Oil spills in the Venetian Lagoon: an analysis of risk management

A. Zitelli, F. Cinquepalmi, C. Benedetti, A. Campagnoli, A. Bergamasco.

*Istituto Universitario di Architettura Venezia - S. Croce 1957, 30135 Venice, Italy - Email: andreina@brezza.iuav.unive.it

Abstract

The possibility of a major oil spill in the Venetian Lagoon or the Upper Adriatic demands a sure response to the classic problems involved.

Though there are prospects for a complete ban on oil tankers entering the Venetian Lagoon, it is necessary in the short term to devise a risk management scheme based on the comprehensive effectiveness of preventative action. The best security in this connection is provided by a synergical combination of integrated information systems (GIS and VTS), simulation models and active and passive risk control technologies.

Cooperation between the Coast Guard services of the countries with coastlines on the Upper Adriatic is essential to efficient supervision of lanes designated for dangerous traffic.

1 Introduction

Venice stands on a group of islands in a lagoon formed 6000 years ago in the North-East Adriatic. It is separated from the sea by a discontinuous sandbar of dunes and beaches.

For about 1000 years the Venetians conserved the transition characteristics of their coastal lagoon through skilfully devised hydraulic projects designed to strike a balance between fluvial sedimentation and the force of the sea.

The present-day brackish lagoon covers about 570 sq. km. and is connected with the sea through three inlets at Lido, Malamocco and Chioggia, each kept practicable by outer breakwaters. The tide ebbs and flows through these inlets...
and along the channels of the lagoon, registering a half-cycle high- and low-point delay of about two hours in the parts furthest from the sea.

The average astronomical amplitude is about 50 cm and reaches Venice approximately one hour after entering the lagoon. When normal conditions are distorted by *scirocco* and *bora* winds - from South and North respectively - Venice and Chioggia and the smaller islands of Murano and Burano are subject to flooding.

Over 75% of the lagoon is less than 1m deep and navigation channels vary in depth from 5 m to 20 at the Malamocco inlet (see Figure 1).

The transition wetlands and intertidal environment areas comprising *velme* (marshes) and *barene* (mudflats) are very important habitats and form the natural landscape of the Venetian Lagoon; they are subject to various forms of protective legislation. Important traditional economic activities include fishing, fish farming and aquaculture of mussels and shellfish, and horticulture thrives on the islands of the Lagoon.

Since the first half of the 20th century intensive economic and industrial development have transformed the lagoon (about a third of the mudflats have gradually been reclaimed and channels serving the industrial port have been deepened).

A vast industrial zone focused on energy production and the petro-chemical industry has grown along the mainland side of the central part of the Lagoon, with the result that the Lagoon as a whole is now the biggest lagoon to be entirely subject to human control in the Northern hemisphere, the scene of unresolved conflict between the forces of development and those that give priority to the conservation of historical and environmental values.

1.1 Oil tanker traffic and the risk of oil spills

By the early 1970s, there was already full awareness of the damaging effect of industrial pollution on Venice and the Lagoon environment.

1973, when the Italian Parliament passed the first Special Law for Venice, coincided with the highpoint in the expansion of the petro-chemical industry at Porto Marghera. As well as setting standards for the quality of water and air allowed to enter the environment, the Law also outlined a strategy for scaling down the petro-chemical pole by banning oil tanker traffic from the Lagoon and boosting commercial trade. The Law was largely ineffective in changing the balance of the economy, as can be seen from the breakdown of Lagoon traffic figures.

Figure 1 shows the Venetian Lagoon, the navigational channels and the industrial zone and compares the total quantity of oil handled between 1986 and 1995 with totals for the non oil industrial and the commercial sectors.

while Table 1 breaks down the hydrocarbon data into crude oil, product oils (petrol, diesel oil, fuel oil, etc.) and liquid chemical products.
Figure 1: The Venetian Lagoon, tonnage/000 of total oils in relation to commercial and non-oil industrial goods unloaded and loaded from 1986 to 1995.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total tonnes/000</th>
<th>Crude oil tonnes/000</th>
<th>Product oils tonnes/000</th>
<th>%</th>
<th>Chemicals tonnes/000</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>14666</td>
<td>5353</td>
<td>7846</td>
<td>36,4</td>
<td>1467</td>
<td>10,1</td>
</tr>
<tr>
<td>1987</td>
<td>14108</td>
<td>4868</td>
<td>7362</td>
<td>34,5</td>
<td>1878</td>
<td>13,3</td>
</tr>
<tr>
<td>1988</td>
<td>13330</td>
<td>4481</td>
<td>6909</td>
<td>33,6</td>
<td>1940</td>
<td>14,5</td>
</tr>
<tr>
<td>1989</td>
<td>13664</td>
<td>4865</td>
<td>6573</td>
<td>35,6</td>
<td>2226</td>
<td>16,2</td>
</tr>
<tr>
<td>1990</td>
<td>12130</td>
<td>4238</td>
<td>5878</td>
<td>34,9</td>
<td>2014</td>
<td>16,6</td>
</tr>
<tr>
<td>1991</td>
<td>12567</td>
<td>4729</td>
<td>6139</td>
<td>37,6</td>
<td>1699</td>
<td>13,6</td>
</tr>
<tr>
<td>1992</td>
<td>13017</td>
<td>5135</td>
<td>6118</td>
<td>39,4</td>
<td>1764</td>
<td>13,5</td>
</tr>
<tr>
<td>1993</td>
<td>12415</td>
<td>5377</td>
<td>5108</td>
<td>43,3</td>
<td>1930</td>
<td>15,5</td>
</tr>
<tr>
<td>1994</td>
<td>12037</td>
<td>5077</td>
<td>4870</td>
<td>42,2</td>
<td>2090</td>
<td>17,3</td>
</tr>
<tr>
<td>1995</td>
<td>12255</td>
<td>5016</td>
<td>5347</td>
<td>40,9</td>
<td>1892</td>
<td>15,4</td>
</tr>
</tbody>
</table>

Table 1: Industrial port of Venice. Dangerous liquids transported (1985 - 1995).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil tanks</td>
<td>850</td>
<td>793</td>
<td>814</td>
<td>985</td>
<td>927</td>
<td>727</td>
<td>798</td>
<td>768</td>
<td>743</td>
<td>789</td>
</tr>
<tr>
<td>Industrial cargos</td>
<td>1515</td>
<td>1584</td>
<td>1576</td>
<td>1850</td>
<td>1794</td>
<td>1433</td>
<td>1232</td>
<td>1051</td>
<td>1040</td>
<td>1081</td>
</tr>
<tr>
<td>Commercial cargos</td>
<td>2293</td>
<td>2282</td>
<td>2401</td>
<td>2355</td>
<td>2519</td>
<td>1869</td>
<td>1844</td>
<td>1997</td>
<td>2141</td>
<td>2486</td>
</tr>
</tbody>
</table>

Table 2 subdivides the total number of vessels that crossed the Lagoon in the same period into carriers for the commercial, industrial and oil refinery sectors.

It is clear from these data that the carriage and storage of hydrocarbons and chemical products is still a very important economic activity for the industrial port; it is also, however, a source of major potential risk and environmental damage from the spillage of oil, liquid chemicals and dangerous industrial waste products.

Confining ourselves for present purposes to liquid products, the environmental risks attendant on oil and chemical spillage in the Venetian Lagoon may be classified as:

- frequent oil slicks arising from the intensive transfer of oil and chemicals from tankers to shore bunkers or barges;
- the substantial potential risk of accidents involving tankers in the main traffic channels in the Lagoon or in the open sea near the Lagoon entrances; these may occur while vessels are sailing, waiting in the roadsteads, or in harbour and may involve sinking, beaching, collisions, explosions, etc..

Moreover, it must be emphasized that the chronic pollution of the Venetian Lagoon arises from leakage from about 10,000 engine-powered boats of all sizes in the Lagoon, which constitute the main source of hydrocarbon bio-accumulation; this is a continuing daily occurrence and as such is more serious than the possible accidental events.

2 Control of the risk

In view of the requirements of the Brussels International Conventions on the prevention and indemnification of marine pollution (Marpol 73/78), of the Barcelona Convention (UN, 1982) and of Italian law (Provisions for the Defence of the Sea, Law 979/82), the Venetian Lagoon is subject to an “Emergency action plan against accidental oil pollution of the sea” organized by the Port Authority and the Coast Guard Service, in association with the National Civil Defence Service. The Coast Guard Service is called, mainly by those involved or by third parties, to assess and clear up cases of oil spillage. So far, the purpose has been to cope with emergency situations. In our opinion it is necessary to pass from an emergency approach to systematic overall management of the risk.

Plan 1, “Guidelines for management of oil spills and slicks in the Venetian Lagoon”, presents a system outline that we have devised for consideration by decision-makers and those responsible for the management of this type of risk. In particular we are concerned that risk management programmes should make routine use of computerized data bases and hydrodynamic modelling, remote sensing and radar control techniques.
Plan 1. Guidelines for management of oil spills and slicks in the Venetian Lagoon and the Upper Adriatic Sea

### Analysis of oil spills and slicks

<table>
<thead>
<tr>
<th>Reality</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recorded oil slicks</td>
<td>A hypothetical major oil spill</td>
</tr>
</tbody>
</table>

A) Analysis
- site
- nature of the event
- type of spill

B) Info system Ve.GIS.O.S. database

C) Cleanup procedures
- effectiveness
- practical limits
- ecological compatibility

### Strategies for risk reduction:

**In the Lagoon**

Present conditions

A) Analysis of practices
- human and technical training
- adequate stockpiles
- operational limits and malfunctions

B) Specific facilities and technologies
- observation of existing procedures
- illuminated navigational channels
- computer databases
- increased vigilance

The immediate future
- reduction of traffic
- new planning of the port area

**In the Upper Adriatic Sea**

Present conditions

A) Analysis of practices
- control of traffic and routes
- observation of existing procedures
- increased vigilance

B) Specific facilities and technologies
- new regulations of roadsteads
- specific lanes for oil tankers
- passive technologies (double hulls)
- active technologies (VTS)

The immediate future
- cooperative agreement between the Coast Guard Authorities of Italy, Slovenia and Croatia.
2.1 Using GIS in analysis and in aid of spill prevention

On the basis of Plan 1 we have made a study of all oil spills and slicks occurring in the Venetian Lagoon between 1984 and 1996, based on 260 records kept by the Coast Guard Service. The records refer not to the quantities spilled but to those recovered.^[5]

Analysis of the spills was followed by the insertion of data acquired from an information system by means of a specially constructed database. Georeferencing of the data enables specific items of information in the database to be identified in response to targeted queries and used to produce printouts showing distribution patterns according to spatial-temporal, qualitative and quantitative criteria. The main processing capacities of the database in the geographical system concern:
- the site and dating of the events;
- selection according to quantitative and qualitative parameters relating to the nature of oil spill;
- cause of the spill: accidental operational-functional, deliberate;
- diachronic processing for one or two parameters of the database.

The Software chosen was developed for the creation of GIS. (Geographical Information Systems); it uses hardware based on a PC platform and will perform modulable processing in response to simple programming instructions.

Spatial analysis (Figure 2, Ve.GIS.O.S., detail) has enabled us to establish clearly that the main cause of spills is operational rather than accidental. Most occur around the docks at Porto Marghera, S. Leonardo and the Marittima, arise from loading and unloading operations and are caused by human error or mechanical defects. Most of the spills involved the recovery of between 100 and 500 kg of hydrocarbons (Figure 3), and larger quantities are rare. The quantities recovered have only an indicative value in relation to the amounts actually spilled, the relationship depending on the time elapsing between the event, when it is reported and when action is taken to contain and recover the slick. The nature of the pollutants, time and meteo-climatic factors obviously condition the rate at which oil slicks will spread and disperse. It has been calculated that the average time lapse between an event being reported and remedial measures being taken varies between one and two hours, depending on the location of the emergency response vessels at the time.

2.2 Hypothesis of a major oil spill, the assistance afforded by mathematical model simulation techniques and its environmental impact

The main arguments of those who advocated the establishment of an industrial port for Venice on the mainland and naturally inaccessible side of the Lagoon focussed on the safe navigation guaranteed by the calm waters and the soft, shallow lagoon bed on either side of the navigable channels. In actual fact, however, the effect of accidents such as a major oil spill would be aggravated
Figure 2: Venice GIS Oil Spill (Ve.GIS.O.S.) for use in spill prevention. Detail of Porto Marghera area: oil spills in a georeferenced stretch of the South Industrial Channel (1978 - 1996)

Table3: The 260 recorded oil spills in the Venetian Lagoon from 1978 to 1996. N.R. (no recovery) and classes of recovery in kilos (kg/00).
and the ability of the authorities to intervene seriously compromised by the geo-morphological conformation of the Lagoon, its hydrodynamics and the tides. Even a medium-sized accident resulting in an oil or chemical spill in the Venetian Lagoon could have catastrophic consequences in environmental, economic and historical terms.\(^8\)[5][6]

### 2.2.1 The simulation of a catastrophic scenario

A decisive contribution to the full understanding of the impact of such an event has been provided by the development of a simulation with mathematical models. The probability of a harmful event occurring in the Upper Adriatic is far greater than in the Lagoon. The Port of Trieste currently receives thirty million tonnes of oil products p.a.; a further increase is expected if the proposed banning of oil tankers from the Port of Venice goes ahead and with the reviving economies of the new republics of Croatia and Slovenia there will probably be an increase in traffic serving the Eastern Adriatic coast.

Currents circulate in an anti-clockwise direction in the Adriatic Sea and the most dangerous coasts therefore lie “upstream” of the Lagoon inlets. If vessels were to collide or run aground on the indented, rocky coastline of the Eastern Adriatic, the resulting pollution would cause havoc on the beaches of the western coast and in the Venetian Lagoon.

In order to study the catastrophic scenario of an oil spill inside the Venetian Lagoon Bergamasco \(^8\)[6] has simulated an accident similar to one that occurred in the Gulf of Genoa, when the Haven tanker exploded. First the hydrodynamical evolution of the basin was mathematically described using an high resolution finite element model. With this technique the whole domain was divided into 8000 triangles where the physical variables (sea surface elevation and horizontal velocity) were defined. The shallow water equation, with the Bousiness approximation were integrated in time to produce the evolution of the field of motion in two different typical situations. Detailed discussion of the model can be found in Bergamasco and Ungiesser “L’implementazione di un Lagrangiano Monte Carlo in un modello idrodinamico lagunare”\(^6\).

The wind and the tide were the forcing terms. Two different winds are considered: the Bora, a north-easterly wind characteristic of the winter-spring season and the south-easterly Sirocco, both producing the typical acqua alta phenomena in the cities of Venice and Chioggia.

A Monte Carlo lagrangian model was used for simulation of the transport dispersion. The oil spill event was situated in the Malamocco channel, the main route of the oil tankers, and the outflowing oil was represented by a continuous source of numerical pseudoparticles. The real oil concentration was simulated by a set of pseudoparticles released in the basin and following the non-linear trajectory of the streamlines. This method gives a very accurate description of the phenomena both in the presence of high gradients with point sources and in a domain with a very complex morphology.
Figure 4: The Venetian Lagoon. A Monte Carlo lagrangian model simulation of an oil spill event in the Malamocco channel. The outflowing oil was represented by a continuous source of numerical pseudoparticles. Evolution in Sirocco wind condition (a) after 12 hours and (b) after 48 hours.
Figure 4 (Sirocco wind simulation) shows the initial distribution of the “oil” after 12 hours of simulation (a). With the advective overrunning the diffusive term, the spilled matter, susceptible in this case to the tide, during its drift towards Venice, reached the industrial area after 48 hours (b) and the city of Venice after 96 hours of simulation. In the Bora wind simulation instead, the diffusion, slow but constant, dominates the advection; the spill reached a large area of the southern part of the Lagoon towards the Chioggia inlet.

The same kind of simulation was applied for an oil spill in the Upper Adriatic Sea, near the Po river mouth and the Gulf of Trieste.

2.2.2 Methodologies for the assessment of the environmental impact

The scenarios predicted by the hydrodynamic model as illustrated above further enhance the effectiveness of the guidelines developed for the assessment of the environmental impact of a major oil spill. We adapt the methodologies of Moore[^3] and Bereano[^4] for application to the case in hand.

Checklists have been devised to assess direct and indirect impact on the lagoon and coastal ecosystems, on the landscape, on the historical and artistic heritage, on human utilization of the environment, on fishing and on the economy and socio-cultural changes to work and life-style (see the scheme below).

![Scheme of direct impacts of oil spills](image)

*Source: Scheme of Moore, detail, modified.*

Following the Bereano method for the consequences of an oil spill at sea a special impact checklist has been drawn up for the *velme* and the *barene*, the typical ecosystems of the lagoon marshes, which occupy vast stretches of the shallow, intertidal areas. As an example, there follows a short section of the list relating to the direct and indirect effect on flora and fauna populations:

- fouling, coverage of the soil and its halophilic vegetation;
- alteration of the exchanges at the air/earth/water interfaces;
- loss of marine phanerogam grasses;
- loss of endemic species;
- erosion caused by the death of vegetation;
- disappearance of the components of the *micro-meio* and *macro-zoobenthos*;
- interruption of the trophic chains;
- destruction of invertebrate fauna;
- disturbances to the behaviour of epigeous and hypogeous macrofauna;
- loss of nesting sites for avifauna;
- abandonment;
- loss of overall characteristics (landscape, etc.).

2.3 Procedures for oil tanker access into the Port of Venice

In order to limit the risk of accidents, oil tankers entering the Port of Venice must observe the following safety procedures.

- application for permission to berth presented by shipping agent;
- differentiated anchorage areas in the roadsteads and compulsory prior notification of anchorage position coordinates;
- request for pilot facilities, obligatory for vessels over 500 tonnes: 2nd pilot compulsory, contact having been established at least 2 hours before arrival in the roadstead;
- obligatory check, carried out by the pilot on taking charge of the vessel, for to safe navigation or the safety of the vessel itself (Law no. 93/75/EEC. '96);
- request for tug facilities (1 tug compulsory, 2 used normally);
- establishment of an alternating one-way system along the Canale dei Petroli;
- request made by shipping agent for permission to load/unload dangerous goods; application must be accompanied by Solas and Marpol certifications;
- avoidance of moorings and routes of other vessels.

The main navigational channel across the Lagoon (Canale dei Petroli) has recently been equipped with a lighting system, which enables vessels to pass at night and improves safety conditions in case of fog or suddenly reduced visibility. The fact that convoy movements can take place at any time reduces pressure on loading/unloading operations and improves general safety.

2.4 Cleanup techniques for the Venetian Lagoon

Scrupulous compliance with access procedures for the Port of Venice is essential to prevention of major oil spills, given the severe restrictions on the use of normal cleanup techniques in the Lagoon. The use of oil dispersives and flocculants is banned because of the shallowness of most of the Lagoon and tidal hydrodynamics. Bio-degrading agents can be employed but oil spill countermeasures are confined mainly to mechanical containment techniques such as curtains of floating booms and various types of suction pumps operated from specific vessels or tugs.
3 Discussion and conclusions

The case of the Venetian Lagoon is emblematic of the problems connected with the occurrence and management of oil spills in a coastal area which is highly developed and where the demands for conservation of existing environmental, historical and cultural accretions are extremely difficult to reconcile with the priorities of economic interests.

3.1 Strategies for risk reduction

In such complex circumstances the approach of coastal management to the question of oil spill risks in the Venice Lagoon, is necessarily preventive and is based on a complex of several elements: human, procedural, technological and active and passive risk control. Furthermore it must include a control system for shipping using all the ports and oil terminals of the Upper Adriatic.

3.1.1 Procedures and the human element

Increasing experience of dealing with oil spills and awareness of the dangers associated with such events constitute the best guarantee against the direct and indirect risks involved.

Unambiguous regulations, experience, information, training, study and above all specific technologies are all needed to ensure maintenance of the requisite standards of safety in terms of both prevention and protection.

The human element is of prime significance in this vision of the problem: in the case of Venice, for example, there are extremely precise and detailed regulations governing the procedures to be adopted in loading, unloading and refuelling.

3.1.2 Specific facilities and technologies

The more efficient the Port and Coastal Authorities are in carrying out their inspection and control functions the greater the deterrent effect of those measures will be. Objective help in oil spill control can be provided by specifically structured databases.

Ve.GIS.O.S. (Venice GIS Oil Spill) is an information system that we have developed as an easily used diagnostic instrument for port authorities. With georeferencing, diachronic processing and data implementation it is possible to exercise real time surveillance of oil spill cases; the system will not only record cases but also identify the incidence of the various causes - management failure, human error, deliberate malfeasance, etc. - suggest specific provisions to reduce the risk and evaluate their effectiveness in time.

3.1.3 Simulation models

The potential risk of a large-scale catastrophe scenario in the Venetian Lagoon may be small but it cannot be discounted and depends on accidental
factors that are all but imponderable. The development of complex models has in this case helped to clarify the direct and indirect implications of a similar event and to influence the development of Environmental Impact Assessment methodologies.

Following the serious accident involving the oil-tanker Haven in 1991 in the Gulf of Genoa, the emergency response unit of the Ministry of the Environment commissioned the National Research Council’s Institute for the Dynamics of Large Masses in Venice and ISMES to develop the models referred to above; the same institutes are currently developing a model for the Upper Adriatic area and the Gulf of Trieste.

3.1.4 Traffic control, passive and active technologies for risk reduction

The scenarios produced by the models have given rise to several studies and to provisions (Ministerial Decree of 22.01.93) concerning the regulation of traffic and a control system.

Study has been completed for a control system using nautical charts with traffic separation procedures for vessels approaching the ports of Venice and Chioggia. It has also been decided that permission to enter the port of Venice will be granted only to vessels with double hulls and similar passive safety constructional features. Nevertheless no effective control system has so far been implemented.

Several VTS (Vectoring Traffic System) projects have been produced that would enable all vessels present in the Upper Adriatic to be recognized in real time and vectored onto safe routes, thus limiting the risk of accidental collisions.

The principal operational importance of a VTS is its function as a decision-making aid to operators responsible for interacting with traffic. A VTS project for the Upper Adriatic must provide for a combination of sensors (radar, radio, radio direction finders, tele-tracking systems and underwater acoustic sensors) and communication devices installed in the area to be controlled.

The equipment would be all connected to a centre, where the information is processed and passed to the operators.

The monitoring of all shipping in the Upper Adriatic would require the cooperative effort of the Coast Guard authorities of Italy, Slovenia and Croatia. Such a system would provide an important support potential in emergency situations, immediately available information on the location of accidents, identification of those responsible for any pollution and more effective management of fish resources.

The VeGISOS information system and the C.N.R.-I.S.D.G.M. hydrodynamic and simulation models for oil spills in the Venetian Lagoon have been developed as part of the Venetian Lagoon System Programme (S.V.L.) financed by the Ministry for the University and Scientific and Technological Research (M.U.R.S.T.).
References


