

ENVIRONMENTAL IMPACT OF LNG TERMINALS IN THE GULF OF TRIESTE (NORTHERN ADRIATIC)

*V. MALAČIČ, J. FAGANELI, AND A. MALEJ
*Marine Biology Station, National Institute of Biology,
Fornace 41, Piran 6330, Slovenia*

Abstract. The environmental impact of the proposed offshore gas terminal of LNG (Liquid Natural Gas) in the centre of the small (20 × 20 km), shallow (maximum depth 24 m) semi-enclosed Gulf of Trieste has been evaluated. The terminal of dimensions 280 × 120 m would affect the marine environment in several ways. First, the temperature of the sea-water used in the heat-exchangers would be decreased by about 5°C. The concentration of chlorine in this seawater has to be no greater than 0.2 mg/L. The spread of the cooled discharged sea-water, which would be released from a pipe at the seabed, has been examined. Secondly, the release of seawater directly from the outfall pipe without diffusers would cause resuspension of the sediment, which is polluted by metals, especially mercury. An operational problem is that the seasonal population of jellyfish and occurrence of suspended macro aggregates (mucilage) could block the intake of warming sea-water.

Keywords: environmental impact, gas terminals, pollution, semi-enclosed sea, coastal waters, dispersion, Adriatic Sea, coastal sediments, mercury

1. Introduction

In the beginning of 2006 two proposals for gas terminals in the Gulf of Trieste, the northernmost part of the Adriatic and Mediterranean Sea, were put forward at the relevant levels of the Italian administration. The first is an offshore project for an LNG (Liquefied Natural Gas) terminal, proposed by the company Terminal Alpi Adriatico S.r.l.¹ The LNG terminal is planned to be placed in the center of the Gulf of Trieste, less than 1 km from the borderline between Slovenia and Italy in the sea (Figure 1). The second was proposed by another private entity, "gasNatural".² This involves an onshore LNG terminal, located in Žavlje (Zaule in Italian), the locality inside the Bay of Muggia, which faces

the Gulf of Trieste at its closed side (Figure 1). This LNG terminal is planned to be placed on shore, next to the terminal of crude oil, where oil tankers of capacity over 100,000 tons are currently docking. Žavlje is less than 4 km from the town of Trieste in Italy (population over 2×10^5 in 2001) and about 8 km from the town of Koper in Slovenia (around 5×10^4 in 2004). There are common features of the two terminals: their capacity for storing LNG at a temperature of -161°C and pressure slightly above atmospheric pressure (up to 200 mbar) is $8.0 \times 10^9 \text{ Sm}^3/\text{year}$ for 310 days/year (1 Sm^3 means 1 m^3 of LNG at around 1 bar and 0°C).

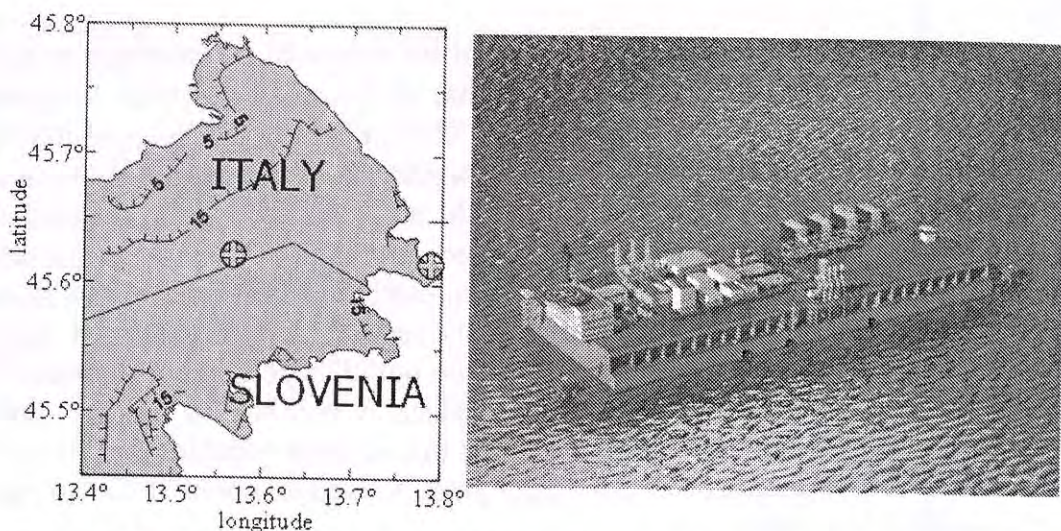


Figure 1. Left: Locations of proposed LNG terminals (circles with a cross) in the Gulf of Trieste. The full line marks the borderline at sea between countries, lines with hashes mark the isobaths of depth in meters. Right: sketch of the offshore LNG terminal.¹

Both terminals are supposed to utilize seawater as the major heat source (open rack vaporizers, or ORV) for the evaporation of LNG for the transportation of gas in the associated network. Around $2.28 \times 10^4 \text{ m}^3/\text{h}$ (maximum $3.0 \times 10^4 \text{ m}^3/\text{h}$) of sea-water is to be pumped through the system of heat exchangers in the offshore terminal and about $2.65 \times 10^4 \text{ m}^3/\text{h}$ through the system in terminal Žavlje. This flow is larger, by about eightfold, than the flux of all industrial and municipal waste waters released in the Gulf of Trieste. In both proposals the same decrease in temperature of sea-water (5°C) is foreseen at the end of the outfall pipe which is placed at the seabed. The diameter of the outfall pipe of the offshore terminal is 2 m, resulting in a mean outfall velocity of 2.0 m/s, while the diameter of the outfall pipe of the terminal in Žavlje is 1.4 m, with an outfall velocity 4.5 m/s. The horizontal dimensions of the offshore terminal are $270 \times 110 \text{ m}$. The tanks are located inside a concrete structure placed on the seabed, with a deck about 20 m above the sea-surface (the depth of the seabed is

around 24 m). The LNG terminal in Žavlje would occupy an area around 23 ha, next to the shore-line.

In addition to environmental considerations, low sea temperatures during winter may impede the utilization of sea-water as the heat source. This problem has been raised in the proposal for the onshore terminal since, according to the measurements of the University of Trieste mean temperatures in February are around 8.7°C, and may drop below 7.5°C, at which the sea-water could not be utilized as the heat source. During these periods of low temperature seawater, heat from burning gas has been proposed for evaporation. The period of low temperatures can last for a month or two.

Cross-border effects were not considered in either project, therefore Slovenia expressed serious concern. According to EU regulations Slovenia, as a neighboring country, has the right to participate in the consideration of the impact of terminals. The cross-border effects include topics like safety at sea, maritime traffic, environmental impacts and security. The Slovenian authorities therefore proposed a procedure for assessing the environmental impact and were in contact with the Italian authorities. The work presented here constitutes the part of those activities related to major issues of the impact of an LNG terminal in the Gulf of Trieste.

The report focuses on four major issues relating to a possible LNG terminal: changes in circulation, temperature and salinity; The effects of chlorine compounds in the outfall sea-water, utilized as a heat source; the effects of resuspension of polluted sediments and pollution from aluminium bars used for protection against steel corrosion; safety issues. Finally, the presented topics will be summarized and discussed.

2. Changes in Circulation, Temperature and Salinity Due to LNG Terminals

2.1. MODEL PRESENTATION

The circulation of the Gulf of Trieste was modelled with the Princeton Ocean Model (POM),^{3,4} which is described elsewhere.⁵ The model covers the Gulf of Trieste with a horizontal resolution of 0.5 km, and its domain is presented in Figure 2. The model grid is composed of 133 × 193 cells in the horizontal directions, and 11 sigma-layers in the vertical, whose thickness varies along the vertical, the surface and the bottom-most layers having the smallest thickness.⁶ The finite-difference model applies the Mellor–Yamada closure of turbulence⁷ and is one-way nested into the coarser climatic model of the northern Adriatic Sea with a resolution of 1.5 km.⁸

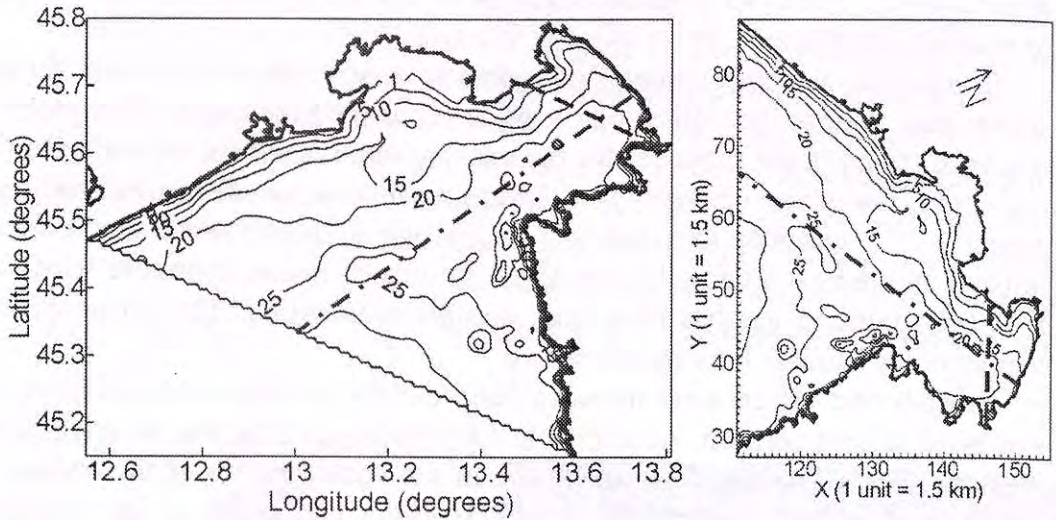


Figure 2. Left: Model domain over the northern Adriatic area. The saw-tooth line is the open-boundary line (OBL), which is the grid line of the coarser northern Adriatic model,⁸ to which the model of the Gulf of Trieste is one-way nested. Right: the model domain in model coordinates. The dash-dotted line marks the profile along which model results were studied in the presence of the offshore LNG terminal, while the dashed line represents the profile along which model results were studied for the onshore terminal. Both terminals are marked with a red circle.

The model is initiated with the temperature and salinity field at time zero of the “perpetual year” (360 days), which are obtained from the objective analysis of seasonal data.⁹ In the model linear variations of seasonal values of temperature and salinity with time are assumed from the seasonal value at the mid-time of a season to the seasonal value at the midtime of the following season. During each baroclinic (“internal”) time step of 150 s, temperature and salinity in the equations of heat and salinity are reduced by a seasonal value. In this way the numerical model is driven towards known climatology fields of temperature and salinity. The barotropic (“external”) time step is 10 s. Tides are excluded in climatic circulation studies. Initial velocities are set to zero.

Along the open boundary (OB) line fluxes of momentum (velocity), heat and salinity as well as the sea-surface elevation are provided from the coarser model of the northern Adriatic. Volume flux was corrected twice – once due to the refinement of topography and the other due to the requirement that the total flux through the OB line is zero at each time step. The outward radiation condition was applied for the depth-averaged velocity through the vertical plane along the OB line, while temperature and salinity were passed across this plane according to the upstream advection scheme.

At the sea surface the ECMWF (European Center for Medium range Weather Forecasting) monthly data of climatology (e.g., wind stress, penetrative solar

irradiation minus the upward heat flux, evaporation minus precipitation) were interpolated on a model grid. The river influences were, however, considered in a way different from that in the coarser model developed by other authors,^{8, 10} where lower values of salinity were imposed in the surface cells around the river mouth. In this work monthly values of river outflows were imposed as a volume flux in the model cells with zero salinity that are furthest upstream. Temperature in the river was extrapolated from the sea-temperature in neighbouring cells where monthly temperatures of rivers were not known. The model topography was adapted to mimic the river estuary along the model grid-line inside the land-domain. We found that it is sufficient to impose about ten model cells "upstream" from the river mouth along the estuary, with a topography which follows the topographic data where these are available. Otherwise, depths of estuaries decrease linearly from the depth at the mouth towards a depth of 2 m at the upstream end.

LNG terminals were included through additional boundary conditions. First, for the offshore LNG terminal one numerical cell was set to be a land-point. There is no normal flow through the side boundaries of this cell, except for the top-most cell at the sea-surface: velocity components through the vertical sides correspond to the inflow of sea-water. Secondly, a submarine outfall is assumed to be placed at the seabed several 100 m from the terminal (for both terminals). In a suitable cell at the seabed the velocity components correspond to the outflow, which is directed according to the project scheme. However, the salinity in cells that neighbour the outflow cell horizontally is equal to the salinity at the surface, where the inflow takes place. The temperature in these cells is, however, set to be 5°C lower than that at the inflow.

Numerical simulations over 3 perpetual years show that the model spins up from zero velocity in 3–4 months. Kinetic energy at each time step in the second perpetual year differs from that at the same time in the 3rd perpetual year by $3.8 \pm 2.8\%$. It therefore appears sufficient to run all simulations for two perpetual years only, while results are considered only for the second perpetual year. Three types of model simulation were performed: the first without LNG terminals, the second with the offshore terminal and the third with the onshore terminal. We did not consider the possibility of both LNG terminals for two reasons: it seemed very unlikely that both LNG terminals would be commissioned. They are also sufficiently distant for that their impact on the environment to be reliably separated. Temperature differences (ΔT) at each model cell due to the presence of the terminal are calculated by subtracting the temperature which resulted from the numerical simulation without the terminal from that obtained at the same time label from the simulation with the terminal. Salinity differences were obtained similarly.

2.2. MODEL RESULTS

This section is focused on the effects the LNG terminals would have on the circulation, temperature and salinity field of the Gulf. These fields, with and without an LNG terminal, will be compared. Analysis of the spread of temperature difference around an offshore LNG terminal shows many interesting features. However, only phenomena in two situations deserve our attention. The first situation is that for mid-April (Figure 3). The general circulation is not changed with the presence of the terminal on the scale of the Gulf. There are deviations of the circulation around the terminal, on a scale of a few km. The temperature difference displays a spread from the terminal around the Gulf with an anticyclonic vortex, especially at a depth of 10 m, at which the drop in temperature $\Delta T = -0.4^\circ\text{C}$ extend around the northern part of the Gulf for about 5 km, which is larger by an order of magnitude than the spread predicted by the project proposers.¹ Near the surface, however, next to the strip of $\Delta T < 0$, there is also a curved strip of $\Delta T > 0$ (yellow), which is probably related to the small horizontal shift of the anticyclonic vortex. Near the seabed (15 m depth) the southern part of the Gulf is slightly cooled (around 0.1°C).

The second interesting situation is that for mid-September (Figure 4). The anticyclonic vortex is no longer present at the surface, and there is an outflow in the central and northern part of the Gulf and an inflow in the southern part. The circulation structure due to the offshore terminal is changed peculiarly: the region where $\Delta T < 0$ is not confined to the vicinity of the terminal, but spreads from the southern side towards the central part of the Gulf. At mid-depths (10 m) the anticyclonic vortex is again present. However, it now brings cooler water towards the location of the LNG terminal, which is not a direct consequence of the water released from the LNG terminal. Clearly, the circulation has been changed in a way that is not clear. Near the seabed, there is a field of $\Delta T < 0$ (up to 0.5°C), that spreads for several kilometers in the southern part of the basin only, since this part is deeper than the northern one.

Vertical profiles of ΔT (Figure 5) along the axis of the Gulf show that during winter (top and bottom plot), and also during autumn (fifth plot from top) the water released from the LNG is confined to the outfall pipe near the seabed. In spring (second plot from top) and summer (third and fourth plot from top), however, the released water rises in a layer to depths around 10 m, where it spreads horizontally according to the advection field in that layer. In April this spread at the depth of 10 m is in the outward direction, while during summer it is also directed inward; $\Delta T = -0.5^\circ\text{C}$ spreads up to 8 km away from the potential terminal in mid-July.

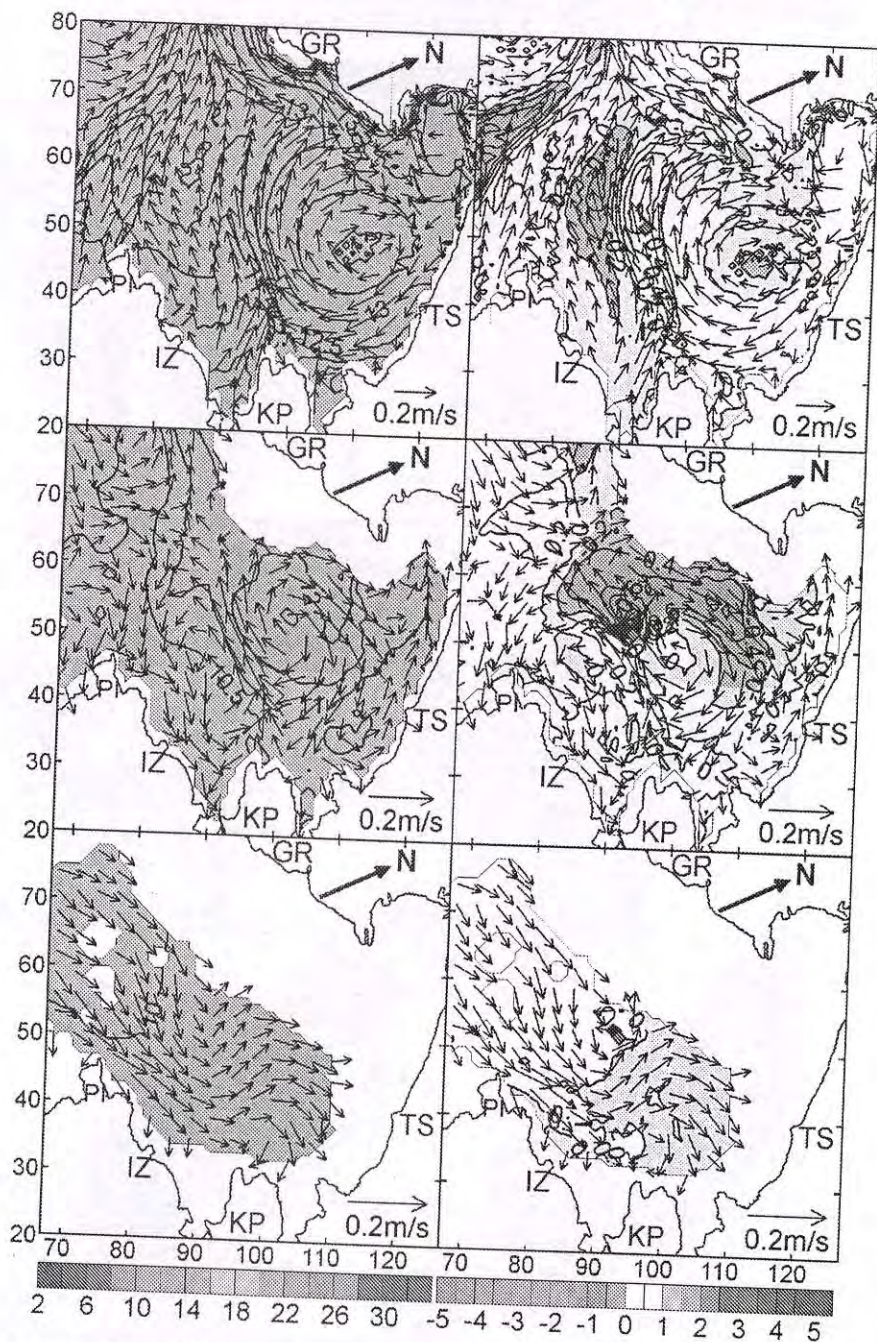


Figure 3. Horizontal distribution of temperature and currents (*left*) and temperature difference (ΔT) with currents (*arrows*) for the case with the offshore LNG terminal (*right*) during mid-April (10 days average) of perpetual year at the depth 1 m (*top*), 10 m (*middle*) and 20 m (*bottom*). The position of the terminal is marked with a red diamond. The arrow scale of currents is placed in each plot in the bottom right corner. The colour scale for temperature (without the LNG terminal) is at the bottom of the left column of plots, while that for ΔT is at the bottom of the right column of plots. One unit on the axes of plots correspond to a distance of 0.5 km. The wind blows from direction 84° (clockwise from north) with a mean speed of 2.7 m/s. PI, IZ, KP, TS and GR are the abbreviations for coastal towns Piran, Izola, Koper, Trieste and Grado.

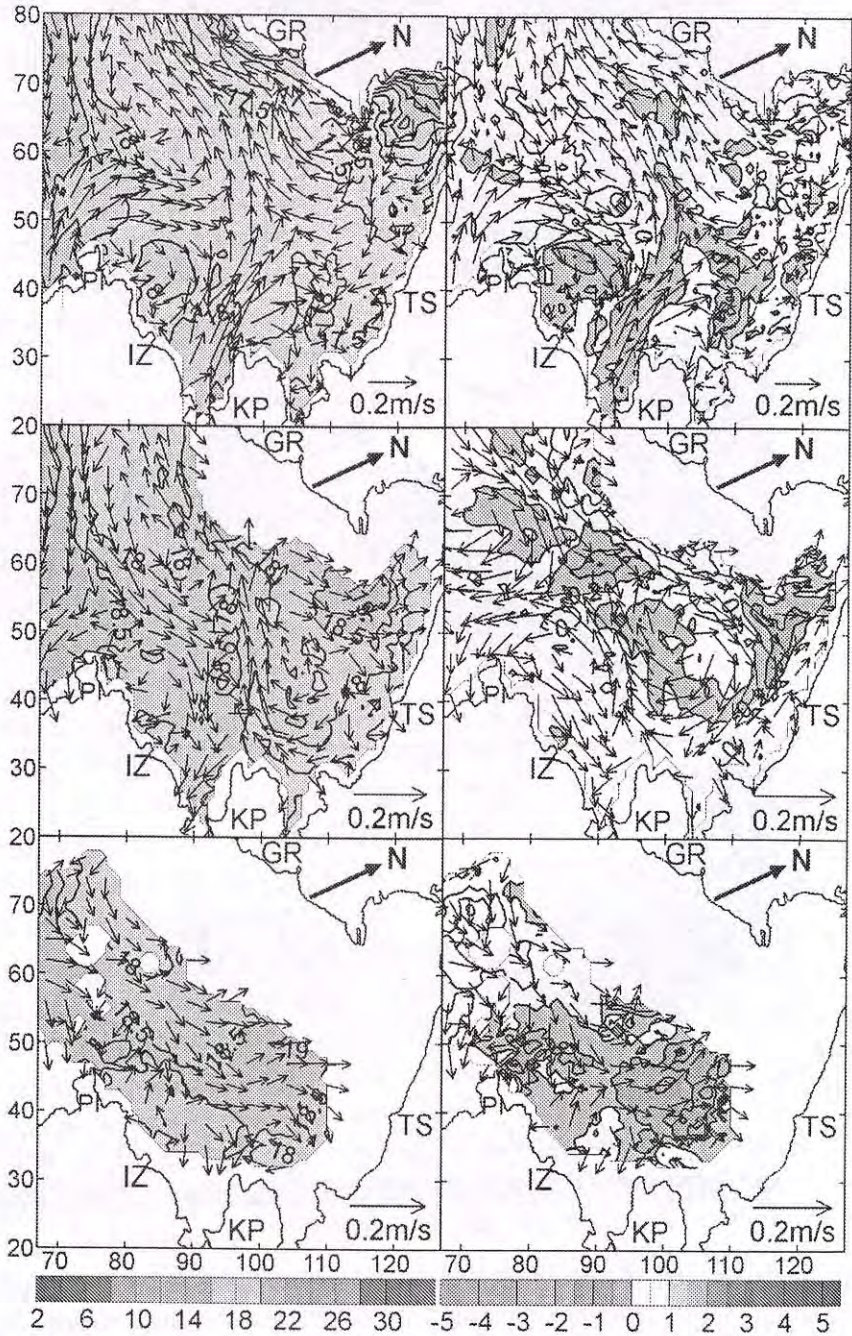


Figure 4. Similar to Figure 3, except for mid-September (10 days average) of perpetual year.

For the horizontal distribution of circulation, temperature and salinity differences (ΔS) in the presence of the onshore LNG terminal only the situation in mid-June is presented (Figure 6), which is zoomed over the Bay of Muggia

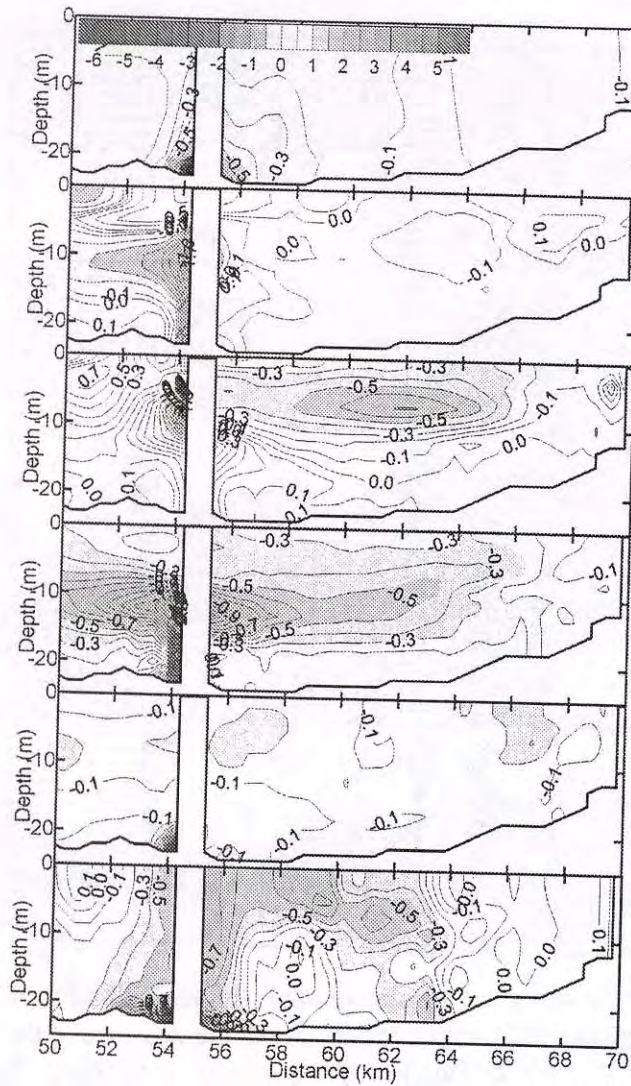


Figure 5. Vertical profiles (note the dash-dotted line in Figure 2) of temperature differences (ΔT) for the case of an onshore terminal. Only the farthest right part of the profile inside the Gulf of Trieste is shown. The right side of plots is the closed end of the Gulf (near the port of Trieste). The vertical white rectangle in all plots is a blank of the LNG terminal. Plots from top to bottom represent ΔT in mid-January, mid-April, mid-June, mid-September, and in the beginning of November (10 days averages). The color bar of temperature differences is placed in the topmost plot.

(south of Trieste). Simulations of circulation demonstrated that during this period the horizontal spread of cooled water is significant, and occurs at the surface and at a depth of 10 m. $\Delta T < -0.5^\circ\text{C}$ spreads over several km, outward the Bay of Muggia in Slovenian waters. The distribution of ΔS is similar, but less pronounced. Near the seabed, however, the released water is confined close to the orifice of the outflow pipe.

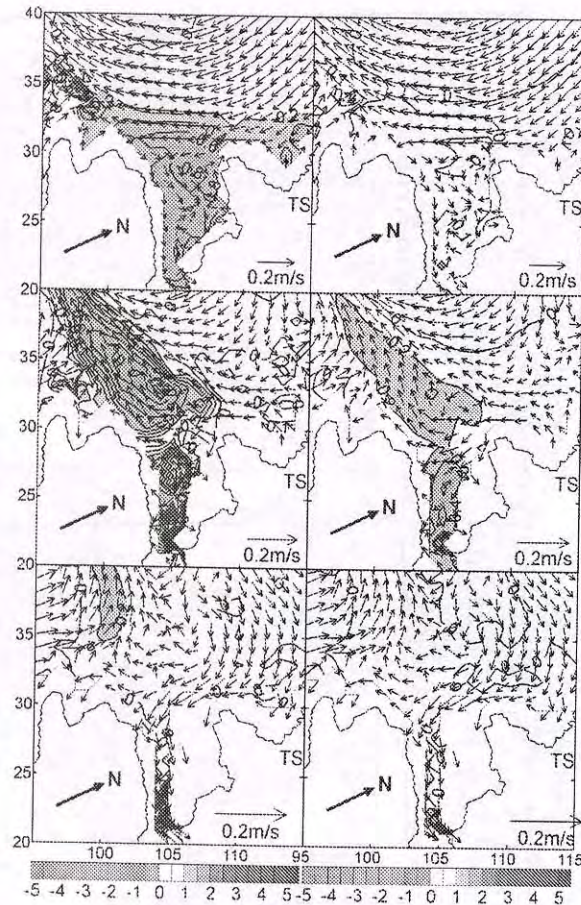


Figure 6. Horizontal plots of temperature differences (ΔT) with currents (*left*) and of salinity differences (ΔS) with currents (*right*) for the case of the onshore LNG terminal during June (10 days average) at the depths of 1 m (*top*), 10 m (*middle*) and 15 m (*bottom*). The colour scale for ΔT is at the bottom of the left column of plots, while that for ΔS is at the bottom of the right column. All other notations are the same as those in Figure 3. The wind blows from the direction of 112° (clockwise from north) with a mean speed of 1.4 m/s. TS is the abbreviation for the town of Trieste.

Vertical profiles of ΔT , which extend northward from the Bay of Muggia, are presented in Figure 7. Similar to the situation for the offshore terminal, the released water from the onshore terminal remains on the seabed around the position of the orifice of the outfall pipe during winter and autumn (top-most and two bottom-most plots), where it spreads for several km. For the onshore terminal this pattern is maintained during April also. The horizontal spread of released water at middepths is most pronounced in June, where $\Delta T = -0.5^\circ\text{C}$ extends up to 4 km from the point of release. The horizontal distribution (Figure 6) shows that the core of the spread is oriented towards the northwest, to Slovenian waters.

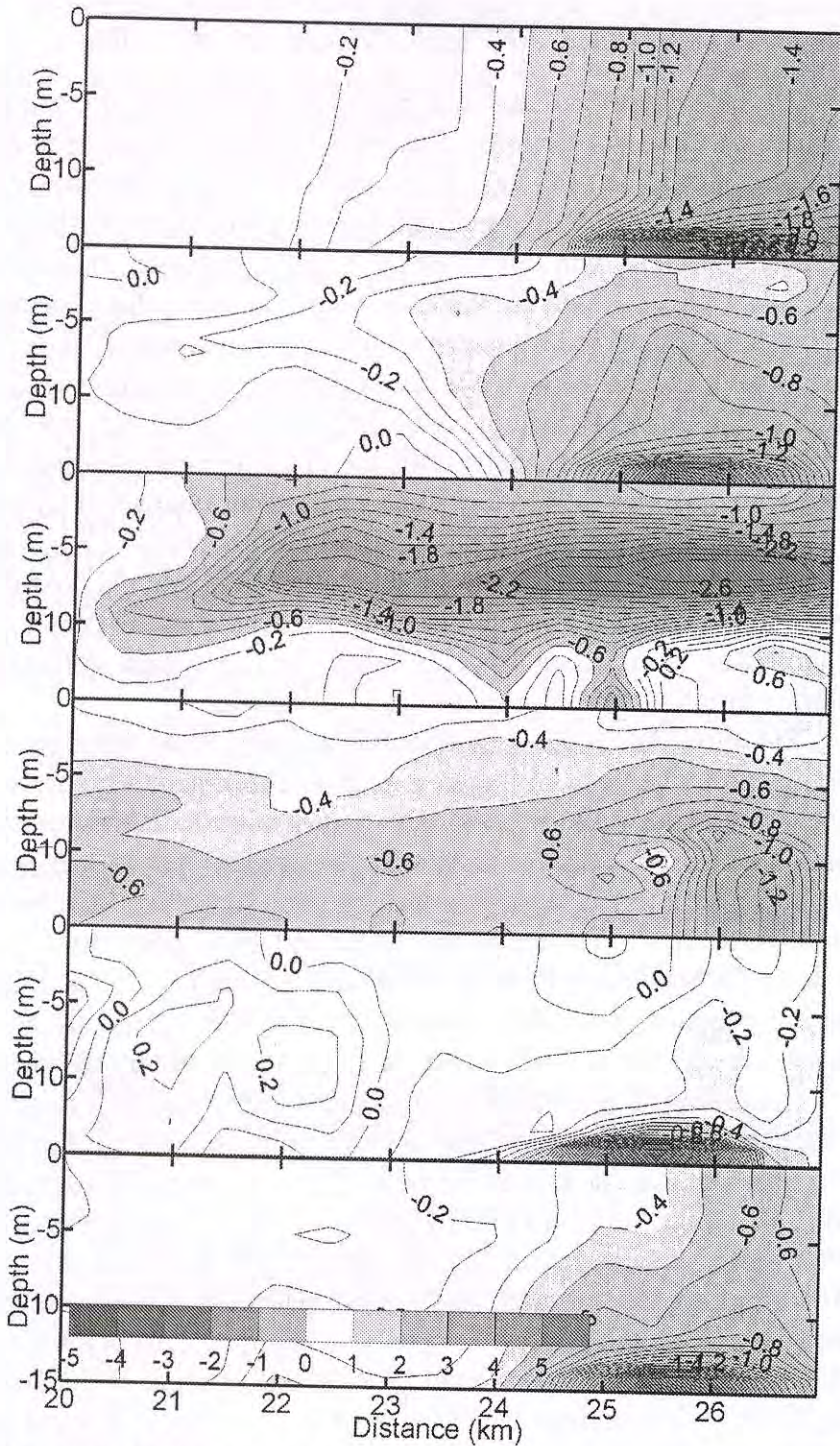


Figure 7. Vertical distribution of ΔT (note the dashed line in Figure 2 with a red diamond near the start of a profile), which extends for 7 km from the interior of the Bay of Muggia northward to the central part of the Gulf. Plots from top to bottom are for ΔT in mid-January, mid-April, mid-June, mid-July, mid-September and for the beginning of November. The color bar of ΔT is placed in the bottom-most plot.

3. Chlorination of Heating Water

The use of chlorine has been proposed to control biofouling in the heating system of the LNG terminal. For both terminals, it has been envisaged that the chlorine would be produced at the terminal by the electrolysis of seawater.^{1,2} It is clearly stated in that the concentration of chlorine in the sea-water released from the terminal will not exceed 0.2 mg/L. However, it is not pointed out that, for power plants which use water as a cooling agent, this concentration is allowed to be released into the environment for only two hours per day.^{11,12} This severely limits this method of antifouling. Moreover, when chlorine is added at regular intervals, it is not efficient in controlling macrofouling, e.g., by clams and mussels, since these close their shells until the chlorine concentration is dissipated.¹³ At moderate pH (the pH in the Gulf of Trieste averages 8.2) chlorine produces HClO very fast, which at pH 7–9 rapidly ionizes to ClO⁻. UV (A and B) light is absorbed by the ClO⁻ ion, decomposing it to Cl⁻ and O₂.¹⁴ At the seabed, higher NH₃ concentrations could be present, especially in the presence of sewage discharged by a submarine outfall,¹⁵ and the subsequent conversion of dissolved ammonia into toxic chloramines can be expected.

Toxic residual organic compounds are formed by chlorination, some of them being carcinogenic or mutagenic, such as chlorinated organic acids, phenols and trihalomethanes (chloroform). The chlorination of humic substances bonded in dissolved (DOC) and particulate (POC) organic matter, which contain hydroxy aromatic structures, leads to carcinogenic chloroform and bromoform, Cl and Br halomethanes. Although the DOC and POC concentrations in the Gulf of Trieste are rather low (1 mg/L DOC and 0.2 mg/L POC) and most of the chlorination products are rather short-lived, they can spread by advection of water mass over the entire Gulf, as is clearly demonstrated by the circulation study.

According to a number of ecotoxicological studies¹⁶ marine plants are less susceptible to chlorination than invertebrates and fishes. For marine organisms the acute toxicity threshold for a chlorine concentration times time level ranges from 0.15 mg/L – 1 min to 0.02 mg/L – 100 min, where the toxic concentration within one minute is smaller by about eight fold than that in fresh water.¹³ According to the same reference, phytoplankton is very susceptible to chlorine exposure, although recovery appears to be rapid. Larval lobsters are affected by chlorine, reflected in decreased growth and changes in metabolic activity; 0.1 mg/L for 60 min causes acute increase in respiration. Several studies show that newly laid fish eggs are less tolerant to chlorine than older eggs, while fish themselves die from anoxia when exposed to sufficiently high chlorine levels, since the biocide attacks the gills. According to Larson et al. (1978) the 96-h LD₅₀ (50% lethal dose) for common sole eggs is 0.25 mg/L which is similar to the chlorine concentration in the vicinity of the outfall orifice. Five days after

spawning, the LD₅₀ is about fivefold lower, similar to the concentration expected in the 100 m radius off the outfall orifice. For larvae, LD₅₀ is about 10-fold lower (0.0016–0.02 ppm) at temperatures of 7.4–9.3°C, which are similar to those expected at the sea bottom in the Gulf of Trieste. No data exist regarding the impact on migratory pelagic fish. Clupeids are seasonally abundant and may spawn in the Gulf of Trieste.^{17, 18} The impact of chlorine could therefore be deleterious to planktonic eggs and larvae. Moreover, eggs and larvae transported by advection from nearby spawning areas into the area around the LNG terminal could also be affected.

The impact of chlorine in the area about 1 km around the terminal can thus be considered important and in the area about 100 m around the terminal, actually deleterious if the proposed project is not modified. Categorization of chlorine as a harmful substance released from ships is already regulated.¹⁹ Those findings can be applied also to LNG terminals. In this context it is relevant to note results of a study on the environmental impact of chlorine in power plant cooling waters conducted in 1995. The power plant is located onshore in the north-eastern corner of the Gulf of Trieste (in the town of Monfalcone, which faces the small Bay of Panzano). The study showed the deleterious effect of heated chlorinated surface seawater on local marine communities (S. Fonda-Umani, personal communication in Piran Slovenia, 2006).

4. Resuspension of Bottom Sediment

4.1. DISTRIBUTION OF POLLUTANTS IN SURFACE SEDIMENT OF THE GULF OF TRIESTE

During the construction of LNG (sediment drillings, area of 300 × 150 m), and operation (discharge of heating water) resuspension of the surface sediment is expected. Sediments in that area are composed mainly of sand²⁰ known to be significantly polluted by metals. In particular, high Hg contents, which originate from the Idrija mining district in Slovenia, and to a lesser extent Pb and Zn²¹ which originate mainly from the Raibel mining district in Italy, are carried into the Gulf with the Isonzo (Soča) river, the mouth of which is located in the northern part of the Gulf coastline. The Hg and MeHg contents in sediments in the area of the planned offshore gas terminal are 1–2 µg/g and greater than 0.2 ng/g, respectively. These concentrations increase to more than 10 µg/g Hg and 4 ng/g MeHg towards the northern coastline, in the vicinity of the Isonzo river mouth, where the submarine gas pipeline would reach the shore.²² According to historical pollution with metals in the Gulf of Trieste,²³ the sediments are

considered “contaminated” when $\text{Hg} > 0.2 \mu\text{g/g}$ and when $\text{MeHg} > 0.2 \text{ ng/g}$. The distribution of Hg in surface sediments is displayed in Figure 8.

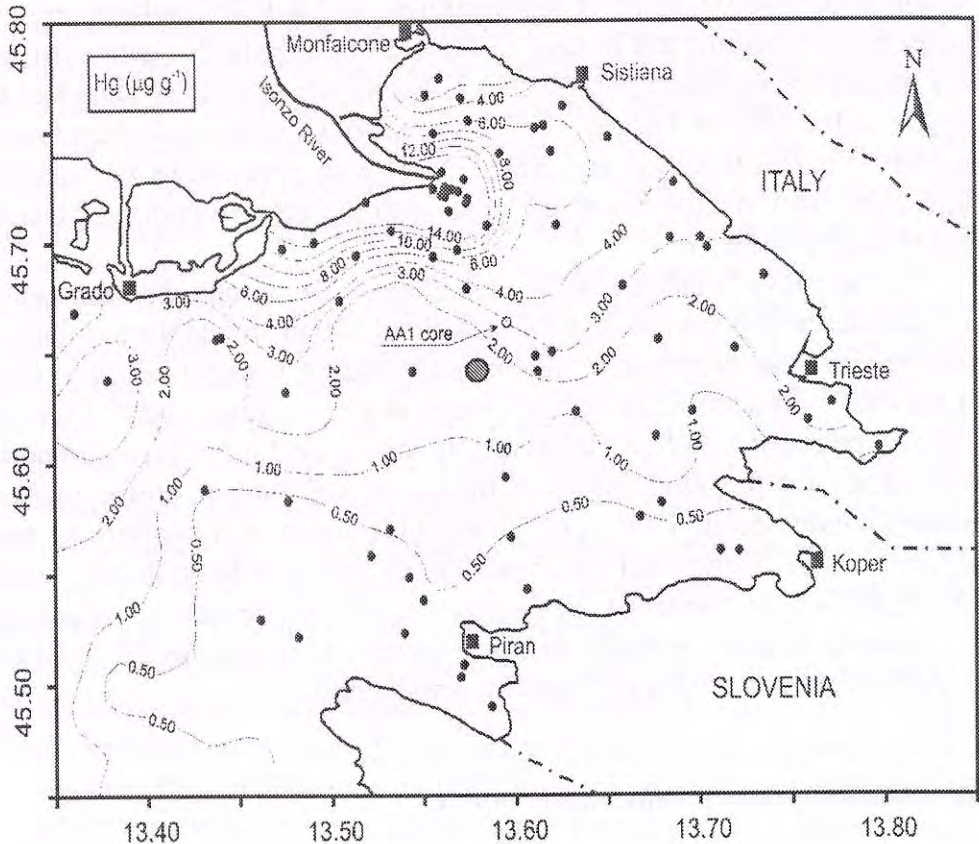


Figure 8. Distribution of mercury in surface sediments in the Gulf of Trieste [22] with isolines in $\mu\text{g/g}$. Position of the offshore LNG terminal is marked with the red dot.

4.2. RESUSPENSION AND REMOBILIZATION OF MERCURY

Sediments can be resuspended in two ways. The first relates to the construction works of the off-shore terminal and the submarine pipe which transports the gas to the land. The project proposers estimated that about $3 \times 10^4 \text{ m}^2$ of the sea-floor area would be affected for the foundations and that about $9,000 \text{ m}^3$ of material would be excavated, which is increased to $13,000 \text{ m}^3$ when the material excavated (and deposited nearby) for the gas pipeline is considered. The concentration of mercury around the off-shore terminal is around $1\text{--}2 \mu\text{g/g}$ and along the pipeline its mean value is around $5 \mu\text{g/g}$.²² From these data the lower limit of the mass of resuspended mercury can be estimated. Dry sediment has a density around 2.6 kg/m^3 and the actual sediment contains about 60% of pore water. In a volume of

9,000 m³ there are about 3,600 m³ of dry sediment (40%) with a mass 9,360 t. Taking the concentration of mercury around the terminal to be 1 µg/g, it then follows that, with the excavations, about 9.36 kg of pure mercury would be released into the water column. The excavated volume of 9,000 m³ for the pipeline would comprise 1,600 m³ of dry sediment with a mass 4,160 tons, in which there would be 20.8 kg of mercury (5 µg/g). This leads to the estimate that around 30 kg of highly toxic mercury would be released into the water column during the construction works only.

The second mode of resuspension of sediments would be continuous during the operation of the terminal. Due to the high outflow rates (velocities) of the jet of discharged sea-water used for the evaporation of LNG, will continuously resuspend sediment.

Sediment resuspension promotes increased remobilization of Hg and MeHg from the solid phase, mostly bonded on fine (<63 µm) sediment particles (pellites), and from pore waters. The latter is evidenced by the difference between the Hg and MeHg concentrations in pore waters of the Gulf, where they average around 50 ng/L and less than 1 ng/L, respectively, and their concentrations in the seawater column, where their average values are smaller than 5 and 0.05 ng/L, respectively. Sediment resuspension leads to higher particle concentrations in the water column, greater transport and, consequently, re-sedimentation of mercury. Higher Hg methylation rates in the presence of sediment resuspension appear feasible due to the redistribution of Hg within the microbially active zone of the sediment.²⁴ Microbial production of toxic MeHg (neurotoxin) in sediments of the Gulf of Trieste is the main source of MeHg in the water column,²⁵ which subsequently enters the marine food web (fishes) due to its high biomagnification.²⁶ Sediment resuspension also enhances oxygen penetration of sediments and enhances nutrient (N, P, Si) efflux from pore waters to overlying water. This fuels benthic and pelagic primary production (increasing eutrophication), DOC and POC production.

The national and international legislation dealing with Hg mobility and transformations in the marine environment is still vague. However, the EU strategy encompasses the lowering of Hg emissions and human exposure.

5. Corrosion Protection

The installation of aluminium sacrificial anodes is planned as a cathodic protection to prevent steel corrosion in the marine environment. Dissolved Al in seawater, present mainly as Al(OH)₃ and Al(OH)₄⁻, exhibits rather low toxicity to marine organisms, probably because it is complexed. Fish generally appear to be more sensitive to aluminium compounds than invertebrates, because Al is a gill toxicant that causes ionoregulatory and respiratory effects. Although marine

data are limited, a low reliability marine trigger value of 0.5 $\mu\text{g/L}$ has been proposed.²⁷ No impact studies were reported in the proposed projects of LNG terminals.

6. Safety Issues

Although the focus of this paper is on the environmental impact of LNG terminals in a small shallow gulf, safety issues also have to be mentioned. The majority of safety problems are related to the maritime traffic. In accordance with the "Memorandum of Understanding" between the governments of Slovenia, Croatia and Italy on the "Establishment of a Common Routing System and Traffic Separation Scheme in North Part of the North Adriatic in year 2000" incoming traffic is restricted to a corridor in Slovenian waters, next to the border line between Italy and Slovenia in the Gulf of Trieste. Outgoing traffic is restricted to the corridor in the Italian waters. The turnover point is very near the proposed offshore terminal. The safe distance between oil and gas tankers has to be greater than 1 km. On average, more than one oil tanker per day comes in the Gulf. Two or more LNG tankers would "feed" the LNG terminal weekly (more than four in case of two LNG terminals). This would certainly affect the safety of the traffic and, consequently, increase the hazard of environmental disaster in the Gulf.

An in-depth study²⁸ has been conducted about the hazards resulting from a large spill over water of LNG from a tanker. The major conclusions from that study are summarized as follow:

- Consequences from an intentional breach can be more severe than those from accidental ones. It is estimated that the size of an LNG cargo tank hole ranges between 2 and 12 m² for unintentional accidents, and around 5 m² while for intentional threats. The tank holes define the areas of impact. The most significant impact arising from thermal hazard from fires is within 500 m of the spill, with much lower impacts (injuries) at distances beyond 1,600 m, even for very large spills. Multiple breaches and cascading LNG tank damage scenarios will not change the hazard ranges greatly, but will increase the expected duration of a fire.
- Management processes and risk management should be conducted in cooperation with stakeholders and public officials. Considerations should include a variety of factors and activities, such as site specific conditions, available intelligence, threat assessments, safety and security operations, improved modeling and analysis, improvements in ship and security system inspections, safety zones, earlier notice of a ships' arrival (at least 24 hours).
- Large unignited LNG vapour releases are unlikely. Unignited vapour clouds could spread farther than 1,600 m, for the intentional spill the hazard range extends to 2,500 m.

Although these consequences were described for a hazard on an LNG tanker, the same holds for (offshore) LNG terminals with low pressure tanks, since they are constructed similarly. The technology of LNG cargo ships has been reviewed and modes of release explained in other reports,²⁹ where phenomena relating to blasts and fires are described, e.g., Rapid Phase Transformation (RPT) which is not negligible, but does not appear to be very significant, fireballs (associated with pressurized liquids), vapour cloud explosions (ignited large flammable mass of hydrocarbon vapour), flash fires (ignited at the edge of a flammable cloud, flashes back to the source of a spill with a velocity less than 20 m/s) and pool fires (ignited by flash fire, the pool of LNG over the surface of water will burn until the LNG is depleted). An RPT phenomenon, where LNG is released from a hollow in a tank above or below the sea-surface was also described.³⁰ The hazard of rapid phase transitions can be severe, but is highly localized within or in the immediate vicinity of the spill area. When released from an opening below the sea-surface small rapid phase transitions can cause damage to the outer hull of the ship but not the tank.

The risk assessment of an LNG spill is still under study, however, numerical simulations of a spill of LNG from a tanker demonstrate that the areas of a pool of LNG on a water surface with burning differs very much from the area of a dispersed cloud area without burning.³¹ When the tanker moves the former area is minimized while the latter is maximized, while if the tanker stops in a few minutes following the release, the inverse situation occurs: the areas of the surface pool and of the incident radiation field with burning are maximized, while the area of the dispersed cloud is minimized. Issues of risk assessment also play a role in classification and certification of LNG terminals for insurance,³²

Possibility of a terrorist attack also has to be considered: LNG vessels have to have a (military) escort to provide the necessary safety in the Gulf. Slovenia has no facility for that, therefore Italy would have to ask for permission for entry into Slovenian waters (entering corridor) of the proper escort for a LNG vessel. Will that happen? So far there have been no diplomatic efforts to resolve these issues of safety between the two (Italy and Slovenia) or even three (also Croatia) countries that face the northern Adriatic area.

7. Discussion and Summary

The impact of the proposed LNG terminals in the Gulf of Trieste can be summarized under the following: (1) products of chlorination in seawater, (2) Input of toxic Hg and other metals by sediment resuspension, (3) toxicity of Al compounds in the seawater due to galvanic protection of metal construction and (4) cooled and chlorinated seawater released by terminals spreading around the Gulf.

Although our numerical simulations provide a good insight into the spread of cooled sea-water, there is still insufficient knowledge about the effects of such temperature changes on the habitat. Unfortunately, the rates of transformations of chlorine compounds are also lacking for coastal waters like the Gulf of Trieste, hence a quantitative assessment of their spread is not yet possible. This is left for the future studies.

There were some public thoughts that in the light of temperature rise due to climatic changes, the LNG terminals would have a positive impact on the environment in the Gulf. Although there are records of a substantial increase of sea temperature over the last decade – more than 0.1°C per year³³ – numerical simulations revealed that the effect of LNG terminals on thermal structure of the basin is complex. The decrease in temperature of up to 0.1°C may spread for over 5 km along the paths of fluid particles, while across those paths it would extend for less than 1 km. In the spring–summer period the chlorinated and cooled outfall water has a density lower than the surrounding fluid near the orifice of the outflow pipe at the seabed and therefore rises towards a layer of neutral buoyancy in which the horizontal advection spreads the ejected fluid horizontally.

Medusas occasionally form dense swarms in the Gulf of Trieste.³⁴ It is known from other coastal seas that jellyfish swarms may impact on coastal activities including the use of sea water as cooling/heating agent.³⁵ The proposals for the LNG terminal(s) have not addressed this problem at all. Moreover, the recurrent appearance of massive mucilage in the Gulf of Trieste³⁶ could have a serious impact on the use of seawater as a heating medium. As for the jellyfish problem, this issue has not been addressed at all.

The proposed technology could be improved to reduce the environmental impact (construction of diffusers at the end of outfall pipes could lead to lower resuspension), use of alternative methods to battle the fouling (e.g., ultrasound as an antifouling approach), but the destruction of anodes remains a problematic source of pollution with aluminium.

New technological solutions are already available. First, there are underwater platforms and pipes, obviating the need for an offshore terminal (e.g., products of the “Advanced Production & Loading AS” company). The LNG is evaporated in the tanker (2). Air can be used as a heating medium instead of seawater (“LNG SMART Vaporization Process”). A new technology of vaporizers is already available³⁷ that utilize waste heat from power plants or industrial facilities, eliminating fuel requirements, reducing emissions and improving thermal efficiency. The onshore LNG terminal in the Bay of Muggia is proposed to be placed a few km from the ironworks, which is now releasing warm waste sea-water, “already” chlorinated. These examples indicate that the proposed LNG terminals are not based on the best available technology.

Safety issues are at least as great as the environmental impacts. In order to resolve the many problems relating to the installation and functioning of LNG terminals in a shallow land-locked sea, collaboration between the countries that share the sea is essential.

Acknowledgments

Authors are indebted to Boris Petelin for numerous model runs and postprocessing of model results. The work was supported by the Ministry of the Environment and Spatial Planning of Slovenia (contract no. 2511-06-200489).

References

1. Anonymous, Terminale Offshore di Rigassificazione di GNL e Condotta a Mare – Golfo di Trieste, Studio di Impatto Ambientale, Sintesi non Technica. Terminal Alpi Adriatico S.r.l., Report no. 04-582-H4, 2006, p. 49 plus references and figures.
2. Anonymous, Terminale di ricezione e rigassificazione GNL Zaule, Studio di impatto ambientale, Sintesi non technica. GasNatural, Medea Engineering, S.A., Report no. 03246-E&E-R-0-001, 2006, p. 115.
3. A. F. Blumberg and G. L. Mellor, in: *Three dimensional coastal ocean models*, Heaps, N. S. (eds) (American Geophysical Union, Washington, DC, 1987), pp. 1–16.
4. G. L. Mellor, Users guide for a three-dimensional, primitive equation, numerical ocean model (June 2003 version). Princeton University Report, Princeton, NJ, 2003, p. 53.
5. V. Malačič and B. Petelin, Numerical modeling of the winter circulation of the Gulf of Trieste (northern Adriatic), *Acta Adriatica*, 47 (Suppl.), 207–217 (2006).
6. V. Malačič, B. Petelin and B. Čermelj, Adriatic Sea integrated coastal areas and river basin management system pilot project (ADRICOSM), Final Science Report, October 2001–September 2004. National Institute of Biology, Marine Biology Station, Report, 2004, p. 1–17.
7. G. L. Mellor and T. Yamada, Development of turbulence closure model for geophysical fluid problems, *Review of Geophysics*, 20, 851–875 (1982).
8. M. Zavatarelli and N. Pinardi, The Adriatic Sea modelling system: a nested approach, *Annales Geophysicae*, 21, 345–364 (2003).
9. A. Artegiani, D. Bregant, E. Paschini, N. Pinardi, F. Raicich and A. Russo, The Adriatic Sea general circulation. Part II: Baroclinic circulation structure, *Journal of Physical Oceanography*, 27, 1515–1532 (1997).
10. M. Zavatarelli, N. Pinardi, V. H. Kourafalou and A. Maggiore, Diagnostic and prognostic model studies of the Adriatic Sea circulation: Seasonal variability, *Journal of Geophysical Research*, 107 (C1), 4/1–4/20 (2002).
11. EPA, Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category. EPA, Report no. EPA 440174029a, 1974, p. 865.
12. Anonymous, Steam Electric Power Generating, Chapter NR 290. Department of Natural Resources, Wisconsin, Report no. 503, 1997, pp. 761–764.

13. M. J. Kennish, *Practical Handbook of Estuarine and Marine Pollution* (CRC Press, Boca Raton, FL, 1997).
14. C. Baird, and M. Cann, *Environmental Chemistry* (W. H. Freeman, New York, 2005).
15. P. Mozetič, V. Malačič and V. Turk, Ecological characteristics of seawater influenced by sewage outfall, *Annales*, 9(2), 177–190 (1999).
16. EPA, Ambient Water Quality Criteria for Chlorine – 1984. EPA, Report no. EPA 440/5-84-030, 1985, p. 57.
17. B. Marčeta, in *Priority Topics related to Small Pelagic Fishery Resources of the Adriatic Sea. Report of the First Meeting of the Adriamed Working Group on Small Pelagic Resources. FAO-MiPAF Scientific Cooperation to Support Responsible Fisheries in the Adriatic Sea*, Mannini, P., Massa, F. and Milone, N. (eds) 24–29 (FAO, Termoli, Italy, 2001).
18. J. E. Štirn and L. Kubik, Prispevki k poznavanju migracij in obsega populacij sardele in inčuna v severnem Jadranu, *Acta Adriatica*, 16 (24), 401–422 (1974).
19. IMO, FAO, Unesco, WMO, WHO, IAEA, UN and UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), The evaluation of hazards of harmful substances carried by ships: Revision of GESAMP Reports and Studies. IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), Report no. 35, 1989, p. 44 plus 11 Annexes and the Appendix.
20. B. Ogorelec, M. Mišič and J. Faganeli, Marine geology of the Gulf of Trieste (northern Adriatic): Sedimentological aspects, *Marine Geology*, 99, 79–92 (1991).
21. J. Faganeli, R. Planinc, J. Pezdič, B. Smodiš and P. Stegnar, Marine geology of the Gulf of Trieste (northern Adriatic): Geochemical aspects, *Marine Geology*, 99, 93–108 (1991).
22. S. Covelli, J. Faganeli, M. Horvat and A. Brambati, Mercury contamination of coastal sediments as the result of long-term cinnabar mining activity (Gulf of Trieste, northern Adriatic sea), *Applied Geochemistry*, 16, 541–558 (2001).
23. S. Covelli, G. Fontolan, J. Faganeli and N. Ogrinc, Anthropogenic markers in the Holocene stratigraphic sequence of the Gulf of Trieste (northern Adriatic Sea), *Marine Geology*, 230, 29–51 (2006).
24. C. R. Hammerschmidt, W. F. Fitzgerald, C. H. Lamborg, P. H. Balcom and P. T. Visscher, Biogeochemistry of metymercury in sediments of Long Island Sound, *Marine Geology*, 90, 31–52 (2004).
25. M. E. Hines, J. Faganeli, I. Adatto and M. Horvat, Microbial mercury transformations in marine, estuarine and freshwater sediment downstream of the Idrija mercury mine, Slovenia, *Applied Geochemistry*, 21, 1924–1939 (2006).
26. M. Horvat, S. Covelli, J. Faganeli, M. Logar, V. Mandič, R. Rajar, A. Širca and D. Žagar, Mercury in contaminated coastal environments, a case study: the Gulf of Trieste, *Science of the Total Environment*, 238, 43–56 (1999).
27. A. Armcanz, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Aquatic Ecosystems-Rationale and Background Information. Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), Report no. Paper No. 4, Vol. 2 (Chapter 8), <http://www.deh.gov.au/water/quality/nwqms/volume2.html>, 2000, p. 8.3–1 – 8.3–99.
28. M. Hightower, L. Gritzko, A. Luketa-Hanlin, J. Covan, S. Tieszen, G. Wellman, M. Irwin, M. Kaneshige, B. Melof, C. Morrow and D. Ragland, Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water. Sandia National Laboratories, Report no. SAND2004-6258, 2004, p. 167.
29. G. Hughes, LNG Marine Release Consequence Assessment, Technical Report. Det Norske Veritas (USA), Inc., Report no. 70004197, Rev. No. 2, 2004, p. 116.

30. G. A. Melhem, S. Saraf and H. Ozog, LNG Properties and Hazards, Understand LNG Rapid Phase Transitions (RPT). ioMosaic Corporation, Report no. An ioMosaic Corporation Whitepaper, 2006, p. 38.
31. M. L. Spaulding, J. C. Swanson, K. Jayko and N. Whittier, An LNG release, transport, and fate model system for marine spills, *Journal of Hazardous Materials*, 7–16 (2006).
32. Anonymous, Classification and certification of offshore gravity based liquefied gas terminals, Guidance notes. Lloyd's Register, Report, 2004, p. 97.
33. V. Malačič, M. Celio, B. Čermelj, A. Bussani and C. Comici, Inter-annual evolution of seasonal thermohaline properties in the Gulf of Trieste (Northern Adriatic) 1991–2003, *Journal of Geophysical Research*, 111, 1–16 (2006) (C08009, doi: 10.1029/2005JC003267).
34. A. Malej, V. Malačič, P. Mozetič, N. Kovač, Z. Sotlar, V. Flander Putrle, B. Petelin and B. Čermelj, Sluz v morju in možni ukrepi za olajšanje posledic. Nacionalni inštituta za biologijo, Morska biološka postaja, Report no. 21, 2001, p. 82.
35. J. E. Purcell, W. M. Graham and H. J. Dumont (eds.), *Jellyfish Blooms: Ecological and Societal Importance* (Kluwer Academic Publishers, Dordrecht, The Netherlands, 2001).
36. A. Malej in *Gelatinous Zooplankton Outbreaks: Theory and Practice* (CIESM, Napoli, 2001), pp. 67–69.
37. C. C. Yang and Z. Huang, Lower emission LNG vaporization, *LNG journal*, 3, (November/December), 24–26 (2004).


Integration of information for Environmental Security

- Environmental Security
- Information Security
- Disaster Forecast and Prevention
- Water Resources Management

edited by

H. Gonca Coskun
H. Kerem Cigizoglu
M. Derya Maktav

Istanbul Technical University,
Turkey

 Springer

Published in cooperation with NATO Public Diplomacy Division

Proceedings of the NATO Advanced Research Workshop on
Integration of Information for Environmental Security
Istanbul, Turkey
26-29 September 2006

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN 978-1-4020-6574-3 (PB)
ISBN 978-1-4020-6573-6 (HB)
ISBN 978-1-4020-6575-0 (e-book)

Published by Springer,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

www.springer.com

Printed on acid-free paper



All Rights Reserved

© 2008 Springer Science+Business Media B.V.

No part of this work may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, microfilming, recording or otherwise, without written permission from the Publisher, with the exception of any material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work.