Spills and Fires from LNG and Oil Tankers in Boston Harbor

James A. Fay

77 Massachusetts Avenue, Rm. 3-258

Cambridge, MA 02139

March 26, 2003

1 Introduction

The events of September 11, 2001 have raised concerns about the potential for terrorist attacks on the energy system infrastructure of the United States. In particular, the possibility of the use of a boat bomb, such as was used against the USS Cole in 2000 and the oil tanker Limburg in 2002, to attack a marine liquid fuel tanker in a U.S. harbor was publicly discussed in Massachusetts, where both LNG (liquified natural gas) and oil product tankers land cargoes in Boston harbor. The consequences of such an incident could be severe, and present a potential problem of great magnitude for public safety officials.

The safety concerns for the public stem from the effects of the burning of the tanker's combustible liquid cargo, which would certainly escape from cargo holds punctured by the force of an explosion. The ensuing fire can spread on the sea surface toward nearby shorelines, and its thermal radiation could produce bodily harm to exposed individuals on shore and possibly set fire to shoreside buildings.

The fire that would ensue from a boat bomb attack on a tanker would be of unprecedented size and intensity. Like the attack on the World Trade Center in New York City, there exists no relevant industrial experience with fires of this scale from which to project measures for securing public safety. Lacking such experience, we must rely on scientific understanding to predict their characteristics, based upon laboratory and field experiments of much smaller fires.

The author has developed a mathematical model for the spills and fires from liquid fuel marine tankers which is based upon published scientific papers in peer-reviewed journals.[1] The purpose of this article is to apply this research to the case of Boston harbor.

Tankers delivering liquid fuel cargoes to Boston proceed through the inner harbor to terminals in Chelsea Creek and the Mystic River. To reach these terminals they must pass by residential and commercial areas on the shorelines of South Boston, downtown Boston, East Boston, Charlestown, Chelsea, and Everett. Along this route the vessel distance from either shore is between 1/2 and 1/4 kilometer. A tanker spill fire at any location along this route would have serious consequences for persons and property on the shore adjacent to the stricken vessel.

Public attention has been focused on LNG tankers, for which the fires are expected to be most severe. This is a consequence of the large cargo holds and expected spill volumes in such vessels and the thermal characteristics of LNG, which burns very rapidly. Nevertheless, substantial fires may also ensue from oil product tankers delivering gasoline, jet fuel, diesel fuel, and home heating oil, all of which burn readily, if not so rapidly as LNG.

2 Tanker spills and fires

Liquid fuels carried in sea-going tankers are stored in separate holds, each of which may be as large as 25,000 cubic meters in LNG tankers but only about one-tenth that size in an oil products tanker. A powerful explosion close along side the tanker can puncture the hold and allow the cargo to drain out upon the surrounding sea surface. That part of the cargo fluid above the sea surface level will first leak out, and additional cargo may also be ejected. Given an explosively formed hole of sufficient size, such cargoes can be disgorged within minutes.

Liquid fuels are lighter than sea water. They float, unmixed, on its surface. Most importantly, they speedily spread sideways, exposing the fuel to the air above. Once ignited, as is very likely when the spill is initiated by a chemical explosion, the floating oil pool will burn vigorously. It will be seen that the time to burn spills of the size mentioned above can be less than five minutes.

[1] J. A. Fay, 2003. *Model of spills and fires from LNG and oil tankers*, Journal of Hazardous Materials, **B96**, 171-188.

Fire that burn thousands of tons of fuel in a few minutes are extraordinarily large, lying well outside the range of domestic firefighting experience. Such fires cannot be extinguished. The thermal radiation from such huge fires can be damaging to people and can set afire combustible buildings.

3 Maximum pool size and fire duration

To illustrate the characteristics of such spills in Boston harbor, we consider two typical spills, one of LNG and the other of gasoline. The relevant spill parameters are listed in Table 1. The LNG spill volume is 14,300 cubic meters (6,000 metric tons). Provided the vessel hole area is greater than ten square meters, the maximum pool fire area is 180,000 square meters and the fire duration is 3.3 minutes. The gasoline spill volume is 1140 cubic meters (820 metric tons). The maximum pool fire area is 80,000 square meters and the fire duration is 5.1 minutes if the vessel hole area is greater than 3 square meters.

The pool fire, initiated at the time of the explosion, grows in area in proportion to the time since initiation, reaching its maximum extent at the end of the burning process.

The maximum pool size for an LNG spill is shown as a solid red line in Figs. 1-2, and for a gasoline spill in Figs. 3-4, superimposed on sections of the Boston harbor marine chart. The spill site is located in mid-channel between downtown Boston and East Boston, but could be anywhere along the path into Chelsea Creek or Mystic River. The black rectangle is the vessel outline. The pool fire could equally well lie on the alternate side of the vessel from that shown.

For both LNG and gasoline spills, at the location shown, the outer edge of the pool fire at its maximum extent would impinge on waterfront structures nearest to the explosion site. This would be equally true at any position along the main channel of the inner harbor. It is almost certain that combustible buildings along the waterfront would be ignited by contact with the pool fire.

The extent of the pool fires, which spread to distances greater than the ship length in a short time, would make it impossible to move the stricken vessel away from waterfront areas. The potential for retarding the pool spread is nonexistent.

4 Pool fire thermal radiation

Burning LNG or oil emits thermal radiation that, if intense enough, can cause skin burns on humans exposed to the radiation and can ignite combustible materials on buildings. The more intense the radiation, the shorter is the exposure time needed to cause a skin burn or combustible material ignition.

For human skin exposure to flame thermal radiation, a thermal flux of 5 kilowatts per square meter (kW/m^2) will result in unbearable pain after an exposure of 13 seconds and second degree burns after an exposure of 40 seconds. Exposure to twice that level, 10 kW/m^2, for 40 seconds is the threshold for fatalities.[2] Wood can be ignited after 40 seconds exposure at a thermal flux of 5 kW/m^2.

We have chosen a thermal flux of 5 kW/m^2 as a criterion for the limit for significant damage to humans and combustible materials and have calculated the distance from the spill site at which that flux would be experienced for each type of spill.[3] As listed in Table 1, this distance is 1.1 kilometers

[2] K. S. Mudan, 1984. *Thermal radiation hazards from hydrocarbon pool fires*, Progress in Energy Combustion Science, **10**, 59-80.

[3] These distances are based upon an analysis contained in J. Fay, *Model of large pool fires*, to be submitted to the Journal of Hazardous Materials.

Table 1: Physical parameters of tanker spills

	LNG	Gasoline
Spill volume (m^3)	14,300	1140
Fire duration (min)	3.3	5.1
Maximum pool area (10^4 m^2)	18	8.0
Maximum pool radius (m)	340	230
Average heat release rate (TW)	1.5	0.12
Distance to average heat flux of 5 kW/m^2 (km)	1.1	0.9

for the LNG spill and 0.9 kilometers for the oil spill. These distances are also shown as dashed red lines in Figs. 1 to 4.

For the LNG spill, the thermal radiation damage zone includes about 1.9 square kilometers of shoreside area. Within this zone, extending 1.1 kilometers from the spill site in the main channel, skin burns to humans exposed for only a fraction of a minute will occur. Beyond the shorefront, at 0.5 kilometer from the spill site, where the thermal radiation flux is 10 kW/m^2, fatalities can ensue. Building fires can be induced in a land area of about 1.9 square kilometers closest to the spill site.

For an oil spill, the thermal radiation danger is only slightly less than for the LNG spill. Some shorefront area, about 0.5 square kilometer, lies within the thermal radiation danger zone. Human fatalities would occur within 0.4 kilometers from the spill site. Buildings adjacent to the edge of the pool fire can be ignited.

One cannot exaggerate the thermal intensity of the LNG pool fire. It's average heat release rate is about twice the average thermal power consumption of all U.S. fossil fuel electric power plants. The gasoline fire intensity is only 8% of that of the LNG fire, but that is still more than the average thermal power consumption of all New England power plants.

5 Conclusion

The analysis summarized in this report, based upon studies published in peer-reviewed scientific journals, sets forth the physical characteristics of the fires to be expected from a boat bomb attack on an LNG or oil tanker in Boston harbor. The major conclusions are:

- The magnitude of the resulting liquid cargo pool fires are unprecedented in scale, both from LNG and oil tankers. There is no possibility of ameliorating the fires' effects, much less extinguishing them, during the short time (several minutes) of burnout.

- At any point along the inner harbor route of ship travel from sea to berth, pool fire thermal radiation that can burn and even kill exposed humans, and ignite combustible buildings, will be experienced along and well inland from the waterfront, as shown in Figs. 1 to 4.

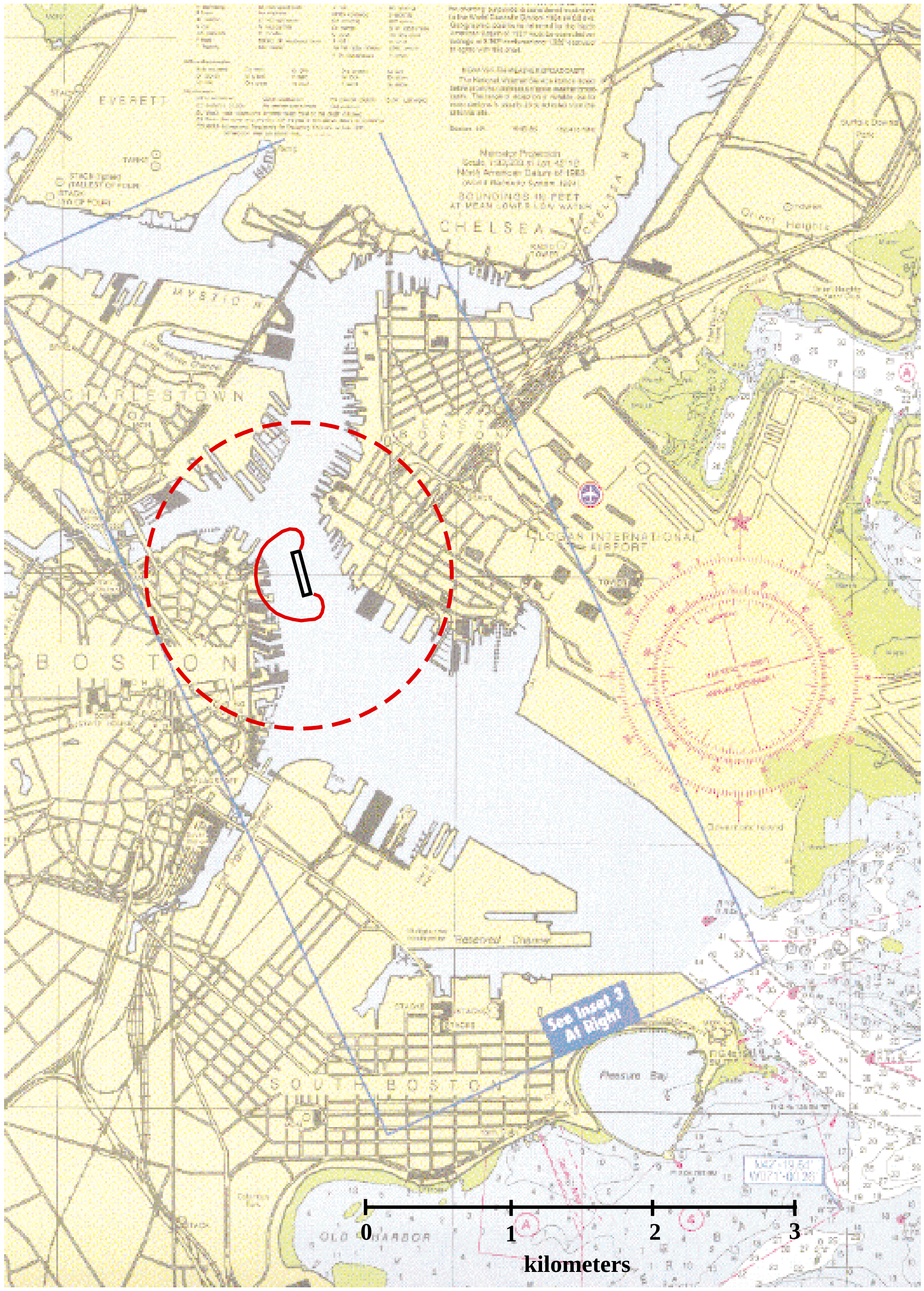

Figure 1: Typical danger zone from an LNG spill and pool fire in Boston harbor. The black rectangle is the vessel outline. Inner solid red line is the maximum extent of the pool fire. Outer dashed line is the outer edge of the thermal radiation zone (5 kW/m^2).

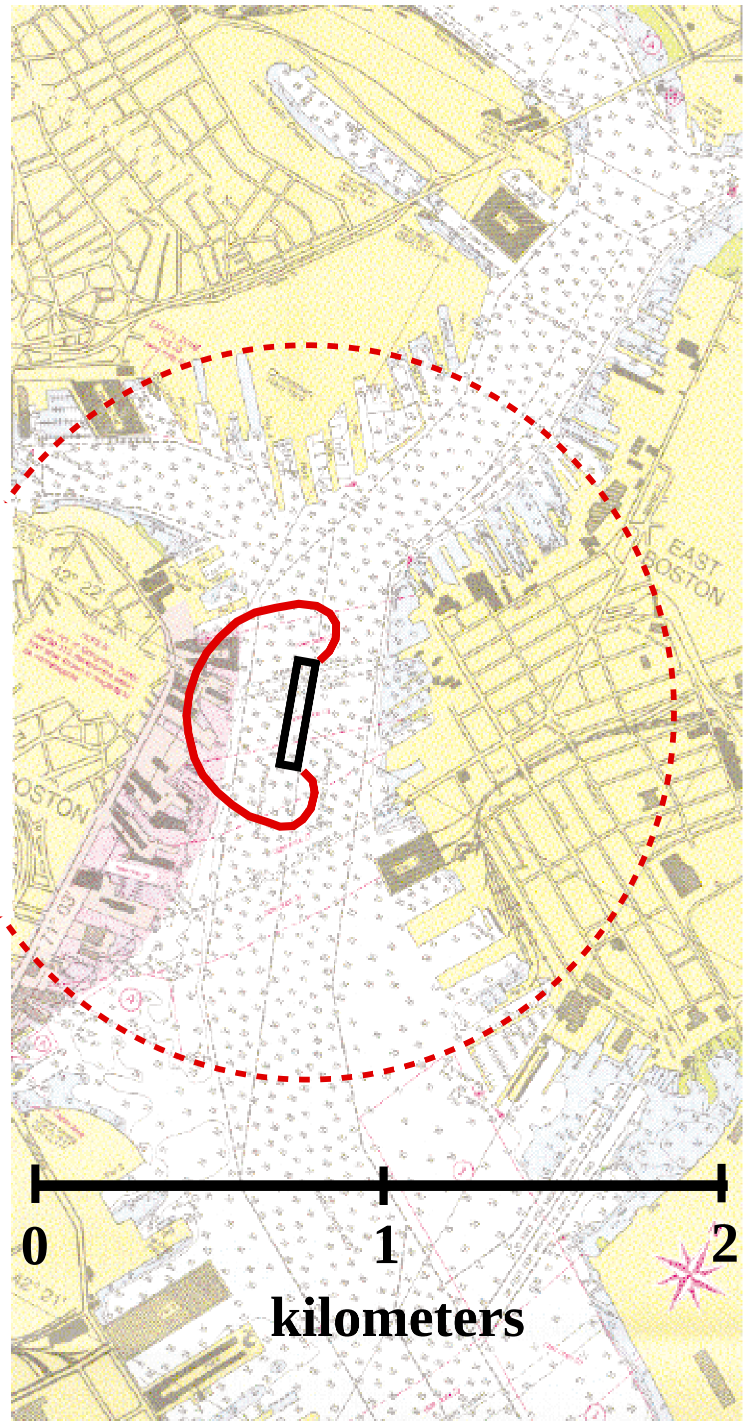

Figure 2: Same as Fig. 1, but displayed at a smaller scale.

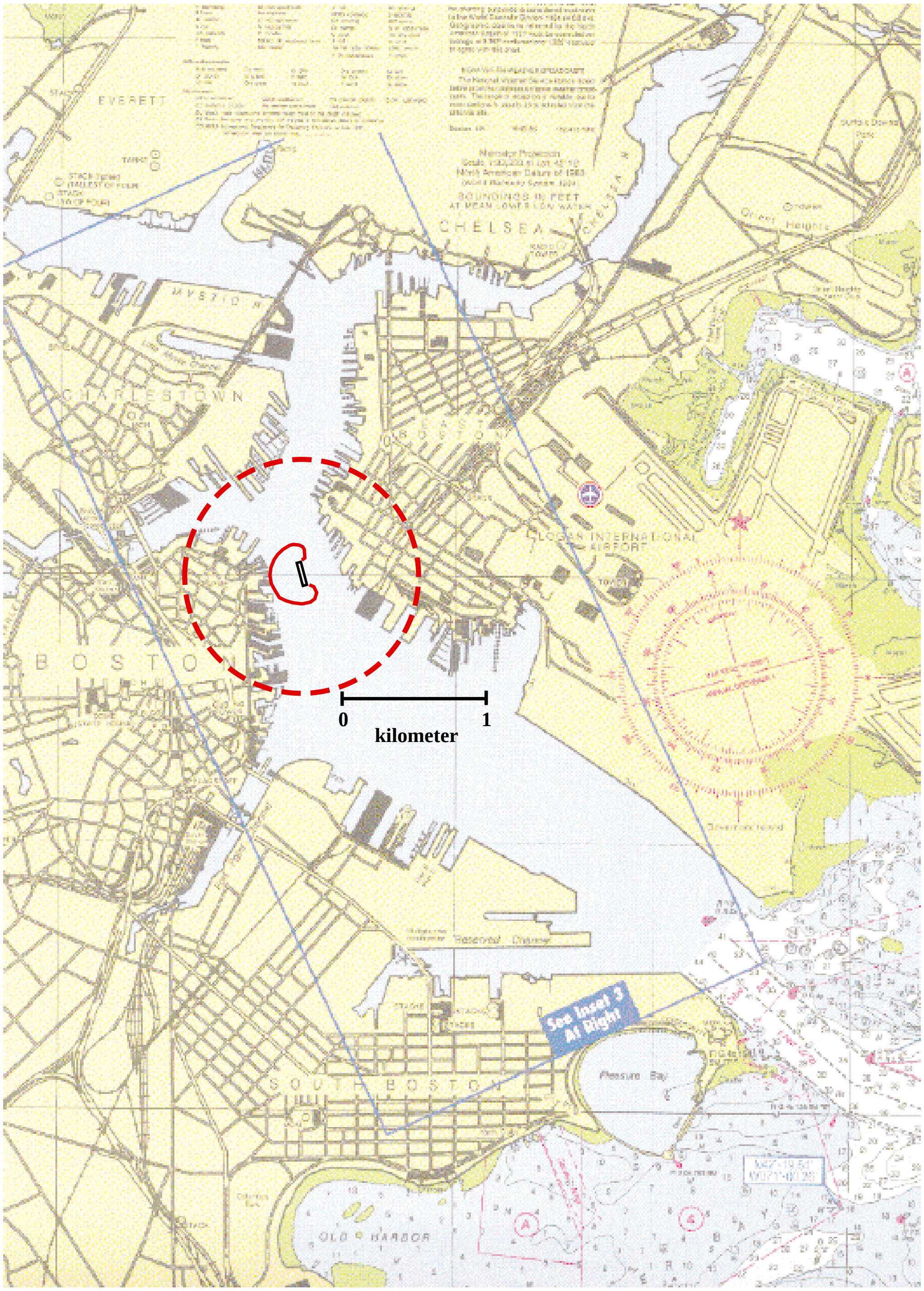

Figure 3: Typical danger zone from a gasoline spill and pool fire in Boston harbor. The black rectangle is the vessel outline. Inner solid red line is the maximum extent of the pool fire. Outer dashed line is the outer edge of the thermal radiation zone (5 kW/m^2).

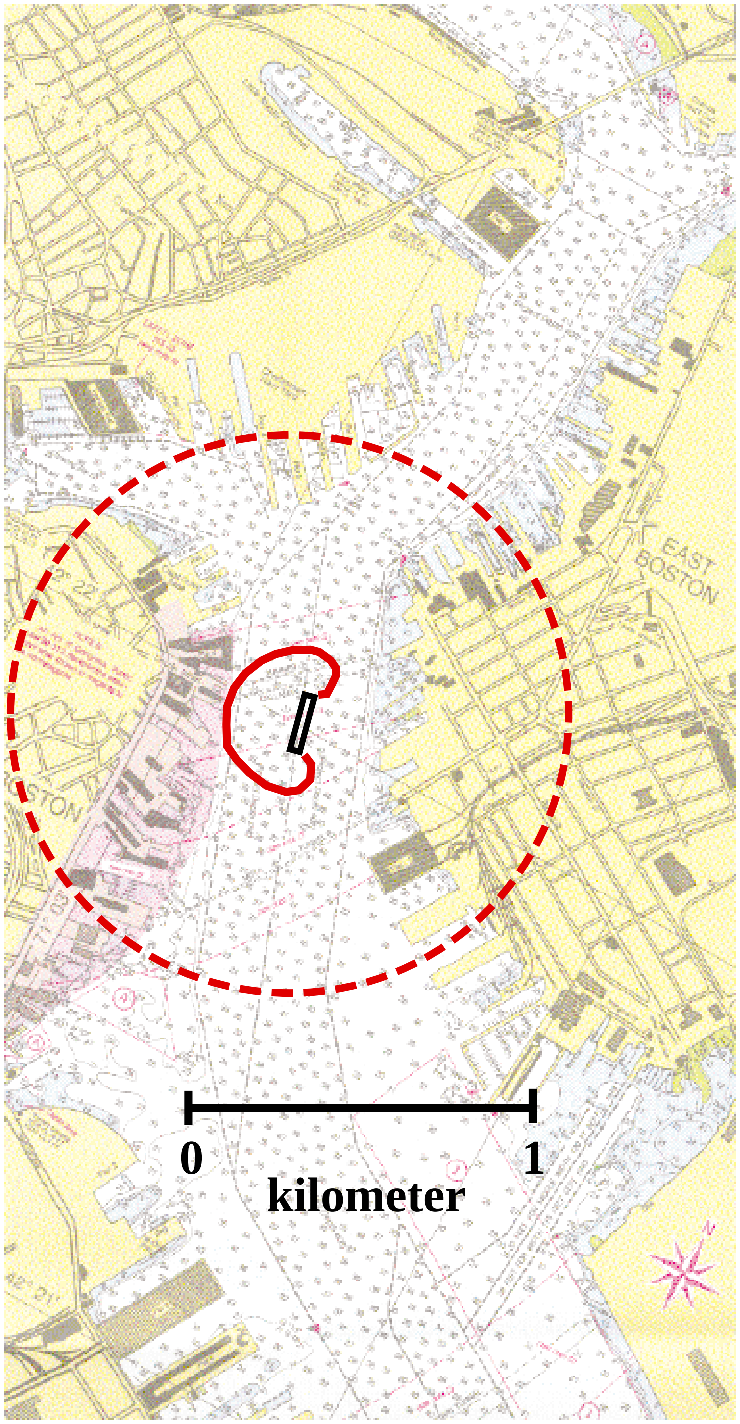

Figure 4: Same as Fig. 3, but displayed at a smaller scale.