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Decision-making tools for a LNG regasification plant siting

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ABSTRACT

The increasing energy demand in Argentina and the delayed development of local sources have forced the government to import natural gas from overseas. Nowadays, one of the most efficient energy carrier is the Liquefied Natural Gas (LNG). Following this trend, Argentina began to import LNG to be regasified and injected into the existing gas network. The conversion from liquid to gas can be done using onshore facilities or regasification ships moored at specially designed docks for this purpose. In this case, Floating Storage and Regasification Units (FSRU) were chosen to satisfy quickly the increasing demand. At this moment, Argentina has two injection sites, one located at Ing. White port (Bahía Blanca) and one at Escobar port (Escobar), both in Buenos Aires province. However, to satisfy the long term demand, new projects of onshore plants are being considered in Bahía Blanca. This paper considers different aspects included in the risk based land use planning. In order to determine the most appropriate place for the construction of LNG terminals, Quantitative Risk Analysis (QRA) techniques are used to complement social and environmental studies. Two alternative operation sites in the Bahía Blanca estuary are analyzed. The first one is located at Cuatreros port, near General Cerri city and the second at Rosales port, near Punta Alta city. Advantages and disadvantages such as the presence of other industrial facilities, distance to populated areas, evacuation routes, social and environmental factors and distance to be traveled by the regasified LNG in the ducts are discussed. As for the onshore accident risks, it can be concluded that both locations are possible if appropriate preventive measures should be taken in each location. However, other environmental considerations like the route of the ship into the estuary and the need for dredging identify Rosales port as the most suitable location.

1. Introduction

The primary energy matrix of Argentina is based on fossil fuels, being natural gas (NG) almost 50% of this quantity (41.71 billion m^3) (Secretaría de Energía de Argentina, 2014). The progressive decline in domestic natural gas production and the growing industrial and home consumption have created an imbalance between supply and demand for this fuel. To meet this increasing demand, the energy authorities began to import liquefied natural gas (LNG) to be regasified and injected to regional gas transmission pipelines. The conversion from liquid to gas can be done using onshore facilities or regasification ships moored at specially designed docks for this purpose. In the last case, the terminal is based on a Floating Storage and Regasification Unit (FSRU) permanently moored at the jetty and periodically supplied by a LNG carrier (Iribarren et al., 2010). This practice, called ship-to-ship operation (STS), allows a continuous operation of the LNG import facility. In Argentina, FSRUs were chosen as ways of quickly fulfilling the market expansion. At this moment, there are two injection sites located in the province of Buenos Aires: Ing. White port, Bahía Blanca and Escobar port, Escobar (Rodríguez, 2011). Each one provides about 10 MMsm^3/d of NG to the national gas network.

However, to satisfy the long term demand, new projects of onshore plants are being considered in Bahía Blanca. In 2011, an important project to construct the first onshore LNG import terminal was launched. The terminal, with storage capacity of 125,000 m^3, would be designed to receive LNG from ships at a rate of 10,500 m^3/h with a pressure of 4.6 bar$_g$ and a temperature of −162 °C. The plant would have a regasification capacity of 10 MMsm^3/d (Consorcio de Gestión del Puerto de Bahía Blanca, 2011). In this type of operation, LNG tankers unload their cargo at dedicated marine terminals that store and regasify the LNG for distribution to domestic markets. Onshore terminals consist of docks, LNG handling equipment, storage tanks, and connections to

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gas network.

Although LNG has had a good safety record for the last 40 years (Alderman, 2005), experts are concerned about the LNG plants siting analysis and regulations, especially with issues related to safety zones, marine hazards, rivers and estuaries navigation, environmental impact, among others. On the other hand, since these terminals would be built onshore, relatively near populated areas, local communities are apprehensive about whether LNG terminals would expose them to unacceptable hazards. This concern was also observed previously in different facility location in other countries (Ártabra21, 2014; Manlove, 2008; Ártabra21, 2014; Huelva-Cateta, 2014; McIlraith et al., 2012; BCLNG-Info, 2014; Ikelegbe, 2013).

Several papers published in recent years are focused on the manner to take into account these aspects in siting LNG terminals. Some of them deal with regulatory compliance and approval processes for siting these facilities. For example, norms and codes like NFPA59A (NFPA59A, 2009; NFPA59A, 2013) and EN-1473 (ENS 1473, 2007) among others are extensively discussed (Raj and Lemoff, 2009; Williams, 2013; Taylor, 2007). In addition, the application of different risk evaluation techniques as an effective decision making tool is also found in many works (Taylor, 2007; Pitblado et al., 2006; Vinnem, 2010; Ramos et al., 2011; Aneziris et al., 2014; Vianello and Maschio, 2014). However, only a few articles consider simultaneously safety and environment issues (Manlove, 2008).

In Argentina, facing with the real need to increase imports of LNG and the public concerns about LNG facilities safety, it is necessary to reach an appropriate balance within local public safety and national energy requirements.

Following these ideas, in this work, the actual risks are evaluated realistically based on the knowledge of potential LNG's hazards, risk control, mitigation measures and environmental protection. It is described the QRA methodology to assess risks and apply the results for land use planning, complemented with social and environmental factors. Two alternative siting areas in Bahía Blanca estuary are analyzed. Risk and environment aspects are used as a decision making tool for determining the best location.

2. Bahía Blanca LNG project

2.1. Description of the onshore LNG regasification terminal

The onshore facility receives LNG from a carrier and stores it in cryogenic liquid state. LNG is further pressurized and vaporized to obtain NG as final product. The terminal can deliver a specified gas rate into the network and maintain a reserve of LNG. Fig. 1 (Lemmers, 2005) shows a schematic flow-sheet of the process to be used in Bahía Blanca project.

2.1.1. Jetty structure

The jetty structure, with a berth to moor the carriers, is a steel construction with a concrete deck. On the pier, articulated piping (unloading arms) is installed to connect the ship to the onshore terminal. The unloading arms can move to allow LNG carrier displacement due to environmental factors while they are connected.

2.1.2. LNG storage tanks

A double containment tank is used for storing LNG at cryogenic temperature. The inner tank meets the low temperature ductility requirements for storage of the product. The outer container serves primarily to keep the insulation and retain vapors.

2.1.3. LNG vaporizers

The LNG is vaporized using open rack vaporizers (ORV). ORVs use seawater in an open falling film type arrangement to vaporize LNG passing through the tubes. The seawater passes through a series of screens to remove debris before entering the intake basin. Then, after being used in the vaporizers, the water falls over aluminum panels and it is collected before discharging back into the sea. The vaporized gas is injected into the 80 bar_g national distribution system.

2.1.4. Vapor handling system

In normal operation, heat transfer from the surroundings produces boil-off gas (BOG) in the tanks and liquid-filled lines. This vapor is collected in the boil-off header and sent to the boil-off compressor suction drum. A BOG recondenser is used to recover the BOG as a product.

During ship unloading, the quantity of vapor in the tank outlet increases significantly. Moreover, in extreme turndown or emergency conditions, vapors generated within the terminal can exceed the capacity of the BOG compressor. If this occurs, the excess vapors are sent to a flare for safe disposal.

2.2. Alternative locations of LNG terminals

Energy companies as well as national authorities agree that the ports in the south of the Buenos Aires province are convenient to place LNG import terminal. Two alternative operation sites in the Bahía Blanca estuary are considered (Fig. 2). The first one is located at Cuatreros port, near General Cerri, a community placed 15 km to the south of Bahía Blanca city. The second option is Rosales port, near Punta Alta city, which lies 30 km northeast of Bahía Blanca.

3. Risk analysis and land use planning

In recent years, local communities have manifested a growing concern regarding the hazards derived from industrial sites, especially when residential areas are neighboring these facilities. To protect the population against the high risks of the production, storage and transport of hazardous materials, separation distances between the hazard source and the population have to be considered (Papazoglou et al., 1998, 2000).

In this sense, land use planning (LUP) is an important tool in government policies (Licari and Weimer, 2011). To introduce safety considerations, two different ways of dealing with risk assessment can be adopted: a 'consequence based' approach and a 'risk based' approach. The first focuses on the calculation of consequences of possible accident scenarios. The second considers the assessment of both, consequences and expected occurrence frequency of the selected scenarios (Christou et al., 1999).

The results presented in this work are based on risk levels estimations obtained using the quantitative risk analysis (QRA) methodology for an LNG terminal (Aneziris et al., 2014). In particular, the individual risk, defined as the annual frequency of death of a person affected by the consequences of an accident, is calculated.

There are several standard levels of acceptable risk to determine the appropriate distance between the population and the industries. Even though in Argentina there is no specific regulation in this matter, it is generally accepted worldwide that the individual risk to third parties should not exceed the annual frequency of death of a person of $1 \cdot 10^{-6}\ y^{-1}$ in the facility limits.

4. QRA of the regasification LNG terminals

This study consists of the hazardous zones definition, evaluating the distances at which effects caused by a Loss of Conteinment

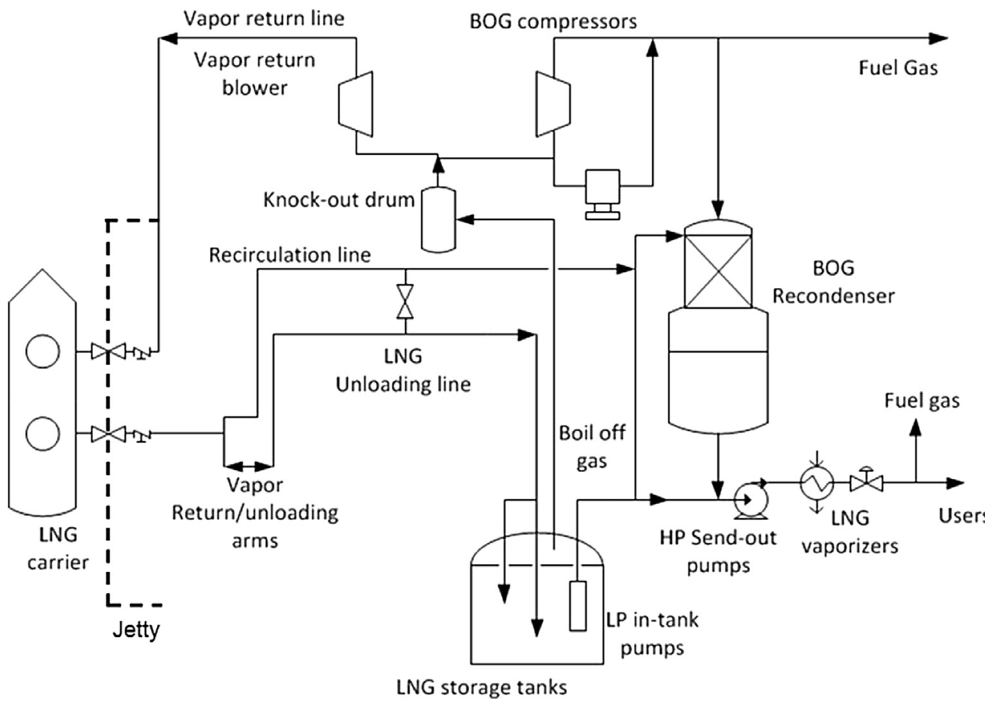

Fig. 1. Onshore LNG regasification process (Lemmers, 2005).

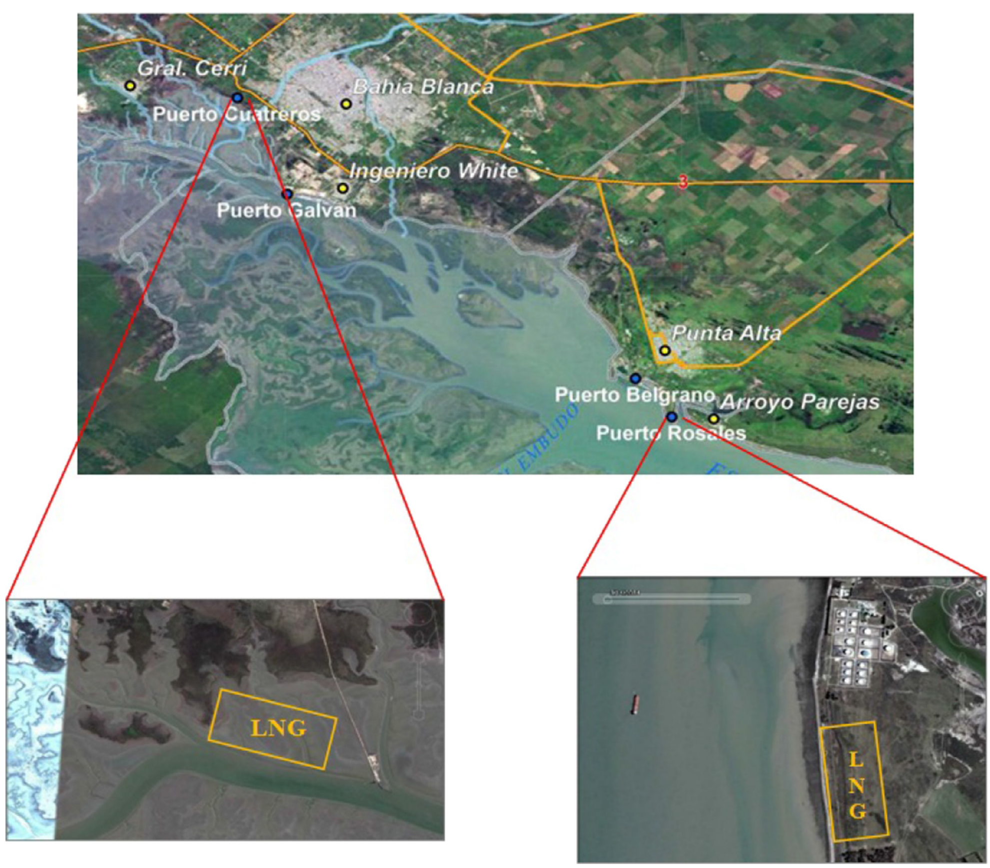

Fig. 2. Selected sites in the Bahía Blanca estuary.

(LOC) occur. According to substance properties, the resulting events may be fire, explosion, or toxic dispersion. The physical effects associated with those events are, respectively: thermal radiation, overpressure and projectiles and toxic dose. After the evaluation of the consequences, vulnerability models are applied to establish mortality levels caused by the exposure to physical effects. One of the most common methodologies, PROBIT calculations (TNO, 1992) give mortality curves in function of the distance. The frequency is evaluated in each case through models such as fault trees and event trees or with information from a database. Finally, the risk is evaluated from the accident consequences and the frequencies at which these consequences occur in a single grid point by the Individual Risk Algorithm (Fig. 3). The frequency of an individual dying is calculated at a grid point for each loss of containment (LOC), each weather class, each ignition event and each wind direction separately. Next, the individual risk at the grid point is determined by adding up all contributions.

For the present QRA, there are few differences between the Terminals. The viaduct length is shorter at Cuatreros port to fit in the dimensions of the channel at the estuary. In addition, although the average wind velocity and direction are similar at both sites because of their proximity, the latter is slightly different due to the relative position of each plant.

4.1. Preliminary hazard analysis (PHA)

The guidelines of the Center for Chemical Process Safety (CCPS, 2008) were used to develop the PHA. As (Wells et al., 1993) recommend, the plant was divided into few sections to simplify the analysis. Critical areas were identified based on the operating conditions of the process (Table 1).

Unloading arm section. The jetty and the unloading arms for the LNG transfer from ship to tanks. It also includes the transfer pipeline from the jetty to the storage tanks.

Storage tanks section. It consists of three containment tanks.

Vaporizer section. The vaporizers as well as their pumping system and the transfer line to distribution net.

4.2. Consequence analysis

Consequence analysis is used to determine the potential for damage or injury from specific incidents (CCPS, 1999). The events are analyzed using source, dispersion, fire and explosion models. Then, effects models are applied to define the consequences for people, structures or environment.

In the analysis, the source terms of the release are defined for the different failure scenarios, and the specified conditions and dimensions. The calculations were performed using the software Effects©, that implement TNO models (TNO, 1997).

4.2.1. Discharge rate

The discharge rate from holes in liquid piping systems was calculated using process conditions and hole sizes detailed in Tables 1 and 2 respectively (ERM-Hong-Kong, 2006). If the value obtained is lower than the pumping rate, the system will remain pressurized and the releases will be a liquid jet. For discharge rates above the pumping rate, this value is taken as the release rate. For full bore failures, the pumping rate was taken as the discharge rate.

On the other hand, gas leaks always lead to pressurized releases. After the piping isolation valves act, the system pressure will gradually fall and discharge rate will decrease over time. In simulations, a constant release rate equal to initial discharge rate is used.

In the case of the storage tanks, only the catastrophic rupture is considered. This is because of the low frequencies of the other cases (leaks of containment) due to the double containment of the structure (TNO, 1999).

4.2.2. Release duration

Given the safety devices and the emergency shutdown system projected for the terminal, it is assumed that releases from piping can be detected and shutdown initiated approximately in two minutes. To take into account possible fails or delays in these protection systems, a ten-minute release scenario is also considered.

A two-minute release duration is assumed for unloading arm failures since the personnel that assist download operations may immediately initiate a manual shutdown. In addition, there are detectors for excessive movement of the arm, which will initiate an automatic shutdown.

4.2.3. Hazard effects

In the case of an accidental release of LNG the following physical phenomena are observed: pool fire (PF), jet fire (JF), flash fire (FF), explosion and roll-over (Raj, 2007). In this study, the PF, JF and FF scenarios were considered to be the most likely to occur. A PF occurs when a LNG spills on land, water or dike and ignited immediately. The pool is evaporated by boiling due to the large temperature range between LNG (cryogenic) and the environment. Therefore, a large proportion of liquid is evaporated to form a cloud of methane. The dispersing vapor cloud may subsequently come in contact with an ignition source and burn rapidly with a sudden FF. Thermal effects outside the vapor cloud are not considered due to the short duration of the FF. In contrast, a direct contact with the burning vapors may cause fatalities.

The third case of interest is the JF, it only occurs where the LNG is being handled under pressure or in a gas phase. The release carries the materials outwards in a long plume entraining air to give a flammable mixture.

In these cases, due to the pressure loss, the release will mostly result in a liquid pool on the ground. This type of release would have minimal momentum, air entrainment and vaporization and hence it would form a liquid pool on the ground. If ignited, this will result in a pool fire (PF); otherwise the pool will vaporize to give a vapor cloud (VC). If ignited, this will result in a jet fire (JF); otherwise the jet will entrain air, vaporize and disperse to give a VC.

If ignited immediately, it would result in a JF; otherwise the gas would disperse as a VC.

4.3. Vulnerability

The physical models described before generate a variety of

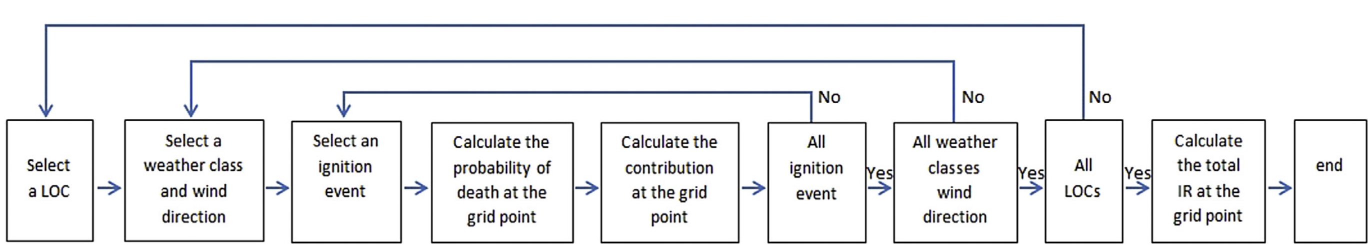

Fig. 3. Risk algorithm.

Table 1
Operating conditions for critical areas.

	Pressure bar_g	Temperature °C	Diameter mm	Length m	Volume m^3
Unloading arm section					
Unloading arms for the LNG transfer	5.5	−161.5	400	30	–
Pipeline from jetty to shore end	5.5	−161.5	700	700	–
Pipeline from shore end to tank	5.5	−161.5	700	300	–
Storage tank section					
Storage tanks	1	−161.5	–	–	160,000
Vaporizer section					
Pipeline from tank to high pressure pumps	7.5	−161.5	500	90	–
Pipeline form high pressure pumps to open rack vaporizer	106	−155.2	400	20	–
High pressure pump	106	−155.2	400	10	–
Gas from vaporizer to gas network	104	5.8	750	108	–

incident outcomes that are caused by release of hazardous material or energy. The magnitude of outcomes is a function of distance from the source of release. The next step in QRA is to assess the consequences of the incident outcomes. The consequence is dependent on the object of the study. For the purpose of assessing effects on human beings, consequences may be expressed as deaths or injuries with the Probit methodology (Santamaría and Braña, 1998).

The method gives simple relations to predict the negative effects of different variables if these can be described by transformation of the normal probability distribution. Probit scale is a very simple tool for measuring probability. Probit units (Y) and probability (P) are related by the expression:

$$P = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{y-5} e^{\frac{-u^2}{2}} du \quad (1)$$

The result is the Probit distribution, which has an average of 5 and a variance of 1. In vulnerability analysis, Probit units are calculated as

$$Y = k_1 + k_2 \cdot \ln(V) \quad (2)$$

In this case k_1 y k_2 are empirical constants, and V is a measure of the intensity of the factor that causes the damage, varying depending on the studied effect.

Probit models were implemented in the software Eduinjuries 1.0 which offers rapidly the expected probabilities because of different causes as exposure to concentration of emissions, radiation, and overpressure. In radiation exposure by thermal effects, the first equation takes the form

$$Y = -14.9 + 2.56 \cdot \ln\left(10^{-4} \cdot I^{4/3} \cdot t\right) \quad (3)$$

where I is the intensity of the received radiation and W/m^2 units are used, and t, measured in seconds, is the exposure time.

4.4. Frequency analysis

The failure frequencies of the initial event (TNO, 1999) are summarized in Table 3.

The frequency of various outcomes following a loss of containment event is estimated using an event tree model (Vílchez et al., 2011) (Fig. 4). The various outcomes considered include pool fire, jet fire and flash fire for liquid releases; jet fire and flash fire for continuous gas releases. Event Tree Analysis is used to describe and analyze how an initiating event may lead to a number of different outcomes, depending upon such factors as the successful implementation of the various emergency response measures and relevant protective safety systems in place.

Immediate ignition of an LNG release would result in a pool fire or a jet fire. For a liquid release under pressure, a jet fire is produced. For a non-momentum liquid release, the liquid is assumed to spill onto the ground producing a pool fire. Gas releases are all pressurized and ignition would result in a jet fire. In the event of non-ignition, a cloud of natural gas would be formed by the gas release or evaporating liquid pool.

If immediate ignition does not occur, the dispersing cloud of natural gas may subsequently be ignited. A flash fire would occur if this cloud were subsequently ignited. If delayed ignition does not occur, the vapor cloud disperses with no effect because the natural gas is not toxic.

The overall ignition probabilities used in this study were taken from ERM (ERM-Hong-Kong, 2006) based in the work of Cox, Lees, & Ang (Cox et al., 1990) and are summarized in Table 4.

Special consideration was given to the ignition probabilities for LNG storage tank failure scenarios. Given the much larger scale of release for this scenario compared to all others, it is more probable that the vapor cloud will find an ignition source. The distribution of this probability was made (Table 5 (TNO, 1999)) with consideration of the location of likely ignition sources. Immediate ignition was deemed unlikely since ignition sources will be present on site and the fact that the release will affect the whole site. A value of 0.3 was adopted. For delayed ignition, a value of 0.1 was adopted.

4.5. Individual risk

The individual risk represents the frequency of an individual dying due to loss of containment events (LOCs). The individual risk is presented as contour lines on a topographic map and is calculated

Table 2
Size of the hole for discharge rate calculation.

Pipeline	Tank
10 mm	Catastrophic rupture
25 mm	
50 mm	
100 mm	
Full bore rupture	

Table 3
Failure frequencies.

Installation (Part)	Catastrophic failure	Leak
Pipeline, nominal diameter <75 mm	$1 \cdot 10^{-6}$ m^{-1} y^{-1}	$5 \cdot 10^{-6}$ m^{-1} y^{-1}
Pipeline, 75 mm< nom. d. <150 mm	$3 \cdot 10^{-7}$ m^{-1} y^{-1}	$2 \cdot 10^{-6}$ m^{-1} y^{-1}
Pipeline, nominal diameter >150 mm	$1 \cdot 10^{-7}$ m^{-1} y^{-1}	$5 \cdot 10^{-7}$ m^{-1} y^{-1}
Pumps without additional provisions	$1 \cdot 10^{-4}$ y^{-1}	$5 \cdot 10^{-4}$ y^{-1}
LNG storage tank	$1.25 \cdot 10^{-8}$ y^{-1}	–

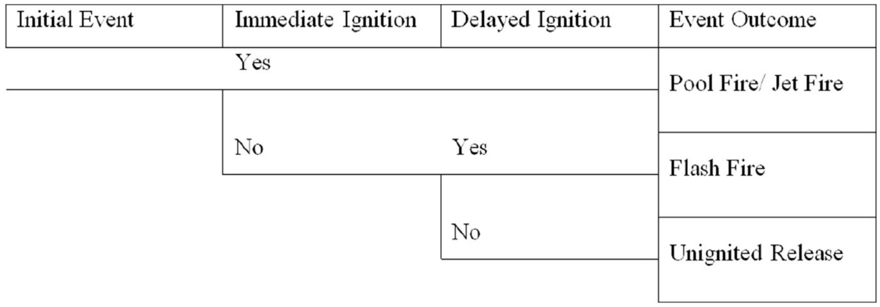

Fig. 4. Simplified LNG event tree.

at each grid point separately. The procedure to determine the Individual Risk in a single grid point was previously outlined in Fig. 3.

5. Results

Risk calculations were performed by Risk-A 1.0, software developed to solve the Individual Risk Algorithm (Aparicio et al., 2006), and the results obtained were plotted as iso-risk curves (Cepin et al., 2006) on the map of the proposed locations. Figs. 5 and 6 show two possible locations for the LNG Terminal in Cuatreros and Rosales ports. In Rosales (Fig. 6), a crude storage plant (Oil Tanking SA) is placed approximately 800 m from the proposed location.

Fig. 5 (Cuatreros port) shows that the curve $1 \cdot 10^{-6}$ y^{-1} reaches a maximum distance of 274 m from the unloading arms in the jetty area. The risk level increases surrounding the jetty because of the presence of the unloading areas. This is caused by the short width of the estuary (300 m) in that point, leading to a shorter jetty. In Fig. 6 (Rosales port) the curve $1 \cdot 10^{-6}$ y^{-1} reaches a maximum distance of 269 m in the jetty area and 136 m from the limit of the plant. In this case, the risks associated with the plant and the jetty can be appreciated separately.

In both locations, all the remaining risk curves turned out to be similar. In particular, the highest risk curve ($1 \cdot 10^{-4}$ y^{-1}) surrounds both the unloading arms and the storage tanks, due to the high flow rate and the storage capacity respectively.

The risk levels obtained at both locations are similar. The small differences observed comparing Figs. 5 and 6 are attributed, as was mentioned before, to the different characteristics of the Terminals, such as the viaduct length or the average wind direction at both locations.

6. Complementary considerations

Considering the similarity in the results in the QRA analysis for both locations, complementary methodology with other studies is needed. For this purpose, social, environmental, geographical and geological aspects were analyzed since environmentally sensitive areas should be avoided (Manlove, 2008).

The main characteristics of the analyzed ports are summed up in Table 6.

Table 4
Ignition Probabilities used in this study.

Leak size	Ignition probability immediate	Delayed
Liquid small leak	0.010	0.035
Liquid large leak/rupture	0.080	0.180
Gas small leak	0.020	0.045
Gas large leak/rupture	0.200	0.100

Cuatreros port is located in the inner sector of the Bahía Blanca estuary. Many research projects carried out over three decades at Universidad Nacional del Sur show the fragility of the wetland ecosystem present in this zone, which are protected by the Argentinian Law 11074 (1998).

This sector of the estuary is the habitat for many different colonies of invertebrates as it is the resting place and hibernation area of numerous migratory birds and a site for feeding and nesting for many seabirds. The site is also inhabited by different cetaceans (Fidalgo et al., 2004), sea wolves (Petracci et al., 2010) and sea turtles.

The water in this place, protected from direct action of the ocean, is a feeding, growing and spawning zone of species whose state of conservation is critical or vulnerable (López Cazorla et al., 2004). Particularly, with reference to the species of commercial interest, this zone is one of the two areas of development of young fish in the whole coast of Buenos Aires province (López Cazorla, 2000).

The work associated to the required harbor infrastructure (dredging, docks installation, etc.) supposes a big magnitude impact on the aquatic and coastal communities (CDBByF-UNS, 2011). Dredging work could also cause release of heavy metals to aquatic environment that currently stay immobilized at the

Table 5
LNG storage tank release ignition probabilities.

Immediate ignition	0.3
Delayed ignition	0.1

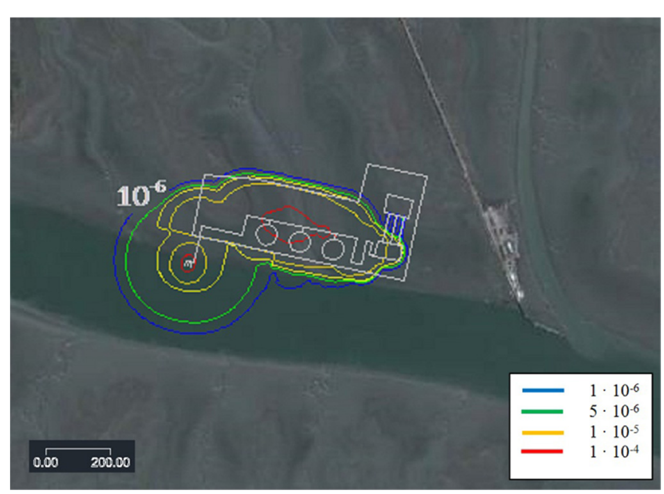

Fig. 5. Isorisk curves in LNG plant (Cuatreros port).

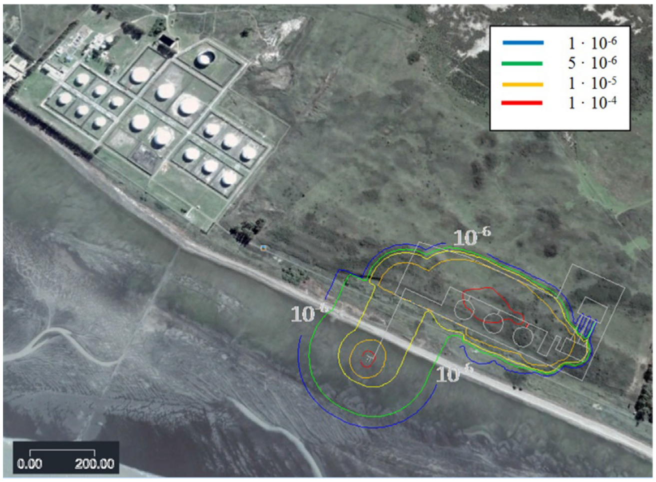

Fig. 6. Isorisk curves in LNG plant (Rosales port).

sediments of the estuary (Botté et al., 2010).

From a geological point of view, the project would generate irreversible changes (IADO, 2011). The necessary dredging work in Cuatreros port would move more than 11,100 m^3 of different kinds of sediments. Additionally, subsequent dredging operations needed to maintain the channel will imply continuous morphological modifications on it.

The other site in the project, Rosales port, is placed at the external zone of the bay (see Fig. 2). This harbor presents the advantage of not having to dredge the zone for the navigation of LNG ships, because at 1,500 m from the coast it has a depth of 45 ft (ENARSA-PDVSA, 2008).

Furthermore, the probability of an accident during the navigation increases with distance being Cuatreros port the most unfavorable location. In addition, the installation of a facility for LNG ships should be sited in places as externally from inner channels of the estuary as possible to evacuate the port in case of an incident.

From all these considerations taken into account, Rosales port is found as a better localization for proposed plant.

7. Conclusions

Choosing acceptable sites for new LNG terminals has been proved controversial. Technologists have proposed terminals near consuming markets to avoid pipeline bottlenecks and to minimize transportation costs. However, this option requires the construction of plants near populated areas or small communities and could impact directly on the wetland ecosystem present in estuaries. The actual risks must be evaluated realistically based on the knowledge of potential LNG's hazards, risk control, mitigation measures and environmental protection. With these ideas in mind, this paper describes the QRA methodology to assess risks and applies the results for land use planning.

Rosales port has the advantages of being located farther from populated areas, and has a deep shipway. On the other hand, Cuatreros port is closer to the main gas distribution network and that is beneficial from an infrastructural point of view. Moreover, in this area, there are no other industrial facilities. Finally, provided that Cuatreros port is farther from the estuary's entrance, the risks associated with the carrier's route are higher. Although the route to Rosales port is shorter, the presence of other industrial facilities in the area calls for different safety measures.

The minor differences observed comparing Figs. 5 and 6 are attributed to small variations in the design, such as the viaduct length, or atmospheric conditions like the average wind direction. As it has been previously mentioned, the risk levels curve corresponding to $1 \cdot 10^{-6}\ y^{-1}$ does not reach a significant distance off-site the battery limits. Then, considering only the risk factor, both locations are plausible, since the risk levels obtained at both places are similar. The effects of LNG marine terminals on environment can be minimized through technological protection means and careful selection of potential terminals sites. Significant contributions from extensive studies, which takes into account environmental and social factors complement the present QRA for the plant siting decision making. Provided that particularly environmentally sensitive areas should be avoided, after analyzing the different alternatives, Rosales port seems to be the most suitable place to locate the LNG regasification plant proposed here.

Table 6
Cuatreros and Rosales ports characteristics.

	Cuatreros port	Rosales port
Nearest settlement	3 km	6.5 km
Nearest industrial facilities	7 km	0.8 km
Nearest gas network	10 km	40 km
Depth	16 ft	45 ft

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