

# STRRAP – A RISK ASSESSMENT AND EMERGENCY PLANNING COMPUTATIONAL TOOL

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**Abstract.** A methodology and a powerful computational tool (Stochastic Toxic Release Risk Assessment Package, STRRAP) useful in risk assessment and emergency planning (safe distance calculation) is presented. This tool is based on a method which lets the handling of stochastic uncertainty of atmospheric parameters, critical when calculating risk, especially when hazardous gases or particulate matter diffusions occur as a result of an accidental release or emission. In fact, the random behaviour of wind intensity, wind direction, atmospheric stability and temperature given a time horizon (seasonal or a complete year), is considered. So, distributions of the meteorological parameters to be used must be specific for the place under study.

This methodology can be used for both releases and emissions from static sources (a stack or a fixed tank in a facility) as well as from transportation accidents (road, train, maritime and pipeline transport). After a stochastic simulation which is based on well-known diffusion models (for particulate matter, dense and light gases) is carried out, downwind concentrations that overcome a given critical toxicity index are obtained. Then, STRRAP can compute individual and societal risks.

Besides, the data stored in a data base provide the distance distributions that are related to the complete set of incidents that this analysis considers. Then safe distances can be determined by selecting the 90<sup>th</sup> percentile value of the distribution. The health criteria used for the analysis are The American Industrial Hygiene Association (AIHA) Emergency Response Planning Guideline Level 2 (ERPG-2) and Level 3 (ERPG-3) for computing Protective Action and Initial Isolation Distances, respectively.

All the subroutines and procedures have been integrated in a computer program which makes information management and result presentation easy.

In order to show STRRAP capabilities, some hazardous events in the area of Rosario city are studied.

**Keywords:** Atmospheric parameters uncertainty, Consequence and Vulnerability Analysis, Risk Assessment, Safe Distances.

## 1. Introduction

Road-accident rates in hazardous material transportation are of the same magnitude of releases due to fixed sources (process equipments, stacks, tank releases, etc.). Indeed, they have increased during the last decades (in fact, 95% of cases reported in the 20<sup>th</sup> Century occurred in the last 30 years) [1]. Consequently, it is necessary to improve the available tools and develop new ones to compute risk indexes and estimate safe distances for both cases (fixed and mobile sources), useful for emergency/contingency planning. For air diffusion of hazardous gases is important to consider the stochastic uncertainty of atmospheric parameters. In this work, an improved system (Stochastic Toxic Release Risk Assessment Package, STRRAP) which can handle uncertainties for both risk and safe distance calculation is presented.

Stochastic uncertainty arises from the natural variability of parameters related to the involved physical processes. For instance, the natural variability of the weather affects

pollutant diffusion processes, and consequently risk calculation. Although additional data cannot reduce the stochastic uncertainty, they can provide information about its probability distribution [2], [3].

So, an approach that takes into account the stochastic nature of meteorological parameters can be very helpful. In a recent work [2] a method for a risk assessment study case considering uncertainty was presented. It demonstrated that it is possible to achieve good approximated distributions over the whole impact area, using the Monte Carlo strategy (Fig.1). In order to improve the system capabilities, particulate matter and Gaussian diffusion models were added to the calculation modules of the previous prototype. All these models are limited to air diffusion of toxic materials.

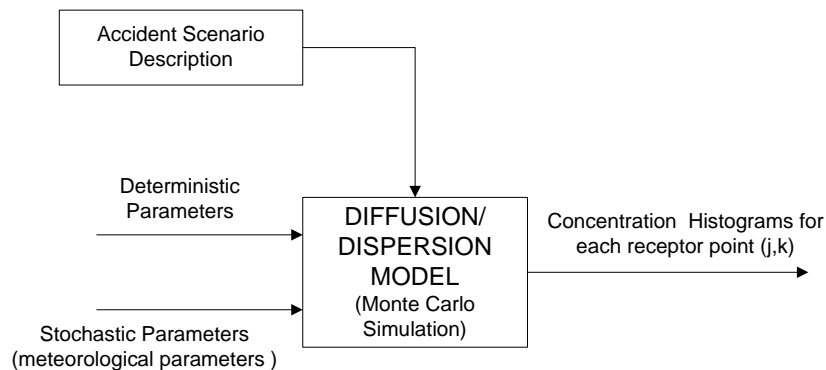


Fig. 1. Simplified scheme of the calculation strategy (Monte Carlo)

The following sections explain the main aspects of the model and the software implementation. As it will be shown, STRRAP can model a toxic substance release as a consequence of transportation accidents or fixed emissions, either involving multiple fixed sources or only one.

## 2. STRRAP System

There are several well-known and very efficient atmospheric dispersion models if the necessary data are available. STRRAP includes models for:

1. Light and neutral gases (Gaussian model)
2. Dense gases
3. Particulate matter diffusion

For dense gases, DEGADIS model [4] was implemented. Its code was translated into FORTRAN 90 and modified so that it can consider the stochastic nature of the problem.

Also, all models are linked to each STRRAP module:

1. The pre-processor
2. The processor
3. The post-processor

Figure 2 shows the system calculus modules interactions for a transport accident case.

The pre-processor module is in charge of the input file generation to the diffusion model. It reads the emission data included within a pattern file (substance properties, flow rates and others accidents scenarios parameters, the region under study, etc) and then generates the random variable values. That is, it writes a file to be used by the calculus module. Since the time horizon (a season or the whole year) and the day or night condition are fixed, the values of the random variables (wind direction, wind velocity, temperature,

humidity, and atmospheric stability) are determined.

It was found that long computing time is spent for a transportation accident case with a fine discretization (grids) and road partition. So, an optimization of this method (Translation Algorithm) was made [2].

It was defined an affected zone considering only one emitter called “Stochastic Reference Emitter (SRE)” and determining all the receptors affected by it. So, we store all the concentration histograms and all the data corresponding to the receptors affected by the SRE in the data base, and the histograms for any receptor are easily determined by means of a translation algorithm. This procedure reduces considerably the computing time without loss of accuracy.

Then, the processor module (using a suitable model) computes the downwind pollutant concentration only for the SRE, according to the conditions previously fixed by the pre-processor.

The post-processor module is in charge of storing and managing the results for all the trials in a data base. Also, it includes the translation algorithm to calculate the concentration histograms for all the affected receptors along the entire road, as a function of the SRE data. In general, each receptor is affected by several emitters, so the translation algorithm must take into account the contribution of all these emitters.

The post-processor can calculate risk values for a given area, safe distances, etc.

Several subroutines or auxiliary programmes have been developed to display all the results in a graphical way, making the user's task easier.

### **3. Risk Calculation Methodology for Transportation Accidents**

Several indexes are possible to be defined to represent the risk analysis results. Common representations for individual risk are its contour plots and different average indexes, e.g. maximum individual risk, average individual risk, etc.

Societal risk includes quantification in terms of the number of affected people. Generally, it is represented as the Frequency-Number (F-N) curve, a plot of the complementary cumulative frequency versus a number of fatalities.

For risk definitions and risk estimation methodologies, see [3], [5-6].

For transport accident releases there are five aspects to be considered in a Quantitative Risk Analysis (QRA):

- a) Involvement of a dangerous vehicle in an accident.
- b) Breakage occurrence and characteristics (type, size, etc.).
- c) Release occurrence and characteristics.
- d) Calculation of the individual risk or societal risk due to each segment of the road in a given area.
- e) Calculation of risk distribution over the impact area.

Many works use a deterministic approach for each or some of the above-mentioned components [7-9].

Recent works have made important contributions to solve the risk assessment problem more precisely. [10] describes a risk assessment procedure which considers various transportation modes, different meteorological conditions and time horizons, a non-uniform wind rose and a precise description of the outdoor and indoor population, both on-route and off-route. Other studies present several integrated models on a software platform solving the risk assessment problem of dangerous goods transportation in a systematic

way ([11-13]). [12] and [13] make an analysis of event frequencies. For instance, [13] presents a deductive model to calculate the containment loss frequency for rail transportation.

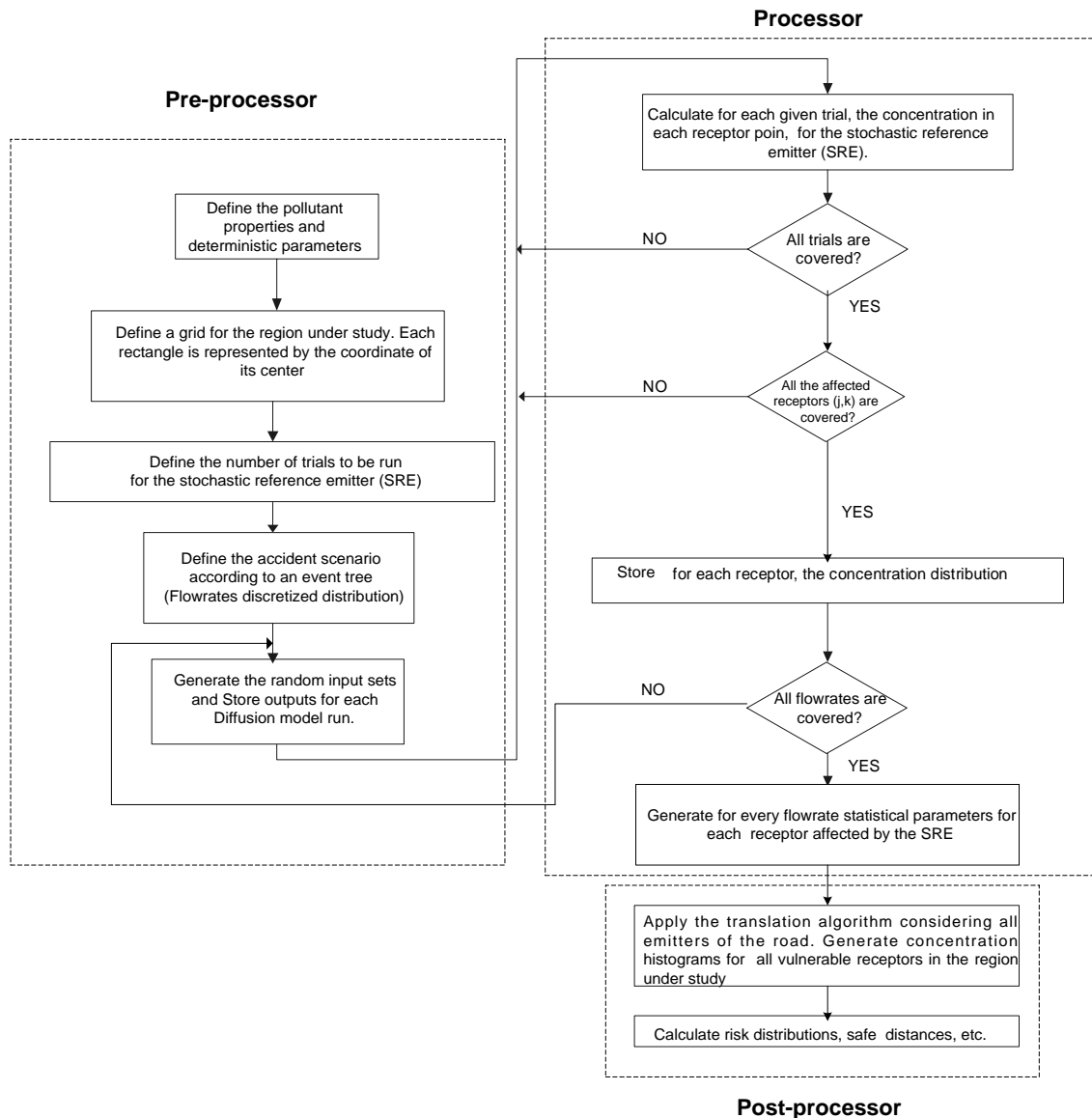


Fig. 2. System calculus modules

In this paper as in [2] the atmospheric parameters are considered uncertain. If a truck road accident and a toxic substance release are particularly considered, the problem is defined as it is represented in Fig. 3.

STRRAP is based on a simple representation of emitters and receptors (grid).  $\Delta L_{Ri}$  are different road segments and  $J \cdot K$  is the number of receptor squares. The emitters are supposed to be placed in the centre of each road segment,  $\Delta L_{Ri}$ , as the receptors are in the centre of each square.

So, the road is cut up into a number of segments and the surrounding area is divided into square sections (grid of receptors). Each road segment,  $\Delta L_{Ri}$ , is considered as a potential fixed point source or emitter (a potential accident point placed in the centre of each road segment).

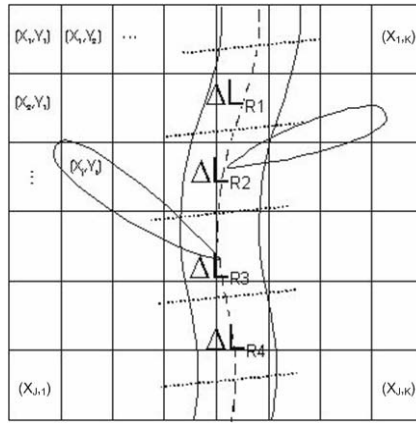


Fig. 3. Discretization of the emission points and the receptor grid points

The expected pollutant concentration is calculated at each grid point or receptor  $(X_j, Y_k)$ , with  $j = 1, \dots, J$ ;  $k = 1, \dots, K$ , considering all the emitters. Assuming the linear composition of emitters effect, the addition of every road segment contribution affecting each receptor must be performed. Indeed, a suitable procedure for generating all possible stochastic variable values should be considered in this calculation. As a result, concentration histograms corresponding to each receptor  $(X_j, Y_k)$  can be achieved according to seasonal, annual, or other time horizons. Once these histograms are obtained, the scheduler has important data to compute the expected resource demands for emergency planning or for risk assessment over the analyzed area.

Consequently, the concentration distribution, the maximum expected concentration, the most probable concentration value, the risk distribution, the expected individual or societal risk curves, among others, over each geographical area, can be easily obtained.

Usually, the breakage and release occurrence and characteristics (the most representative accident scenarios) are known through an event tree covering all the possibilities [2].

In this way, the total risk is the addition of partial results corresponding to each branch of the adopted tree. So, the following formula is used.

$$R_{jk} = \sum_{m=1}^S EP_m \sum_{i=1}^I R_{mijk} \quad (1)$$

where  $S$  is the number of accident scenarios,  $I$  the number of road segments, and  $EP_m$  the scenario probability.

For each scenario ( $m$ ) and emitter ( $i$ ), we have:

$$R_{mijk} = F_i \cdot \Omega_{mijk} \quad (2)$$

where  $F_i$  is the accident probability in each road segment ( $i$ ) and  $\Omega_{mijk}$  the accident consequence at each receptor ( $j, k$ ) corresponding to the emitter ( $i$ ) and scenario ( $m$ ). The accident probability,  $F_i$ , can be calculated by multiplying the truck accident probability,  $p_i$ , the road segment length,  $\Delta L_{Ri}$ , and the number of shipments per year,  $N_T$ .

$$F_i = p_i \cdot \Delta L_{Ri} \cdot N_T \quad (3)$$

The accident consequence  $\Omega_{mijk}$  can be calculated as follows:

$$\Omega_{mijk} = \sigma_{jk} \Phi_{mijk} A_{jk} \quad (4)$$

where  $\sigma_{jk}$  is the population density in each square (j, k),  $A_{jk}$  is the area and  $\Phi_{mijk}$  is a measure of the vulnerability of each receptor.

In order to estimate the number of affected people, usually the probit methodology is used. As it is known the calculation of the vulnerability ( $\Phi_{mijk}$ ) depends strongly on the stochastic meteorological conditions. Then, the Monte Carlo simulation is used to obtain the concentration distribution for each receptor (j, k) introducing distributions for the wind direction, wind velocity and atmospheric stability. Consequently, the total risk  $R_{jk}$  involves the whole relevant information about the problem. In fact, the whole set of scenario possibilities is covered for the  $\Omega_{mijk}$  calculations. For more details see [2].

#### 4. Risk Calculation for Static Source Emissions

The risk calculation for fixed source releases can be solved as a particular case of the above described transport risk calculation model.

In fact, now only one emitter must be considered. The total risk is the addition of all contributions due to the different scenarios. The risk calculation formula used for this case is:

$$R_{jk} = \sum_{m=1}^S EP_m R_{mjk} \quad (5)$$

where  $S$  is the number of possible scenarios, and  $EP_m$  the corresponding scenario probability. For each scenario (m), Equation (4) is valid, but now the subindex "i" is not necessary.

In general, for gas diffusion accidents, different scenarios are characterized by different release flowrates. If a release distribution is available, a new stochastic variable can be introduced. If only different probabilities for fixed release flowrates are known in an event tree, each of its branches is solved using this methodology and the final result is a weighted average of all of them.

#### 5. Safe Distances Calculation Methodology

The downwind concentration of the toxic gas or particulate matter decreases as distances increase. We will use the 2000ERG [14] definitions to determine safe distances. According to that, the *Initial Isolation Distance (IID)* defines a circular area surrounding the place of the incident, where the downwind concentration of the toxic gas is such that could endanger exposed people's lives. The *Protective Action Distance (PAD)* defines a square downwind region where the exposed people can have irreversible health effects and/or be unable to escape, thus causing their death.

For the calculation of *PADs*, the ERPG2 health criterion is used in the filtering step. The *IID* is calculated in a same way, with the life-threatening health criterion defined as an ERPG3.

Once obtained all the receptors where the critical health criterion was reached, considering the SRE, distances between each receptor (j, k) and the SRE can be calculated ( $j = 1, \dots, J$ ;  $k = 1, \dots, K$ ;  $i=1, \dots, I$ ).

As previously pointed out, all data provided by the post-processor are stored in a data base. It gives information about each vulnerable receptor, its geographic coordinates, concentrations obtained in each trial and meteorological variables.

Then, the distance distributions are calculated using

$$d_{ijk} = \sqrt{(Y_i - Y_k)^2 + (X_i - X_j)^2} \quad (6)$$

where  $(X_j, Y_k)$  are the receptor coordinates and  $(X_i, Y_i)$  are the SRE coordinates. In both cases, to calculate the protective action and isolation distances, the 90-percentile of their distribution is selected.

## 6. Study Cases Using STRRAP

### 6.1 Risk map for a SO<sub>2</sub> transportation accident – FN curve

The risk associated to the SO<sub>2</sub> transportation in the circumvallation road of Rosario city is analysed applying the improved version of STRRAP system (Translation Algorithm). The most representative scenarios involving sulphur dioxide are selected from a typical event tree as reported in the literature ([15-16]). A time horizon for the analysis (an annual base), mean temperature, pressure and humidity for this zone and for this time horizon are included in the input files. Figure 4 shows the gas properties and all the variables adopted for each case to define DEGADIS input files completely. Indeed, wind velocity; wind direction and stability class distributions must be provided for this zone and time horizon. Data gathered during the last ten years are used in this work to get the histograms for each stochastic parameter. So, probability density functions taking into account the variability of the local meteorological conditions are used. For more details see [2]. The pre-processor generates every input file, sweeping all the trials.

Fig. 4. Gas properties and simulation parameters

The risk distribution in the area of interest is computed using risk Equations (1-4). Figure 5 show the risk distribution along the studied road.

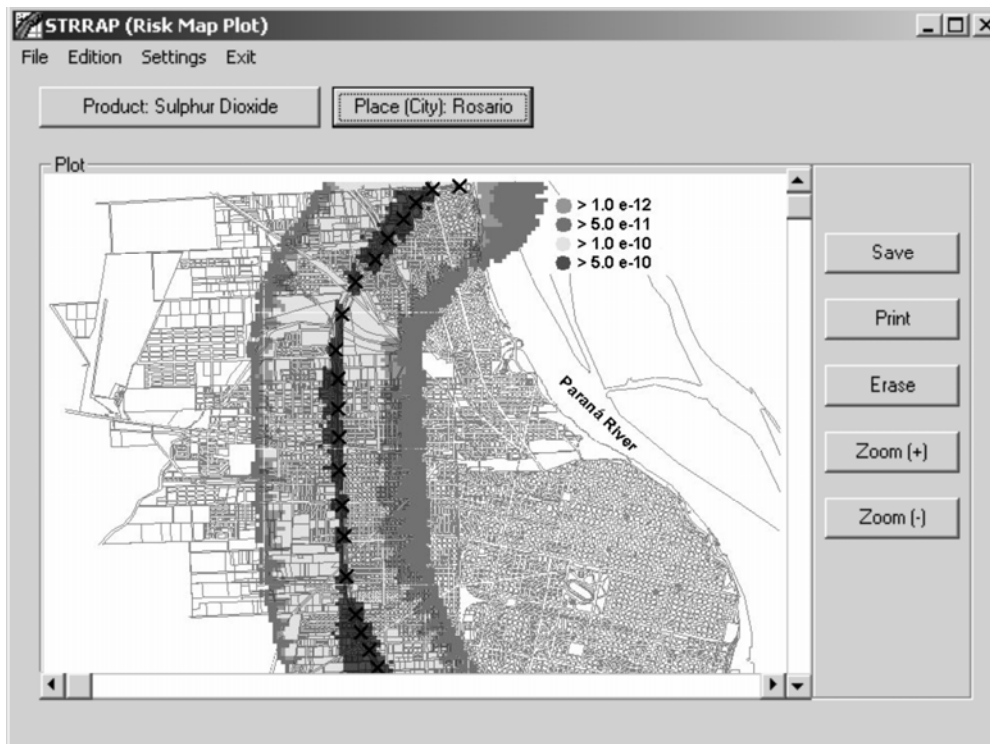


Fig. 5. Risk distribution (transportation case)

## 6.2 Risk map for a fixed source chlorine release

The risk associated to a fixed chlorine release is analysed.

An annual base is used to generate distributions for the input vector for DEGADIS model. Figure 6 shows gas properties and simulation parameters used for this example.

Fig. 6. Gas properties and simulation parameters

Figure 7 shows the risk distribution.



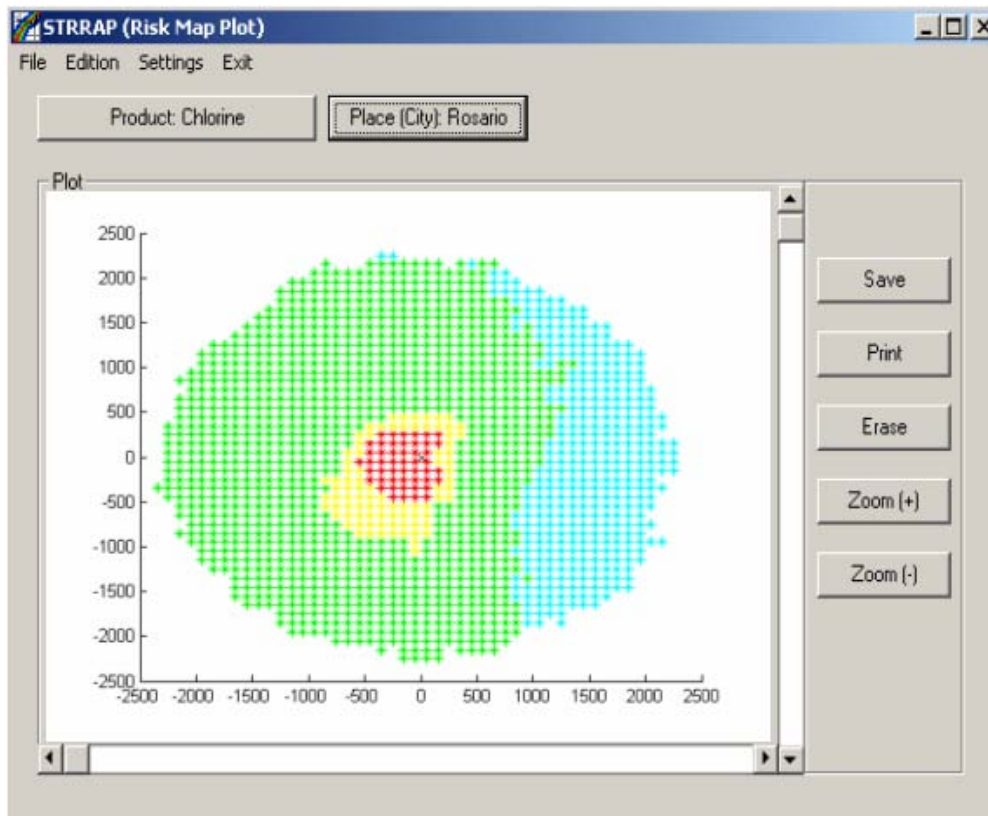


Fig. 7. Risk distribution (fixed source)

### 6.3 Safe distance calculation for a fixed source chlorine release

The protective action distances versus the emission flowrates curve for a fixed chlorine release is presented. Gas properties and simulation parameters are the same as those used in the case studied in Section 6.2.

After all simulations are performed (applying Monte Carlo method), the distance distributions are obtained, as explained before (using Eq. 6). First, the distance distribution for each flowrate is calculated. Then, the 90-percentile is taken from each distribution as the safe value. Finally, the protective action distance curve is plotted as a function of the emission flowrates (Fig. 8).

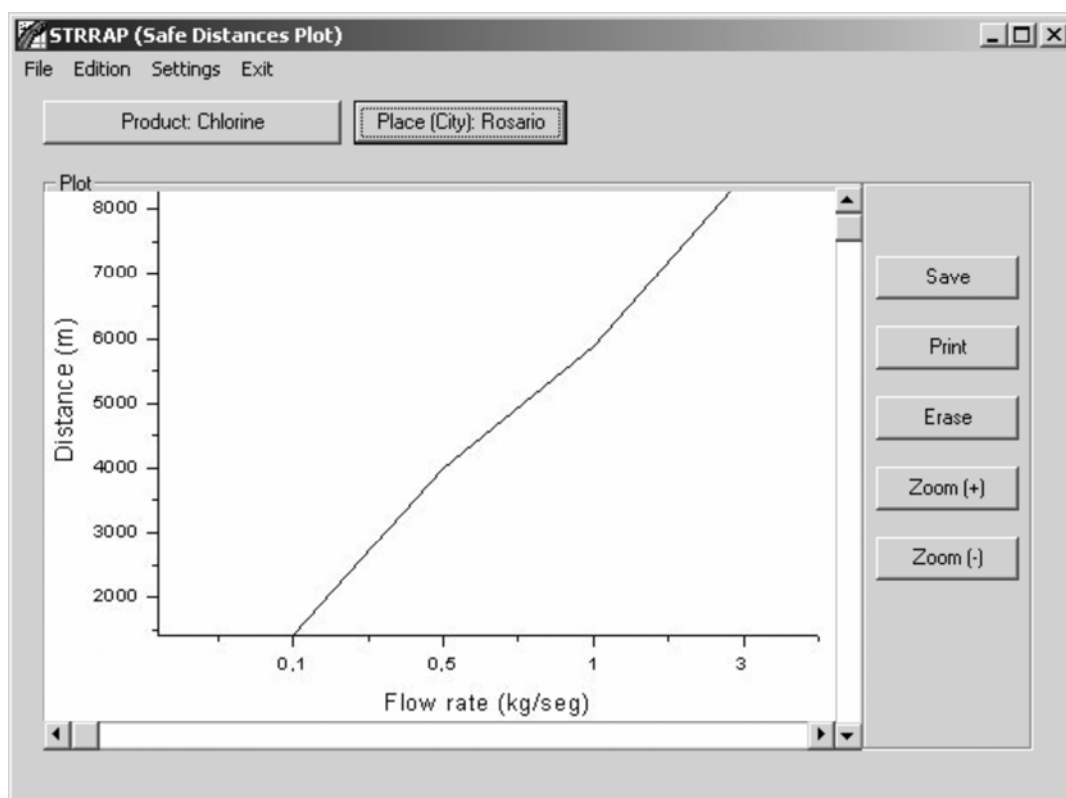


Fig. 8. Safe distance-flowrate curve

## 7. Conclusions

A computational tool (STRRAP) useful for risk assessment and emergency planning is described. It is shown that the system can be used for static emission sources (e.g. storage tanks, stacks, etc.) or for mobile sources, like hazardous material transportation accidents. In the last case, the road or “emission line” is discretized in several segments. The number of trials is proportional to the number of emitters and receptors. Consequently, the computational time grows with desired resolution (number of emitters and receptors). This problem is overcome applying the Translation Algorithm which greatly reduces the computation effort.

In this version the system includes light and dense gases diffusion models and particulate matter dispersion models. Other types of models as microorganism diffusion or water pollutant dispersion will be included in future works.

Also, it is evident that risk analysis for railway or maritime transport can be solved in this way as well as pipelines for gas transport.

Finally, as STRRAP can consider the local atmospheric random parameter variability, more realistic safe distances can be computed, being an important tool for emergency planning.

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