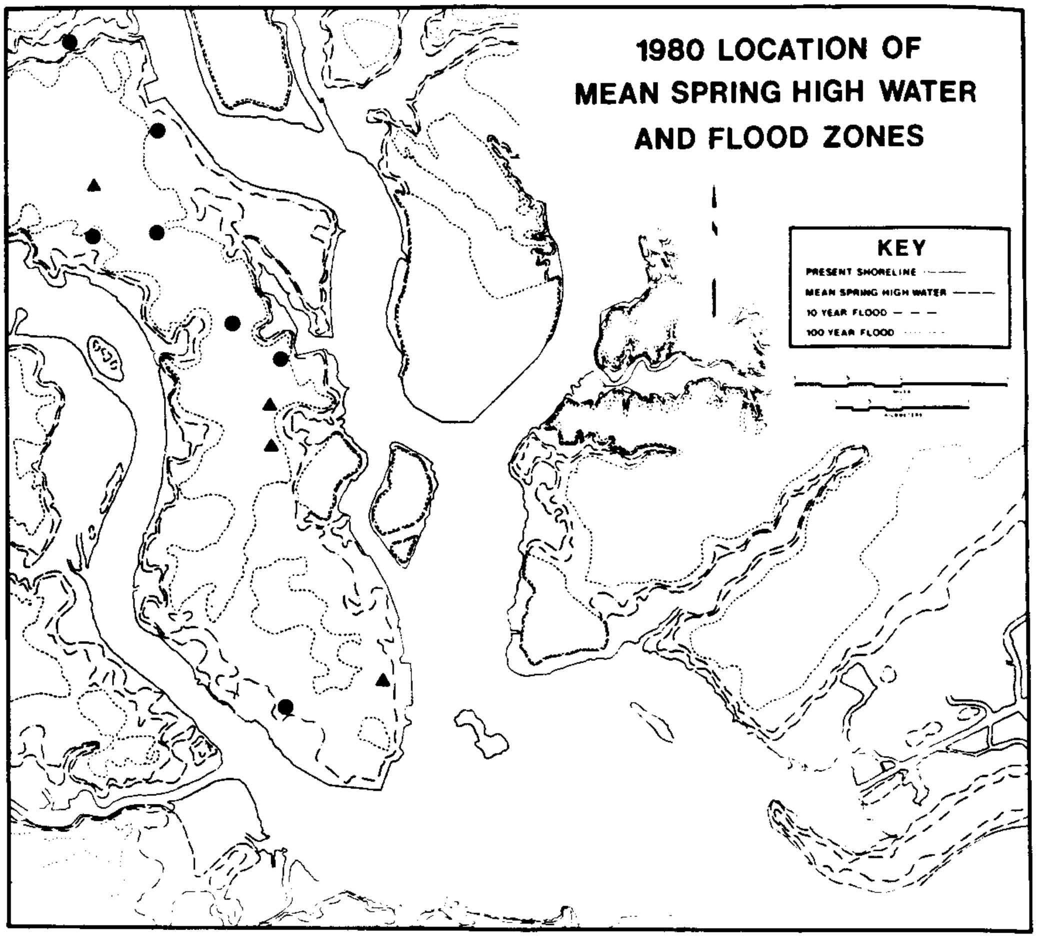

Figure 9-1. Map of Charleston study area showing the locations of hazardous waste facilities relative to the 10- and 100-year floodplains for 1980. • = active hazardous waste management facility; ▲ = inactive hazardous waste management facility.

We could not obtain information on the 4 inactive sites. However, given the stable history of industrial activity in the Charleston region, the types of hazardous waste found at the active RCRA facilities are probably a good indication of the types of waste at the inactive sites. Four active sites and one inactive site are located within the 100-year floodplain, with one active site in the 10-year floodplain.

Figures 9-2 and 9-3 show how the sea level rise scenarios would bring additional waste sites into the 10- and 100-year floodplains, respectively, for the year 2075. Under the high scenario, 5 additional hazardous waste facilities would be within the 10-year floodplain, and all but one would be within the 100-year floodplain. Table 9-1 summarizes the number of facilities (active and inactive) located within the floodplain under the high scenario for 1980, 2025, and 2075.

Figure 9-2. Map of Charleston study area showing the locations of hazardous waste facilities relative to the 10-year floodplain

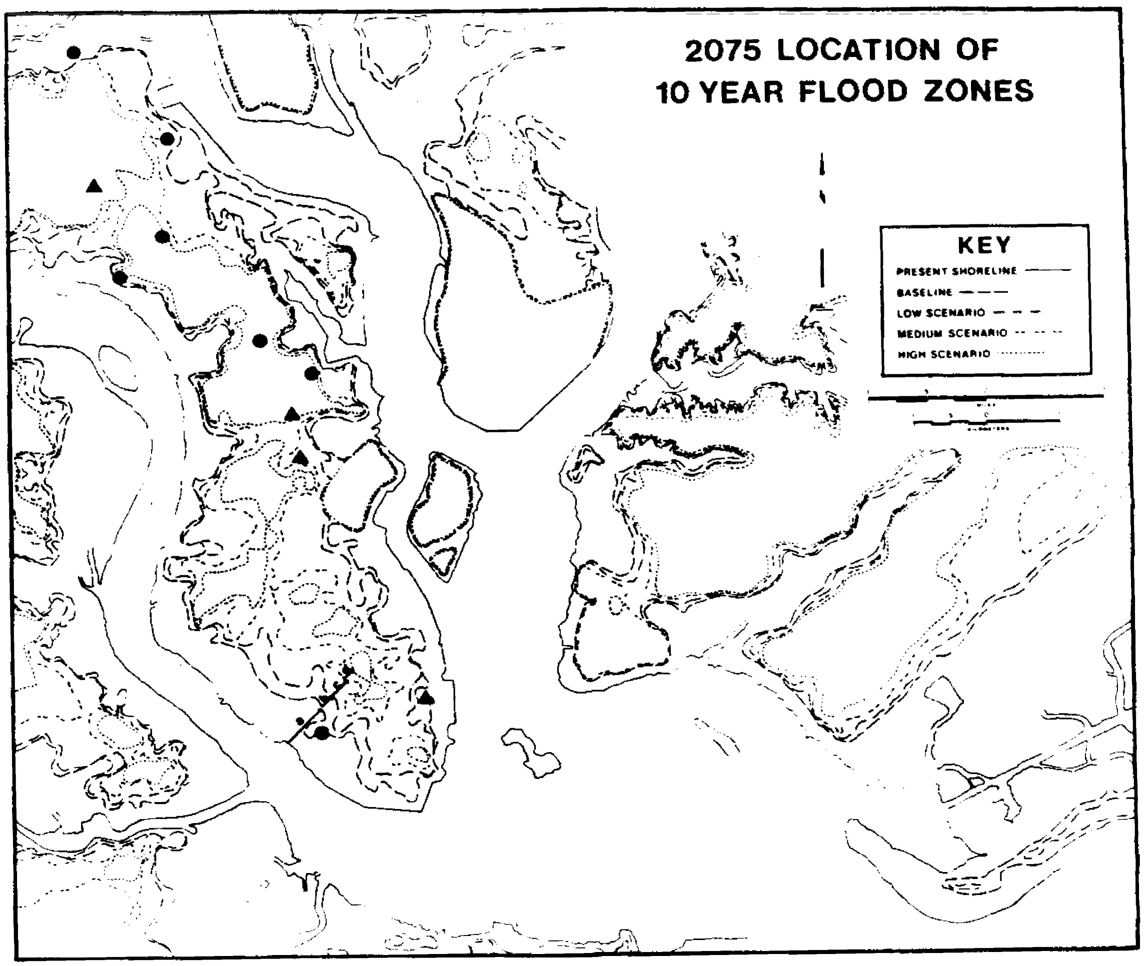

Figure 9-2. Map of Charleston study area showing the locations of hazardous waste facilities relative to the 10-year floodplain for 2075. • = active hazardous waste management facility; ▲ = inactive hazardous waste management facility.

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Table 9-1. Charleston Study Area Change in Number of Hazardous Waste Facilities (HWF) in 100-Year and 10-year Floodplains for 1980, 2025, and 2075 (based on the high sea level rise scenario)

Table 9-1. Charleston Study Area Change in Number of Hazardous Waste Facilities (HWF) in 100-Year and 10-Year Floodplains for 1980, 2025, and 2075 (based on the high sea level rise scenario)

	Number of HWF in 100-Year Floodplain			*Number of HWF in 10-Year Floodplain*		
Year	*Active*	*Inactive*	*Total*	*Active*	*Inactive*	*Total*
1980	4	1	5	1	0	1
2025	4	2	6	2	1	3
2075	7	3	10	4	2	6

Source: Data from U.S. Environmental Protection Agency, 1982, RCRA data base, Part A, and author.

Note: Out of a total of 11 hazardous waste facilities (7 active, 4 inactive)

Galveston, Texas

Thirty of the Galveston area's hazardous waste facilities are located in Texas City, and the other two sites are located in Galveston. Figures 9-4 and 9-5 show the study area's 14 active and 18 inactive hazardous waste facilities. In 1980, 10 facilities (4 active and 6 inactive) were located in the 100-year floodplain and 8 facilities (4 active and 4 inactive) were located in the 15-year floodplain. The facilities include landfills, waste piles, surface impoundments, storage tanks, incinerators, injection wells, and land treatment areas. Because most of the Galveston area is low-lying, these facilities would be vulnerable to flooding. A large number of inactive sites may be abandoned and not specifically protected against flooding, although the Texas City Levee System provides general protection

Figure 9-3. Map of Charleston study area showing the locations of hazardous waste facilities relative to the 100-year floodplain for 2075.

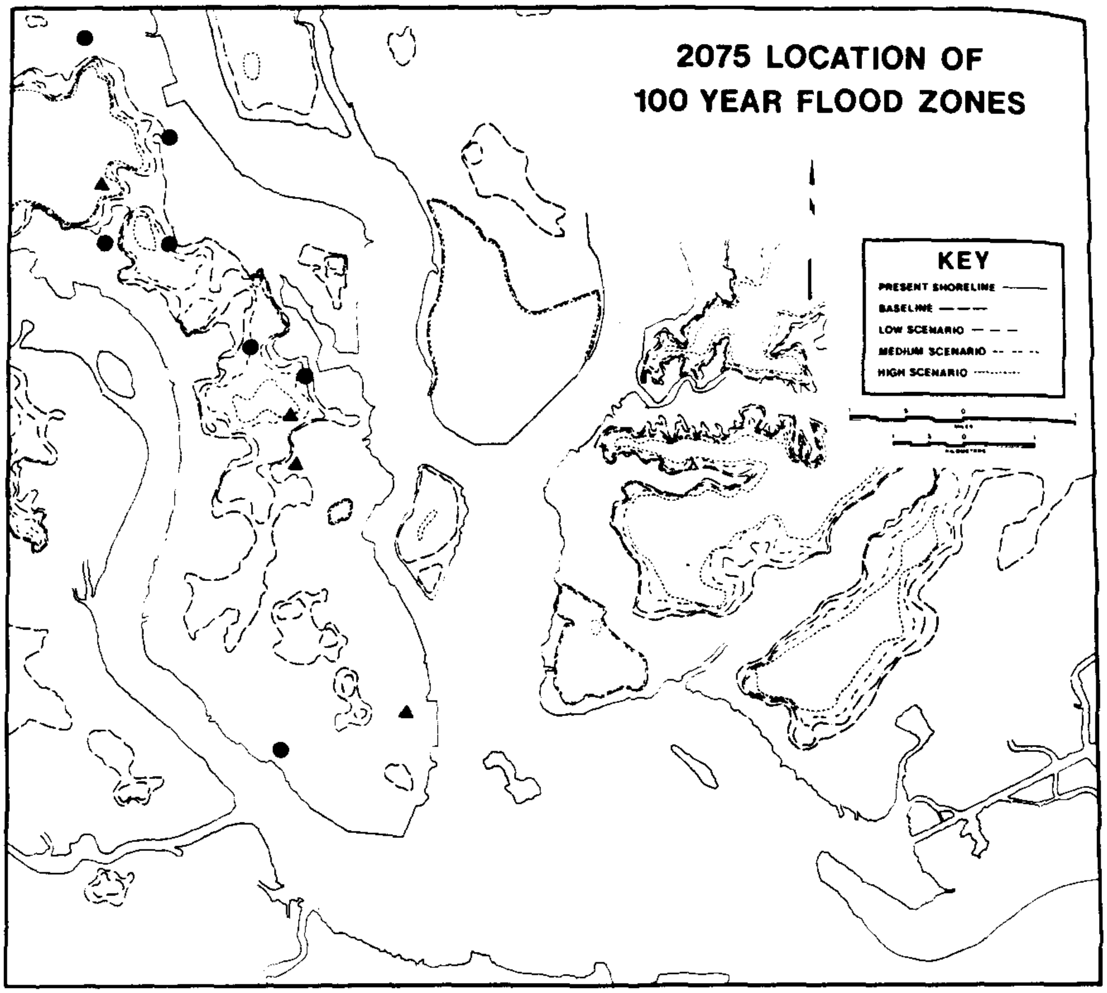

Figure 9-3. Map of Charleston study area showing the locations of hazardous waste facilities relative to the 100-year floodplain for 2075. • = active hazardous waste management facility; ▲ = inactive hazardous waste management facility.

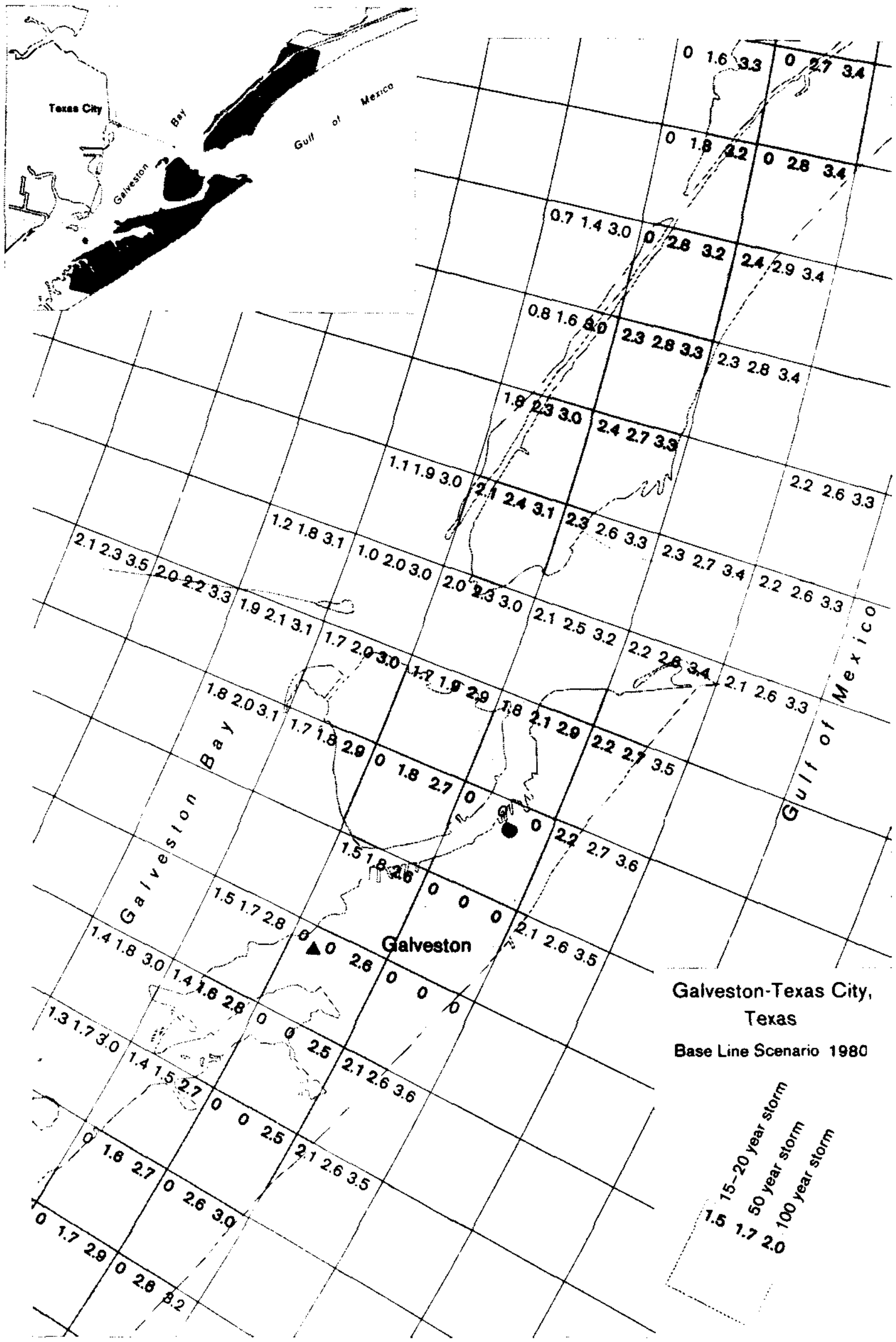

Figure 9-4. Map (Galveston section) of Galveston study area showing locations of hazardous waste facilities and 15-20-, 50-, 100-year storm surge elevations for 1980. • = active hazardous waste management facility; ▲ = inactive hazardous waste management facility.

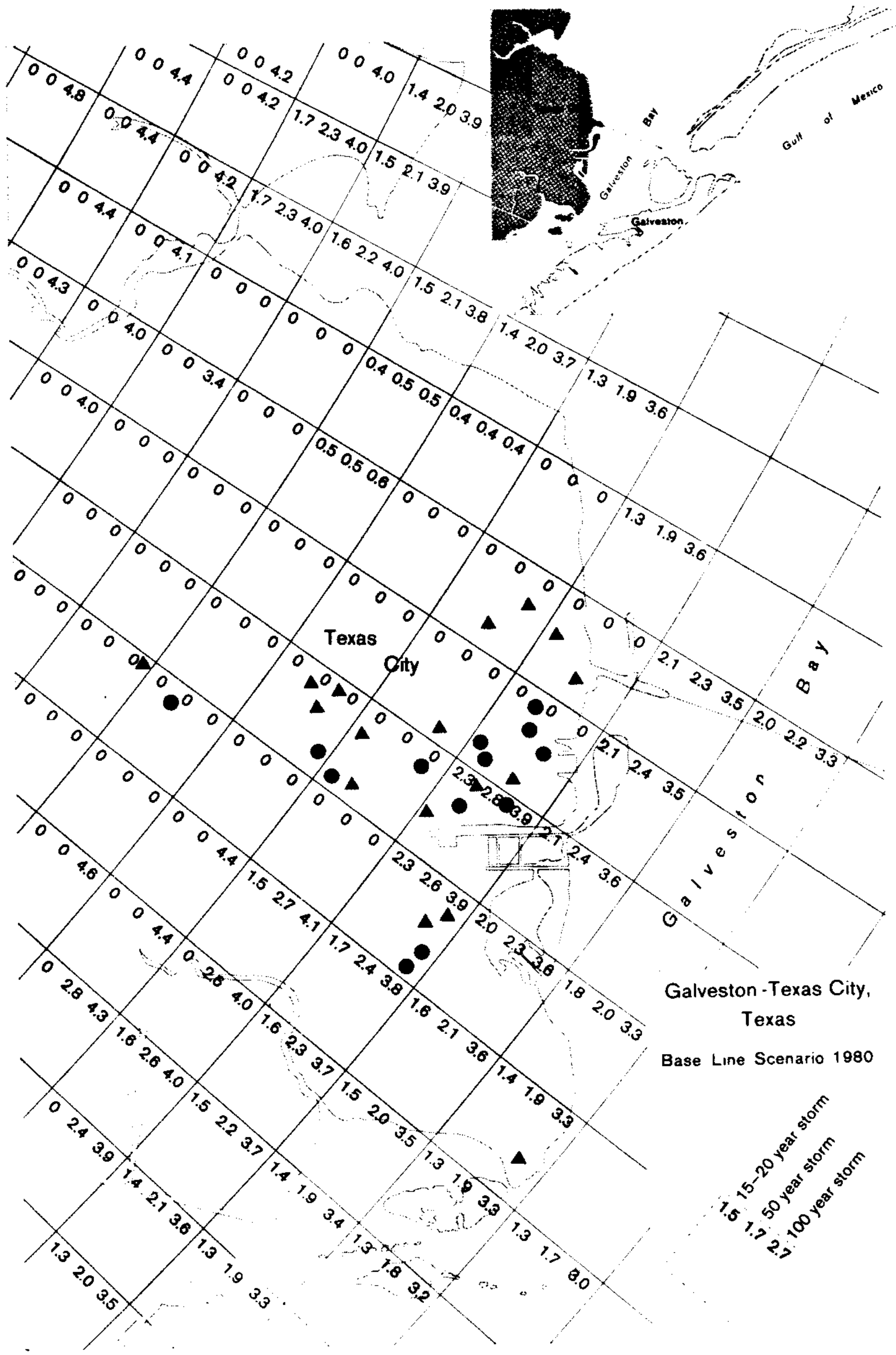

Figure 9-5. Map (Texas City) section of Galveston study area showing locations of hazardous waste facilities and 15-20-, 50-, and 100-year storm surge elevations for 1980. • = active hazardous waste management facility; ▲ = inactive hazardous waste management facility.

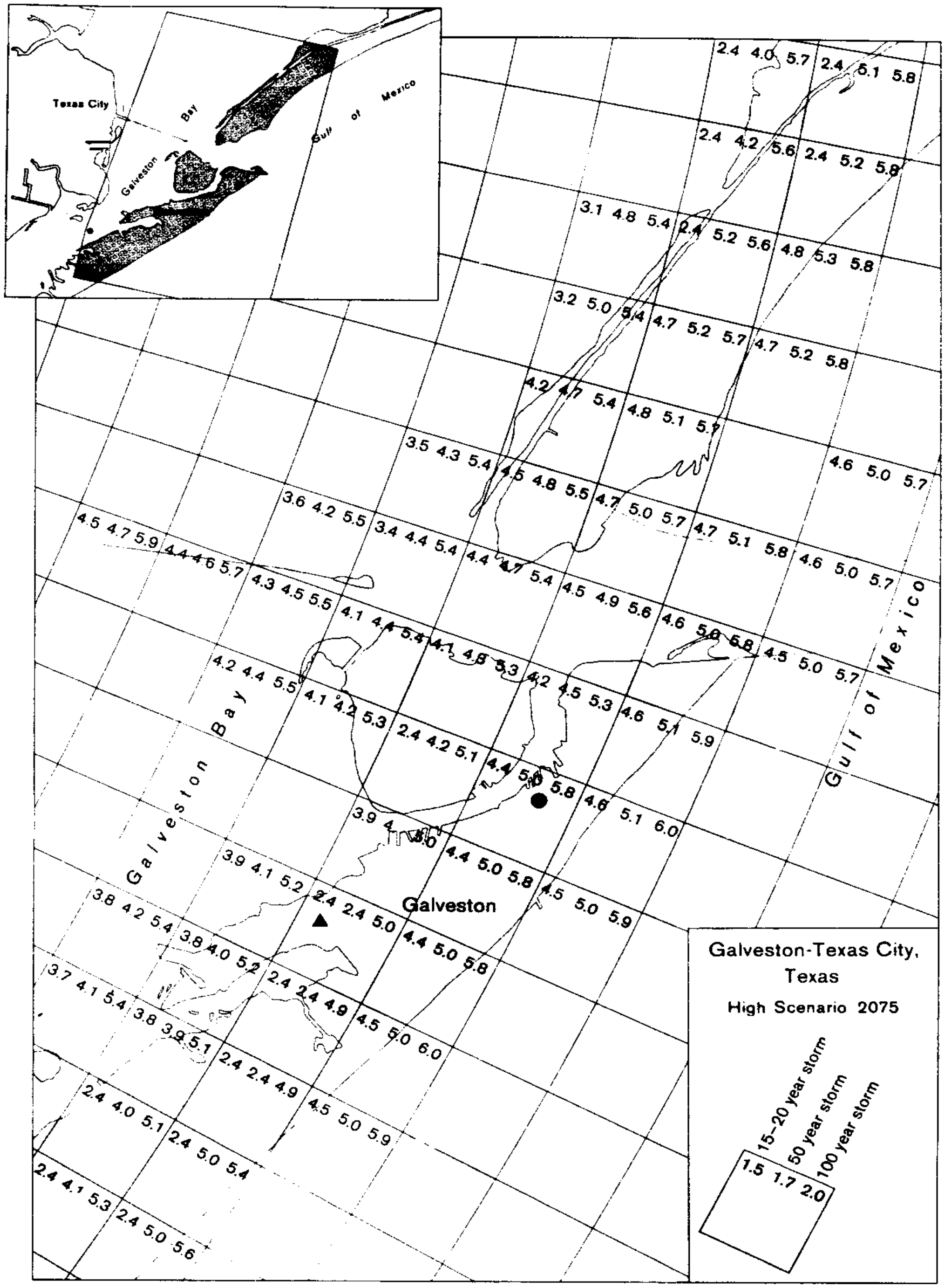

Figure 9-6. Map (Galveston section) of Galveston study area showing locations of hazardous waste facilities and 15–20-, 50-, and 100-year (high scenario) storm surge elevations for 2075. • = active hazardous waste management facility, ▲ = inactive hazardous waste management facility.

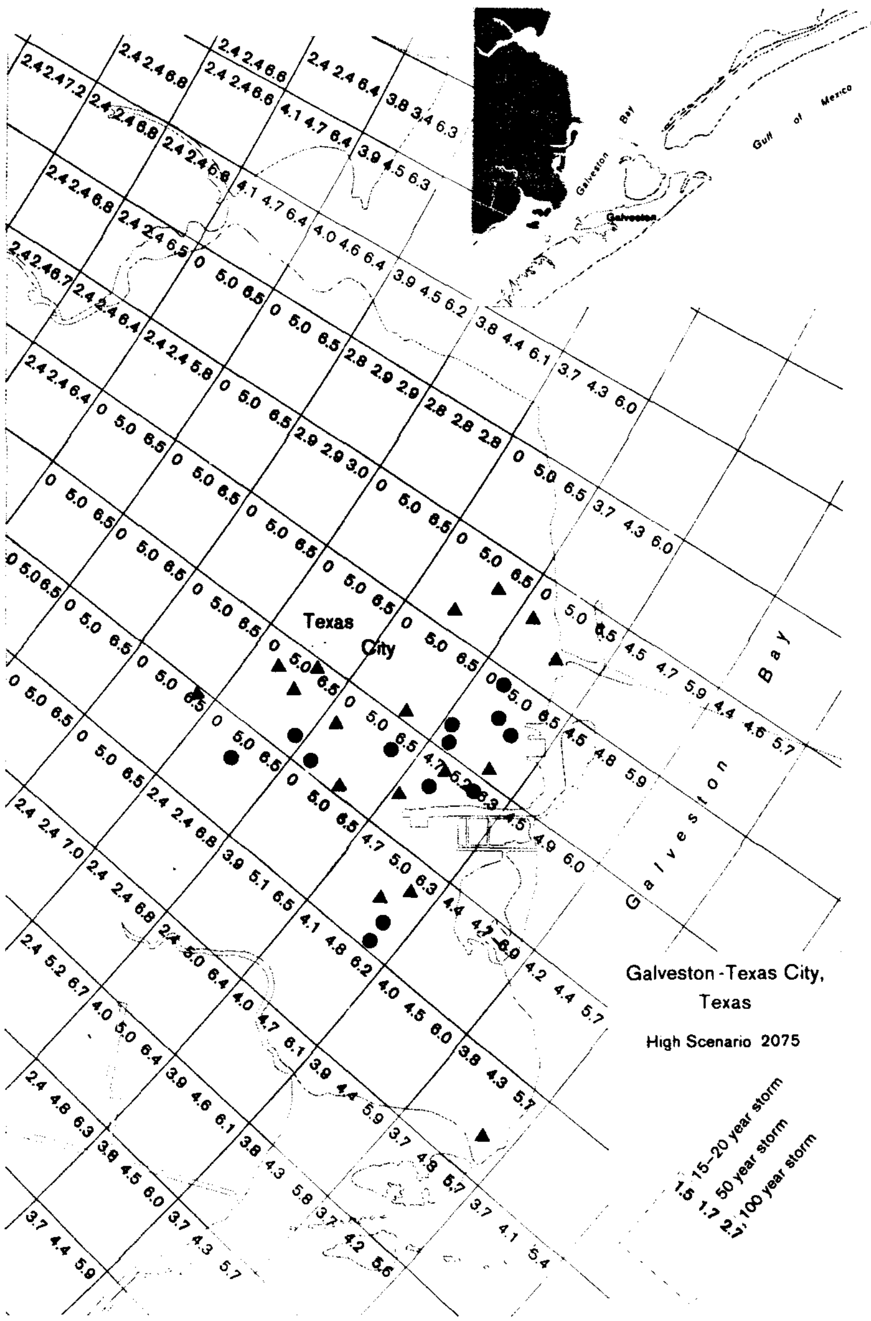

Figure 9-7. Map (Texas city section) of Galveston study area showing locations of hazardous waste facilities and 15–20-, 50-, and 100-year (high scenario) storm surge elevations for 2075. • = active hazardous waste management facility, ▲ = inactive hazardous waste management facility.

Table 9-2. Galveston Study Area Change in Number of Hazardous Waste Facilities (HWF) in 100-Year and 15-20- Year Floodplains for 1980, 2025, and 2075 (based on the high sea level rise scenario)

	Number of HWF in 100-Year Floodplain			*Number of HWF in 15-20-Year Floodplain*		
Year	*Active*	*Inactive*	*Total*	*Active*	*Inactive*	*Total*
1980	4	6	10	4	4	8
2025	13	18	31	4	5	9
2075	14	18	32	5	6	11

Source: Data from U.S. Environmental Protection Agency, 1982, RCRA data base, Part A, and author.

Note: Out of 32 hazardous waste facilities (14 active, 18 inactive)

The facilities in the area containing nine known carcinogens and two ecotoxins are listed as follows:

xylene	methyl parathion [a]
toluene	lindane [a]
cyanide	benzene [b]
lead	carbon tetrachloride [b]
mercury	chromium VI [b]
napthalene	polyanuclear aromatic hydrocarbons [b]
phenol	beryllium [b]
acrylic acid	Nickel [b]
nitrobenzene	Cadmium [b]
iron ferro (IC) cyanide	arsenic [b]
chlorotoluene	vinyl chloride [b]

[a] ecotoxins (chemicals that are toxic to ecological systems)
[b] known carcinogens

Figures 9-6 and 9-7 show the 15-20-, 50-, and 100-year high scenario storm surge elevations and the hazardous waste sites in the Galveston study area. Thirty-two facilities (14 active, 18 inactive) would be within the 100-year floodplain by 2075, and 11 (5 active and 6 inactive) would be within the 15-year floodplain. This result assumes that the levees and seawall would not be raised, an assumption that Gibbs dismisses in Chapter 7. A summary of the number of facilities located within designated floodplains under the high scenario for 1980, 2025, and 2075 is presented in Table 9-2.

Table 9-2. Galveston Study Area Change in Number of Hazardous Waste Facilities (HWF) in 100-Year and 15-20- Year Floodplains for 1980, 2025, and 2075 (based on the high sea level rise scenario)

Table 9-2. Galveston Study Area Change in Number of Hazardous Waste Facilities (HWF) in 100-Year and 15–20- Year Floodplains for 1980, 2025, and 2075 (based on the high sea level rise scenario)

	Number of HWF in 100-Year Floodplain			*Number of HWF in 15–20-Year Floodplain*		
Year	*Active*	*Inactive*	*Total*	*Active*	*Inactive*	*Total*
1980	4	6	10	4	4	8
2025	13	18	31	4	5	9
2075	14	18	32	5	6	11

Source: Data from U.S. Environmental Protection Agency, 1982, RCRA data base, Part A, and author.

Note: Out of 32 hazardous waste facilities (14 active, 18 inactive)

Flood Control Measures for Hazardous Waste Sites in the Study Areas

If no additional floodproofing or protection measures are taken by the waste sites in the case study areas, risks from flooding, particularly in Charleston, could be substantially increased by sea level rise.

The Charleston facilities are primarily storage/treatment units; thus floodproofing options such as fencing, movable containers, elevating facilities on fill or piers, and secure storage structures could be used. Flood protection options would include constructing levees and floodwalls around facilities to cut off impeding floodwaters and digging channels to divert water around facilities. A less expensive alternative for storage facilities would be the development of emergency evacuation plans to remove all wastes before a flood.

The Galveston study area contains more diverse types of hazardous waste facilities including landfills, waste piles, land treatment areas, surface impoundments, storage tanks, injection wells, and incinerators. Thus, flood protection and floodproofing options will vary more in Galveston. However, if local governments decide to raise their seawalls and levees in anticipation of sea level rise, additional measures by the waste sites may be necessary.

CONCLUSIONS

The flood mitigation measures in place at hazardous waste facilities vary widely in their flood mitigation effectiveness. Accordingly, serious health and environmental problems may result from the flooding of some active facilities, even in the absence of sea level rise.

Although the site visits of Walash and Raasch suggest that there is a wide variation in design flood levels and in the use of freeboard, the existing flood mitigation measures have one element in common: they generally will not, in their present condition and configuration, provide protection against flooding associated with a large rise in base sea level.

The need for anticipating sea level rise and reconsidering the adequacy of existing regulations varies according to the operating status of hazardous waste sites. Owners and operators of proposed facilities should consider whether the prospect of increased flooding justifies changing the planned location. Proposed facilities may minimize flood mitigation investments in the long run by designing for the flood levels to be experienced over the project's lifetime rather than those currently to be expected. We believe, however, that existing regulations, if enforced, Will protect the public from increased exposure to wastes from proposed and operating facilities. As sea level rises, flood maps should be redrawn and facilities retrofitted with additional required flood mitigation measures. The fact that FEMA has yet to complete the preparation of flood insurance risk studies for a substantial fraction of communities in the United States suggests that higher priority may have to be accorded to this function in the future.

Currently operating facilities scheduled to close would not be protected by existing regulations. To address this inadequacy, closure plans required by federal and state agencies should go beyond the level of protection required of operating facilities and incorporate measures to protect these sites from the inundation, erosion, and flooding that could occur in the next century.

Currently inactive facilities, particularly those that were improperly closed or that do not have an identifiable owner or operator, may already present environmental hazards. These hazards would be aggravated by a rising sea. Identification and decontamination of these sites may pose the most troublesome of the problems discussed here.

Proven flood mitigation measures exist to address the risks that could be created by sea level rise. Environmental programs should be expanded in order to address this challenge explicitly.

NOTES

1. Active hazardous waste facilities are defined as those sites that filed a RCRA Part A application to EPA before November 19, 1980.
2. (PL 94-580).
3. Section 3004, Part 264, Subpart B.
4. 24 CFR 1910.3(c)(3).
5. The following description of flood characteristics is an adaptation from a recent EPA report (EPA, August 6, 1981) on locating hazardous waste facilities in special environmental areas. For further information, see Department of the Army, Office of the Chief of Engineers, 1972, *Flood-Proofing Regulations, EP* 1165-2-314. Washington, D.C.: U.S. Army Corps of Engineers. This study identified the characteristics of floods that are critical in determining the degree of flood damage.
6. A computer literature search of the GEOREF and Pollution Abstracts found virtually no references to the subject.
7. In April 1983 FEMA issued a request for proposals for "Identification of the Universe of Remaining Flood Insurance Studies" (RFP EMW-R-1187). Seven thousand U.S. communities that have been designated as flood prone have not had flood risk studies completed.

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