Università Politecnica delle Marche
Master-degree in Environmental Engineering

From diffusive analysis of airborne pollutants to health risk assessment

Final dissertation supervisor

Prof. Eng. Giorgio Passerini

Student

Pierangelo Colombo

Supervisor

Dr. Enrico Mancinelli

academic year 2018/2019

Summary

ABSTRACT 5

1)INTRODUCTION 8

1.1) AIR POLLUTION 8

1.2) Natural and artificial sources of pollution 11

1.3) Primary and secondary pollutants 15

1.4) Limits and target values for pollutants 21

1.5) Effects on human health 26

1.6) Risk assessment (RA) and health impact assessment (HIA) 37

2. MATERIALS AND METHODS 49

2.1) Making of air dispersion modelling 49

2.2) The HARP model 56

2.3) Risk analysis 65

2.3) AERMOD STRUCTURE 68

2.3.1) The choice of Aermod 68

2.3.2) Aermod source code 74

3) RESULTS 86

3.1) Results from Aermod 86

3.2) Results from HARP 95

3.3) Comparison between flat and elevated Aermod model setup 101

3.4) Risk analysis 104

Conclusions 106

Limitations and future perspectives of the present study 108

Bibliography 110

ABSTRACT

In the present master thesis the atmospheric dispersion of pollutants are discussed and, in particular, are exposed the results of a work carried out in the summer 2019 at the Department of industrial engineering and mathematical science (DIISM) of the Università Politecnica delle Marche.

Mainly in the case study the pollutant referred to is PM_{10} (and therefore $PM_{2.5}$). HARP-hot spots analysis and reporting program, a project of California (USA) is the international reference for our project. It correlates the gaseous emissions present on a territory with the risk to the human health of the population that inhabits the same areas through air dispersion modelling and dose-response functions.

The idea is to express health impact through some indices instead of expressing it through impacting pollution concentrations, which is the idea of HARP.

Therefore, the focus of our project was on assessing exposure related to an emission scenario and to evaluate the related risk. Exposure tells us how much and for how long the populations is subject to a source of pollution. The final objective is therefore the creation of a tool capable, through few input data (such as the emission source, the type of pollutant and meteorological data etc.) of providing directly health impact scenarios with the corresponding numerical values.

The project consisted in searching for the implementation of a software able to elaborate long-term predictions looking at the impact on the ground of the various pollutants released into the atmosphere by a punctual source, like that of a chimney. To do this, the open source code

of the AERMOD software was used; it is made up of different modules: they are, firstly, an air dispersion model for air pollutants from stationary sources, then AERMAP, regarding terrain features, and AERMET, regarding weather data elaborations. Initially AERMOD open source code is applied in flat mode, meaning we assume a completely flat territorial configuration with the aim of predicting the impact that the installation of a new emission source can have in a certain area.

In particular, meteorological data of Camerano station (AN) were exploited, thanks to which it was possible to preprocess the file containing the weather part. Later these were processed by the AERMOD code to elaborate the forecasts about the concentrations of pollutants to which the population is exposed after a period of one hour, 24 hours and in particular at 1 year.

Precisely these last ones, called "period", were the ones we were interested in and were values for which the risk for human health was associated, or rather the risk resulting from the exposure was assessed for a period of one year.

Another component of the AERMOD software, AERPLOT, was also used. This tool was useful for the final graphic display of the results, in fact it allows to project, through the GoogleEarth interface, a list of pollutants directly on the territory.

In this case points are projected in 36 radial directions from the emission source and to do this, the open source code of AERPLOT was implemented with the geographical coordinates of the emission center, written both as latitude and longitude and subsequently transformed into UTM coordinates.

Results show realistic values, but it is important to remember that the input data do not refer to a real situation and we applied software with flat setup.

Moreover, data of deaths or hospitalizations still miss and are not published by competent authorities.

In any case the comparison between the results of Aermod opensource and those of HARP show same values, confirming the correct input data file.

We tested elevated setup using AermodView and some differences were found in the analysis of peak concentration but, in any case, the results are in the same order of magnitude.

Regarding the location of the point of maximum exposure, the two softwares are agreed and place it at almost the same distance.

Leaving out the peak concentrations, for which there is a deviation of about 0.1 µg/m3, for the rest of the simulations the values obtained are very similar, with differences that, regarding the particulate matter, are negligible.

We conclude our study by analysing the risk assessment for the studied area and predicted concentrations found considering long term (1 year) exposure to diesel engine exhaust.

To do this, we calculated the risk (hazard quotient (HQ) and cancer risk) per each concentration found around the emissions source. Results show that there is no toxic risk (HQ=0.005-0.08 < 1) in the studied area with respect to the input data assumed. Based on risk assessment standalone tool by HARP, the cancer risk is up to 10^{-4}.

1)INTRODUCTION

1.1) AIR POLLUTION

Air is the gaseous, colorless and odorless mixture that makes up the Earth's atmosphere. It is composed of nitrogen (78%), oxygen (21%) and, minimally, of carbon dioxide and some inert or rare gases such as argon, helium, xenon and crypto. This mixture has allowed the development of life on Earth, given that nitrogen and oxygen are indispensable to most living beings.

- **Nitrogen**, which is the fundamental constituent of animal protoplasm, does not take part in respiratory turnover and seems to have only the function of diluting oxygen in the proportion most suited to breathing.
- **Oxygen** is an indispensable element for life. With increasing altitude there is a decrease in the partial tension of this gas, which conditions the onset of hypoxic phenomena (altitude sickness); but also variations in the opposite direction can cause disturbances called hyperoxia in humans. On average it is found in quantities of 1-5 mg for every 100 m^3 of air, its proportion increases with altitude. The air of the forests and mountains is richer than that of the plains, during the spring we have larger quantities than in autumn and winter. [ISPRA,2006]

Furthermore, air has a fundamental function in the complex system of heat distribution on our planet: its movements are based on variations in **temperature**, **humidity** and **atmospheric pressure**. For instance, wind is simply air movements. The farther we move away from the

earth's surface, the more the air becomes progressively thinner and breathing becomes difficult.

Air pollution means the presence of one or more unwanted substances in the air. Air pollutants have negative effects on humans, animals, plants and air quality.

Italian legislation in article 268 of **law 152/2006** defines atmospheric pollution as "*any modification of atmospheric air, due to the introduction into it of one or more substances in quantities and with characteristics such as to damage or to constitute a danger to human health or to the quality of the environment or such as to damage material goods or compromise the legitimate uses of the environment* ".

The types of air pollutants most frequently present are sulfur oxides, nitrogen oxides, volatile organic residues (VOC) and small dust particles such as aerosols [Lenntech.it]. Air pollution is the most widespread single environmental risk recognized, in May 2015, by the resolution of the World Health Assembly (WHA), as one of the major global public health problems. In 2012 it was estimated that one death per nine was due to health problems related to air pollution [Stefania Russo,2018].

In the euro area, according to the WHO, particulate pollution is responsible for a 1-year reduction in life on average [WHO,2019]

Because of these reasons, health problems related to air pollution is becoming a topic of increasingly common interest and studies are being carried out all over the world, as the

Surely the **orographic and meteorological factors** are the most influential about atmospheric dispersion and, in particular, the intensity

of the wind and the intensity of precipitation are very important in this field, as the first factor favours the dispersion while the second tends to bring pollutant on the ground.

Consequently, one can guess how in cities, where there are important emission points and poor air circulation, pollution finds little space to disperse and, especially on sultry and poorly ventilated summer days, it can create many problems for citizenship.

Over the years the legislative measures taken aiming at the reduction of atmospheric pollution values are different, also of an international nature.

The Italian legislation on the protection of pollution, issued in implementation of the European Union directives is essentially divided into two levels: air quality and the regulation of emissions into the atmosphere.

The first one sets the acceptability limits and the air quality requirements in urban centers and, more generally, in the territory. The second one, instead, aims to control the pollution produced by companies through the identification of reference parameters that must be set for the various polluting substances.[G.Miserocchi,2019 and InquinamentoItalia.com].The regulations on the protection of the air and the reduction of emissions into the atmosphere are also contained in the aforementioned environmental single text, legislative decree 152/2006, which integrates and modifies the pre-existing provisions [“Gazzetta ufficiale Camera dei deputati,2006]

1.2) Natural and artificial sources of pollution

There are many sources of natural pollutants that sometimes take on more relevance than those originating from humans. Natural air pollutants have always been part of human history. Dusts and various gases emitted by **volcanoes**, **forest fires** and the **decomposition of organic compounds** enter the atmosphere at almost regular intervals, as shown in figure 1, and in some cases at levels that cause dramatic effects on the climate. In any case, natural pollutants do not necessarily represent a serious problem as can pollutants of anthropic origin because they are often considerably less dangerous than compounds produced by man and are never concentrated on large cities. Natural sources of nitrogen oxides include volcanoes, oceans, organic decompositions and the action of lightning, while those of sulfur dioxide include volcanoes, organic decompositions and forest fires. The importance of natural particulate sources (volcanoes and sandstorms) is instead less important than anthropic ones, since they give rise to

Figure 1. Natural sources of air pollution [Amazonaws.com]

particles of a size such that they cannot cause significant damage to the respiratory system. These sources usually do not cause episodes of particularly acute pollution as pollution generally occurs on a relatively short time scale.

Most gaseous air compounds are part of natural cycles, that is the reason for which ecosystems are able to maintain the balance between the various parts of the system. However, the introduction of large quantities of additional compounds can also permanently compromise the natural pre-existing biochemical cycles. Given that, very little can be done by humans with regard to natural pollution, the major concern must be to reduce polluting emissions produced by human activities. [ISPRA-2006]

Speaking about artificial sources, highest air pollution is what humans produce to meet their civil and industrial needs, as shown in figure 2. The various combustion processes used to cook food, to heat up, to power motor vehicles and machinery, produce the most common pollutants. The air pollution of anthropic origin is released by the large fixed springs (**industries, plants for the production of electricity and incinerators**); from small fixed sources (systems for **domestic heating**) and from mobile sources (**vehicle traffic**). Many of these sources are closely linked to the production and consumption of energy, especially from fossil fuels. The use of fossil fuels for domestic heating, particularly heavy fuel oils, biomass and coal is a significant source of environmental pollution from dust and sulfur dioxide.

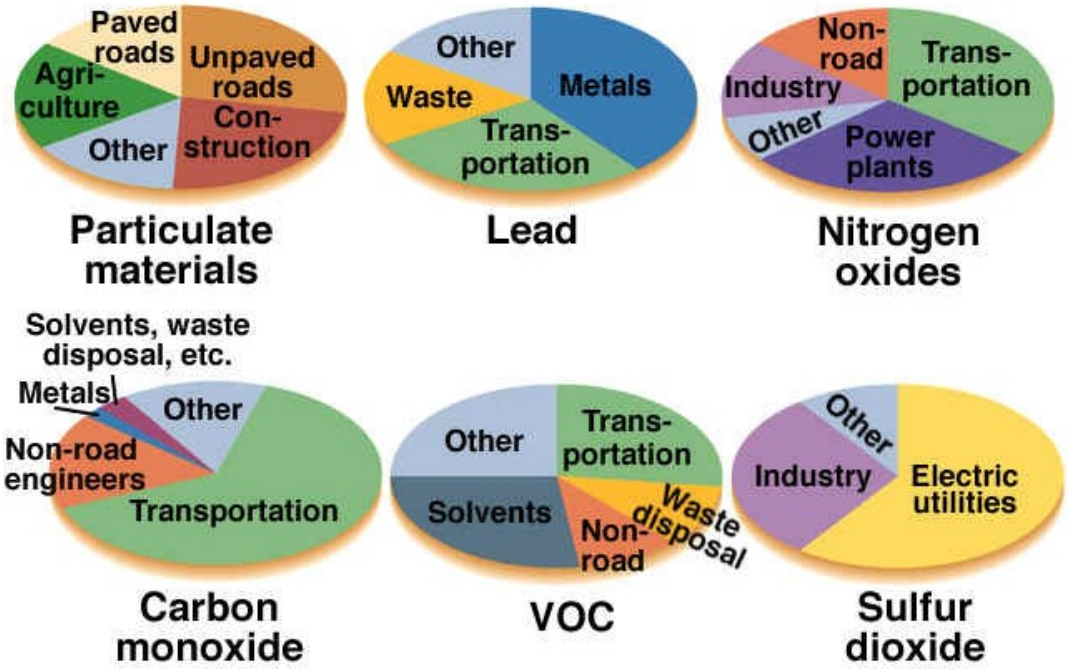


Figure 2.Different sources of air pollution [zo.utexas]

Traffic also largely contributes to the emissions of these pollutants in cities characterized by large vehicular congestion. As for the other main pollutants, anthropic sources play a fundamental role as much as natural ones in the emission of ozone and volatile organic compounds; combustions generally represent the main cause of **nitrogen oxide** emissions; transport vehicle engines typically represent the main cause of **carbon monoxide** emissions.

In addition to the substances produced by the various combustion processes, there are other pollutants that are produced during particular technological cycles. These compounds are released in considerably smaller quantities and for this reason they are of little relevance as a global impact on a global level; in any case, they are highly toxic, and their presence is particularly important at the local level. The

approach strategy is clearly different: the specific pollutants of industrial origin have to be found not after their diffusion in the environment (atmospheric inputs), but at the time of their release (atmospheric emissions). The impact of pollutants on humans depends on the area of production of pollutants and their dispersion. The large **fixed emission sources**, often located far from the larger inhabited centers, disperse in the air at great heights, while the domestic heating and traffic produce pollutants that are released at ground level in density populated areas. [ISPRA,2006]

As a consequence, mobile and small fixed sources contribute more to air pollution in urban areas and, consequently, constitute a danger to public health more than people could suppose.

1.3) Primary and secondary pollutants

Pollutants are divided into primary and secondary. The **primary pollutants** that are released directly into the environment following the process that produced them. The main primary pollutants are those emitted during combustion processes of any kind:

- Carbon monoxide CO
- Carbon dioxide CO_2
- Nitrogen monoxide NO_x
- Dust
- Unburned hydrocarbons
- Sulfur dioxide SO_2, in the case in which the fuels also contain sulfur

The **secondary pollutants** are those substances that are formed from primary pollutants following changes of various kinds generated by reactions that often involve atmospheric oxygen and light. After their emission into the atmosphere, the primary pollutants are subject to diffusion, transport and deposition processes. They also undergo chemical-physical transformation processes that can lead to the formation of secondary pollutants that are often more toxic and have a wider range of action than the original compounds. Turbulent diffusion and air mass transport phenomena determine the dispersion of contaminants in the atmosphere. [ISPRA,2006]

Primary pollutants can be gaseous or particulate. Among the gases we note in particular:

- **Sulfur compounds** (SO_2, H_2S)

This pollutant is mainly emitted during combustion of fossil fuels containing sulfur, such as crude oil and coal. The concentrations of sulfur dioxide in the air have decreased in the past two decades, mainly because we no longer use sulfur-containing fuels for energy production. Sulfur dioxide is a gas that burns and consequently can cause breathing problems for humans. In humid environments, sulfur dioxide can be transformed into sulfuric acid. This acid causes the formation of winter smog and acidification [Lenntech.it].

- **Nitrogen compounds** (NO_x)

  These pollutants are emitted by traffic, combustion plants, such as power plants and industries. Nitrogen oxides are also released from cultivated land in the agricultural sector. The use of catalytic converters in car exhausts can prevent emissions of nitrogen oxides. Nitrogen oxides are gases that react with other atmospheric pollutants if present in the air. For example, nitrogen oxides play an important role in the formation of ozone in the lower layer of the atmosphere, and in the processes of eutrophication and acidification. They can penetrate deeply into the lungs and damage human lung functions [Lenntech.it].

- **Ammonia** (NH_3)

  Ammonia is formed during agricultural activities. It plays an important role in acidification and eutrophication processes [Lenntech.it].

- **Carbon monoxide** (CO)

  This gas is formed during the incomplete combustion of fuels. If we leave the car turned on in a closed room, the concentrations of carbon monoxide in the air increase considerably. Carbon monoxide contributes to the greenhouse effect, to smog and to acidification. The gas can bind to hemoglobin in the blood, inhibiting the transport of oxygen through the body. This causes the emptying of oxygen from the heart, brain and blood vessels, eventually causing death [Lenntech.it].

- **Halogenated compounds** (HCl, HF)

- **Methane** (CH_4)

  The main source of methane pollution is agriculture. But smaller amounts of methane can also be released during the extraction of natural gas and waste incineration. Methane is a greenhouse gas that contributes to the greenhouse effect and to the ozone hole [Lenntech.it].

- **Particulate** (PM_x)

is classified according to the particle diameter: coarser ones with a diameter greater than 2.5 µm and fines with a diameter smaller than 2.5 µm.

Particles with a diameter smaller than 10 µm (PM_{10}) are also distinguished as inhalable [Lenntech.it].

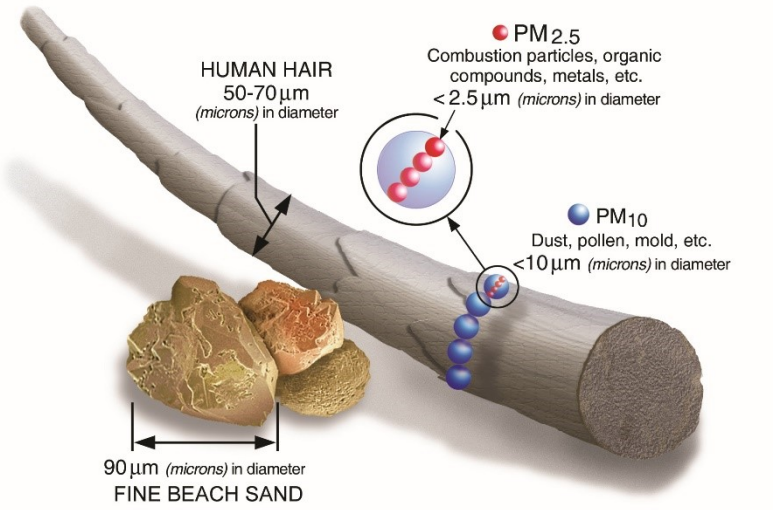


Figure 3. Particulate matter dimensions [EPA.gov]

An idea of the dimensions of particulate matter is shown in figure 3, if compared to hair.

There can be a further classification of particulate matter if compared to its size, in particular:

1. **2-100 µm**: This interval corresponds to coarse particulate, and typically comes from mechanical and erosion processes or from marine and desert aerosols. These particles are predominantly inorganic, highly dependent on the geographical area in which they are taken, and include also biogenic compounds (pollen, spores, ...). It is important to highlight that for particles of this size the contribution of gravitational attraction is much more significant than the motion of thermal agitation, and their tendency to spontaneous sedimentation is therefore marked. The characteristic time of stay in the atmosphere turns out to be small
2. **0.08-2 µm**: This interval is called "accumulation" and is characterized by fine particulate matter. The particles characterized

by these dimensions are typically formed by coagulation of smaller particles or by condensation phenomena of chemical species on pre-existing particles. Because of the small size, the energies associated with gravitational action and Brownian motion are of similar orders of magnitude, with a consequent low tendency to sedimentation. Fine particulate matter tends to remain in the atmosphere and, until it is removed from the rain, has a profound influence on the chemical equilibrium of the atmosphere itself.

3. **10-80 nm**: Particles belonging to this dimensional range are also referred to as Aitken nuclei and form ultrafine particulate. They can be formed by nucleation mechanisms at low temperature of supersaturated vapours, or in the context of combustion processes. These particles, through condensation phenomena, increase their size and contribute to the creation of the accumulation interval. They consist almost entirely of elemental or organic carbon.
4. **<10 nm**: Through a series of new experimental techniques is possible to analyze smaller orders of magnitude. Particles smaller than 10nm, consisting mainly of organic carbon, form hyperfine particulate and belong to the defined nucleation range [Tecnosida].

On the other hand, most important secondary gaseous pollutants are:

- **Nitrogen dioxide** (NO_2)

  Result of the transformation of primary NO.

- **Ozone** (O_3)

  formed photochemically. Ozone is formed by the photochemical transfer of oxygen. This process takes place under the influence of

ultraviolet (UV) sunlight, favoured by the pollutants present in the outside air. Ozone causes smog and contributes to climate change and acidification. Ozone is an aggressive gas, which can easily penetrate deeply into the respiratory tract. When humans are exposed to ozone, the consequences can be irritation of the eyes and respiratory tract.

Both these gases intervene in the complex reaction mechanisms that constitute the "photochemical smog". [F.Liguori,1996/97]

1.4) Limits and target values for pollutants

The United Kingdom was the first European country to legislate on air quality. Until then the quality of the air was given for granted.

Looking at the first European directives, these spoke, in general, of dust suspended in the air, regardless of the diameter and therefore with one **poor level of approximation**; while well-defined chemicals - sulfur dioxide, nitrogen dioxide and carbon monoxide - they were easily identifiable and have been identified since from the beginning in the firsts European directives. These date back to the 1980s.

In 1996 we enter a new phase: the framework directive **1996/62/EC** which, in addition to asking Member States to respect the limit values, introduces a series of instrumental obligations with respect to the main objective.

We find these obligations in the directive here under consideration: **2008/50/EC** which brought together in a single text all previous directives.

First of all, the framework directive obliges Member States to designate competent authorities and it is at this stage that Italy decided to delegate to the regions and local authorities most of the competences in matters of air quality.

Returning to the 2008/50/EC directive, **three great news can be identified**.

The possibility is envisaged to request an extension or a derogation in relation to the deadlines established for compliance with limit values.

Article. 22 of the 2008/50/EC directive introduces the possibility of requesting an **extension**, for instance for the PM_{10} limit values up to June 2011 (from January 2005), but to do this a State is required to certify the plan through documentation in which it must be clarified the planned repayment plan, otherwise the committee's opinion on an extension would have been negative.

The second change introduced by Directive 2008/50/EC, of particular importance for Mediterranean countries such as Italy, Greece, Spain and Portugal, is found in art. 20 and concerns the possibility of **discounting natural sources**. In the Mediterranean cities there are many days of overcoming PM_{10} due to the transport of sand from the desert and other phenomena well known to experts. The directive has recognized the possibility of discounting these exceeding days

The third important modification of directive 2008/50/EC is the introduction, for the first time, of **the objectives in the field of $PM_{2.5}$,** even finer particles whose diameter is such that there is no doubt that they are harmful to human health. Even the PM_{10} are dangerous, but not as these, being a chemical compound, they can also contain harmless elements. $PM_{2.5}$ instead, in principle, are a sign of anthropogenic pollution [Gasparinetti,2014]

The following are the main parameters for assessing air quality, referring to the text of the decree (Legislative Decree 155/10) for details. Decree has fully implemented the 2008/50/EC directive, keeping both the threshold limits and the exceeding thresholds unchanged [ArpaLombardia,2010 and Chiamamilano.it]

	HOUR LIMIT	DAILY LIMIT	ANNUAL LIMIT	LIMIT VALUE	TARGET THRESHOLD	ALARM THRESHOLD	CRITICAL THRESHOLD
SO_2	350µg/m^3 max 24times/year	125 µg/m^3 max 3days/year				500 µg/m^3 over 3 hours	20 µg/m^3 to protect vegetation
CO				10 mg/m^3 as MM8			
C_6H_6			5 µg/m^3				
NO_2	200 µg/m^3 max 18 times/year		40 µg/m^3			400 µg/m^3 over 3 hours	30 µg/m^3 to protect vegetation
O_3					120 µg/m^3 as MM8 max 25 timee/year	240 µg/m^3	AOT40 18000 µg/m^3*h over 5 years
PM_{10}		50 µg/m^3 max 35 times/year	40 µg/m^3				
$PM_{2.5}$			25 µg/m^3				
AS			6 ng/m^3*				
CD			5 ng/m^3*				
NI			20 ng/m^3*				
B(A)P			1 ng/m^3*				
PB			0.5 µg/m^3				

Table 1.Objectives and limits for the protection of human and environmental health D.Lgs 155/10 [ArpaLombardia,2010]

For the purpose of assessing air quality, Legislative Decree 155/10 establishes sulfur dioxide (SO_2), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), Particulate Material (PM), benzene, ozone (O_3) and carbon monoxide (CO), the following definitions:

- **Limit Values**: atmospheric concentrations established on the basis of scientific knowledge in order to avoid, prevent or reduce harmful effects on human health and the environment

- **Alarm Thresholds**: atmospheric concentrations beyond which there is a risk to human health in the event of short-term exposure and which must be immediately acted upon
- **Critical Level**: level established on the basis of scientific knowledge beyond which there may be direct negative effects on receptors (trees, plants, ecosystems, excluded human beings)
- **Tolerance Margin**: percentage of the limit value within which the limit value can be exceeded
- **Target Value**: fixed limit in order to avoid, prevent or reduce harmful effects on human health or the environment as a whole, to be achieved, where possible, by a predetermined date
- **Alarm Threshold**: level beyond which there is a risk to human health in the event of short-term exposure to the population as a whole and whose achievement requires immediate action to be taken
- **Information Threshold**: level beyond which there is a risk to human health in the event of short-term exposure for some particularly sensitive groups of the population as a whole and whose achievement requires the provision of adequate and timely information
- **Long-Term Objective**: level to be achieved in the long term by proportionate measures, in order to ensure effective protection of human health and the environment
- **Higher Assessment Threshold**: atmospheric concentration below which measurements can be combined with modeling techniques
- **Lower Assessment Threshold**: atmospheric concentration below which it is possible to use only modeling techniques or objective estimation
- **Mediation Periods**: period of time during which the data collected is used to calculate the reported value. In particular:
- **Annual Average**: average of the daily values between 1 January and 31 December of the calendar year,
- **Daily Average**: the average of the hourly values included between 01.00 and 23.00 for which at least 75% of the values are present,

- **Maximum Average Daily Concentration Over 8 Hours (MM8**): it is determined with reference to the consecutive averages over 8 hours, calculated on the basis of hourly data and updated every hour. Each 8-hour average calculated in this way refers to the day on which the 8-hour series ends: the first calculation range for a day is the one between 17.00 on the previous day and 01.00 on the same day; the last calculation range for a day is the one between 16.00 and 24.00 of the same day.
- **Aot40**: parameter evaluated for the purposes of ozone objectives and intended as the sum of the difference between hourly concentrations above 80µg / m³ and 80µg / m³ over a given period of time, using only the hourly values recorded every day between the hours 08.00 and 20.00 with reference to Central European Time (CET).

1.5) Effects on human health

Many environmental and health problems are due to atmospheric pollution, for the former there is now a fair knowledge of the consequences on the environment with respect to certain massive air emissions, for example the greenhouse effect, the most famous, due to the huge production of CO_2, or acid rain and photochemical smog due to the introduction into the air of large quantities of NO_x accompanied by certain meteorological characteristics.

However, what will be discussed in the following chapter is the health impact of pollutants, particularly with reference to particulate matter.

Starting from the 50's a series of important events - like the case of London smog, led attention to the importance of environmental protection in relation to industrial and urban development.

At the same time, the need to "control" the risks for the health derived from the environment has been increasingly raised up, through monitoring measures both on environment and health of the exposed populations. Some typical effects of different pollutants over human health are shown in figure 4.

Different disciplines contribute to characterize the potential effect of human exposure to factors of environmental risk (**risk process assessment**). Among these, epidemiology certainly plays a role fundamental role in the identification of causal links, in the identification of preventive measures, in the definition of priorities of public health interventions, and contributes to the evaluations of the damage to insurance companies and penalties and public information.

Environmental epidemiology is the area of epidemiology that deals specifically with environmental exposures and can be defined as the study of distribution of illness cases in space, in time and in the different subgroups of the population, and the correlation with **exposure** to environmental risk factors.

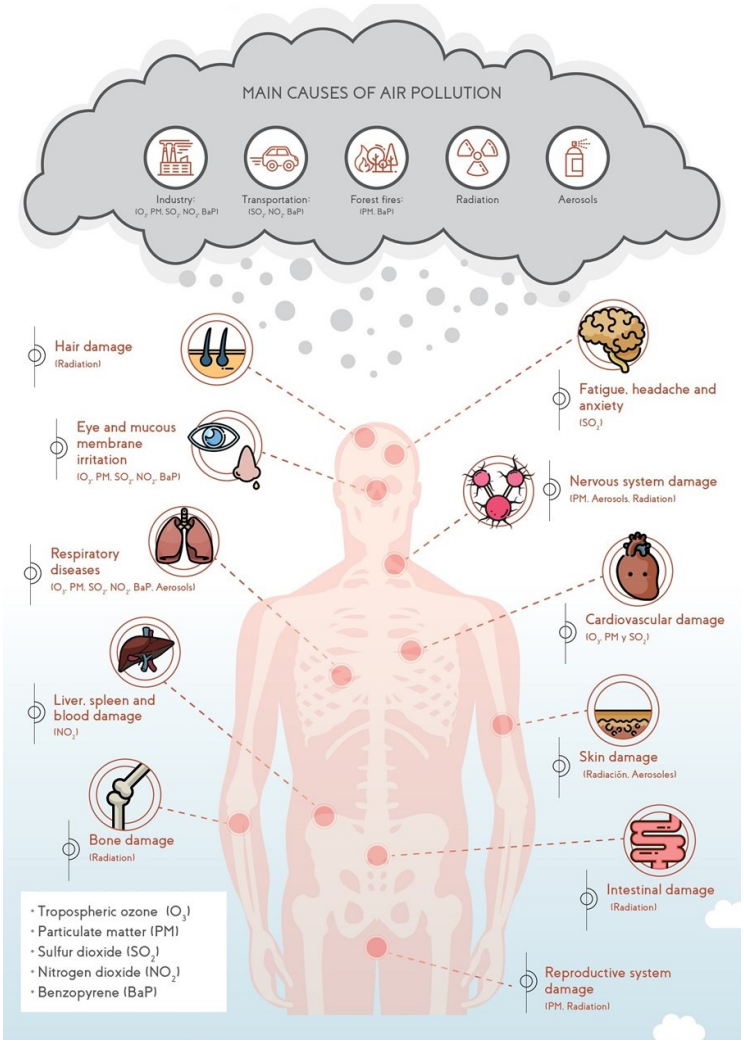


Figure 4. Effects of some pollutants on human health [Activesustenibility.com [15]]

With regarding to **PM**, until a few years ago in Italy the particulate matter was measured as total suspended particles (TSP).

The decrease in this was also interpreted as an air quality improvement. Already in the 70s in the United States however, the size of the PTS is been placed side by side, and then replaced, from the size of the component of diameter less than 10 microns, also called PM_{10}. Experiments conducted subsequently showed that particles even finer, can be breathed and get to the deepest parts of the respiratory system up to pass into the bloodstream, this because particles belonging to this size are able to remain suspended into the air for a lot of time. In particular during stable weather conditions, it is very easy to breath them.

The particles of greatest interest in air pollution are between 0.01 and 100 µm in diameter. Between these dimensions we can find cement dust, fly ash, carbon particles or sulfuric acid vapors.

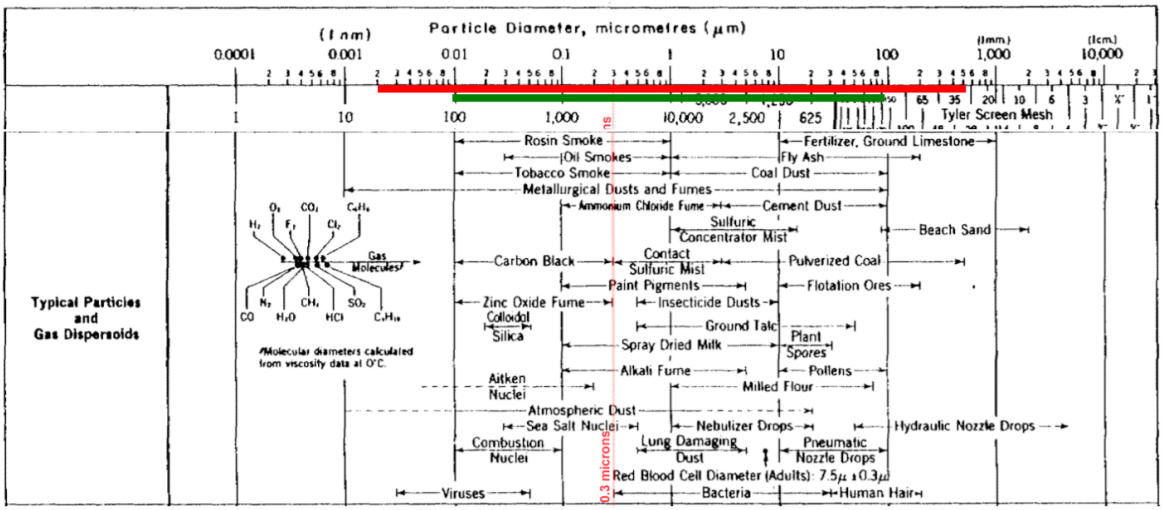


Figure 5. Air contaminants contributing to release of PM_x [G.Buguna,2018]

Among the disorders attributed to fine and ultrafine particulate matter (PM_{10} and above all $PM_{2.5}$) there are acute and chronic pathologies affecting the **respiratory system** (asthma, bronchitis, emphysema, allergy, tumors) and **cardio-circulatory diseases** (aggravation of cardiac symptoms in predisposed subjects) as shown in figure 6. The detailed mechanism with which the particulate interferes with the organisms is not yet completely clarified: it is known that as the size decreases the possibility of biological interaction increases, since the smallest particles can reach the larynx, trachea, lungs and alveoli, and here release part of the polluting substances it carries (eg polycyclic aromatic hydrocarbons, SO_x and NO_x).

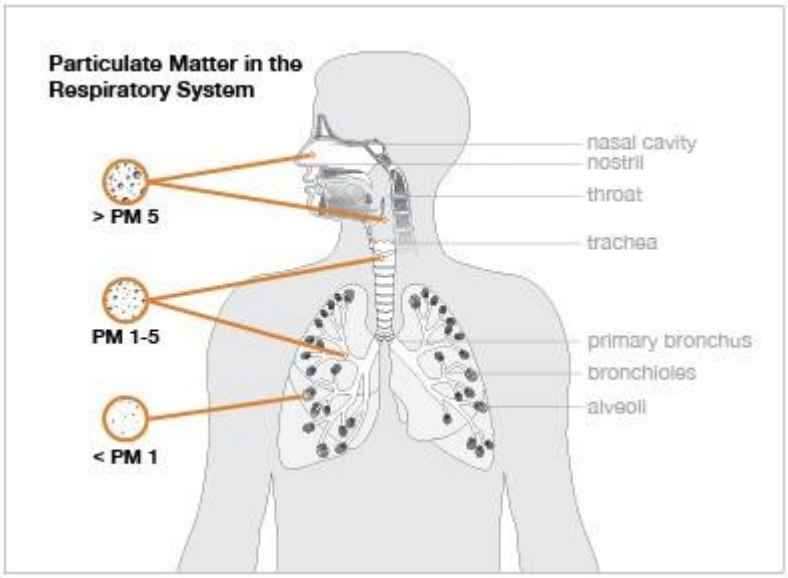


Figure 6. Penetration ability of different particles size [cdn.shopify.com]]

The so-called nanopowders would even penetrate the cells, directly releasing the transported substances, with obvious greater danger. According to some, they would therefore be responsible for specific pathologies (studied in the field of nanotoxicology), but so far the studies (today still at an early stage, and related not only to the study of dust dispersed in aerosols but in general to nanotechnologies) have not led to to any definitive epidemiological evidence [Particolato sulla salute – Wikipedia].

Regarding the health effects induced by **sulfur oxides (SOx)**, the significant route of exposure is constituted by inhalation. SO_2 is a very soluble and irritant in the watery surface of the respiratory tract. Precisely because of this **high water solubility**, it is quickly absorbed by the mucosa of the nose-pharyngeal and upper respiratory tract, and only a small fraction can reach the lungs directly. From the respiratory tract the SO_2 then passes into the bloodstream. Excretion occurs mainly via the urine after sulphate biotransformation in the liver.

Before or during inhalation, SO_2 can react with water to form H_2SO_3 or be oxidized to form SO_3. The latter reacts rapidly with water to form

H_2SO_4 which, subsequently, in the presence of ammonium (NH_4^+), is transformed into ammonium sulphate. The H_2SO_3 rapidly dissociates into sulfite ions ($SO_3^=$) and bisulfite (HSO_3^-). SO_2 can therefore be treated indifferently as sulfite ion, bisulfite and vice versa.

For this reason, the toxic effects of sulfur oxides and suspended particles overlap and complex mixtures of acid aerosols (H_2SO_4, NH_4HSO_4, $(NH_4)\ 2SO_4$, etc), can reach the peripheral airways and alveoli, and become important in determining deep respiratory diseases.
The main target organ for SO_2 and derivatives is the **respiratory system**. High concentrations of SO_2 may induce severe effects such as bronchoconstriction, bronchitis, tracheitis, bronchospasm and/or dyspnoea in asthmatics, and possibly death. A known phenomenon is also that of eye irritation. Different effects related to different concentrations are shown in figure 7.

Quantity of SO^{2*}		Air quality description	Recommended actions	
µg/m³	ppm		Sensitive Groups **	Healthy individuals
		Good		
0-300	0-0.1	Poses little or no health risk.	Can experience mild respiratory symptoms.	No health effects expected.
		Moderate		
300- 600	0.1-0.2	May cause respiratory symptoms in individuals with underlying diseases.	Caution advised. Follow SO2 measurements closely.	Health effects unlikely.
		Unhealthy for sensitive individuals		
600-3,000	0.2-1.0	Individuals with underlying diseases likely to experience respiratory symptoms. Health effects unlikely in healthy individuals.	Avoid outdoor activities.	Health effects not expected. Heavy outdoor activities not advised.
		Unhealthy		
3,000-9,000	1.0-3.0	Everyone may experience respiratory symptoms especially individuals with underlying diseases.	Remain indoors and close the windows. Shut down air conditioning.	Avoid outdoor activities. Remaining indoors advised. Close the windows and shut down air conditioning.
		Very unhealthy		
9,000-14,000	3.0-5.0	Everyone may experience more severe respiratory symptoms.	Remain indoors and close the windows. Shut down air conditioning. Follow closely official advises.	Remain indoors and close the windows. Shut down air conditioning. Follow closely official advises.
		Hazardous		
>14,000	>5.0	Serious respiratory symptoms expected.	Remain indoors and close the windows. Shut down air conditioning. Follow closely official advises.	Remain indoors and close the windows. Shut down air conditioning. Follow closely official advises.

*Based on 15-minute average
**Children and adults with pre-existing bronchial asthma, bronchitis, emphysema and/or heart diseases.

Figure 7. Effects of human health from SO_x exposure [G.Buguna, 2018]

Long-term exposure causes the **aggravation of respiratory diseases** such as chronic bronchitis, asthma, emphysema, as well as changes in lung function. The groups "at risk" are therefore made up of asthmatics and bronchitics which are often used in epidemiological studies as they represent the fraction of the most sensitive population. Even children are often selected for such studies because they are more sensitive than adults, and because the confounding factor "cigarette smoke" is thus eliminated [Trezzo, Università degli studi di Parma]

The individual variability, as far as the sensitivity to SO_2 is concerned, is however considerable and the magnitude of the effects induced depends on several other parameters such as concentration, duration of exposure and level of physical activity.

A superadditive effect ("synergic") has now been ascertained following the combined exposure to SO_2 and suspended particles. In fact, a 3-4-fold increase in the irritative response to this gas was observed in the presence of suspended particulate matter, probably attributable to the particles' ability to transport SO_2 more deeply into the respiratory system

Speaking about the effects on human health of **nitrogen oxides (NOx)**, Among the various nitrogen oxides, NO_2 is the most important for human health; this gas is 4 times more dangerous than NO; but it must be remembered that the latter is able to oxidize easily in NO_2 once in the air. The mechanisms by which NO_2 induces its toxic effects in humans have been hypothesized by experimental animal models and can be described in terms of airway irritation up to bronchospasm in asthmatics, and maintenance of chronic inflammation. Other animal studies have suggested that NO_2 increases susceptibility to bacterial and, perhaps, viral infections. The basic mechanism is that the gas causes serious damage to cell membranes following the oxidation of proteins and lipids (oxidative stress). Summarizing, the acute effects of NO_2 on the **respiratory system** include exacerbations of chronic

inflammatory diseases of the respiratory tract, such as chronic bronchitis and asthma, and reduction of lung function, as shown in figure 8.

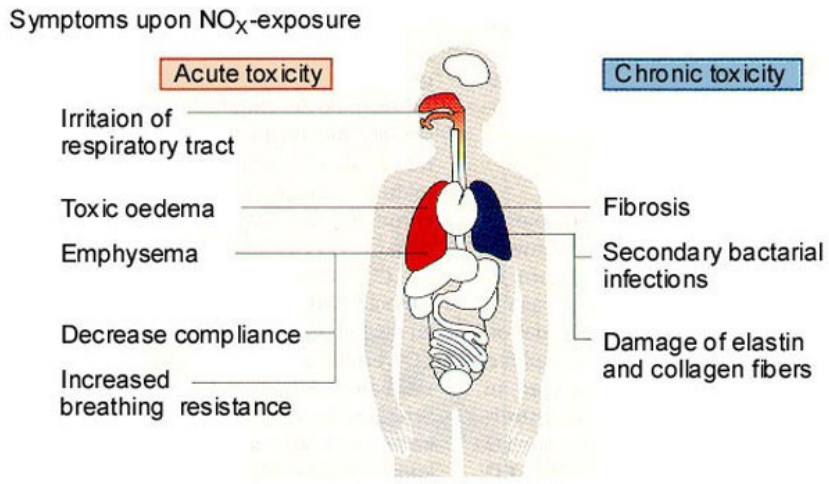


Figure 8. Symptons under NO_x-exposure [Desktopclass.com]

More recently the possible damages of NO_2 on **the cardio-vascular apparatus** have been defined as ability to induce myocardial ischemic pathologies, heart failure and cardiac arrhythmias. On the other hand, long-term effects include pulmonary alterations at the cellular and tissue level, and increased susceptibility to bacterial and viral lung infections. There is no evidence of association with malignant tumors or damage to fetal development (teratogenesis). It should be emphasized how significant prolonged exposures to low concentrations of nitrogen oxides can be, which makes pollution in homes (indoor pollution) due to the use of gas stoves or water and / or room heating boilers dangerous. It is known that concentrations of NO_2 of 1-3 ppm are perceived by the smell due to the **pungent odor**, while concentrations of 13 ppm lead to irritation of the eyes and nose. Nitrogen oxides during respiration easily reach the pulmonary alveoli where they originate nitrous and nitric acid, drastically reducing the pulmonary defenses with a consequent increase in the risk of respiratory tract diseases. The effects of NO2 occur generally several hours after exposure and people

do not realize that their malaise is due to the polluted air they previously breathed.

Table 2 shows the main effects on human health and the NO_2 levels to which they refer:

Main effects on human health	*NO_x [ppm]*
Perceptible presence	3
Irritation to eyes and mucous membrane	15
Respiration problems	100

Table 2. Main effects on human health caused by nitrogen oxides [ArpaLazio]

While about **carbon oxides**, we have to distinguish between carbon monoxide CO and carbon dioxide CO2. The latter, although is emitted in huge concentrations, has, mainly, effects over the environment as the well-known "Greenhouse effect", while the former regards strictly our health. Carbon monoxide, as already mentioned, is a colorless, odorless and highly toxic gas: it exerts its action on humans by forming with the hemoglobin an irreversible complex (carboxyhemoglobin) that **inhibits the transport of oxygen in the blood**, causing problems to the respiratory system and, at high concentrations, death by asphyxia, as shown in figure 9. The affinity of the CO for hemoglobin is more than 200 times greater than

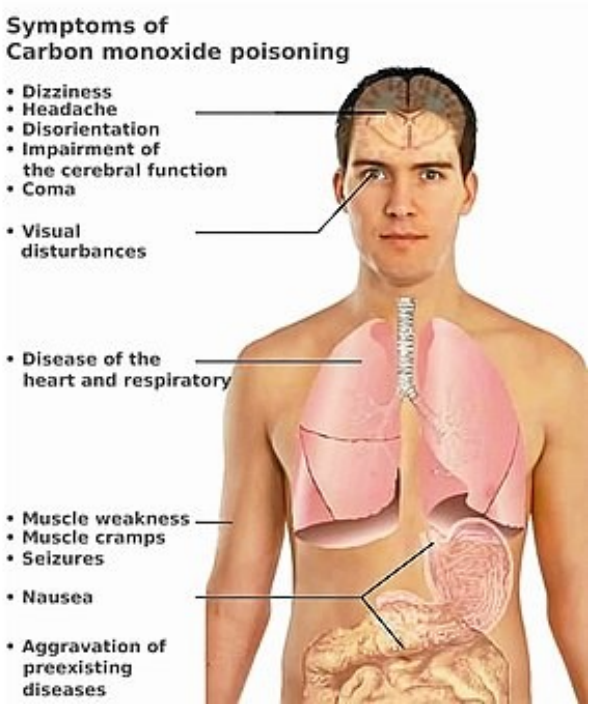


Figure 9. Symptoms of CO poisoning [Wikimedia.org]

that of oxygen: the carboxyhemoglobin that forms prevents the oxygenation of the tissues: the first symptoms of poisoning are headache and vertigo. Strong concentrations of CO in closed environments, caused by the malfunctioning of stoves and water heaters (generally due to poor installation or to block the chimneys), cause **death in a short time**: 90 minutes in the presence of 1000 ppm of CO. Lower concentrations give a lethal outcome after a few hours: but the fact that carbon monoxide is odorless prevents the victims, also affected by drowsiness, from feeling the danger and from ventilating the room. Prolonged exposure to concentrations of 50 ppm (a value that is often exceeded in high traffic streets) is considerably harmful. The amount of CO emitted by vehicle exhausts has decreased in recent years due to the improved efficiency of the engines, the control of vehicle emissions and the use of catalytic converters. Currently, the localized atmospheric concentration of this pollutant is generally decreasing. [De Munari , Pessina]

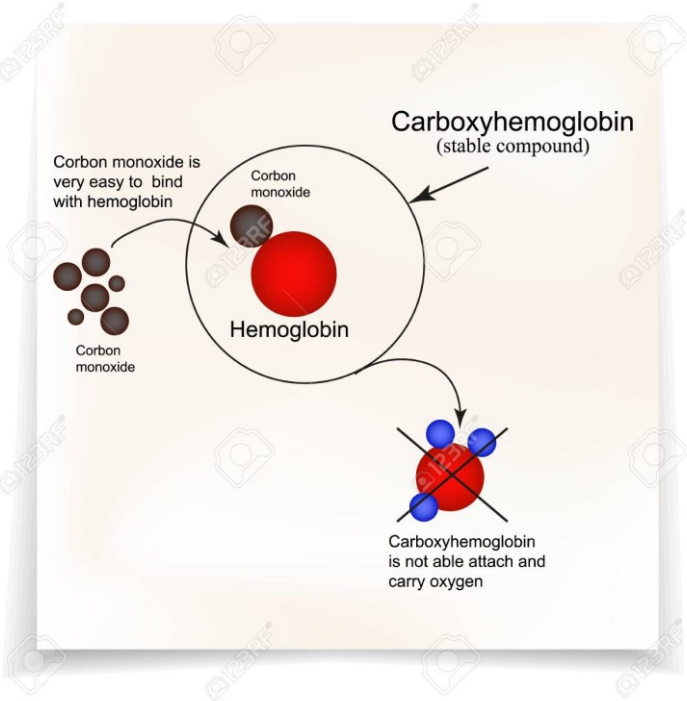


Figure 10. Structure of Carboxyhemoglobin, a stable compound that inhibits transport of oxygen into blood [previews.123rf.com]

The only route of exposure for humans is **inhalation**. It follows that the absorption increases with increasing lung ventilation, as occurs under stress, and decreases as the ability to spread through the lung decreases, as occurs in different lung diseases and in conditions of altered blood circulation.

Being not very soluble, the CO easily reaches the alveoli together with the oxygen (O_2), diffuses through the walls of the alveoli and passes into the blood where it competes with the O_2 for the bond with the iron atom (Fe) present in the hemoglobin (Hb) molecule of red blood cells. The carboxyhemoglobin (COHb), shown in figure 9, forms a compound about 250 times more stable than oxyhemoglobin (OHb). The presence of COHb **reduces the ability of the blood to carry O_2** to the tissues and, therefore, induces anoxia. This effect is further amplified by the fact that the binding of CO with one of the Fe atoms of the Hb molecule not only excludes that site as a potential transporter of an O_2 molecule, but also induces an increase in the strength of the bond between the other atoms of Fe of the molecule and the O_2 they are carrying.

There is a certain level of endogenous COHb, between 0.1 and 1.0%, due to the production of CO by the catabolism. The formation of COHb is a reversible process; the half-life is between 2 and 8 hours. Its elimination basically follows the same physical-chemical laws that regulate its absorption. [Trezzo, Unipr]

CO should be classified toxicologically as an **asphyxiating gas**. In fact the health symptoms are due to the inadequate supply of O_2 to the tissues. This explains why the effects are mainly on the tissues that need a continuous and consistent supply of oxygen (nervous, cardiovascular and muscular system) and why at high doses (lack of air exchange in the presence of stoves or fireplaces) you can have of fatal cases.

The effects on the **nervous system** include decreased ability to concentrate, memory disorders, behavioral changes, mental confusion; **cardiovascular** ones include alterations in blood pressure, acceleration

of the heartbeat, extrasystoles, aggravation of angina symptoms under stress, vasodilation, vasopermeability; those on the **muscular system** include alterations of haemorrhagic origin responsible, for example, for renal lesions that are sometimes found, such as oliguria and hematuria. The effects induced by CO are well correlated with the percentages of COHb in the blood, as shown in table 3:

CO in the air [ppm]	COHb [%]	Effects
0.96-1.22	2.90 - 4.50	Decreased ability to perform physical activity and increased duration of angina attacks in predisposed patients; perhaps some problems for patients with advanced heart disease.
1.30-1.38	5.00 – 5.55	Decrease in max oxygen consumption and endurance during physical activity
1.30-3.22	5.00 – 17.00	Decreased visual perception, manual ability, learning ability, and psychomotor skills (eg driving)
3.06-3.70	16.00 – 20.00	Headache; can be lethal to patients with severe heart problems
3.70-5.30	20.00 - 30.00	Pulsating headache, nausea, reduced mental acumen
5.30-6.90	30.00 – 40.00	Severe headache, nausea and vomiting, syncope
6.90-8.50	30.00 – 40.00	Severe headache, nausea and vomiting, syncope
8.50-10.10	50.00 – 60.00	Convulsions and coma
10.10-11.70	67.00 – 70.00	Deadly if not treated

Table 3. Typical effects of carbon monoxides on human health [Trezzo, Unipr]

1.6) Risk assessment (RA) and health impact assessment (HIA)

In the study of potential risks and benefits of projects with an interest in a community, the Integrated **Environmental and Health Impact Assessment** takes on increasing importance. If properly used, the procedure for evaluating and characterizing health risk is a fundamental support for administrations. In the activities of the ARPAs, the integrated environmental and health impact assessment (**VIIAS**) is of particular interest, which is expressed in particular in the procedures of Via, Vas, Aia. It must be implemented through an integrated use of environmental and epidemiological knowledge relevant to the project itself [Ecoscienza, 2014]

Examples of applications in ordinary practice are: new high voltage electrical lines or modifications or extension of existing power lines, new chemical plants or expansion of existing plants, steelworks, hydroelectric or thermoelectric plants, incinerators, highways (new or variants of current highways), railways, municipal plans “PRG”. The heart of the Viias is its characterization of risk, or **risk assessment**, that is conducted in 4 phases:

1. **Hazard identification**, the environmental agent is potentially able to cause adverse health effects?
    - Collection and analysis of relevant data on the work
    - Identification of potential chemical agents of health interest

2. **Determination of dose response**, what is the relationship between dose and incidence on humans?

- Collection of toxicity information quantitative and qualitative
- Determine the appropriate values for the toxicity

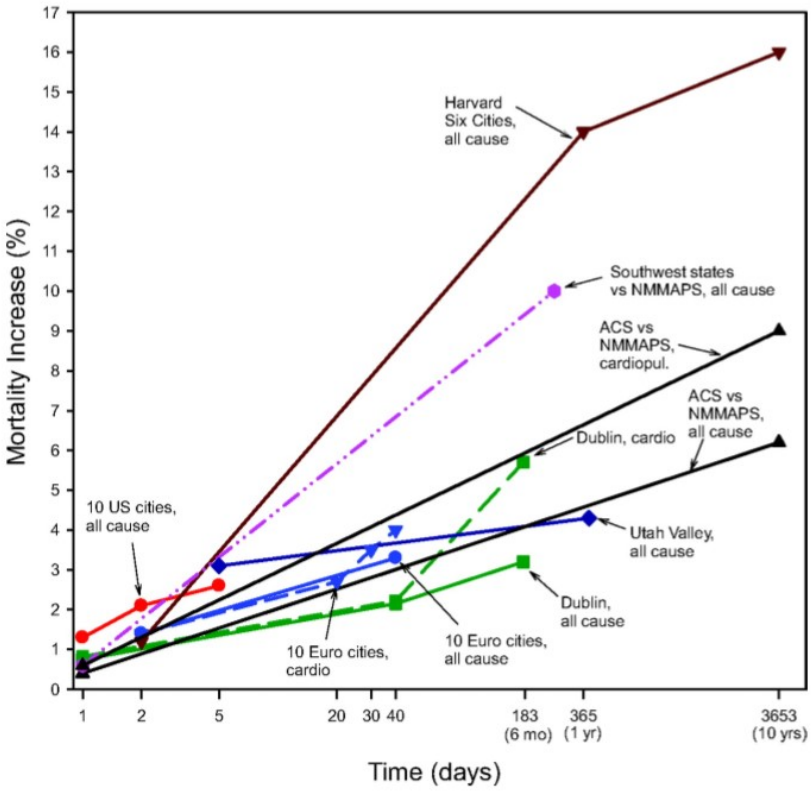


Figure 11.Comparison of estimates of percent change in mortality risk associated with an increment of 10 µg/m³ in $PM_{2.5}$ or 20 µg/m³ of PM_{10} or British Smoke (BS) for different time scales of exposure [E.Mancinelli, 2018]

3. **Exposure assessment**, what are the levels of exposure to which the community will be submitted? What are the levels of exposure to which the community will be submitted?

Step 1

- Analyze the release of contaminants
- Identify potential routes of exposure
- Estimate exposure concentrations for the different routes of exposure

Step 2

- Estimate the intake of the contaminant for the different routes of exposure
- Identify the exposed populations

The exposure assessment is conducted in order to estimate the relevance of the current and / or potential exposure of the population to the identified chemical contaminants, the extent of this exposure and the ways in which people are potentially exposed. The estimate of the current exposure is used to determine if there is a current health threat based on the exposure conditions existing on the site [Ecoscienza,2014]

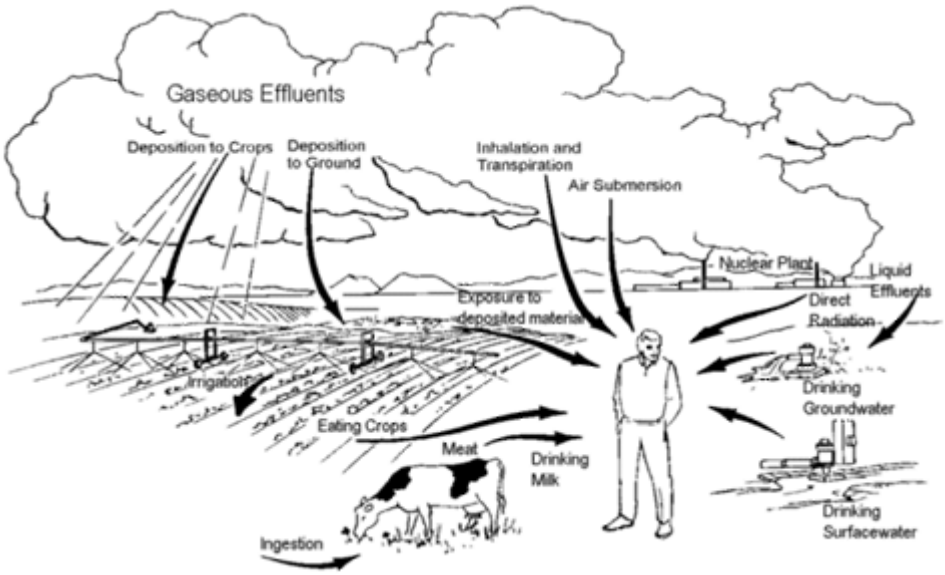


Figure 12. Different types of pathways [sphweb.bumc.bu.edu]

At this stage we investigate how, how and for how long a substance comes into contact with the individuals of a population [Ranzi, Cordioli, 2015]

In fact, exposure is defined in human toxicology as the contact by the external surface (barrier) of an individual with a chemical, physical or biological agent and is calculated by determining, through measurements or estimates, the **quantity of the substance available**

(concentrates - exposure) at the level of this surface during a certain period of time. Usually the contaminant is present in the air, in the water, in the soil, in a product or transported by a carrier. The concentration of this contaminant at the point of contact is equivalent to the exposure concentration. Exposure assessment can consider, in addition to the current exposure, also future exposures: the estimate of the current exposure is based on the measurements of the existing conditions, that of the future exposures can be based on forecast models of the forecast conditions in the times to come.

4. Risk characterization

What is the estimated incidence and number of people affected within the community?

- Estimate the carcinogenic risk
- Estimate the non-carcinogenic risk quotients
- Assess uncertainties
- Summarize risk information

The problem is faced from the point of view of operators such as managers or technicians of the departments of prevention and environmental protection, therefore the guidelines imply a 'first level' approach to risk analysis , in which the estimate is usually carried out according to the 'worst case possible' (worst case) or 'higher theoretical limit' [Ranzi, Cordioli, 2015].

For an accurate assessment of the risk to human health, risk assessment involves the combination of **toxicological and epidemiological information**:

Risk Assessment method: the application of the Risk Assessment in the environmental field arose at the end of the 1970s from a **toxicological approach**, based on laboratory tests conducted on animals, aimed at

obtaining incremental risk estimates due to exposure to specific substances. The data necessary for the performance of the study is the exposure to the substance, understood as environmental concentration or taken dose, and the exposure-effect relationship, intended as cancer slope factor or maximum reference dose [Ranzi, Cordioli, 2015].

In the RA risk coefficients are used that link exposure to a probability of developing an adverse effect on the organism. The risk factors do not rely on the characteristics of the specific population in question but derive from laboratory toxicological models.

In the case of carcinogenic substances: a generic value of incremental risk is needed;

In the case of non-carcinogenic substances: there is a danger index for exceeding the reference doses [E.Mancinelli,2018].

Estimation of **toxic risk** by inhalation

Toxic risk factor HQ

$$HQ = \frac{EC}{RfC * 1000} \leq 1$$

- RfC- reference concetration, mg/m^3

  Reference concentration (RfC), represents the estimate of the daily exposure, for the entire life span, of the human population, including sensitive subgroups, which is expected to be free of harmful effects.
- EC - exposure concentration for non-carcinogenic substances, μg / m^3.

Exposure concentration EC (μg / m^3) for non-carcinogenic toxic substances:

$$EC = \frac{CA * ET * EF * ED}{ATnc}$$

- CA - concentration of the contaminant in the air, µg / m^3;
- ET - exposure time (hours / day);
- EF - exposure frequency (days / year);
- ED - duration of exposure (years);
- AT_{nc} - time on which the exposure is averaged (ED in years x 365 days / year x 24 hours / day)

Risk index (hazard index – (HI)), is calculated in the case of more substances acting on the same target organ

$$HI = \sum HQi \leq 1$$

"The **additive effect** manifests when the combined effect of two or more chemical compounds is equal to that of the sum of the individual effects of each agent. In practice, each toxic substance acts as if the others were not present. Usually this is the most common effect that occurs following simultaneous exposure to multiple pollutants.

The **synergism** occurs when the combined effect of two or more toxic substances is greater than the sum of the effects of each substance taken individually. Particulate-gas interaction in the lungs is an important synergistic mechanism in atmospheric pollution toxicology. The toxic substances adsorbed in the particulate can penetrate into the lungs and act much more effectively than they could if they were inhaled in the gas phase.

In **antagonism**, two or more chemical compounds interfere in their action in such a way that their combined effect is less than the sum of the effects of each individual chemical compound. Antagonistic interaction underlies most antidotes to poisons" [E.Mancinelli,2018] .

Estimation of the **carcinogenic risk** by inhalation

Carcinogenic risk exposure via inhalation

$$Risk = \ IUR\ x\ EC\ x\ ADAF$$

- IUR – inhalation unit risk (µg/m^3) -1. IUR is defined as the incremental risk that results from continuous exposure to the course of a whole wash of a concentration of 1 µg/m^3 of a constant weight in carcinogenic carcinoma.
- EC - Exposure concentration for carcinogenic substances (µg/m^3)
- ADAF – Age Dependent Adjustment Factor

Risk	**Measures**
$< \mathbf{10^{-6}}$	No intervention on emissions
$\mathbf{10^{-4} < R < 10^{-5}}$	Discretionary interventions (Evaluate quantitatively the contribution of the establishment)
$> \mathbf{10^{-4}}$	Planned intervention (e.g. reopen the procedure

Table 4. Estimation of cancer risk through inhalation [E.Mancinelli,2018[i]]

Exposure concentration EC (µg / m^3) for non-carcinogenic toxic substances:

$$EC = \frac{CA * ET * EF * ED}{ATc}$$

- CA - concentration of the contaminant in the air, µg / m^3;
- ET - exposure time (hours / day);

- EF - exposure frequency (days / year);
- ED - duration of exposure (years);
- AT_c - time on which exposure is mediated (life in years x 365 days/year x 24 hours/day)

Health impact assessment HIA - Many criticisms have been made on the traditional toxicological approach, accused of using a method of calculation of considerable scientific rigor in a field where there are still too many uncertainties and where the model used imposes a series of assumptions that do not always appear justified [Ecoscienza,2014 [(29)]].
"The results of epidemiological studies provide an estimate of the relative risk (RR) of developing a health event (death, hospitalization) for those exposed to a specific environmental condition when facing the risk of cancer. The presence or absence of an association between exposure and outcome in the well-known population is therefore evaluated. The RR can be estimated for situations of absence / presence of the exposure or for different types of exposure to the polluting lodge. RR: function that correlates to the concentration of the pollutant, the answer in terms of incremental rate of a health event. Example: RR attributable to exposure from $PM_{2.5}$ is 1.07: at each increment of 10 µg / m^3, mortality increases by 7%.
The HIA procedure uses RRs from epidemiological evidence to:

- make an estimate of health events attributable to the difference between the observed concentrations and a reference concentration value below which it is assumed that the health effect can be considered negligible (burden of disease) (retrospective approach);
- make an estimate of health events attributable to an increase (or decrease) in the concentrations observed, due to the activation (reduction) of emissive sources (VIA, perspective).

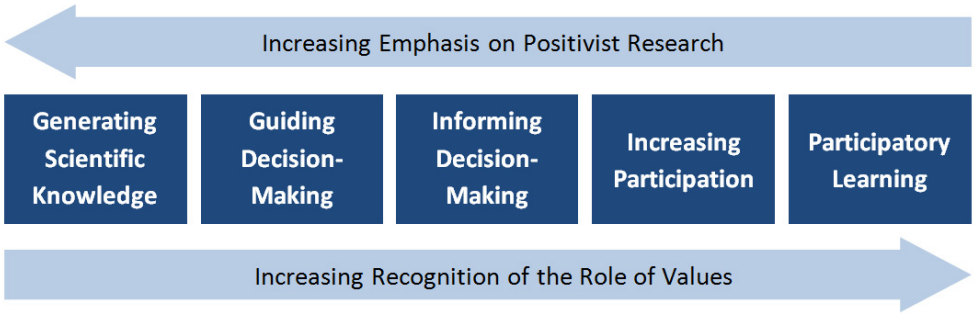


Figure 13. Purposes of health impact assessment HIA [Harris, Rocas, 2008 [31]]

The **retrospective analysis** is carried out in the case in which we want to estimate the number of health events attributable to the current or past exposure levels of the population. Given a certain observed incidence of the pathology, we want to determine what intensity is linked to exposure to a specific pollutant and the reduction of the load that would be obtained in the exposed population if the exposure were removed.

The **prospective analysis** is carried out in the case in which we want to estimate the increase (or decrease) of the incidence currently observed due to an increase (decrease) in concentrations due to the activation (or reduction) of polluting sources." [E.Mancinelli,2018]

In order to undertake an HIA, different stages have to be covered and different parameters must be identified such as:

a) Identification of the reference **value RR** for the health effect considered derived from the concentration / response function described in the scientific literature

Contaminante	Cause ICD X	RR (I.C. 95%)	Popolazione studiata	Riferimento bibliografico
$PM_{2,5}$	A00-R99	1,07 (1,04-1,09)	30-99 anni	Hoek K., Forastiere F. et al 2014 (16)
$PM_{2,5}$	C34	1,09 (1,04-1,14)	30-99 anni	Hamra GB 2014 (17)
$PM_{2,5}$	I00-I99	1,10 (1,05-1,15)	30-99 anni	Hoek K., Forastiere F. et al 2014 (16)
$PM_{2,5}$	J00-J99	1,10 (0,98-1,24)	30-99 anni	Hoek K., Forastiere F. et al 2014 (16)

Figure 14. Risk function caused by long-term exposure [E.Mancinelli,2018]

b) The exposure values of the study population with particular reference to the exposure considered as reference and which can therefore also be in a future time.

b) The size of the reference population from which the data relating to the incidence of the healthcare event in study and the population affected by the potential exposure variation are derived

c) The baseline occurrence (baseline) of the healthcare event being studied, morbidity or mortality in the reference population

Example of calculation of the number of attributable cases that represents the number of events attributable to the increase in concentration of a pollutant in the air with respect to the counterfactual of the same (retrospective), or with respect to the currently observed concentrations, ie of background:

$$AC = A * B * \frac{\Delta C}{10} * Pexp$$

- A = proportion of effect on health attributable to pollution: A = $\frac{(RR-1)}{RR}$
- B = background morbidity / mortality rate of the considered health outcome, or the rate that is observed in the absence of exposure;
- P_{exp} = exposed population

Case study: deaths and hospitalizations attributable due to $PM_{2.5}$ expositions in provincial capital cities and regional totals, in the year 2007

Retrospective analysis

Town	All causes	Cardiovascular issues	Respiratory issues	Lung cancer	Coronary issues
Pesaro	26.80	16.06	2.50	1.85	42.26
Urbino	3.06	1.70	0.44	0.20	5.71
Ancona	28.97	16.65	2.30	2.21	45.70
Macerata	11.50	6.91	1.08	0.80	14.96
Ascoli Piceno	5.41	2.88	0.47	0.38	10.47
Fermo	9.38	6.08	0.50	0.68	16.62
Marche Region	331.26	195.65	28.16	23.23	493.81

Table 5. Deaths and hospitalizations due to PM2.5 in year 2007 in Marche Region [E.Mancinelli,2018]

Table 7 are shown deaths and hospitalizations attributable due to $PM_{2.5}$ expositions in provincial capital cities and regional totals, in the year 2020.

Prospective analysis

	All causes	Cardiovascular issues	Respiratory issues	Lung cancer	Coronary issues
Pesaro	23.47	13.74	2.51	1.90	32.33
Urbino	0.07	0.04	0.01	0.01	0.12
Ancona	35.59	19.76	2.95	2.32	42.02
Macerata	4.10	2.27	0.36	0.23	6.29
Ascoli Piceno	0.96	0.54	0.09	0.08	1.49
Fermo	5.86	3.32	0.45	0.30	7.95
Marche Region	248.24	138.97	21.96	16.95	308.63

Table 7. Deaths and hospitalizations due to PM2.5 in year 2020 in Marche Region [E.Mancinelli,2018]

The assessment of the Health Risk Assessment, however**, is not without uncertainties** that can lead to an underestimation or overestimation of the values. The origin of these uncertainties is varied:

- uncertainty due to the extrapolation of toxicity data in animals rather than in humans;
- uncertainty in estimating emissions;
- uncertainty on the calibration of dispersion modeling of pollutant substances in the environment;
- uncertainty related to the natural range of variability in the population (height, weight, metabolism, susceptibility to different chemical factors, diet, immunological and genetic response);
- uncertainty on the estimation of exposures [G.Sacco]

2. MATERIALS AND METHODS

2.1) Making of air dispersion modelling

As we have seen in previous chapter, a fundamental parameter of health risk assessment is the **evaluation of the exposure** of a population with respect to a specific pollutant. This is not easy to identify, also because it often speaks of very little concentrations, even in the order of nanograms, so also a small difference in results could lead to different conclusions.

Using models of atmospheric dispersion has the advantages of being relatively inexpensive and fast enough provided [G.Sacco [34]].

It thus becomes one of the most important tools in a study of atmospheric dispersion, which is a function of so many variables that only a calculation code, can be able to solve the problem and the complicated equations present behind the software itself.

From a theoretical point of view, there are two philosophies about the approach to the phenomenon of atmospheric dispersion: **Eurelian** and **Lagrangian**.

In the first case we will have a fluid dynamics description of a continuous means and presupposes a totally deterministic vision of the phenomenon. The state of the PBL-planetary boundary layer, the layer immediately in contact with the earth's surface, and the dispersion of pollutants are described in a reference frame. The various properties of the fluid such as the speed u (x,y,z,t) and the concentration of the pollutant c (x, y, z, t) are defined at each point x of space and time t.

In essence, this description is made by writing:

- the various equations that describe the motion of the fluid (air)
- the conservation equations of the different polluting species introduced into the air.

Then, through some assumptions, reaching the Euler Semiempirical equation for the description of the dispersion of a pollutant in the air. [Sozzi, Bolignano, 2011[36]]

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} + V\frac{\partial C}{\partial y} + W\frac{\partial C}{\partial z} = -\left\{\frac{\partial}{\partial x}\left[Kxx\frac{\partial C}{\partial x}\right] + \frac{\partial}{\partial y}\left[Kyy\frac{\partial C}{\partial y}\right] + \frac{\partial}{\partial z}\left[Kzz\frac{\partial C}{\partial z}\right]\right\} + S$$

In which

- C = average concentration
- U, V, W = mean velocity
- K_{xx}, K_{yy}, K_{zz} = dispersion coefficients

On the other hand, following Lagrangian approach considers the concentration of pollutants in the PBL by analyzing the trajectory (position in time) of each particle within the fluid.

The position of each particle X (X_o, t_o, t) and its velocity U (X_o, T_o, t) at each time instant depends on the position of the particle at the initial instant, from the current time te by the level of fluid turbulence. The emitted particle will move apparently messy, like the air of the PBL, and its motion can be described only in probabilistic terms.

The Lagrangian theory therefore abandons a description deterministic of the phenomenon of transport and dispersion of a especially in the air in favor of a purely description statistics [Sozzi,Bolignano - 2011 [36]]

$$< c(x,y,z,t) > = \iiint_{-\infty}^{+\infty} Q(x,y,z,t|x0,y0,z0,t0) * < c(x0,y0,z0,t0) > dx0 * dy0 * dz0 + \iiint_{-\infty}^{+\infty} dx'dy'dz' * \int_{t0}^{t} Q(x,y,z,t|x',y',z',t')dt'$$

Follow equation is the general relation that describes the average concentration of a pollutant at time t at a point in space x, which is the sum of 2 main contributors: the first is the concentration deriving from

all the particles already present at time t_0 and the second is the contribution to the resulting concentration from the particles that are issued from t_0 to t.

Eurelian and lagrangian are **totally parallel and equivalent visions** of the dispersion of pollutants in the air, both widely used and sometimes used simultaneously for the same events [Arianet, 2019 [37]]

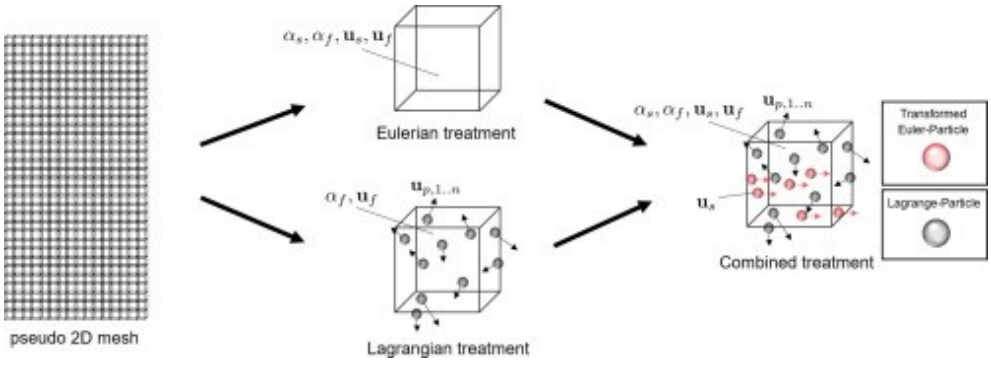


Figure 15. Different approach between Lagrangian and Eulerian treatment [ars.els-cdn.com]]

This is what concerns the most theoretical aspect of the problem and the two different approaches on which atmospheric dispersion software can be based. But from a more practical point of view, the **implementation of a software follows several steps**.

A very practice way to have a look at concentrations of pollutants over territory are the monitoring stations, but air dispersion models have several advantages over monitoring. Modeling can provide greater spatial detail and the costs are relatively cheap by comparison with monitoring stations.

The identification of the characteristic elements of the problem and the analysis of the present constraints are two important aspects to identify the most suitable model and be able to use it correctly and efficiently.

HARP in the risk assessment guidelines of "Air Toxics Hot Spots Program " proposes a list of different stages to be reached in order to build a dispersion model system, as shown in figure 16.

The main features that can describe the problem, as well-described in "I modelli di riferimento per la diffusione in atmosfera degli inquinanti: cenni teorici e applicazioni pratiche" of M.Sinesi, are:

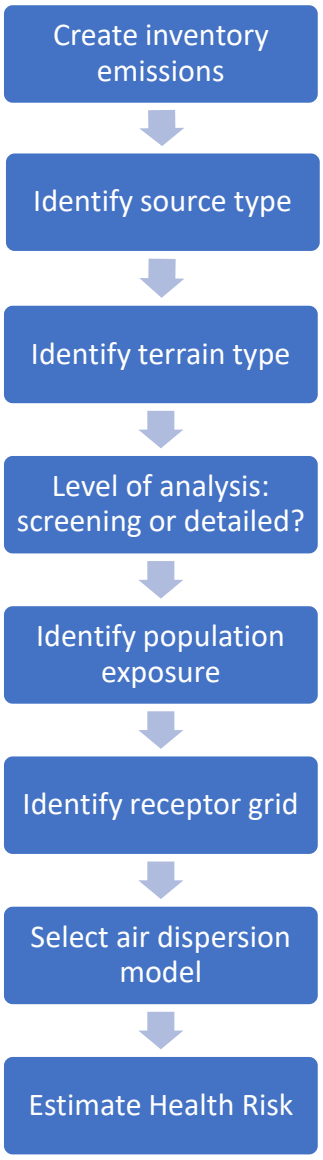


Figure 16. Overview of air dispersion modeling system proposed by HARP-2015 [EPA, 2015]

Spatial Scale: The models are able to reproduce the trend of atmospheric pollutants on different spatial scales depending on the type of phenomenon to be analyzed. The stairs taken into consideration are divided into microscale (100 m ÷ 1 km), local scale (1 km ÷ 100 km), mesoscale (100 km ÷ 1000 km), regional scale (1000 km ÷ 5000 km) and global scale (the whole terrestrial surface).

Time Scale: We can distinguish in short-term or short-term applications (for the study of critical episodes) and long-term or long-term applications (for the exhibition study Cumulative).

Domain: The importance of the type of geographical area in influencing atmospheric phenomena and polluted dispersion requires the identification of the domain on which you intend to apply simulation. Flat lands are defined, those totally flat domains or those domains on which there is a single relief or an isolated valley, while defining terrains complex all other domains. You can also talk about urban land, if you are interested in calculating the concentration of pollutants in densely built urban areas, or rural land if yes considers the open campaign. The land-sea type discontinuities, city-countryside, aquifer systems internal, like superficial inhomogeneities are another aspect to consider and to define to when the model is used.

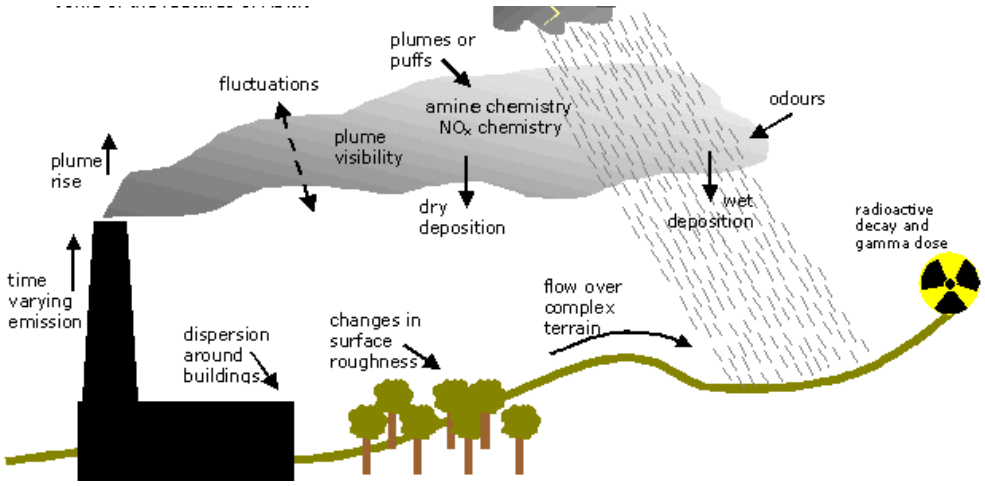


Figure 17. Different situations that could face a pollutant emission[E.Pace,2016]

Pollutant: It is distinguished as gas, aerosol or particulate and can be inert or reactive. If reactive the pollutant may undergo homogeneous gas phase reactions, reactions in the heterogeneous phase, hydrolysis and reactions in the aqueous phase, reactions and processes involving

aerosols and particulates. Models must then include a chemical transformation module if you want to observe the behavior of reactive pollutants in the atmosphere or the formation of secondary pollutants. To add are the deposition processes dry and moist.

Meteorology: There are two main phenomena that influence the distribution of concentrations, transport by the wind field and turbulent diffusion. Such phenomena can be considered homogeneous and stationary or they can have a space-time evolution. The wind field depends on the orography of the area considered and on the presence of particular systems of circulation, while turbulent diffusion is both a function of the field of motion (turbulence mechanical) and heat exchanges with the surface (convective turbulence). We can therefore say that the turbulence depends on the wind field, on the radiative budgets and on the geophysical characteristics of the soil (inclination, surface roughness, albedo). In condition extremely simplified (flat, homogeneous terrains) the dispersive characteristics can be described on the basis of simple parameters; in complex conditions the reconstruction of the fields meteorological conditions requires the use of actual models.

Emissive sources: Also the typology of the sources determines the category of the models, usually yes has to do with single or multiple point sources (chimneys of industrial plants), spring linear (emissions along road sections), aerated or volumetric sources (an industrial area, sources from domestic heating, traffic in an urban areas, agricultural areas).

Regime: We speak of stationary regime if the phenomena are constant over time, on the contrary in presence of the temporal variable the regime will be called evolutionary.

In the management of a model, in order to verify its real applicability, the constraints to be considered are:

- The budget
- The available computing resources
- The availability and quality of the input data (emission data, meteorological data, data of air quality)
- The degree of complexity of the problem
- The level of detail and accuracy required to output data - The skills needed to apply the model correctly

2.2) The HARP model

"The air toxics hot spots information and assessment act" is designed to provide information to state and local agencies and to the general public on the extent of airborne emissions from stationary sources and the potential public health impacts of those emissions. In response, office of environmental health hazard assessment (OEHHA) of California developed a tiered approach to risk assessment where a point estimate approach is first employed. If a more detailed analysis is needed, OEHHA has developed a stochastic, or probabilistic, approach using exposure factor distributions that can be applied in a stochastic estimate of the exposure.

The ARB and the districts have identified a critical need for software to assist the programmatic aspects of the hot spots program. HARP is **computer software** used by the ARB, OEHHA, districts, and facility operators to promote statewide consistency, efficiency, and cost-effective implementation of HRAs and the hot spots program. The HARP software package includes:

1) Emissions Inventory Database Module,
2) Air Dispersion Modeling Module
3) Risk Analysis Module.

The **user-friendly** windows-based package provides for:

a. Electronic implementation of the risk assessment methods presented in the OEHHA guidelines (Guidance Manual)
b. Electronic data transfer from facilities and districts
c. The production of reports
d. Facility prioritization
e. Air dispersion modeling (AERMOD) of multiple emission releases or facilities for cumulative impact evaluations

f. A summary report of acute, 8-hour, and chronic health hazard quotients or indices, and cancer risk at the point of maximum impact (PMI), maximally exposed individual resident (MEIR), maximally exposed individual worker (MEIW) and other receptors to be evaluated as needed
g. Mapping displays of facility property boundaries, risk isopleths, and elevation contours
h. The ability to display combined risk contours from multiple emission sources
i. Output of data for use in other "off-the-shelf" geographic information systems (GIS) programs for additional types of analysis
j. Census data for determining population-related health impacts showing the number of people exposed at various cancer risk levels and cancer burden" [EPA, 2015]

Figure 18-22 show the interface of the HARP software and the different modules regarding the **exposure assessment**, i.e. the second module of HARP.

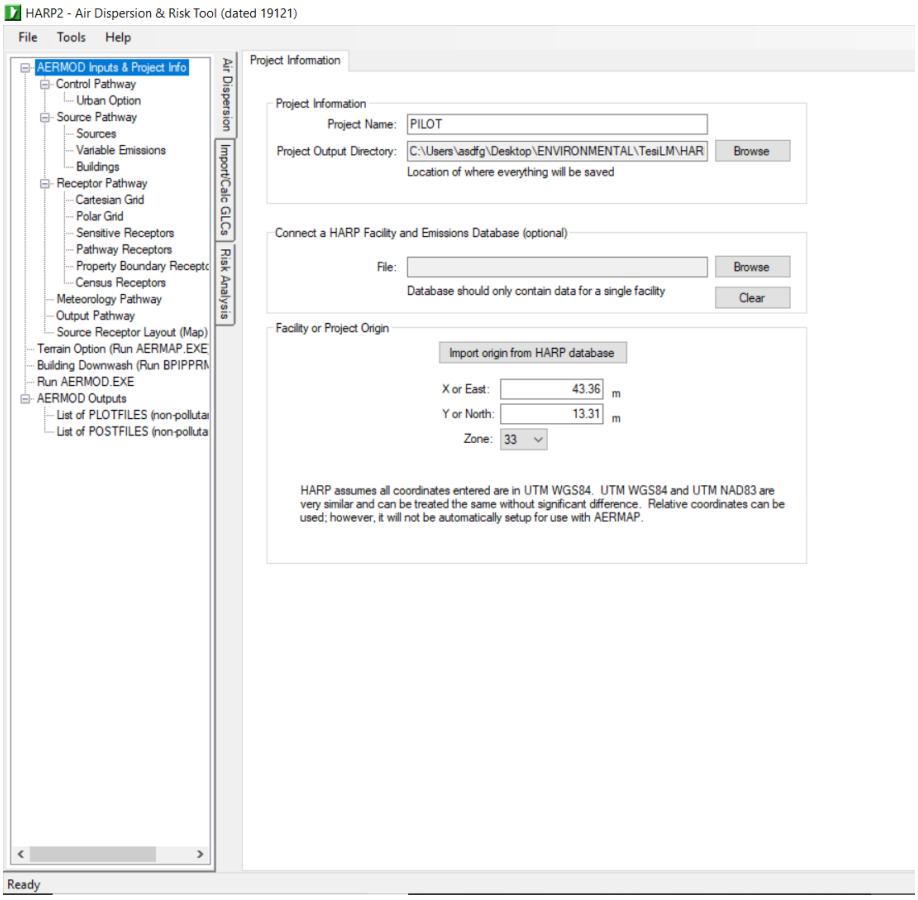


Figure 18. HARP inputs and project info section

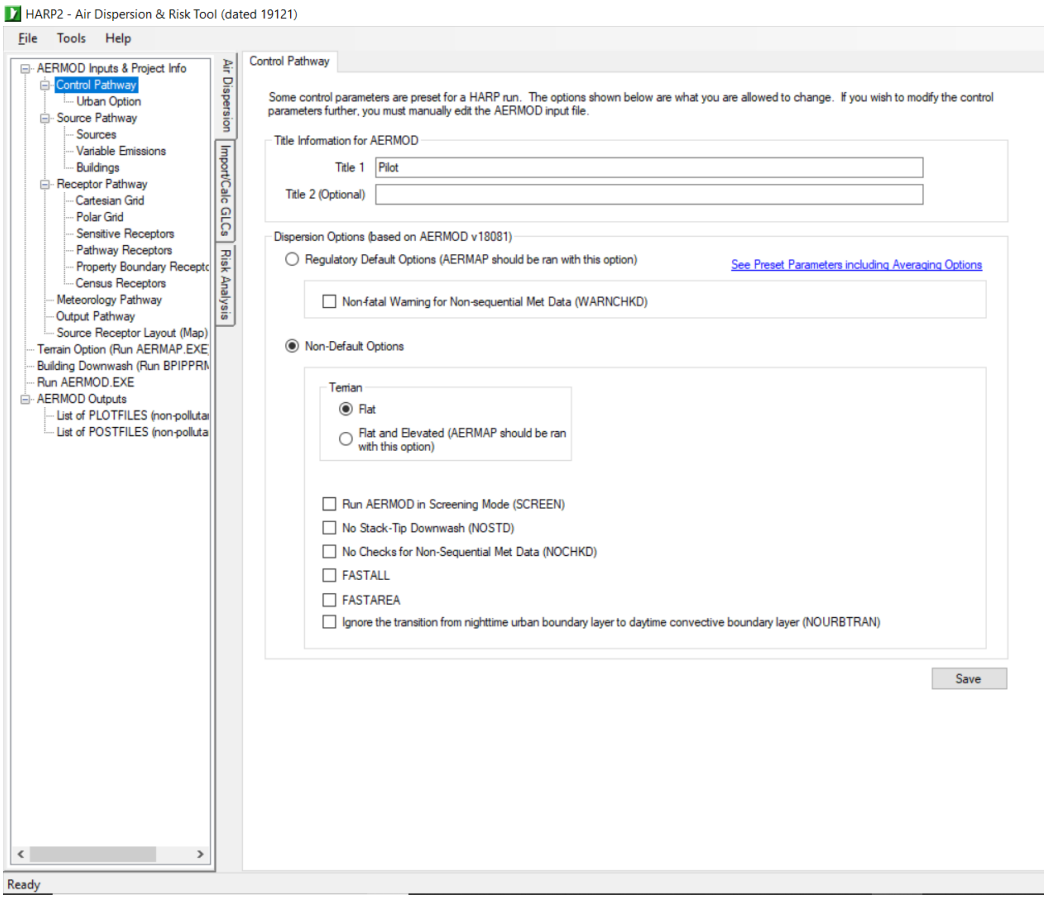


Figure 19. Some control parameters present for the HARP run

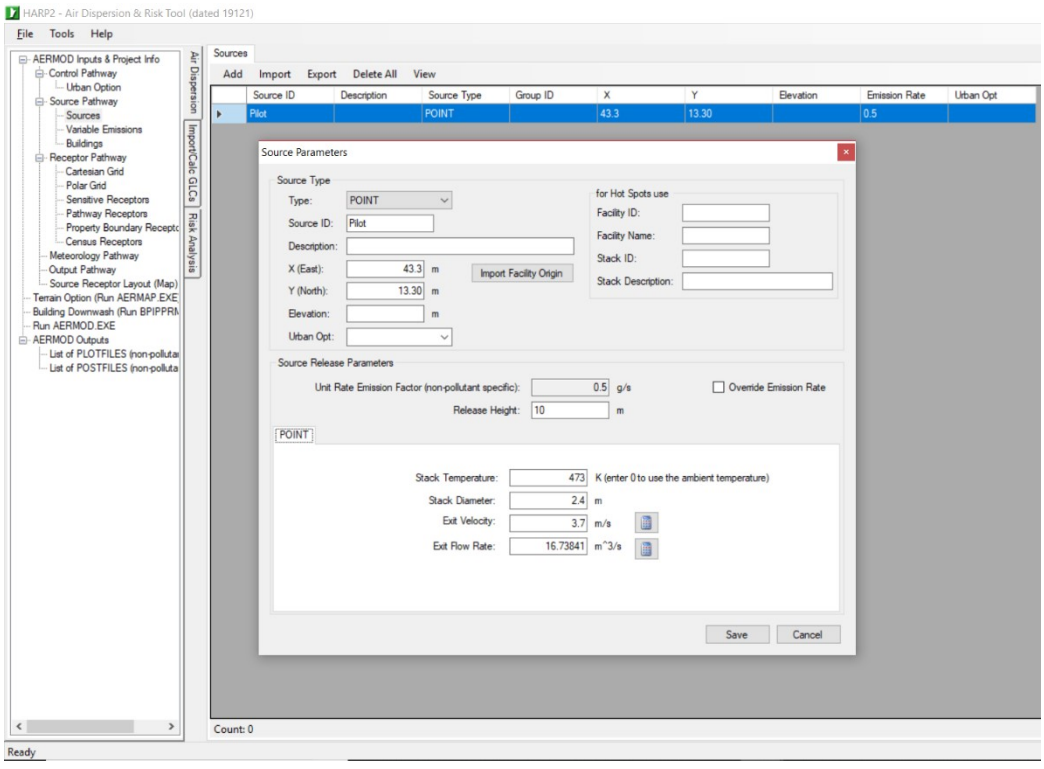


Figure 20. Section in which can be included the sources

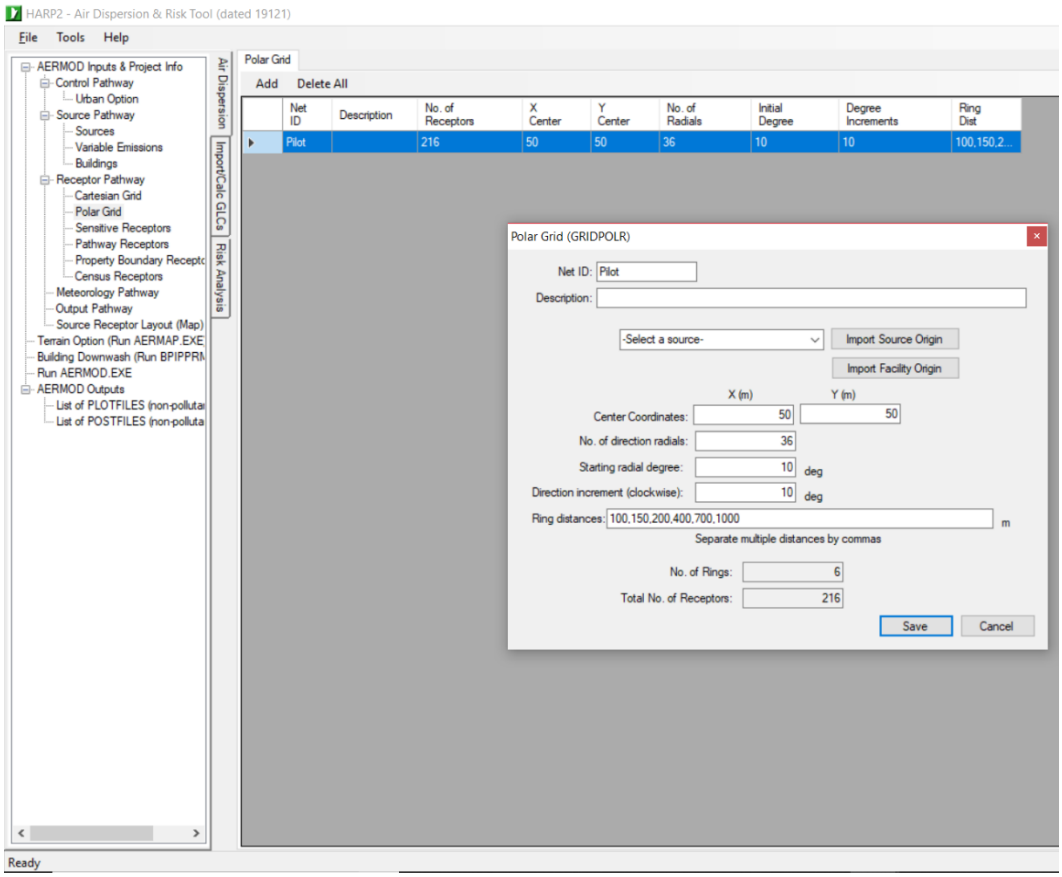


Figure 21. Section where is to possibile to set the outputs options

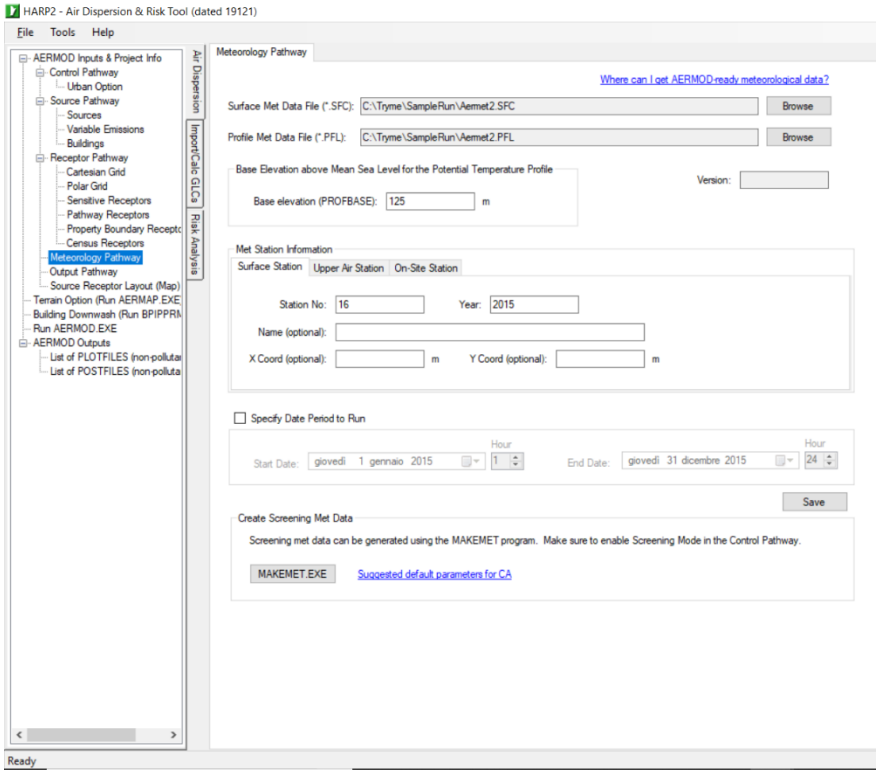


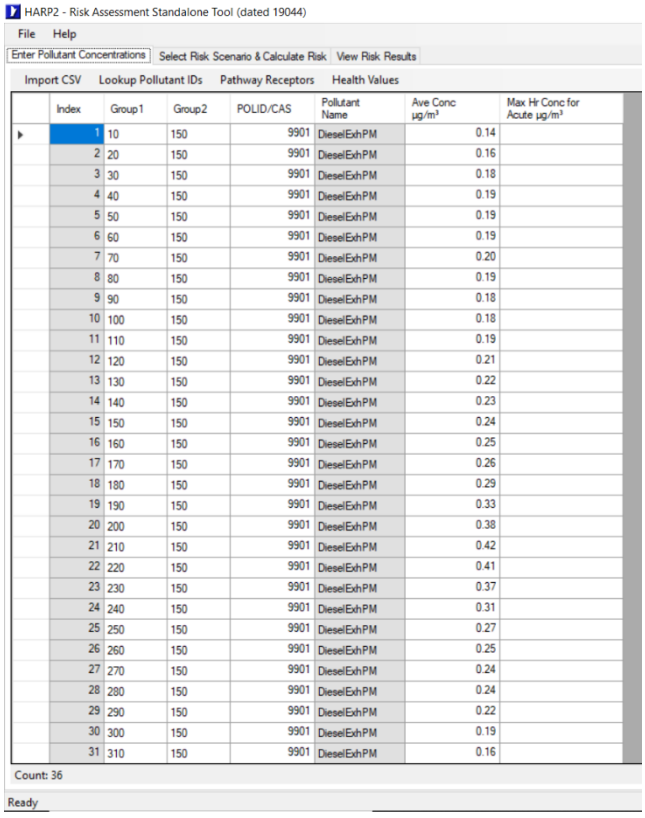
Figure 22. Section regarding the metereological input data

Figures 23-26 show the interface of HARP concerning the **risk assessment** standalone tool, i.e. the third module.

We used this module setting as input data the resulting concentrations provided by the first module, referring to the particulate matter coming from diesel engine. That choice was due because, for this pollutant, we had into the database of HARP the corresponding reference concentration (code polid 9901).

We decided to focus on the distance in which we have the worst case scenario (150 m), spacing with an angle of 10° around the emission source as shown in figure 18.

We searched for the cancer risk by inhalation with an exposure time of 70 years as shown in figure 19-20.



Index	Group1	Group2	POLID/CAS	Pollutant Name	Ave Conc µg/m³	Max Hr Conc for Acute µg/m³
1	10	150	9901	DieselExhPM	0.14	
2	20	150	9901	DieselExhPM	0.16	
3	30	150	9901	DieselExhPM	0.18	
4	40	150	9901	DieselExhPM	0.19	
5	50	150	9901	DieselExhPM	0.19	
6	60	150	9901	DieselExhPM	0.19	
7	70	150	9901	DieselExhPM	0.20	
8	80	150	9901	DieselExhPM	0.19	
9	90	150	9901	DieselExhPM	0.18	
10	100	150	9901	DieselExhPM	0.18	
11	110	150	9901	DieselExhPM	0.19	
12	120	150	9901	DieselExhPM	0.21	
13	130	150	9901	DieselExhPM	0.22	
14	140	150	9901	DieselExhPM	0.23	
15	150	150	9901	DieselExhPM	0.24	
16	160	150	9901	DieselExhPM	0.25	
17	170	150	9901	DieselExhPM	0.26	
18	180	150	9901	DieselExhPM	0.29	
19	190	150	9901	DieselExhPM	0.33	
20	200	150	9901	DieselExhPM	0.38	
21	210	150	9901	DieselExhPM	0.42	
22	220	150	9901	DieselExhPM	0.41	
23	230	150	9901	DieselExhPM	0.37	
24	240	150	9901	DieselExhPM	0.31	
25	250	150	9901	DieselExhPM	0.27	
26	260	150	9901	DieselExhPM	0.25	
27	270	150	9901	DieselExhPM	0.24	
28	280	150	9901	DieselExhPM	0.24	
29	290	150	9901	DieselExhPM	0.22	
30	300	150	9901	DieselExhPM	0.19	
31	310	150	9901	DieselExhPM	0.16	

Figure 23. Interface of Risk assessment tool of HARP concerning pollutant concentrations.

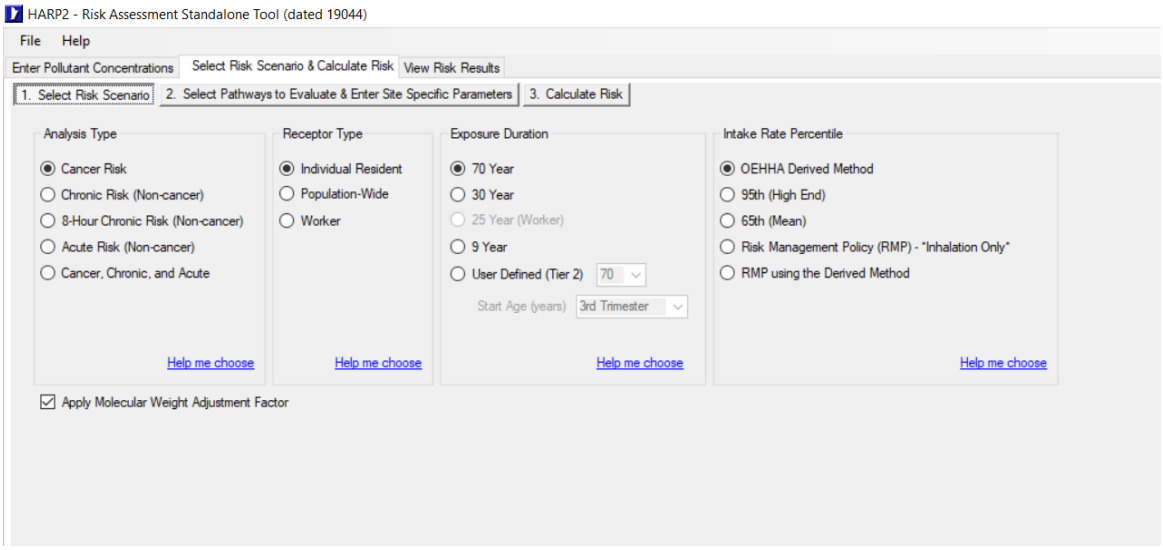


Figure 24.Interface of Risk assessment tool of HARP concerning type analysis, receptor type, exposure duration and percentile

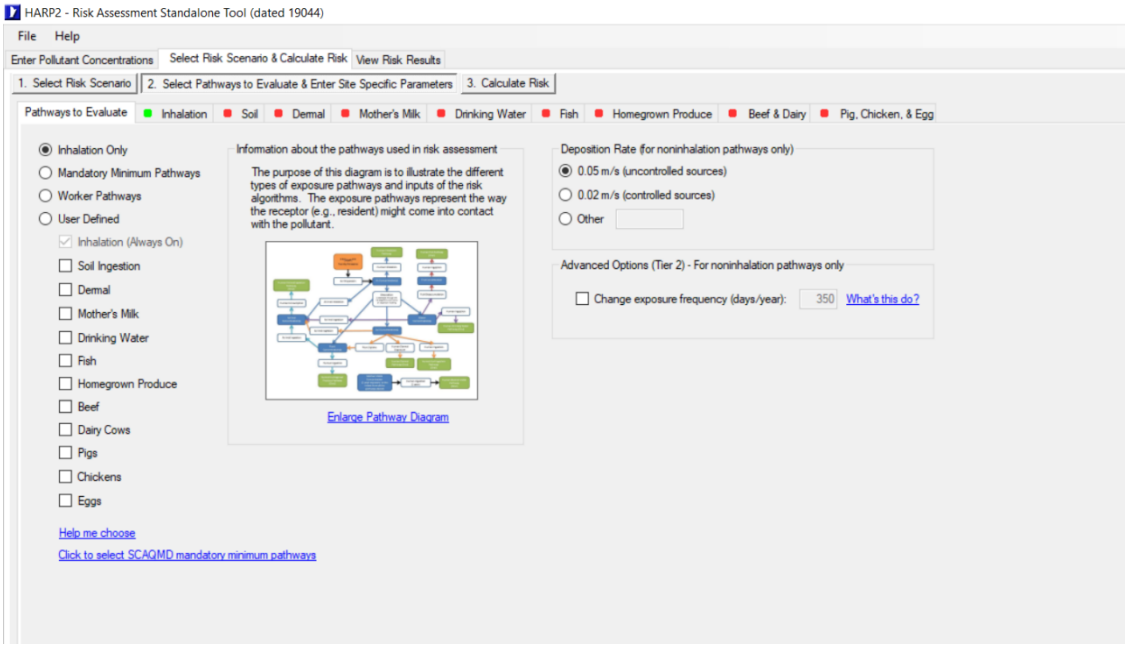


Figure 25. Interface of Risk assessment tool of HARP concerning risk outputs

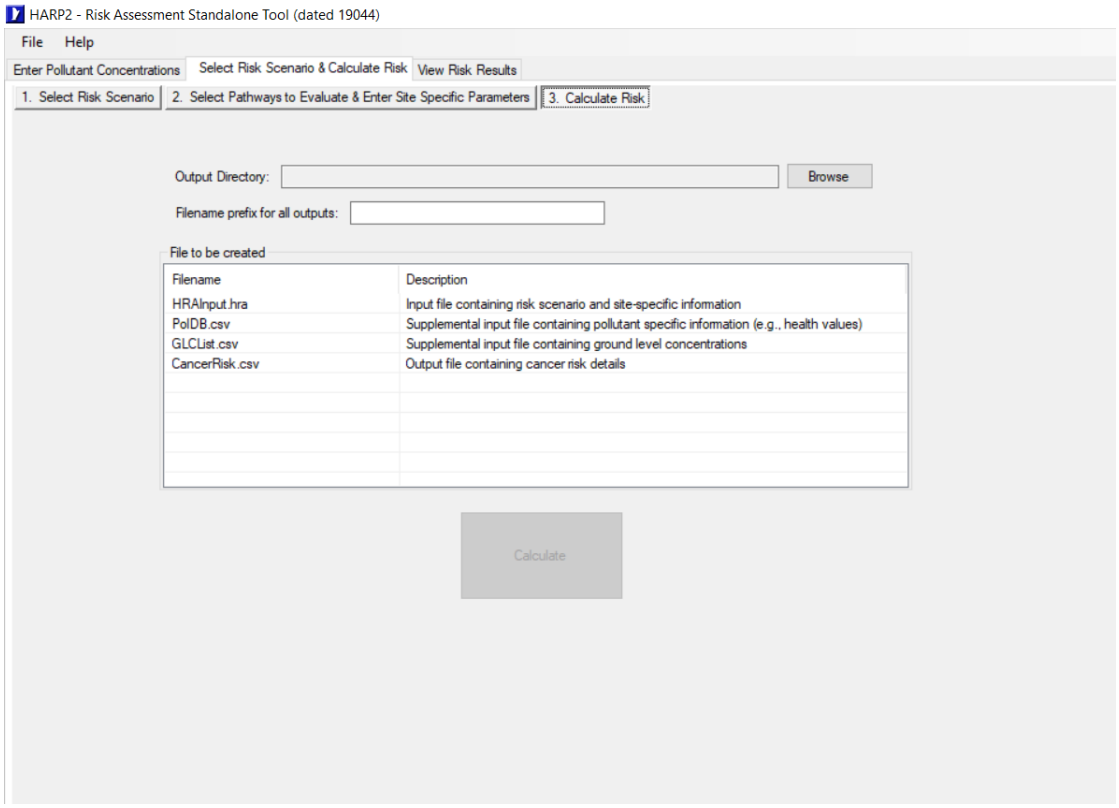


Figure 26. Interface of Risk assessment tool of HARP concerning pollutant pathway

"OEHHA has striven to use the best science available in developing these risk assessment guidelines. However, there is a **great deal of uncertainty** associated with the process of risk assessment. The uncertainty arises from lack of data in many areas necessitating the use of assumptions. The assumptions used in these guidelines are designed to err on the side of health protection in order to avoid underestimation of risk to the public. Sources of uncertainties, which may overestimate or underestimate risk, include:

1) extrapolation of toxicity data in animals to humans
2) uncertainty in the estimation of emissions
3) uncertainty in the air dispersion models
4) uncertainty in the exposure estimates.

In addition to uncertainty, there is a natural range or variability in measured parameters defining the exposure scenario. Scientific studies with representative sampling and large enough sample sizes can characterize this variability." [EPA, 2015]

2.3) Risk analysis

The final step of health risk assessment is the risk characterization. The information obtained through the exposure assessment is combined with information from the dose-response assessment to characterize risks.

Risk characterization should present both individual and population-wide health risks.

Reminding the estimation of **toxic risk** by inhalation

Toxic risk factor HQ

$$HQ = \frac{EC}{RfC * 1000} \leq 1$$

- RfC - reference concentration - **5 x 10^{-3} mg/m^3**
- EC - exposure concentration for non-carcinogenic substances, µg / m^3.

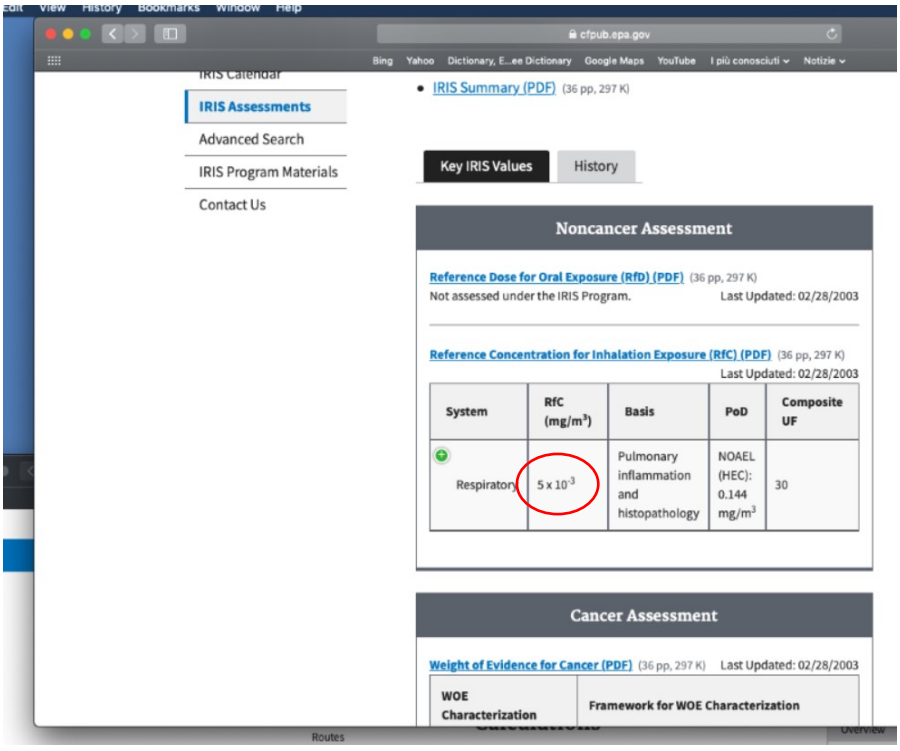


Figure 27. Reference concentration for inhalation exposure of PM from diesel engine [epa.gov.com]

Following formula is concerning **exposure concentration EC** (µg / m^3) for non-carcinogenic toxic substances:

$$EC = \frac{CA * ET * EF * ED}{ATnc}$$

- CA - concentration of the contaminant in the air, µg / m^3;
- ET - exposure time (hours / day);
- EF - exposure frequency (days / year);
- ED - duration of exposure (years);
- AT_{nc} - time on which the exposure is averaged (ED in years x 365 days / year x 24 hours / day)

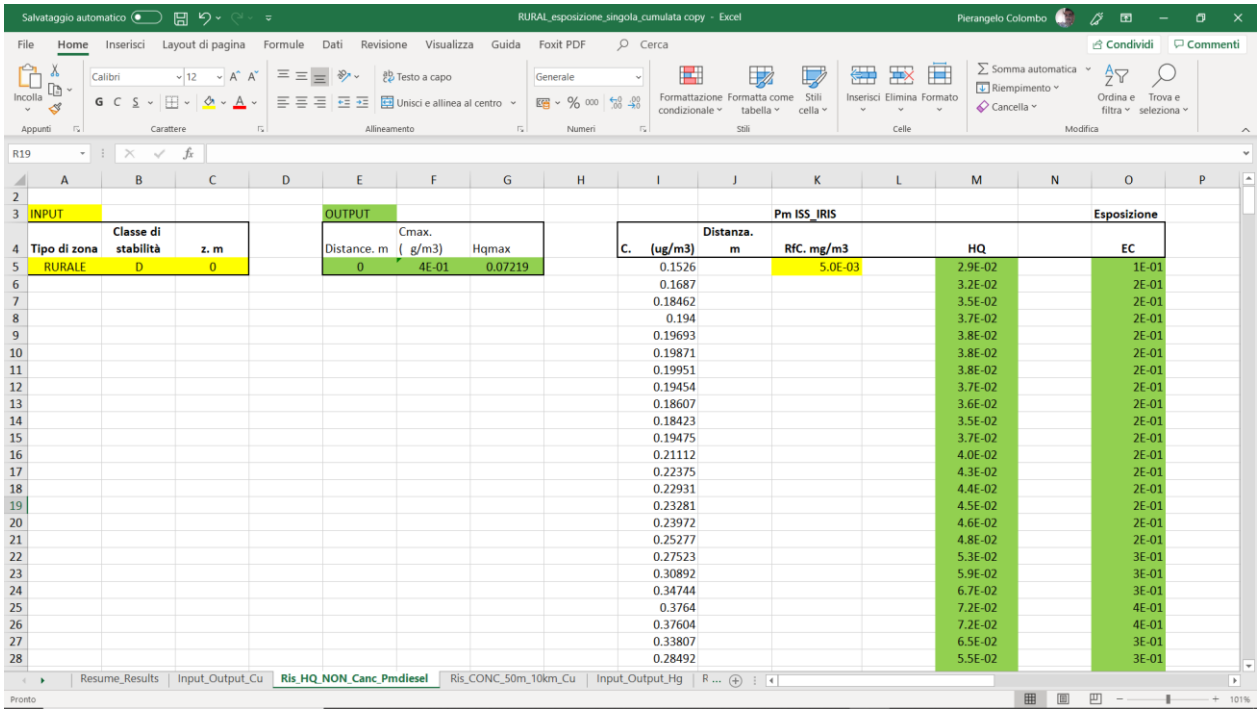
Risk index (hazard index – (HI)), is calculated in the case of more substances acting on the same target organ

$$HI = \sum HQi \leq 1$$

Table 6 shows parameters used for the calculation of the exposure concentration

Adult exposure			
Exposure time	Exposure frequency	Exposure time	Exposure averaged time
ET. [hour/day]	EF. [day/year]	ED. [years]	[Atnc]
24	350	24	210240

Table 6. Parameters used for the calculation of EC



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
2																
3	INPUT				OUTPUT						Pm ISS_IRIS				Esposizione	
4	Tipo di zona	Classe di stabilità	z. m		Distance. m	Cmax. (g/m3)	Hqmax		C. (ug/m3)	Distanza. m	RfC. mg/m3		HQ		EC	
5	RURALE	D	0		0	4E-01	0.07219		0.1526		5.0E-03		2.9E-02		1E-01	
6									0.1687				3.2E-02		2E-01	
7									0.18462				3.5E-02		2E-01	
8									0.194				3.7E-02		2E-01	
9									0.19693				3.8E-02		2E-01	
10									0.19871				3.8E-02		2E-01	
11									0.19951				3.8E-02		2E-01	
12									0.19454				3.7E-02		2E-01	
13									0.18607				3.6E-02		2E-01	
14									0.18423				3.5E-02		2E-01	
15									0.19475				3.7E-02		2E-01	
16									0.21112				4.0E-02		2E-01	
17									0.22375				4.3E-02		2E-01	
18									0.22931				4.4E-02		2E-01	
19									0.23281				4.5E-02		2E-01	
20									0.23972				4.6E-02		2E-01	
21									0.25277				4.8E-02		2E-01	
22									0.27523				5.3E-02		3E-01	
23									0.30892				5.9E-02		3E-01	
24									0.34744				6.7E-02		3E-01	
25									0.3764				7.2E-02		4E-01	
26									0.37604				7.2E-02		4E-01	
27									0.33807				6.5E-02		3E-01	
28									0.28492				5.5E-02		3E-01	

Figure 28. Excel paper for the calculations of EC and HQ with respect to each predicted concentration

In figure 28 are shown the calculation for the risk assessment in terms of exposure concentration and then hazard quotient.

They are calculated per each concentration predicted by Aermod, at 100-150-200-250-300-350-400-500-750 m every 10° around the emission source.

2.3) AERMOD STRUCTURE

2.3.1) The choice of Aermod

In the initial phase of our study an in-depth research was carried out aimed at identifying a tool, which was freescource and available online, and which could satisfy our input data needs. That is a tool capable of being **user-friendly** and that, by inserting a **few input data**, could provide a scenario about the emission of fumes from a source into the atmosphere. It therefore had to provide a multidimensional scenario in which, through a territorial framework, it was possible to assign indices to the corresponding values of the scenario.

The international reference model for our case study is HARP, the hot spots analysis and reporting program developed in California.

The calculation of the concentration of pollutants in the air environment is an important element to characterize the **exposure** of the population, in general following the routes of inhalation. The concentrations of pollutants are therefore necessary for the evaluation of the HRA to estimate the potential risk of cancer or the danger indexes associated with pollutant emissions into the air. [G.Sacco].

For this purpose, atmospheric dispersion models are used, which have the advantage of being relatively **inexpensive** and fairly fast provided that the necessary input data are already available to run the model. In our case, the data available were sufficients to be processed by a calculation code.

In this case, an inventory of the emissions around the area examined was created, so all the point, area and volume sources were included in the database. As well as the meteorological data relating to the Camerano weather station (AN) were derived from the station itself.
We mainly talk about data such as temperature, pressure, wind speed and direction calculated on an hourly basis.

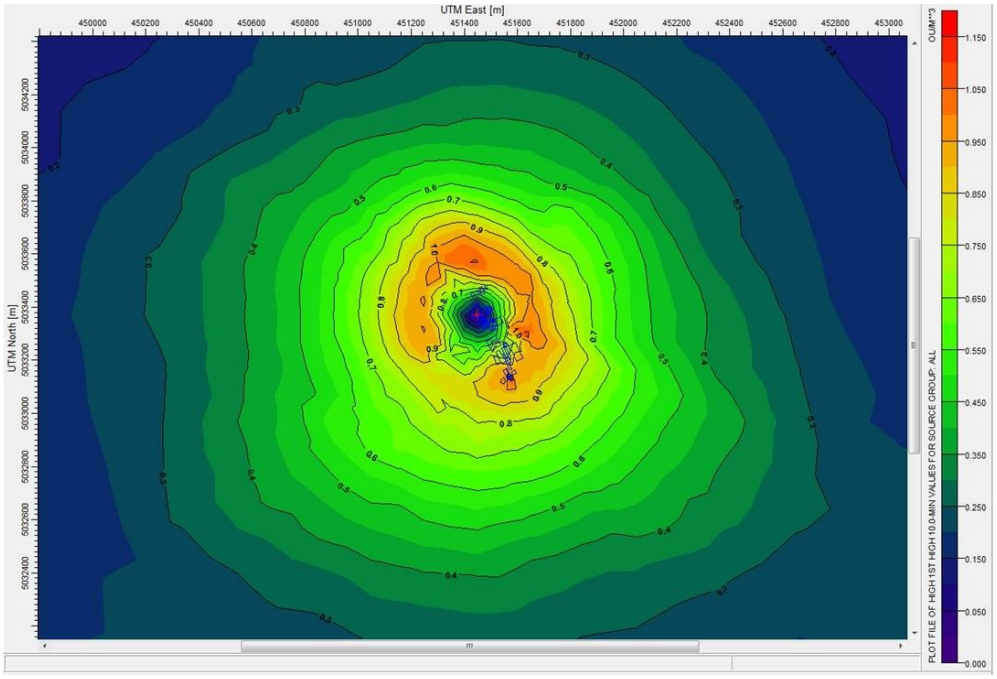


Figure 29. Typical 2D representation of a dispersion analysis, in which we have the lines of iso-concentrations and colours representing different values [vgengineering.com]

This analysis could not therefore be solved with instruments that were able to give a result about the propagation in the atmosphere of a certain concentration referring only to the worst case scenario.
The worst case scenario represents the worst configuration obtainable when there is a discharge into the atmosphere, having as reference basis the data relating to the wind, the atmosphere and even the terrain. This configuration, however, is provided monodirectionally, i.e.

indicating at which angle with respect to the source and at what distance there would have been the greatest impact in terms of the planned ground concentration.

Among our objectives, however, there was the desire to identify a tool that must outputs in **two-dimensional form**, in order to create maps of the territory related to the health risk arising from the installation of one or more sources, as shown in figure 16.

In our research we came into contact with more freeware softwares, the first of which was SCREEN view, the view and user-friendly interface of the more complex American model SCREEN3, signed EPA. What follows is taken by the presentation of the software:

"The SCREEN3 model can be used to estimate worst-case ground level concentrations for a single source as well as concentrations in the cavity zone, and concentrations due to inversion break-up and shoreline fumigation. SCREEN View can model scenarios with simple or complex terrain, with or without building downwash and give results at discrete or automated distances. SCREEN3 is the screening version of the ISC3 model " [Webalakes.com, 2018]. In this way there was the possibility to have only the worst scenario, so we moved on.

Another tested software was RDTM, an acronym of Rough Diffusion Terrain Model, developed by ERT (Environmental Research and Technology) as it was able to work with only a few input data available, but, since the release date of the latest version of software was 1989, it presented itself with a dated configuration, which discouraged its use at the present time. The same reason for which the software Valley wasn't taken into account.

Then we found the screen version of Aermod and, using this, some test cases were executed.

Figure 30. Picture presentation of Aerscreen model [EPA.gov[j]]

The model produces estimates of "worst-case" 1-hour concentrations for a single source, without the need for hourly meteorological data, and also includes conversion factors to estimate "worst-case" 3-hour, 8-hour, 24-hour, and annual concentrations." AERSCREEN code including the latest MAKEMET code is provided below along with documentation and test cases. The MAKEMET program interfaces with AERSCREEN to generate a site-specific matrix of screening meteorological conditions based on inputs provided by the user in order to use them as inputs into AERMOD. In order to use AERSCREEN, users must have the latest AERMOD executable as well as the AERMAP terrain preprocessor and BPIPPRM executables." [EPA.gov]

aerscreen - Blocco note

File Modifica Formato Visualizza ?

```
grtgr

           grtgr


        -----------------  DATA ENTRY VALIDATION  -----------
                          METRIC              ENGLISH
 ** STACKDATA **  ---------------     ----------------

 Emission Rate:       0.5000 g/s             3.968 lb/hr
 Stack Height:         10.00 meters          32.81 feet
 Stack Diameter:       2.400 meters          94.49 inches
 Stack Temperature:    473.0 K               391.7 Deg F
 Exit Velocity:        3.700 m/s             12.14 ft/s
 Stack Flow Rate:      35466 ACFM
 Model Mode:           RURAL
 Dist to Ambient Air:          1.0 meters             3. feet


 ** BUILDING DATA **

 No Building Downwash Parameters


 ** TERRAIN DATA **

 No Terrain Elevations
 Source Base Elevation:  32.5 meters      106.6  feet

 Probe distance:   5000. meters       16404. feet

 No flagpole receptors

 No discrete receptors used


 ** FUMIGATION DATA **

 No fumigation requested


 ** METEOROLOGY DATA **

 Min/Max Temperature:  271.0 / 311.0 K   28.1 / 100.1 Deg F
```

Figure 31. Aerscreen input data in the pilot test

A test was done giving into AERSCREEN database the following inputs, as also shown in the picture 31:

- Emission Rate [µg/m^3]

- Stack Height [m]
- Stack Diameter [m]
- Stack Temperature [°K]
- Exit Velocity [m/s]

There wasn't requirement for hour metereological data, that was one of our points of interest but, however, we move on.

Results were written in a .txt file in which there was a prediction about ground concentration at 1 hour, 3 hours, 8 hours and the annual average, as showed in picture 15. Apart of these, still we hadn't an "impact mapping" but only the worst-case scenario and the concentration at this point or concentrations along distances on that direction, as in this case.

```
2475.00     3.126                    5000.00     1.993
2500.00     3.109

--------------------------------------------------------------------------------
**********  AERSCREEN MAXIMUM IMPACT SUMMARY  **********
--------------------------------------------------------------------------------

                    MAXIMUM       SCALED       SCALED       SCALED       SCALED
                     1-HOUR       3-HOUR       8-HOUR      24-HOUR       ANNUAL
  CALCULATION          CONC         CONC         CONC         CONC         CONC
   PROCEDURE         (ug/m3)      (ug/m3)      (ug/m3)      (ug/m3)      (ug/m3)
---------------    ----------   ----------   ----------   ----------   ----------
FLAT TERRAIN        129.3        129.3        116.3        77.56        12.93

DISTANCE FROM SOURCE          40.00 meters


IMPACT AT THE
AMBIENT BOUNDARY    0.3458E-02   0.3458E-02   0.3112E-02   0.2075E-02   0.3458E-03

DISTANCE FROM SOURCE           1.00 meters
```

Figure 32. Results of Aerscreen pilot test

As we can see there was reported the scaled annual concentration, that was the one we were interested in. So we tried to repeat the test into

the Aermod view software, available in computers of the Department of industrial engineering and mathematic science of Marche Polytecnic University and we found that, although the direction was the same predicted by AERSCREEN and the predicted concentration at 1 hour was comparable, speaking about the concentration as annual average the difference between the freeware software and the view version one, was an order of magnitude.

From this, we deduce that probably having a software able to read the hour metereological data and with the possibility to put inside the terrain features, was indispensable.

This was the reason why we rejected the idea of using Aerscreen and decided to go directly to the Aermod version in open-source mode.

2.3.2) Aermod source code

As anticipated in the previous chapter, at the end of our research we chose to opt for the open source version of Aermod.

This is due to several reasons: first of all it is a **reliable** and well tested software for years, in fact the Environmental Protection Agency of the USA makes use of it, which were also the producers of the software itself, born through a collaboration with the scientists of the AMS-American Meteorological Society.

Aermod is the result of a work that lasted 14 years, from 1991 to 2005 in which there was the official release date [Aermod, Wikipedia [(41)]]

In particular, Aermod allows us to enter the sources of pollution, in a single or even multiple way and in addition it allows the insertion of the hourly meteorological data that is preprocessed by a special form.

This has proved to be a fundamental point for the correct analysis of the dispersion in a given context and often makes the difference between a software in a screening version, which accepts very little data as input,

and a refined software, whose calculation capacity and forecast is definitely better.

Another reason that led us to the use of Aermod was the possibility of having as an output a **2D mapping** (an example in figure 33) from which it is possible to obtain isolines of concentration and forecast values scattered over the territory surrounding the emission source; not only, therefore, in the direction of the worst case scenario as many other models do.

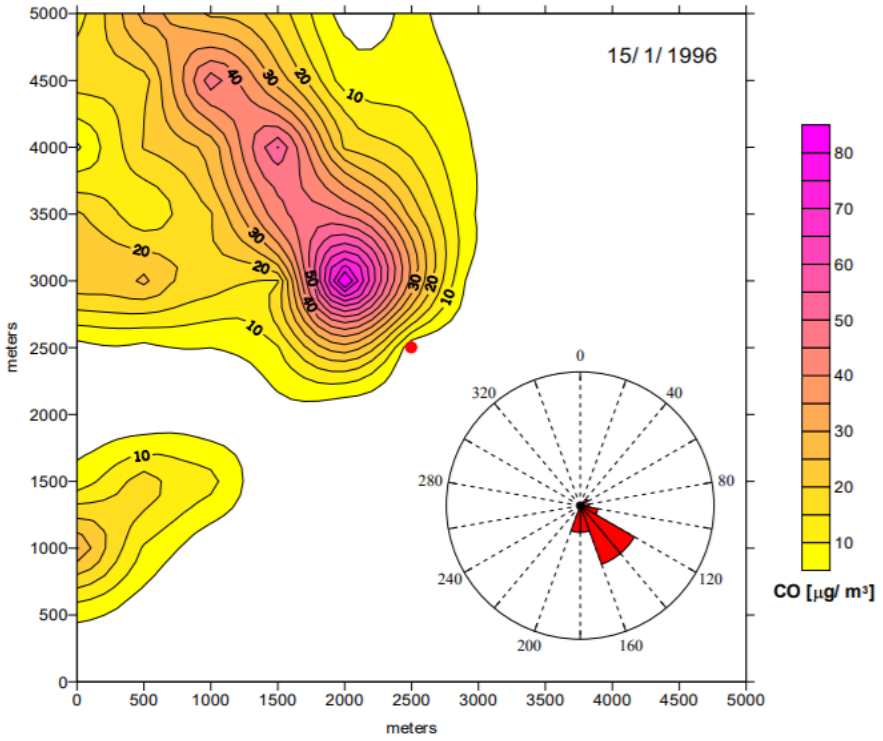


Figure 33. Typical 2D results from Aermod use [encrypted.com]

As mentioned above what was interesting was the "**period**", the concentration one year from the issue and Aermod has no problem in being able to diagnose this data.

Furthermore, Aermod is suitable for **implementation over time**, so if in the first phase of the study it was used in FLAT mode, in the future it could be updated and implemented by inserting the orographic and vegetation characteristics of the studied area. This is possible through the insertion of a land elevation file such as a digital elevation model (DEM) capable of being preprocessed and from which it is possible to

extrapolate the heights of the terrain and their respective characteristics.

The use of the AERMOD code is divided into three distinct operational phases, as shown in figure 34, each of which is assigned a particular function performed by specific codes. The orographic and meteorological features of the scenarios covered by the dispersive study are prepared respectively from the AERMAP and AERMET codes which operate separately and calculate the orographic and meteorological parameters that contribute to the description of the planetary boundary layer in which the pollutants spread, which are then simulated with the AERMOD dispersion code. Figure 34 shows the flow of the operational phases in which the operation of the code is articulated.

The AERMAP code, which represents the orographic preprocessor, after reading the orographic data and the characteristics of the horizontal receptors grid (x_r, y_r) assigned by the user for the subsequent calculation

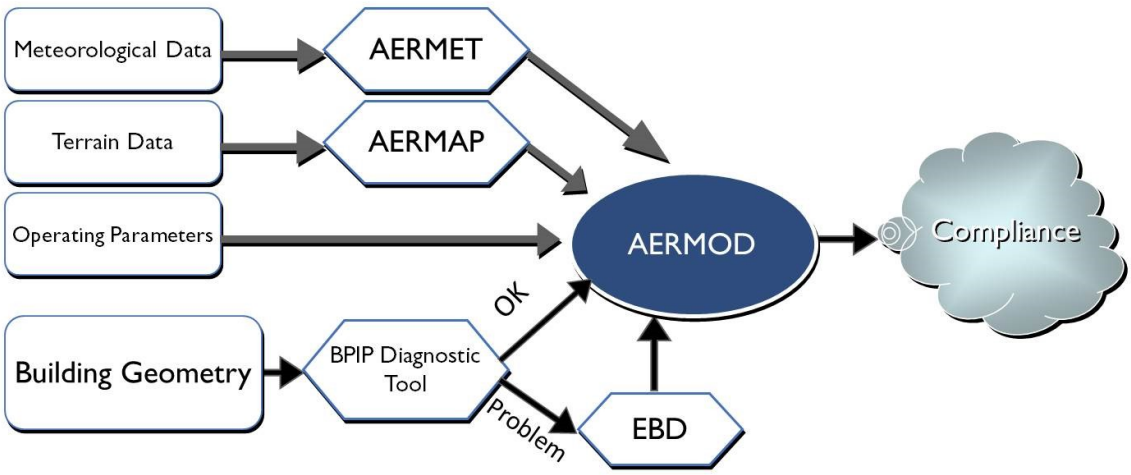


Figure 34. Aermod modeling approach [i.ytimg.com]

of concentrations, determines for each individual receptor the dimension *zr* and calculates a parameter *hc*, called "scale height" of the terrain, which represents the height within which the influence of the nearby orographic reliefs in the point is expressed (x_r, y_r, z_r).

The AERMET code, which represents the **meteorological preprocessor**, provides for the reading at a time level of a series of meteorological parameters, such as:

- wind speed
- direction
- temperature
- cloud cover

These values measured in a ground station representative of the site under study are read daily wind speed and temperature profile and direction. The data read are then used to calculate the value of the parameters, such as:

- the sensible heat flux,
- the friction velocity u*,
- the Monin Obukhov L length,
- the convective speed of scale w *,
- the mixing heights, both mechanical and convective Zim Zic, which define the boundary layer (PBL) in which pollutants spread.

The algorithms used from the code are different depending on the conditions of stable or convective atmosphere. Finally, the AERMOD dispersion code, after integrating the characteristics of the mixing layer in the phase called "meteorological interface", calculates the concentrations at soil of pollutants emitted into the atmosphere assuming particular hypotheses. In the case of a stable atmosphere, the code assumes that the pollutant diffuses in space maintaining a shape both in the horizontal and vertical direction similar to a Gaussian distribution, while in the case of a convective atmosphere the form

adopted by the code to spread the plume reflects the non-Gaussian nature of the vertical component of wind speed [Renzi, Cordioli, 2015 [(27)]]

We find what we have spoken so far in next lines which are taken by the Aermod User's Guide for the AMS/EPA Regulatory Mode of April,2018:

"*One of the basic inputs to AERMOD is the runstream setup file which contains the selected modeling options, as well as source location and parameter data, receptor locations, meteorological data file specifications, and output options. The runstream file is also commonly referred to as the control file. Another type of basic type of input data needed to run the model is the meteorological data. AERMOD requires two types of meteorological data files that are provided by the AERMET meteorological preprocessor program (EPA, 2018c). One file consists of surface scalar parameters, and the other file consists of vertical profiles of meteorological data(...)*

The AERMOD model includes a wide range of options for modeling air quality impacts of pollution sources, making it a popular choice among the modeling community for a variety of applications(…)

The model is capable of handling multiple sources, including point, volume, area, open pit, and both buoyant and non–buoyant line source types(…)

The model contains algorithms for modeling the effects of aerodynamic downwash due to nearby buildings on point source emissions and depositional effects on particulate emissions.(…)

The model contains algorithms for modeling the effects of aerodynamic downwash due to nearby buildings on point source emissions and depositional effects on particulate emissions.(…)

The AERMOD model has considerable flexibility in the specification of receptor locations. The user has the capability of specifying multiple receptor networks in a single run, and may also mix Cartesian grid receptor networks and polar grid receptor networks in the same run. This is useful for applications where the user may need a coarse grid over

the whole modeling domain, but a denser grid in the area of maximum expected impacts. There is also flexibility in specifying the location of the origin for polar receptors, other than the default origin at (0,0) in x,y, coordinates. The user can input elevated receptor heights in order to model the effects of terrain above (or below) stack base, and may also specify receptor elevations above ground level to model flagpole receptors (…)

The basic types of printed output available with AERMOD are:

- *Summaries of high values (highest, second highest, etc.) by receptor for each averaging period and source group combination;*
- *Summaries of overall maximum values (e.g., the maximum 50) for each averaging period and source group combination;*
- *Tables of concurrent values summarized by receptor for each averaging period and source group combination for each day of data processed.*

These "raw" concentration values may also be output to unformatted (binary) files, as described below.

```
CO STARTING
CO TITLEONE A Simple Example Problem for the AERMOD-PRIME Model
CO MODELOPT CONC FLAT
CO AVERTIME 3 24 PERIOD
CO POLLUTID SO2
CO RUNORNOT RUN
CO FINISHED

SO STARTING
SO LOCATION  STACK1  POINT 0.0 0.0 0.0
SO SRCPARAM  STACK1  500.0 65.00 425. 15.0 5.
SO BUILDHGT  STACK1  36*50.
SO BUILDWID  STACK1  62.26   72.64   80.80   86.51   89.59   89.95
SO BUILDWID  STACK1  87.58   82.54   75.00   82.54   87.58   89.95
SO BUILDWID  STACK1  89.59   86.51   80.80   72.64   62.26   50.00
SO BUILDWID  STACK1  62.26   72.64   80.80   86.51   89.59   89.95
SO BUILDWID  STACK1  87.58   82.54   75.00   82.54   87.58   89.95
SO BUILDWID  STACK1  89.59   86.51   80.80   72.64   62.26   50.00
SO BUILDLEN  STACK1  82.54   87.58   89.95   89.59   86.51   80.80
SO BUILDLEN  STACK1  72.64   62.26   50.00   62.26   72.64   80.80
SO BUILDLEN  STACK1  86.51   89.59   89.95   87.58   82.54   75.00
SO BUILDLEN  STACK1  82.54   87.58   89.95   89.59   86.51   80.80
SO BUILDLEN  STACK1  72.64   62.26   50.00   62.26   72.64   80.80
SO BUILDLEN  STACK1  86.51   89.59   89.95   87.58   82.54   75.00
SO XBADJ     STACK1 -47.35  -55.76  -62.48  -67.29  -70.07  -70.71
SO XBADJ     STACK1 -69.21  -65.60  -60.00  -65.60  -69.21  -70.71
SO XBADJ     STACK1 -70.07  -67.29  -62.48  -55.76  -47.35  -37.50
SO XBADJ     STACK1 -35.19  -31.82  -27.48  -22.30  -16.44  -10.09
SO XBADJ     STACK1  -3.43    3.34   10.00    3.34   -3.43  -10.09
SO XBADJ     STACK1 -16.44  -22.30  -27.48  -31.82  -35.19  -37.50
SO YBADJ     STACK1  34.47   32.89   30.31   26.81   22.50   17.50
SO YBADJ     STACK1  11.97    6.08    0.00   -6.08  -11.97  -17.50
SO YBADJ     STACK1 -22.50  -26.81  -30.31  -32.89  -34.47  -35.00
SO YBADJ     STACK1 -34.47  -32.89  -30.31  -26.81  -22.50  -17.50
SO YBADJ     STACK1 -11.97   -6.08    0.00    6.08   11.97   17.50
SO YBADJ     STACK1  22.50   26.81   30.31   32.89   34.47   35.00
SO SRCGROUP  ALL
SO FINISHED

RE STARTING
RE GRIDPOLR  POL1 STA
RE GRIDPOLR  POL1 ORIG STACK1
RE GRIDPOLR  POL1 DIST 175. 350. 500. 1000.
RE GRIDPOLR  POL1 GDIR 36 10 10
RE GRIDPOLR  POL1 END
RE FINISHED

ME STARTING
ME SURFFILE AERMET2.SFC
ME PROFFILE AERMET2.PFL
ME SURFDATA 14735 1988 ALBANY,NY
ME UAIRDATA 14735 1988 ALBANY,NY
ME SITEDATA
ME PROFBASE  0.0 METERS
ME FINISHED

OU STARTING
OU RECTABLE ALIVE FIRST-SECOND
OU MAXTABLE ALIVE 50
OU FINISHED
```

Figure 35. Example of Aermod code taken from the Guide

The tables by receptor and maximum value tables can be output for the source group values or for the individual source values, or both. In addition, when maximum values for individual sources are output, the user has the option of specifying whether the maximum source values are to be the maximum values for each source independently, or the contribution of each source to the maximum group values, or both."

In the operational phase, as regards the flat mode, the Aermod module was then downloaded in open source code mode and, next to this module, also the indispensable AERMET and AERMAP preprocessors, were inserted in the same folder of the dispersive model.

Another optional module has also been downloaded, called AERPLOT, which represents a useful interface for displaying results in open source mode since, in this mode, the outputs are in written form in a .txt file, therefore not very obvious with respect to a **graphic representation** provided by Aerplot.

Actually, Aerplot plots the results at the emissive source and the territory involved in the dispersion through GoogleEarth. Aerplot only needs the coordinate data about the emissive source, after which it plots the results in terms of concentration and the precision about the plot of the results can be optimized by the operator.

At first Aermod was installed on a "Linux" platform available within the Polytechnic University of Marche, while later it was also mounted on a device "windows.

Below, in figure 36, we find the code used for a pilot version of the software, in which input data used in a previous study were entered.

As we can see in table 6 only 5 parameters are needed for the elaboration:

Qs – discharge into the atmosphere	0.5	[g/s]
Hs – height of the chimney	10	[m]
Ts – outer temperature	473	[°K]
Vs – exit velocity	3.7	[m/s]
Ds – chimney diameter	2.4	[m]

Table 7. Data and unit measures used as inputs

aermod - Blocco note

File Modifica Formato Visualizza ?

```
CO STARTING
   TITLEONE A Simple Example Problem for the AERMOD Model with PRIME
   MODELOPT  CONC   FLAT
   AVERTIME  1 24  PERIOD
   POLLUTID  SO2
   RUNORNOT  RUN
   EVENTFIL  aertest_evt.inp
   ERRORFIL  ERRORS.OUT
CO FINISHED

SO STARTING
   ELEVUNIT  METERS
   LOCATION  STACK1  POINT  0.0   0.0   0.0

** Point Source       QS      HS     TS    VS    DS
** Parameters:       ----    ----   ----  ----   ---
   SRCPARAM  STACK1   0.5   10.00    473.0  3.7   2.4


   SRCGROUP  ALL
SO FINISHED

RE STARTING
RE GRIDPOLR POL1 STA
               ORIG STACK1
               DIST 100. 150. 200. 250. 300. 350. 400. 500. 750. 1000.
               GDIR 36 10 10
RE GRIDPOLR POL1 END
RE FINISHED

ME STARTING
   SURFFILE  aermet2.sfc
   PROFFILE  aermet2.pfl
   SURFDATA  16  2015
   UAIRDATA  16  2015
   PROFBASE  125.0  METERS
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE  FIRST-THIRD
   MAXTABLE  ALLAVE  50
   SUMMFILE  AERTEST.SUM
   PLOTFILE  PERIOD ALL AERMOD.PLT
OU FINISHED
```

Figure 36. Aermod code for pilot case

The modeling options are input to the model on the Control pathway. The mandatory keywords for the CO pathway are listed below taken from the Aermod user guidelines:

- STARTING - Indicates the beginning of inputs for the pathway; this keyword is mandatory on each of the pathways.

- TITLEONE - A user-specified title line (up to 68 characters) that will appear on each page of the printed output file (an optional second title line is also available with the keyword TITLE TWO).

- MODELOPT - Controls the modeling options selected for a particular run through a series of secondary keywords.

- AVERTIME - Identifies the averaging periods to be calculated for a particular run.

- POLLUTID - Identifies the type of pollutant being modeled. At the present time, this option has no influence on the results.

- RUNORNOT - A special keyword that tells the model whether to run the full model executions or not. If the user selects not to run, then the runstream setup file will be processed and any input errors reported, but no dispersion calculations will be made.

- FINISHED - Indicates that the user is finished with the inputs for this pathway; this keyword is also mandatory on each of the other pathways.

Then in the SO STARTING section there is information about the source which in this case was placed at zero height above sea level and the data characterizing the emission, in particular:
the Source pathway has the following mandatory keywords:

- LOCATION - Identifies a particular source ID and specifies the source type and location of that source.

In the third part ''RE STARTING'' there are indications that we ask the program about the outputs and their speciation. In this example, concentration values (at one year) are requested for spatial values **from 100 to 1000m** from the source and in all directions, with an angle of 10 ° between one datum and another.

The meteorology pathway has the following four mandatory keywords in addition to the common STARTING and FINISHED keywords:
SURFFILE - Specifies the filename and format for the input surface meteorological data file.

- PROFFILE - Specifies the filename and format for the input profile meteorological data file.

- SURFDATA - Specifies information about the surface meteorological data which will be used in the modeling.

- UAIRDATA - Specifies information about the upper air meteorological data which will be used in the modeling.

- PROFBASE - Specifies the base elevation above MSL for the potential temperature profile.

All of the keywords on the output pathway are optional, although the model will warn the user if no printed outputs are requested and will halt processing if no outputs (printed results or file outputs) are selected. The user has considerable flexibility to select only the outputs that are needed for a particular application. The printed table keywords are:

- RECTABLE - Specifies the selection of high value by receptor table output options.

- MAXTABLE Specifies the selection of overall maximum value table output options.

3) RESULTS

3.1) Results from Aermod

The following chapter discusses the results of the implementation of Aermod open source software.

For ease of viewing, they will be screened using GoogleEarth, remembering that the **flat mode** has been assumed.

Below, in picture 37, we report again the input data of the pilot case and then the relative results concerning weather and soil conditions.

```
   LOCATION   STACK1   POINT   0.0     0.0     0.0

** Point Source         QS       HS       TS      VS      DS
** Parameters:         ----     ----     ----    ----    ---
   SRCPARAM   STACK1    0.5    10.00     473.0   3.7     2.4
```

Figure 37. Input data parameters in terms of flow rate QS, stack height HS, temperature TS, exit velocity VS and stack diameter. Input data and unit measures are shown in table 6.

aermod - Blocco note

File Modifica Formato Visualizza ?

```
 *** AERMOD - VERSION  15181 ***   *** A Simple Example Problem for the AERMOD Model with PRIME            ***        09/09/19
 *** AERMET - VERSION  18081 ***   ***                                                                    ***       11:43:19
                                                                                                                    PAGE    6

 **MODELOPTs:    NonDFAULT CONC       FLAT       RURAL

                                  *** UP TO THE FIRST 24 HOURS OF METEOROLOGICAL DATA ***

   Surface file:   aermet2.sfc                                                                  Met Version:  18081
   Profile file:   aermet2.pfl
   Surface format: FREE
   Profile format: FREE
   Surface station no.:       16                  Upper air station no.:       16
                Name: UNKNOWN                                 Name: UNKNOWN
                Year:   2015                                  Year:   2015

 First 24 hours of scalar data
 YR MO DY JDY HR     H0     U*     W*  DT/DZ ZICNV ZIMCH  M-O LEN    Z0  BOWEN ALBEDO  REF WS   WD     HT  REF TA     HT
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 15 01 01   1 01   -4.4  0.114 -9.000 -9.000 -999.   93.     28.5  0.04   0.93   1.00    4.60  351.  125.0  275.6    2.0
 15 01 01   1 02   -4.5  0.114 -9.000 -9.000 -999.   93.     28.3  0.04   0.93   1.00    4.60  298.  125.0  272.4    2.0
 15 01 01   1 03   -5.5  0.127 -9.000 -9.000 -999.  108.     31.3  0.04   0.93   1.00    5.10  304.  125.0  271.9    2.0
 15 01 01   1 04   -6.8  0.142 -9.000 -9.000 -999.  128.     35.0  0.04   0.93   1.00    5.70  313.  125.0  271.9    2.0
 15 01 01   1 05   -5.5  0.127 -9.000 -9.000 -999.  108.     31.4  0.04   0.93   1.00    5.10  313.  125.0  272.1    2.0
 15 01 01   1 06   -6.8  0.142 -9.000 -9.000 -999.  128.     35.1  0.04   0.93   1.00    5.70  312.  125.0  272.2    2.0
 15 01 01   1 07   -6.8  0.142 -9.000 -9.000 -999.  128.     35.1  0.04   0.93   1.00    5.70  305.  125.0  272.4    2.0
 15 01 01   1 08   -5.5  0.127 -9.000 -9.000 -999.  108.     31.4  0.04   0.93   1.00    5.10  303.  125.0  272.5    2.0
 15 01 01   1 09   -3.5  0.127 -9.000 -9.000 -999.  108.     48.8  0.04   0.93   0.58    5.10  287.  125.0  272.9    2.0
 15 01 01   1 10   11.4  0.288  0.257  0.005   50.  370.   -175.7  0.04   0.93   0.43    5.10  291.  125.0  274.4    2.0
 15 01 01   1 11   29.1  0.304  0.628  0.005  287.  403.    -81.8  0.04   0.93   0.37    5.10  314.  125.0  276.6    2.0
 15 01 01   1 12   39.1  0.311  0.784  0.005  415.  416.    -64.6  0.04   0.93   0.35    5.10  306.  125.0  276.9    2.0
 15 01 01   1 13   40.3  0.311  0.862  0.005  533.  417.    -62.9  0.04   0.93   0.35    5.10  313.  125.0  276.4    2.0
 15 01 01   1 14   33.1  0.283  0.854  0.005  632.  362.    -57.7  0.04   0.93   0.36    4.60  309.  125.0  276.6    2.0
 15 01 01   1 15   17.8  0.248  0.729  0.005  730.  296.    -71.6  0.04   0.93   0.40    4.10  312.  125.0  276.6    2.0
 15 01 01   1 16   -1.6  0.114 -9.000 -9.000 -999.  105.     76.9  0.04   0.93   0.52    4.60  304.  125.0  276.8    2.0
 15 01 01   1 17   -4.5  0.127 -9.000 -9.000 -999.  108.     38.0  0.04   0.93   0.82    5.10  301.  125.0  277.0    2.0
 15 01 01   1 18   -2.3  0.090 -9.000 -9.000 -999.   64.     26.8  0.04   0.93   1.00    3.60  317.  125.0  277.1    2.0
 15 01 01   1 19   -2.9  0.102 -9.000 -9.000 -999.   78.     30.5  0.04   0.93   1.00    4.10  304.  125.0  276.8    2.0
 15 01 01   1 20   -4.1  0.114 -9.000 -9.000 -999.   93.     31.2  0.04   0.93   1.00    4.60  307.  125.0  276.9    2.0
 15 01 01   1 21   -4.4  0.114 -9.000 -9.000 -999.   93.     28.5  0.04   0.93   1.00    4.60  310.  125.0  276.9    2.0
 15 01 01   1 22   -4.4  0.114 -9.000 -9.000 -999.   93.     28.5  0.04   0.93   1.00    4.60  312.  125.0  276.4    2.0
 15 01 01   1 23   -4.5  0.114 -9.000 -9.000 -999.   93.     28.5  0.04   0.93   1.00    4.60  290.  125.0  275.6    2.0
 15 01 01   1 24   -4.5  0.114 -9.000 -9.000 -999.   93.     28.5  0.04   0.93   1.00    4.60  290.  125.0  275.9    2.0
```

Figure 38. The first 24 hours of meteorological data

In picture 38 Aermod processes the first 24 hours of meteorological data and different parameters, such as friction velocities U*, W* and the values characterizing the surface, the bowen ratio and the albedo.

aermod - Blocco note

File Modifica Formato Visualizza ?

*** THE PERIOD (8760 HRS) AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL ***
INCLUDING SOURCE(S): STACK1 ,

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 100.00	150.00	200.00	250.00	300.00	350.00	400.00	500.00	750.00
10.00	0.15260	0.14399	0.12572	0.10727	0.09139	0.07846	0.06825	0.05345	0.03367
20.00	0.16870	0.16151	0.14232	0.12217	0.10452	0.08999	0.07844	0.06159	0.03891
30.00	0.18462	0.17929	0.15954	0.13792	0.11867	0.10264	0.08984	0.07099	0.04539
40.00	0.19400	0.18959	0.16935	0.14677	0.12649	0.10953	0.09598	0.07596	0.04876
50.00	0.19693	0.19227	0.17134	0.14805	0.12715	0.10970	0.09576	0.07527	0.04759
60.00	0.19871	0.19421	0.17280	0.14902	0.12771	0.10994	0.09570	0.07481	0.04663
70.00	0.19951	0.19562	0.17434	0.15063	0.12936	0.11162	0.09739	0.07641	0.04796
80.00	0.19454	0.18979	0.16871	0.14564	0.12506	0.10803	0.09443	0.07445	0.04743
90.00	0.18607	0.17918	0.15814	0.13592	0.11641	0.10051	0.08797	0.06968	0.04518
100.00	0.18424	0.17605	0.15450	0.13231	0.11308	0.09764	0.08562	0.06806	0.04467
110.00	0.19475	0.18801	0.16557	0.14214	0.12173	0.10539	0.09261	0.07374	0.04823
120.00	0.21112	0.20773	0.18471	0.15946	0.13700	0.11881	0.10436	0.08282	0.05337
130.00	0.22375	0.22386	0.20069	0.17375	0.14927	0.12904	0.11280	0.08860	0.05549
140.00	0.22931	0.23170	0.20853	0.18038	0.15448	0.13279	0.11533	0.08948	0.05433
150.00	0.23282	0.23739	0.21473	0.18600	0.15923	0.13660	0.11830	0.09130	0.05480
160.00	0.23972	0.24734	0.22520	0.19567	0.16775	0.14384	0.12437	0.09563	0.05680
170.00	0.25277	0.26394	0.24200	0.21087	0.18093	0.15499	0.13371	0.10221	0.05966
180.00	0.27523	0.29146	0.26981	0.23619	0.20308	0.17402	0.14997	0.11421	0.06569
190.00	0.30892	0.33364	0.31241	0.27515	0.23754	0.20405	0.17614	0.13435	0.07728
200.00	0.34744	0.38199	0.36010	0.31824	0.27534	0.23692	0.20479	0.15648	0.09023
210.00	0.37640	0.41652	0.39232	0.34613	0.29896	0.25701	0.22207	0.16949	0.09748
220.00	0.37604	0.41364	0.38783	0.34114	0.29406	0.25255	0.21815	0.16633	0.09554
230.00	0.33807	0.36871	0.34548	0.30432	0.26290	0.22635	0.19608	0.15025	0.08744
240.00	0.28492	0.30799	0.28846	0.25414	0.21934	0.18840	0.16269	0.12385	0.07070
250.00	0.24704	0.26508	0.24839	0.21919	0.18921	0.16236	0.13993	0.10616	0.06008
260.00	0.23019	0.24680	0.23202	0.20577	0.17841	0.15361	0.13268	0.10101	0.05734
270.00	0.22513	0.24221	0.22875	0.20402	0.17790	0.15391	0.13344	0.10231	0.05876
280.00	0.21936	0.23596	0.22342	0.20013	0.17538	0.15242	0.13272	0.10258	0.05994
290.00	0.20328	0.21652	0.20441	0.18318	0.16084	0.14009	0.12226	0.09499	0.05621
300.00	0.17914	0.18672	0.17427	0.15529	0.13594	0.11824	0.10314	0.08019	0.04772
310.00	0.15510	0.15633	0.14292	0.12576	0.10919	0.09455	0.08225	0.06379	0.03808
320.00	0.13852	0.13479	0.12041	0.10446	0.08989	0.07750	0.06731	0.05224	0.03157
330.00	0.13118	0.12456	0.10946	0.09399	0.08043	0.06918	0.06012	0.04684	0.02881
340.00	0.13044	0.12232	0.10662	0.09109	0.07774	0.06681	0.05811	0.04546	0.02838
350.00	0.13397	0.12510	0.10874	0.09271	0.07903	0.06792	0.05911	0.04638	0.02927
360.00	0.14108	0.13197	0.11475	0.09777	0.08327	0.07151	0.06222	0.04880	0.03086

Figure 39. The period (1year-8760 hours) concentration

In figure 39 we can see predicted concentrations at 1 year after the release.

Figures 39 and 40 show results at 100,150,200,250,300,350,450,500 and 750 m far from the emission source, further we can find the concentration characterization every 10° in a radial way.

Maximum predicted concentration is found at a distance of about **150m** with a radial angle with respect to the emission source of 210° and a concentration of 0.42 µg /m^3, as shown is picture 40.

190.00	0.30892	0.33364	0.31241	0.27515	0.23754
200.00	0.34744	0.38199	0.36010	0.31824	0.27534
210.00	0.37640	0.41652	0.39232	0.34613	0.29896
220.00	0.37604	0.41364	0.38783	0.34114	0.29406
230.00	0.33807	0.36871	0.34548	0.30432	0.26290

Figure 40. Highlighted the highest predicted period concentration

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 100.00	150.00	200.00	250.00	300.00
10.0	5.66178 (15091610)	5.37515 (15041510)	4.91778 (15040412)	4.36550 (15040412)	3.73517 (15040412)
20.0	6.10289 (15030210)	6.51919 (15030210)	5.92842 (15030210)	5.08197 (15030210)	4.32222 (15030210)
30.0	7.16585 (15030210)	7.73397 (15030210)	7.19409 (15092311)	6.36597 (15092311)	5.41305 (15092311)
40.0	6.98911 (15062308)	7.26272 (15092310)	6.72295 (15091715)	5.97487 (15091715)	5.16997 (15091715)
50.0	6.98911 (15062308)	7.08553 (15062308)	6.25661 (15062308)	5.35232 (15091510)	4.56882 (15091714)
60.0	6.99378 (15072709)	8.34132 (15072709)	7.49314 (15072709)	6.31511 (15072709)	5.25570 (15072709)
70.0	7.40837 (15072709)	9.54991 (15011112)	9.25635 (15011112)	7.93252 (15011112)	6.73325 (15011112)
80.0	6.53915 (15051408)	7.52668 (15020411)	7.57608 (15011113)	6.84028 (15011113)	5.96900 (15011113)
90.0	6.16496 (15020411)	7.52668 (15020411)	7.01405 (15020411)	6.49164 (15011115)	5.82000 (15011115)
100.0	5.97311 (15072809)	6.54722 (15061709)	6.54124 (15020413)	6.12560 (15020413)	5.40562 (15020413)
110.0	6.82154 (15051608)	8.01741 (15112211)	7.56609 (15112211)	6.62563 (15112211)	5.71850 (15112211)
120.0	8.13908 (15092409)	9.57617 (15092409)	8.61057 (15092409)	7.34921 (15092409)	6.24265 (15092409)
130.0	7.58390 (15081209)	8.63480 (15101109)	8.00951 (15101109)	6.94424 (15101109)	5.97434 (15101109)
140.0	7.64146 (15092410)	9.66653 (15092410)	9.20763 (15092410)	7.89091 (15092410)	6.59429 (15092410)
150.0	9.90337 (15040110)	11.39420 (15040110)	10.15712 (15040110)	8.53617 (15040110)	7.07437 (15040110)
160.0	9.82435 (15040111)	11.08803 (15040111)	9.65940 (15040111)	7.98804 (15040111)	6.57436 (15040111)
170.0	9.03147 (15040113)	10.25147 (15040113)	9.22244 (15040113)	7.75581 (15040113)	6.47570 (15040113)
180.0	7.04725 (15062409)	8.53855 (15102311)	8.44717 (15102311)	7.51300 (15102311)	6.48536 (15102311)
190.0	7.02487 (15102210)	9.35033 (15102210)	9.30894 (15102210)	8.26528 (15102210)	7.01672 (15102210)
200.0	8.45456 (15040710)	9.70349 (15102209)	9.80428 (15102209)	8.70860 (15102209)	7.50450 (15102209)
210.0	11.40200 (15040710)	12.62492 (15040710)	11.00956 (15040710)	9.07019 (15040710)	7.48088 (15040709)
220.0	18.95791 (15030514)	16.50658 (15030514)	12.48176 (15030512)	9.85784 (15030512)	7.89021 (15030512)
230.0	19.38493 (15030515)	17.36497 (15030515)	13.20522 (15030515)	11.81241 (15030518)	11.97922 (15030518)
240.0	11.83437 (15030516)	11.32335 (15030516)	9.42374 (15030510)	8.38483 (15030518)	8.49146 (15030518)
250.0	7.32331 (15092610)	8.15911 (15101010)	7.12975 (15101010)	6.11228 (15092610)	5.25674 (15031713)
260.0	6.09458 (15041909)	6.73270 (15040311)	6.49055 (15040311)	5.69291 (15040311)	4.84232 (15040311)
270.0	11.21373 (15032511)	12.44713 (15032511)	10.80006 (15032511)	8.91183 (15032511)	7.34034 (15032511)
280.0	10.50117 (15032512)	11.66244 (15032512)	10.20404 (15032512)	8.45425 (15032512)	6.98659 (15032512)
290.0	10.11370 (15032510)	11.32196 (15032510)	9.95306 (15032510)	8.17338 (15032510)	6.70135 (15032510)
300.0	8.48118 (15032509)	10.68588 (15032509)	10.35276 (15032509)	8.96142 (15032509)	7.61445 (15032509)
310.0	5.84967 (15091710)	6.57290 (15091710)	6.04160 (15091710)	5.19692 (15091710)	4.40318 (15091710)
320.0	5.97706 (15091709)	5.84580 (15091709)	5.23411 (15091709)	4.57472 (15091709)	3.96471 (15091709)
330.0	5.29080 (15091709)	5.13740 (15091709)	4.55624 (15091709)	3.94164 (15091709)	3.45808 (15021511)
340.0	5.48758 (15032010)	5.38384 (15040411)	4.81262 (15040411)	4.17183 (15032010)	3.61637 (15032010)
350.0	5.40724 (15062209)	5.53832 (15040411)	5.25399 (15022113)	4.70420 (15022113)	4.08806 (15022113)
360.0	6.14508 (15040210)	6.05435 (15041510)	5.38151 (15041510)	4.56389 (15041510)	3.87696 (15040210)

*** AERMOD - VERSION 15181 *** *** A Simple Example Problem for the AERMOD Model with PRIME *** 10/03/19

Figure 41. First highest 1hour concentration

File Modifica Formato Visualizza ?

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 350.00	400.00	500.00	750.00	1000.00
10.0	3.16625 (15040412)	2.71138 (15101309)	2.23783 (15101309)	1.47581 (15101309)	1.18565 (15011611)
20.0	3.70182 (15030210)	3.20269 (15030210)	2.47679 (15011713)	1.49245 (15011611)	1.49131 (15011611)
30.0	4.58493 (15030210)	4.00392 (15030210)	3.11887 (15030210)	1.86603 (15030210)	1.57159 (15121811)
40.0	4.43632 (15091715)	3.81374 (15091715)	2.86196 (15091715)	1.63560 (15011716)	1.52331 (15111610)
50.0	3.94446 (15091714)	3.40522 (15091714)	2.62857 (15030215)	1.66717 (15050108)	1.46404 (15111610)
60.0	4.39093 (15072709)	3.75216 (15033113)	2.84854 (15030215)	1.75117 (15042708)	1.53448 (15112010)
70.0	5.74202 (15011112)	4.94078 (15011112)	3.76035 (15011112)	2.17024 (15011112)	1.53448 (15112010)
80.0	5.11875 (15011113)	4.37120 (15011113)	3.25334 (15011113)	1.83209 (15013009)	2.18818 (15013009)
90.0	5.11304 (15011115)	4.48056 (15011115)	3.48593 (15011115)	2.03664 (15011115)	1.48403 (15062507)
100.0	4.65998 (15020413)	4.02066 (15020413)	3.05961 (15020413)	1.74170 (15020413)	1.62976 (15020810)
110.0	4.94228 (15112211)	4.30227 (15112211)	3.35540 (15112210)	2.01489 (15112210)	1.84685 (15112910)
120.0	5.34352 (15092409)	4.61903 (15092409)	3.54365 (15092409)	2.07557 (15092409)	1.68150 (15112910)
130.0	5.17391 (15101109)	4.51931 (15101109)	3.58737 (15012310)	2.22568 (15012310)	1.65493 (15122611)
140.0	5.53046 (15092410)	4.68647 (15092410)	3.47857 (15092410)	2.06879 (15022310)	1.39091 (15022310)
150.0	5.86014 (15040110)	4.89630 (15040110)	3.53097 (15040110)	1.93240 (15013011)	1.55452 (15111910)
160.0	5.44017 (15040111)	4.54788 (15040111)	3.28423 (15040111)	1.76578 (15031011)	1.71414 (15122811)
170.0	5.49584 (15013012)	4.71416 (15013012)	3.56934 (15013012)	2.04069 (15013012)	1.52262 (15111410)
180.0	5.52541 (15102311)	4.71198 (15102311)	3.48852 (15102311)	1.90039 (15102311)	1.58538 (15010711)
190.0	5.90666 (15102210)	5.02319 (15102210)	3.75002 (15102210)	2.09269 (15102210)	1.46262 (15010711)
200.0	6.41145 (15102209)	5.49054 (15102209)	4.13475 (15102209)	2.31789 (15102209)	1.96502 (15112716)
210.0	6.26997 (15040709)	5.28954 (15040709)	3.88995 (15040709)	2.78853 (15112616)	2.53944 (15040707)
220.0	6.52736 (15030610)	5.54994 (15030609)	4.55771 (15030522)	3.36869 (15030521)	2.66776 (15030521)
230.0	11.35963 (15030518)	10.43666 (15030518)	8.51506 (15030518)	5.70972 (15030522)	4.03534 (15030522)
240.0	8.03953 (15030518)	7.37320 (15030518)	5.99188 (15030518)	3.92105 (15030608)	2.68524 (15030608)
250.0	4.55960 (15031713)	3.94124 (15031713)	2.98625 (15031713)	1.78991 (15020909)	1.32753 (15020909)
260.0	4.11339 (15041911)	3.51199 (15031712)	2.63034 (15031712)	1.50176 (15041909)	1.18079 (15022610)
270.0	6.08844 (15032511)	5.10341 (15032511)	3.71067 (15032511)	1.95049 (15032511)	1.18340 (15032511)
280.0	5.81237 (15032512)	4.88444 (15032512)	3.56451 (15032512)	2.17485 (15032508)	1.49002 (15032508)
290.0	5.53566 (15032510)	4.62373 (15032510)	3.34141 (15032510)	1.73584 (15032510)	1.24217 (15021610)
300.0	6.43767 (15032509)	5.46707 (15032509)	4.06354 (15032509)	2.23292 (15032509)	1.42312 (15032509)
310.0	3.73044 (15091710)	3.18984 (15091710)	2.40200 (15091710)	1.35653 (15091710)	1.23537 (15091708)
320.0	3.44819 (15091709)	3.02000 (15091709)	2.36870 (15091709)	1.50882 (15091708)	1.50080 (15091708)
330.0	3.04008 (15021511)	2.68869 (15021511)	2.14028 (15021511)	1.33947 (15021511)	1.24200 (15032009)
340.0	3.14445 (15032010)	2.75385 (15032010)	2.15906 (15032010)	1.32010 (15032010)	1.28570 (15032009)
350.0	3.52223 (15022113)	3.04364 (15022113)	2.32785 (15022113)	1.34454 (15022113)	1.30137 (15021510)
360.0	3.32935 (15040210)	2.88401 (15040210)	2.27136 (15101310)	1.39823 (15101310)	1.25808 (15011711)

*** AERMOD - VERSION 15181 *** *** A Simple Example Problem for the AERMOD Model with PRIME *** 10/03/19
*** AERMET - VERSION 18081 *** *** 18:53:30

Figure 42.First highest 1hour concentration

In figure 41 and 42 we can see predicted concentrations regarding the highest 1-hour concentration predicted at 100, 150, 200, 250, 300, 350, 450, 500, 750 and 1000 m from the emission source spacing around 360°.

We found the highest value of about **19 µg /m^3 at 100 m** far from the source with an angle of 230°, confirming the trend of the predicted period concentrations.

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 100.00	150.00	200.00	250.00	300.00
10.0	5.36059 (15040210)	5.34184 (15091610)	4.74717 (15041510)	3.99681 (15041510)	3.40170 (15090213)
20.0	5.45040 (15030211)	5.67475 (15011713)	5.42731 (15011713)	4.85290 (15011713)	4.23411 (15011713)
30.0	7.07411 (15092310)	7.66120 (15092310)	7.08320 (15030210)	6.15048 (15030210)	5.29514 (15030210)
40.0	6.71221 (15092310)	7.18837 (15062309)	6.69556 (15062309)	5.86836 (15091511)	5.05172 (15091511)
50.0	6.59320 (15032610)	6.74855 (15091510)	6.21714 (15091510)	5.28323 (15062308)	4.53668 (15091510)
60.0	6.21846 (15043009)	6.48838 (15043009)	6.34884 (15033113)	5.75179 (15033113)	5.03753 (15033113)
70.0	7.25383 (15033010)	8.83961 (15072709)	8.25765 (15033011)	7.27551 (15033011)	6.22522 (15033011)
80.0	6.27083 (15081709)	7.33132 (15011113)	7.01405 (15020411)	6.08671 (15072711)	5.22864 (15072711)
90.0	5.60076 (15072809)	6.39126 (15011115)	6.74207 (15011115)	6.06947 (15020411)	5.18940 (15020411)
100.0	5.89210 (15061709)	6.25813 (15020413)	6.00264 (15061709)	5.16466 (15061709)	4.38151 (15061709)
110.0	6.12490 (15112211)	7.95028 (15112210)	7.44308 (15112210)	6.57630 (15112210)	5.65918 (15112210)
120.0	7.92721 (15051608)	8.34978 (15051608)	7.51661 (15051608)	6.51800 (15101110)	5.58455 (15101110)
130.0	7.30650 (15101109)	8.17085 (15081209)	7.80455 (15010112)	6.76268 (15012310)	5.83378 (15012310)
140.0	7.48986 (15092009)	8.98674 (15022311)	8.24250 (15022311)	7.10372 (15022311)	6.03989 (15022311)
150.0	9.82435 (15040111)	11.08803 (15040111)	9.65940 (15040111)	7.98804 (15040111)	6.57436 (15040111)
160.0	8.34260 (15040115)	9.39500 (15040115)	8.46060 (15040115)	7.21051 (15040112)	6.11259 (15040112)
170.0	8.13886 (15040114)	9.29446 (15022811)	8.88687 (15013012)	7.62237 (15013012)	6.46275 (15013012)
180.0	6.72975 (15032310)	8.11122 (15062409)	7.50546 (15062409)	6.32631 (15062409)	5.24064 (15062409)
190.0	6.46045 (15012311)	8.21917 (15102310)	8.09814 (15102310)	7.07967 (15102310)	5.93372 (15102310)
200.0	7.96500 (15040711)	9.45325 (15102211)	9.21856 (15102211)	8.11725 (15102211)	6.97368 (15102211)
210.0	11.36522 (15040711)	12.54138 (15040711)	10.81645 (15040711)	8.92074 (15040711)	7.46206 (15040710)
220.0	18.85792 (15030513)	16.15962 (15030513)	12.39750 (15030514)	9.55553 (15030611)	7.82958 (15030610)
230.0	18.85792 (15030513)	16.96248 (15030516)	13.10045 (15030517)	10.29826 (15030517)	8.86067 (15030522)
240.0	11.81568 (15030515)	10.75861 (15030515)	9.26331 (15030811)	7.88512 (15030811)	6.60237 (15030811)
250.0	6.76488 (15101010)	7.81148 (15092610)	7.10733 (15092610)	5.96048 (15031713)	5.19777 (15092610)
260.0	5.83158 (15032511)	6.51572 (15032511)	6.20869 (15041911)	5.58913 (15041911)	4.83800 (15041911)
270.0	7.95762 (15032513)	9.15622 (15032513)	8.35105 (15032513)	7.03869 (15032513)	6.03849 (15040311)
280.0	10.11370 (15032510)	11.32196 (15032510)	9.95306 (15032510)	8.17338 (15032510)	6.70135 (15032510)
290.0	8.14794 (15032512)	9.08211 (15032512)	7.91342 (15032512)	6.47620 (15032512)	5.29058 (15032512)
300.0	5.74557 (15091310)	6.31540 (15091710)	5.79270 (15091710)	4.97126 (15091710)	4.30386 (15040312)
310.0	5.79423 (15051209)	5.92010 (15032509)	5.74032 (15032509)	4.80287 (15032509)	3.95379 (15032509)
320.0	5.18710 (15051209)	4.77968 (15061310)	4.74648 (15041712)	4.29057 (15041712)	3.71206 (15041712)
330.0	4.92774 (15021511)	4.98428 (15021511)	4.43584 (15021511)	3.93943 (15021511)	3.38212 (15091709)
340.0	5.12137 (15101211)	5.34942 (15032010)	4.77141 (15032010)	4.08616 (15040411)	3.43827 (15040411)
350.0	5.28558 (15062208)	5.34230 (15022113)	4.95764 (15040411)	4.21876 (15022114)	3.75315 (15022114)
360.0	5.78497 (15091610)	5.90098 (15040210)	5.27498 (15040210)	4.53499 (15040210)	3.84382 (15041510)

*** AERMOD - VERSION 15181 *** *** A Simple Example Problem for the AERMOD Model with PRIME *** 10/03/19

Figure 43. Second highest 1 hour predicted concentrations

aermod - Blocco note

File Modifica Formato Visualizza ?

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 350.00	400.00	500.00	750.00	1000.00
10.0	2.99122 (15101309)	2.69476 (15040412)	2.00662 (15040412)	1.26348 (15091408)	1.10089 (15101309)
20.0	3.67445 (15011713)	3.20106 (15011713)	2.45007 (15030210)	1.45027 (15011713)	1.37703 (15120211)
30.0	4.56524 (15092311)	3.87805 (15092311)	2.87938 (15092311)	1.64739 (15011714)	1.51309 (15041108)
40.0	4.26912 (15091511)	3.62532 (15091511)	2.72023 (15091714)	1.58511 (15043008)	1.31372 (15101809)
50.0	3.85645 (15030215)	3.38646 (15030215)	2.58963 (15050108)	1.54994 (15072708)	1.45645 (15062707)
60.0	4.34881 (15033113)	3.70912 (15072709)	2.83129 (15033113)	1.63734 (15030215)	1.32009 (15011411)
70.0	5.26405 (15033011)	4.45153 (15033011)	3.27466 (15033011)	1.78518 (15011113)	1.52300 (15111510)
80.0	4.45221 (15020411)	3.85350 (15020411)	2.96764 (15011512)	1.82857 (15011512)	1.57446 (15121711)
90.0	4.45221 (15020411)	3.85350 (15020411)	2.95414 (15020411)	1.71057 (15020411)	1.45017 (15071707)
100.0	3.85105 (15020414)	3.35499 (15020414)	2.57250 (15020414)	1.59530 (15020810)	1.45017 (15071707)
110.0	4.90119 (15112210)	4.29240 (15112210)	3.33325 (15112211)	1.97590 (15112211)	1.58146 (15121111)
120.0	4.79050 (15101110)	4.13973 (15101110)	3.17204 (15101110)	1.91458 (15112410)	1.52230 (15122611)
130.0	5.08414 (15012310)	4.50504 (15012310)	3.52260 (15101109)	2.11415 (15101109)	1.53039 (15012310)
140.0	5.17504 (15123013)	4.48466 (15123013)	3.45745 (15022310)	2.00302 (15123013)	1.31634 (15123013)
150.0	5.44017 (15040111)	4.54788 (15040111)	3.29645 (15013013)	1.90856 (15112212)	1.45331 (15041208)
160.0	5.16858 (15040112)	4.39313 (15040112)	3.25075 (15040112)	1.73418 (15040112)	1.62078 (15111910)
170.0	5.42722 (15040113)	4.58718 (15040113)	3.37343 (15040113)	1.92325 (15022811)	1.50893 (15122811)
180.0	4.34868 (15062409)	3.72287 (15021713)	2.82614 (15021713)	1.62496 (15032310)	1.35457 (15111410)
190.0	4.96387 (15020712)	4.27635 (15020712)	3.25494 (15020712)	1.99323 (15112715)	1.34520 (15102210)
200.0	5.93425 (15102211)	5.06119 (15102211)	3.76964 (15102211)	2.16149 (15102309)	1.49515 (15102209)
210.0	6.18365 (15040710)	5.17826 (15040710)	3.76225 (15040710)	2.32047 (15040707)	2.37930 (15112616)
220.0	6.51538 (15030609)	5.49206 (15030610)	4.14775 (15030609)	3.11124 (15030522)	2.37930 (15112616)
230.0	9.21511 (15030522)	9.09634 (15030522)	8.22125 (15030522)	5.16299 (15030518)	3.67264 (15030524)
240.0	5.98814 (15030608)	6.10397 (15030608)	5.67988 (15030608)	3.59352 (15030518)	2.66523 (15030520)
250.0	4.43197 (15092610)	3.81205 (15092610)	2.90118 (15092610)	1.67457 (15092610)	1.16227 (15041908)
260.0	4.10415 (15031712)	3.50079 (15041911)	2.59642 (15041911)	1.49757 (15041817)	1.16227 (15041908)
270.0	5.12168 (15040311)	4.33604 (15040311)	3.19807 (15040311)	1.72869 (15040311)	1.11010 (15092609)
280.0	5.53566 (15032510)	4.62373 (15032510)	3.51776 (15032508)	1.88322 (15032512)	1.15008 (15040310)
290.0	4.35635 (15032512)	3.64680 (15032414)	2.79051 (15032414)	1.59433 (15031709)	1.21672 (15031709)
300.0	3.70042 (15040312)	3.18707 (15032014)	2.44058 (15032014)	1.43345 (15051518)	1.15979 (15021610)
310.0	3.25585 (15032509)	2.70587 (15032509)	1.92789 (15032509)	1.27319 (15091708)	0.87904 (15091710)
320.0	3.15099 (15041712)	2.68055 (15041712)	2.08431 (15040415)	1.45202 (15091709)	1.03656 (15091709)
330.0	2.91566 (15091709)	2.53260 (15091709)	1.95483 (15091709)	1.30398 (15040309)	1.23537 (15091708)
340.0	2.90358 (15040411)	2.47449 (15040411)	1.86526 (15022115)	1.31803 (15032009)	1.05668 (15021510)
350.0	3.26967 (15022114)	2.84067 (15022114)	2.18362 (15022114)	1.30533 (15021510)	1.17285 (15011711)
360.0	3.28345 (15101310)	2.88352 (15101310)	2.22423 (15040210)	1.32540 (15040210)	1.21558 (15012911)

*** AERMOD - VERSION 15181 *** *** A Simple Example Problem for the AERMOD Model with PRIME *** 10/03/19

*** AERMET - VERSION 18081 *** *** *** 18:53:30

PAGE 13

Figure 44. Second highest 1 hour predicted concentrations

In figure 43 and 44 we can see predicted concentrations regarding the second highest 1-hour concentration predicted at 100, 150, 200, 250, 300, 350, 450, 500, 750 and 1000 m from the emission source spacing around 360°.

We found the highest value of about **18 µg /m^3** at 100 m far from the source with an angle of 220-230°.

aermod - Blocco note

File Modifica Formato Visualizza ?

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 100.00	150.00	200.00	250.00	300.00
10.0	0.93395 (15091424)	0.98627 (15091424)	0.90963 (15091424)	0.79665 (15091424)	0.68615 (15091424)
20.0	1.22785 (15091424)	1.33757 (15091424)	1.25583 (15091424)	1.11928 (15091424)	0.97750 (15091424)
30.0	1.55842 (15062324)	1.85404 (15062324)	1.83690 (15062324)	1.67259 (15062324)	1.47754 (15062324)
40.0	1.71179 (15062324)	2.02979 (15062324)	2.01311 (15062324)	1.83745 (15062324)	1.62859 (15062324)
50.0	1.36834 (15062324)	1.61129 (15062324)	1.58960 (15062324)	1.44168 (15062324)	1.26916 (15062324)
60.0	1.38025 (15051424)	1.58181 (15051424)	1.51759 (15051424)	1.35074 (15051424)	1.17055 (15051424)
70.0	1.72733 (15051424)	1.99160 (15072724)	1.93924 (15072724)	1.74110 (15072724)	1.51614 (15072724)
80.0	1.68642 (15072724)	2.04769 (15072724)	2.02530 (15072724)	1.83812 (15072724)	1.61445 (15072724)
90.0	1.28014 (15072724)	1.56844 (15072724)	1.55619 (15072724)	1.41167 (15072724)	1.23667 (15072724)
100.0	0.86885c(15040824)	0.87960 (15072724)	0.87070 (15072724)	0.78255 (15072724)	0.67814 (15072724)
110.0	0.75920c(15040824)	1.09098 (15112224)	1.09647 (15112224)	1.00199 (15112224)	0.89307 (15112224)
120.0	1.22234 (15092424)	1.54491 (15092424)	1.50616 (15092424)	1.36342 (15092424)	1.19805 (15092424)
130.0	1.34525 (15092424)	1.70989 (15092424)	1.67659 (15092424)	1.51408 (15092424)	1.32692 (15092424)
140.0	1.53756c(15022324)	1.91899c(15022324)	1.89141c(15022324)	1.70817c(15022324)	1.50209c(15022324)
150.0	2.07715c(15040124)	2.41351c(15040124)	2.20903c(15040124)	1.87789c(15040124)	1.57609c(15040124)
160.0	2.47208c(15040124)	2.88743c(15040124)	2.64409c(15040124)	2.25925c(15040124)	1.90623c(15040124)
170.0	1.80014c(15040124)	2.10640c(15040124)	1.92803c(15040124)	1.63404c(15040124)	1.36869c(15040124)
180.0	1.38385c(15080424)	1.63721c(15080424)	1.58727c(15080424)	1.41869c(15080424)	1.22972c(15080424)
190.0	1.57935c(15080524)	1.84369c(15080524)	1.80245c(15080524)	1.62605c(15080524)	1.42282c(15080524)
200.0	1.79574 (15040724)	2.22709c(15102224)	2.24483c(15102224)	2.00482c(15102224)	1.73081c(15102224)
210.0	2.85394 (15040724)	3.36283 (15040724)	3.11406 (15040724)	2.67671 (15040724)	2.26723 (15040724)
220.0	4.62936 (15030524)	4.55615 (15030524)	3.80048 (15030524)	3.16100 (15030524)	2.70209 (15030524)
230.0	5.63509 (15030524)	5.68375 (15030524)	5.01213 (15030524)	4.41563 (15030524)	3.99840 (15030524)
240.0	2.65460 (15030524)	2.70621 (15030524)	2.36316 (15030524)	2.03884 (15030524)	1.81291 (15030524)
250.0	1.50744 (15071024)	1.77890 (15071024)	1.74306 (15071024)	1.56566 (15071024)	1.36264 (15071024)
260.0	1.27998c(15062924)	1.44118 (15041924)	1.40116 (15041924)	1.25581 (15041924)	1.09214 (15041924)
270.0	1.42937 (15032524)	1.64496 (15032524)	1.49934 (15032524)	1.26264 (15032524)	1.04531 (15032524)
280.0	1.94581 (15032524)	2.26444 (15032524)	2.09329 (15032524)	1.78612 (15032524)	1.49814 (15032524)
290.0	1.52375 (15032524)	1.76354 (15032524)	1.64904c(15032424)	1.52337c(15032424)	1.36267c(15032424)
300.0	1.12213 (15100224)	1.27264c(15032424)	1.26358c(15032424)	1.15982c(15032424)	1.03121c(15032424)
310.0	0.90898c(15091724)	0.98957c(15091724)	0.92327 (15100224)	0.82284 (15100224)	0.71876 (15100224)
320.0	0.78801c(15091724)	0.83579c(15091724)	0.75652c(15091724)	0.65008c(15091724)	0.55522c(15091724)
330.0	0.68420 (15040424)	0.78293 (15040424)	0.76110 (15040424)	0.69793 (15040424)	0.61833 (15040424)
340.0	0.81408 (15101324)	0.90487 (15040424)	0.86624 (15040424)	0.77936 (15040424)	0.68058 (15040424)
350.0	0.93886 (15101324)	0.98398 (15101324)	0.92977 (15022124)	0.84047 (15022124)	0.73822 (15022124)
360.0	0.95826 (15101324)	1.02110 (15101324)	0.93529 (15101324)	0.81494 (15101324)	0.70091 (15101324)

*** AERMOD - VERSION 15181 *** *** A Simple Example Problem for the AERMOD Model with PRIME *** 10/03/19

*** AERMET - VERSION 18081 *** *** *** 18:53:30

Figure 45. First highest 24hour concentrations

aermod - Blocco note

File Modifica Formato Visualizza ?

*** NETWORK ID: POL1 ; NETWORK TYPE: GRIDPOLR ***

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 350.00	400.00	500.00	750.00	1000.00
10.0	0.59060 (15091424)	0.51109 (15091424)	0.39144 (15091424)	0.22651 (15091424)	0.15526 (15091424)
20.0	0.84857 (15091424)	0.73893 (15091424)	0.57083 (15091424)	0.33280 (15091424)	0.22438 (15091424)
30.0	1.29062 (15062324)	1.12980 (15062324)	0.87399 (15062324)	0.49902 (15062324)	0.32019 (15062324)
40.0	1.42744 (15062324)	1.25556 (15062324)	0.98056 (15062324)	0.57446 (15062324)	0.37690 (15062324)
50.0	1.10137 (15062324)	0.95717 (15062324)	0.73276 (15062324)	0.41009 (15062324)	0.25725 (15062324)
60.0	1.00495 (15051424)	0.86428 (15051424)	0.64972 (15051424)	0.35161 (15051424)	0.21361 (15051424)
70.0	1.30655 (15072724)	1.12827 (15072724)	0.85478 (15051424)	0.48801 (15051424)	0.31346 (15051424)
80.0	1.40117 (15072724)	1.21744 (15072724)	0.93191 (15072724)	0.52327 (15072724)	0.32865 (15072724)
90.0	1.06995 (15072724)	0.92572 (15072724)	0.70173 (15072724)	0.38217 (15072724)	0.23248 (15072724)
100.0	0.59431 (15020424)	0.52030 (15020424)	0.40614 (15020424)	0.23707 (15020424)	0.15474 (15020424)
110.0	0.79000 (15112224)	0.69978 (15112224)	0.55693 (15112224)	0.34458 (15112224)	0.23693 (15112224)
120.0	1.04305 (15092424)	0.90525 (15092424)	0.69201 (15092424)	0.38871 (15092424)	0.24440 (15092424)
130.0	1.15521 (15092424)	1.00337 (15092424)	0.76956 (15092424)	0.43842 (15092424)	0.28017 (15092424)
140.0	1.31473c(15022324)	1.14969c(15022324)	0.89674c(15022324)	0.53665c(15022324)	0.36008c(15022324)
150.0	1.32635c(15040124)	1.12403c(15040124)	0.83000c(15040124)	0.44615c(15040124)	0.28040c(15032724)
160.0	1.61082c(15040124)	1.37007c(15040124)	1.01763c(15040124)	0.55163c(15040124)	0.34002c(15040124)
170.0	1.15009c(15040124)	0.98564c(15021724)	0.78057c(15021724)	0.47529c(15021724)	0.32318c(15021724)
180.0	1.05383c(15080424)	0.91073c(15021724)	0.71218c(15021724)	0.42052c(15021724)	0.27730c(15021724)
190.0	1.22842c(15080524)	1.06089c(15080524)	0.80209c(15080524)	0.44037c(15080524)	0.27205c(15080524)
200.0	1.48314c(15102224)	1.26986c(15102224)	0.95137c(15102224)	0.52025c(15102224)	0.35011 (15112724)
210.0	1.92777 (15040724)	1.65426 (15040724)	1.25999 (15040724)	0.75263 (15040724)	0.51147 (15040724)
220.0	2.36584 (15030524)	2.12424 (15030524)	1.71014 (15030524)	1.09416 (15030524)	0.76470 (15030524)
230.0	3.69756 (15030524)	3.47354 (15030524)	2.98414 (15030524)	2.10665 (15030524)	1.55121 (15030524)
240.0	1.65161 (15030524)	1.54221 (15030524)	1.29844 (15030524)	0.87878 (15030524)	0.62975 (15030524)
250.0	1.17300 (15071024)	1.01026 (15071024)	0.76028 (15071024)	0.41393 (15071024)	0.25597 (15071024)
260.0	0.94139 (15041924)	0.81372 (15041924)	0.62231 (15041924)	0.36368 (15041924)	0.24474 (15041924)
270.0	0.88511c(15070224)	0.77265c(15070224)	0.59664c(15070224)	0.34470c(15070224)	0.22200c(15070224)
280.0	1.26318 (15032524)	1.07446 (15032524)	0.79890 (15032524)	0.43456 (15032524)	0.28273c(15021624)
290.0	1.20088c(15032424)	1.05450c(15032424)	0.82274c(15032424)	0.48249c(15032424)	0.31550c(15032424)
300.0	0.90414c(15032424)	0.78902c(15032424)	0.62043 (15100224)	0.39460 (15100224)	0.27915 (15100224)
310.0	0.62214 (15100224)	0.54113 (15100224)	0.41882 (15100224)	0.25083 (15100224)	0.17439c(15091724)
320.0	0.47996c(15091724)	0.42160c(15091724)	0.33791c(15091724)	0.22343c(15091724)	0.17039c(15091724)
330.0	0.53808 (15040424)	0.46593 (15040424)	0.35513 (15040424)	0.19775 (15040424)	0.12284 (15040424)
340.0	0.58646 (15040424)	0.50490 (15040424)	0.38253 (15040424)	0.22038 (15022124)	0.14493 (15022124)
350.0	0.64215 (15022124)	0.55904 (15022124)	0.43289 (15022124)	0.25714 (15022124)	0.17499 (15022124)
360.0	0.60261 (15101324)	0.52220 (15101324)	0.40218 (15101324)	0.23689 (15101324)	0.16152 (15101324)

*** AERMOD - VERSION 15181 *** *** A Simple Example Problem for the AERMOD Model with PRIME *** 10/03/19

Figure 46. First highest 24hour concentrations

In figure 45 and 46 we can see predicted concentrations regarding the highest 24-hour concentration predicted at 100, 150, 200, 250, 300, 350, 450, 500, 750 and 1000 m from the emission source spacing around 360°.

We found the highest value of about **5.7 µg /m^3** at 150 m far from the source with an angle of 230°.

File Modifica Formato Visualizza ?

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 100.00	150.00	200.00	250.00	300.00
10.0	0.78910 (15101324)	0.83955 (15101324)	0.76812 (15101324)	0.66746 (15101324)	0.57245 (15101324)
20.0	1.02140 (15062324)	1.22130 (15062324)	1.20434 (15062324)	1.08799 (15062324)	0.95060 (15062324)
30.0	1.30778 (15092324)	1.50358 (15092324)	1.45637 (15092324)	1.31978 (15050124)	1.16047 (15050124)
40.0	1.49357 (15050124)	1.71111 (15050124)	1.67280 (15050124)	1.51560 (15050124)	1.33188 (15050124)
50.0	1.31336 (15050124)	1.49910 (15050124)	1.45418 (15050124)	1.30992 (15050124)	1.14664 (15050124)
60.0	1.21507 (15072724)	1.43963 (15072724)	1.36929 (15072724)	1.20899 (15072724)	1.04974 (15033124)
70.0	1.65528 (15072724)	1.98169 (15051424)	1.90055 (15051424)	1.69619 (15051424)	1.47885 (15051424)
80.0	1.53272 (15051424)	1.73886 (15051424)	1.64861 (15051424)	1.45448 (15051424)	1.25522 (15051424)
90.0	1.02020b(15081724)	1.15837b(15081724)	1.10330b(15081724)	0.96647b(15081724)	0.82250b(15081724)
100.0	0.82422 (15051324)	0.86872 (15061724)	0.80890 (15061724)	0.75292 (15020424)	0.67669 (15020424)
110.0	0.75598c(15052324)	0.91408 (15092424)	0.89193 (15092424)	0.80184 (15092424)	0.69874 (15092424)
120.0	1.03649 (15101124)	1.27835 (15101124)	1.24411 (15101124)	1.10346 (15101124)	0.95506 (15101124)
130.0	1.20838c(15022324)	1.50264c(15022324)	1.48088c(15022324)	1.32550c(15022324)	1.15295c(15022324)
140.0	1.38807b(15081624)	1.50891b(15081624)	1.38841b(15081624)	1.19818b(15081624)	1.01858 (15123024)
150.0	1.44450b(15081624)	1.59158b(15081624)	1.47665b(15081624)	1.28723c(15032724)	1.13077c(15032724)
160.0	1.27031b(15052624)	1.48257c(15032724)	1.46607c(15032724)	1.33168c(15032724)	1.17662c(15032724)
170.0	1.14886c(15021724)	1.46835c(15021724)	1.47896c(15021724)	1.38504c(15021724)	1.25577c(15021724)
180.0	1.36312c(15051724)	1.51058c(15080524)	1.46804c(15080524)	1.31972c(15080524)	1.17577c(15021724)
190.0	1.55381c(15080424)	1.84125c(15080424)	1.79648c(15080424)	1.61835c(15080424)	1.41304c(15080424)
200.0	1.70124c(15102224)	2.10149 (15040724)	1.93070 (15040724)	1.62895 (15040724)	1.36708 (15052224)
210.0	2.19779 (15030724)	2.64923 (15030724)	2.50800 (15030724)	2.16306 (15030724)	1.83519 (15030724)
220.0	3.40854 (15030624)	3.94372 (15030624)	3.59883 (15030624)	3.06071 (15030624)	2.58503 (15030624)
230.0	2.27872 (15030624)	2.65611 (15030624)	2.43916 (15030624)	2.12858 (15030624)	1.85568 (15030624)
240.0	1.83359 (15071024)	2.15166 (15071024)	2.11641 (15071024)	1.91025 (15071024)	1.67124 (15071024)
250.0	1.30436c(15062924)	1.42268c(15042424)	1.38895c(15042424)	1.24709c(15042424)	1.08579c(15042424)
260.0	1.25138 (15041924)	1.40839c(15062924)	1.33249c(15062924)	1.18520c(15062924)	1.03054c(15062924)
270.0	1.19570c(15052924)	1.34198c(15052924)	1.28940c(15052924)	1.15578c(15052924)	1.01371c(15070224)
280.0	1.27615c(15052924)	1.44164c(15032424)	1.42947c(15032424)	1.30747c(15032424)	1.15774c(15032424)
290.0	1.36419c(15032424)	1.64986c(15032424)	1.63013 (15032524)	1.38325 (15032524)	1.15545 (15032524)
300.0	1.06581c(15032424)	1.26641 (15100224)	1.22795 (15100224)	1.11898 (15100224)	0.99839 (15100224)
310.0	0.89668 (15100224)	0.97758 (15100224)	0.89975c(15091724)	0.77167c(15091724)	0.65576c(15091724)
320.0	0.69149 (15061324)	0.73103 (15061324)	0.68294 (15061324)	0.60621 (15061324)	0.52659 (15061324)
330.0	0.65846 (15101324)	0.67948 (15101324)	0.60543 (15101324)	0.51722 (15022124)	0.45269 (15022124)
340.0	0.80749 (15040424)	0.85057 (15022124)	0.83178 (15022124)	0.75234 (15022124)	0.65977 (15022124)
350.0	0.87726 (15022124)	0.95486 (15022124)	0.90150 (15040424)	0.79996 (15040424)	0.69155 (15040424)
360.0	0.82979 (15040424)	0.89335 (15040424)	0.83688 (15040424)	0.73585 (15040424)	0.63225 (15040424)

*** AERMOD - VERSION 15181 *** *** A Simple Example Problem for the AERMOD Model with PRIME *** 10/03/19
*** AERMET - VERSION 18081 *** *** *** 18:53:30
PAGE 18

Figure 47. Second highest 24-hour concentrations

aermod - Blocco note

File Modifica Formato Visualizza ?

** CONC OF PM IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 350.00	400.00	500.00	750.00	1000.00
10.0	0.49189 (15101324)	0.42660 (15101324)	0.32806 (15101324)	0.19304 (15101324)	0.13267 (15101324)
20.0	0.81868 (15062324)	0.70476 (15062324)	0.52777 (15062324)	0.27766 (15062324)	0.19656c(15020324)
30.0	1.00807 (15050124)	0.87833 (15050124)	0.67262 (15050124)	0.38570 (15091424)	0.26730c(15020324)
40.0	1.15865 (15050124)	1.01107 (15050124)	0.77716 (15050124)	0.44499 (15050124)	0.28716 (15050124)
50.0	0.99361 (15050124)	0.86165 (15050124)	0.65668 (15050124)	0.36848 (15050124)	0.23503 (15050124)
60.0	0.90430 (15033124)	0.78153 (15033124)	0.59400 (15033124)	0.33250 (15033124)	0.21331 (15033124)
70.0	1.28173 (15051424)	1.11348 (15051424)	0.85452 (15072724)	0.46974 (15072724)	0.29058 (15072724)
80.0	1.07816 (15051424)	0.92884 (15051424)	0.70213 (15051424)	0.38804 (15051424)	0.24257 (15051424)
90.0	0.69303b(15081724)	0.58966 (15033024)	0.44821 (15033024)	0.24528 (15033024)	0.15584 (15072924)
100.0	0.57924 (15072724)	0.49407 (15072724)	0.36353 (15072724)	0.20405 (15061724)	0.13938 (15061724)
110.0	0.60163 (15092424)	0.52985 (15020424)	0.41667 (15020424)	0.24622 (15020424)	0.16126 (15020424)
120.0	0.82973 (15101124)	0.72277 (15101124)	0.55616 (15101124)	0.32404 (15101124)	0.21307 (15101124)
130.0	0.99503c(15022324)	0.85857c(15022324)	0.65549 (15010124)	0.39535 (15010124)	0.26878 (15010124)
140.0	0.89175 (15123024)	0.78053 (15123024)	0.60727 (15123024)	0.35827 (15123024)	0.27463c(15012024)
150.0	0.98122c(15032724)	0.85230c(15032724)	0.65597c(15032724)	0.39191c(15032724)	0.27419c(15040124)
160.0	1.02784c(15032724)	0.89732c(15032724)	0.69590c(15032724)	0.41566c(15032724)	0.29038c(15032724)
170.0	1.11572c(15021724)	0.97196c(15040124)	0.71232c(15040124)	0.39067 (15022824)	0.25367 (15022824)
180.0	1.03735c(15021724)	0.90343c(15080424)	0.67353c(15080424)	0.35868c(15080424)	0.23974c(15111424)
190.0	1.21855c(15080424)	1.05085c(15080424)	0.79205c(15080424)	0.43189c(15080424)	0.26532c(15080424)
200.0	1.19023 (15052224)	1.03689 (15052224)	0.80162 (15052224)	0.48344 (15112724)	0.32488c(15102224)
210.0	1.56217 (15030724)	1.33495 (15030724)	0.99947 (15030724)	0.55043 (15030724)	0.34910c(15092124)
220.0	2.19032 (15030624)	1.87261 (15030624)	1.41370 (15030624)	0.82427 (15030624)	0.56342 (15030624)
230.0	1.62078 (15030624)	1.43853 (15030624)	1.17158 (15030624)	0.84501 (15030624)	0.72883 (15030624)
240.0	1.44588 (15071024)	1.25182 (15071024)	0.95234 (15071024)	0.53267 (15071024)	0.33698 (15071024)
250.0	0.93431c(15042424)	0.80539c(15042424)	0.60787c(15042424)	0.33741c(15042424)	0.21951c(15062924)
260.0	0.88876c(15062924)	0.76928c(15062924)	0.58763c(15062924)	0.33546c(15062924)	0.22079c(15083124)
270.0	0.87114 (15032524)	0.74910c(15090124)	0.57960c(15090124)	0.33087c(15090124)	0.21642c(15083124)
280.0	1.01238c(15032424)	0.88285c(15032424)	0.68074c(15032424)	0.39549c(15021624)	0.26998 (15032524)
290.0	0.96675 (15032524)	0.83395 (15040324)	0.64287 (15040324)	0.38674 (15100224)	0.27288 (15100224)
300.0	0.87926 (15100224)	0.77703 (15100224)	0.60802c(15032424)	0.34683c(15032424)	0.22218c(15032424)
310.0	0.56202c(15091724)	0.48891c(15091724)	0.38393c(15091724)	0.24140c(15091724)	0.16940 (15100224)
320.0	0.45474 (15061324)	0.39488 (15061324)	0.30457 (15061324)	0.18012 (15061324)	0.12040 (15061324)
330.0	0.39026 (15022124)	0.33676 (15022124)	0.25726 (15022124)	0.15003c(15091724)	0.11696c(15091724)
340.0	0.57200 (15022124)	0.49575 (15022124)	0.38078 (15022124)	0.21479 (15040424)	0.13663 (15040424)
350.0	0.59218 (15040424)	0.50825 (15040424)	0.38478 (15040424)	0.22003 (15040424)	0.14377 (15040424)
360.0	0.53972 (15040424)	0.46325 (15040424)	0.35229 (15040424)	0.20710 (15040424)	0.13991 (15040424)

*** AERMOD - VERSION 15181 *** *** A Simple Example Problem for the AERMOD Model with PRIME *** 10/03/19

*** AERMET - VERSION 18081 *** *** *** 18:53:30

Figure 48. Second highest 24-hour concentrations

In figure 47 and 48 we can see predicted concentrations regarding the second highest 24-hour concentration predicted at 100, 150, 200, 250, 300, 350, 450, 500, 750 and 1000 m from the emission source spacing around 360°.

We found the highest value of about **3.9 µg /m^3** at 150 m far from the source with an angle of 220°.

In figure 49 we can see the summarizing of period predicted concentrations with respect to the highest values and their position with respect to the emission source, expressed in meters.

The emission source is placed with UTM coordinates 43.61 east and 13.61 north, so placed over the city of Ancona, for simplicity sake.

In figure 50 we find the plot over GoogleEarth of the predicted period concentrations , reminding we are assuming terrain as flat.

GROUP ID		AVERAGE CONC	RECEPTOR (XR, YR, ZELEV, ZHILL, ZFLAG)	OF TYPE	NETWORK GRID-ID
ALL	1ST HIGHEST VALUE IS	0.41652 AT (-75.00, -129.90, 125.00, 125.00, 0.00)	GP	POL1
	2ND HIGHEST VALUE IS	0.41364 AT (-96.42, -114.91, 125.00, 125.00, 0.00)	GP	POL1
	3RD HIGHEST VALUE IS	0.39232 AT (-100.00, -173.21, 125.00, 125.00, 0.00)	GP	POL1
	4TH HIGHEST VALUE IS	0.38783 AT (-128.56, -153.21, 125.00, 125.00, 0.00)	GP	POL1
	5TH HIGHEST VALUE IS	0.38199 AT (-51.30, -140.95, 125.00, 125.00, 0.00)	GP	POL1
	6TH HIGHEST VALUE IS	0.37640 AT (-50.00, -86.60, 125.00, 125.00, 0.00)	GP	POL1
	7TH HIGHEST VALUE IS	0.37604 AT (-64.28, -76.60, 125.00, 125.00, 0.00)	GP	POL1
	8TH HIGHEST VALUE IS	0.36871 AT (-114.91, -96.42, 125.00, 125.00, 0.00)	GP	POL1
	9TH HIGHEST VALUE IS	0.36010 AT (-68.40, -187.94, 125.00, 125.00, 0.00)	GP	POL1
	10TH HIGHEST VALUE IS	0.34744 AT (-34.20, -93.97, 125.00, 125.00, 0.00)	GP	POL1

Figure 49. Summarizing of highest predicted period concentrations

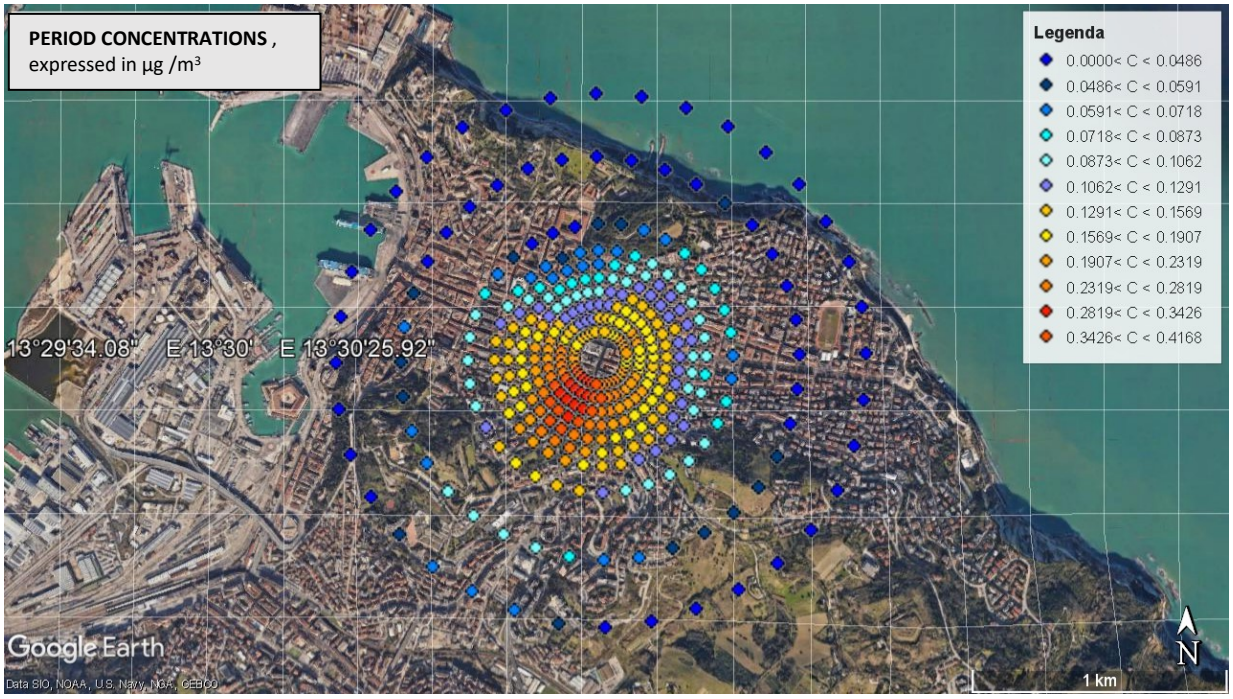


Figure 50. Plot of period concentrations around the emission source

3.2) Results from HARP

During our study, we used also the HARP software provided by California. Although the emission inventory is different, we assumed the same input data we used for Aermod opensource in order to have a comparison between the two tools.

While our software is in a preliminary step and many information miss in the database, HARP is a full-working tool largely used in USA so we expect some differences between the two.

PILOT_AERMOD - Blocco note di Windows

File Modifica Formato Visualizza ?

** CONC OF OTHER IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 100.00	150.00	200.00	250.00	300.00	350.00	400.00	500.00	750.00
10.00	0.15260	0.14399	0.12572	0.10727	0.09139	0.07846	0.06825	0.05345	0.03367
20.00	0.16870	0.16151	0.14232	0.12217	0.10452	0.08999	0.07844	0.06159	0.03891
30.00	0.18462	0.17929	0.15954	0.13792	0.11867	0.10264	0.08984	0.07099	0.04539
40.00	0.19400	0.18959	0.16935	0.14677	0.12649	0.10953	0.09598	0.07596	0.04876
50.00	0.19693	0.19227	0.17134	0.14805	0.12715	0.10970	0.09576	0.07527	0.04759
60.00	0.19871	0.19421	0.17280	0.14902	0.12771	0.10994	0.09570	0.07481	0.04663
70.00	0.19951	0.19562	0.17434	0.15063	0.12936	0.11162	0.09739	0.07641	0.04796
80.00	0.19454	0.18979	0.16871	0.14564	0.12506	0.10803	0.09443	0.07445	0.04743
90.00	0.18607	0.17918	0.15814	0.13592	0.11641	0.10051	0.08797	0.06968	0.04518
100.00	0.18423	0.17605	0.15450	0.13231	0.11308	0.09764	0.08562	0.06806	0.04467
110.00	0.19475	0.18801	0.16557	0.14214	0.12173	0.10539	0.09261	0.07374	0.04823
120.00	0.21112	0.20773	0.18471	0.15946	0.13700	0.11881	0.10436	0.08282	0.05337
130.00	0.22375	0.22386	0.20069	0.17375	0.14927	0.12904	0.11280	0.08860	0.05549
140.00	0.22931	0.23170	0.20853	0.18038	0.15448	0.13279	0.11533	0.08948	0.05433
150.00	0.23281	0.23739	0.21473	0.18600	0.15923	0.13660	0.11830	0.09130	0.05480
160.00	0.23972	0.24734	0.22520	0.19567	0.16775	0.14384	0.12437	0.09563	0.05680
170.00	0.25277	0.26394	0.24200	0.21087	0.18093	0.15499	0.13371	0.10221	0.05966
180.00	0.27523	0.29146	0.26981	0.23619	0.20308	0.17402	0.14997	0.11421	0.06569
190.00	0.30892	0.33364	0.31241	0.27515	0.23754	0.20405	0.17614	0.13435	0.07728
200.00	0.34744	0.38199	0.36010	0.31825	0.27534	0.23692	0.20479	0.15648	0.09023
210.00	0.37640	0.41652	0.39232	0.34613	0.29896	0.25701	0.22207	0.16949	0.09748
220.00	0.37604	0.41364	0.38783	0.34114	0.29406	0.25255	0.21815	0.16633	0.09554
230.00	0.33807	0.36871	0.34549	0.30432	0.26290	0.22635	0.19608	0.15025	0.08744
240.00	0.28492	0.30799	0.28846	0.25414	0.21934	0.18840	0.16268	0.12385	0.07070
250.00	0.24704	0.26508	0.24839	0.21919	0.18921	0.16236	0.13993	0.10616	0.06008
260.00	0.23019	0.24680	0.23202	0.20577	0.17841	0.15361	0.13268	0.10101	0.05734
270.00	0.22513	0.24221	0.22875	0.20402	0.17790	0.15391	0.13344	0.10231	0.05876
280.00	0.21936	0.23596	0.22342	0.20013	0.17538	0.15242	0.13272	0.10258	0.05994
290.00	0.20328	0.21652	0.20441	0.18318	0.16084	0.14009	0.12226	0.09499	0.05621
300.00	0.17914	0.18672	0.17427	0.15529	0.13594	0.11824	0.10314	0.08019	0.04772
310.00	0.15510	0.15633	0.14292	0.12576	0.10919	0.09455	0.08225	0.06379	0.03808
320.00	0.13852	0.13479	0.12041	0.10446	0.08989	0.07750	0.06731	0.05224	0.03157
330.00	0.13118	0.12456	0.10946	0.09399	0.08043	0.06918	0.06012	0.04684	0.02881
340.00	0.13044	0.12232	0.10662	0.09109	0.07774	0.06681	0.05811	0.04546	0.02838
350.00	0.13397	0.12510	0.10874	0.09271	0.07903	0.06792	0.05911	0.04638	0.02927
360.00	0.14108	0.13197	0.11475	0.09777	0.08327	0.07151	0.06222	0.04880	0.03086

*** AERMOD - VERSION 18081 *** *** Pilot *** 10/09/19

Figure 51. Period concentrations provided by HARP

Also HARP is run assuming flat terrain, but there isn't the possibility to plot results over GoogleEarth

In figure 51 we can see predicted concentrations regarding the period concentration predicted at 100, 150, 200, 250, 300, 350, 400, 500 and 750m from the emission source spacing around 360°.

We found the highest value of about **0.42 µg /m³ at 150 m** far from the source with an angle of 210°.

More in general we can see that values are exactly that provided by our software.

PILOT_AERMOD - Blocco note di Windows

File Modifica Formato Visualizza ?

DIRECTION (DEGREES)	DISTANCE (METERS) 100.00	150.00	200.00	250.00	300.00
10.0	5.66178 (15091610)	5.37515 (15041510)	4.91778 (15040412)	4.36550 (15040412)	3.73517 (15040412)
20.0	6.10289 (15030210)	6.51919 (15030210)	5.92842 (15030210)	5.08197 (15030210)	4.32222 (15030210)
30.0	7.16585 (15030210)	7.73397 (15030210)	7.19409 (15092311)	6.36597 (15092311)	5.41305 (15092311)
40.0	6.98911 (15062308)	7.26272 (15092310)	6.72295 (15091715)	5.97487 (15091715)	5.16997 (15091715)
50.0	6.98911 (15062308)	7.08553 (15062308)	6.25661 (15062308)	5.35232 (15091510)	4.56882 (15091714)
60.0	6.99378 (15072709)	8.34132 (15072709)	7.49314 (15072709)	6.31511 (15072709)	5.25570 (15072709)
70.0	7.40837 (15072709)	9.54991 (15011112)	9.25635 (15011112)	7.93252 (15011112)	6.73325 (15011112)
80.0	6.53915 (15051408)	7.52668 (15020411)	7.57608 (15011113)	6.84028 (15011113)	5.96900 (15011113)
90.0	6.16496 (15020411)	7.52668 (15020411)	7.01405 (15020411)	6.49164 (15011115)	5.82000 (15011115)
100.0	5.97311 (15072809)	6.54722 (15061709)	6.54124 (15020413)	6.12560 (15020413)	5.40562 (15020413)
110.0	6.82154 (15051608)	8.01741 (15112211)	7.56609 (15112211)	6.62563 (15112211)	5.71850 (15112211)
120.0	8.13908 (15092409)	9.57617 (15092409)	8.61057 (15092409)	7.34921 (15092409)	6.24265 (15092409)
130.0	7.58390 (15081209)	8.63480 (15101109)	8.00951 (15101109)	6.94424 (15101109)	5.97434 (15101109)
140.0	7.64146 (15092410)	9.66653 (15092410)	9.20763 (15092410)	7.89091 (15092410)	6.59429 (15092410)
150.0	9.90337 (15040110)	11.39420 (15040110)	10.15712 (15040110)	8.53617 (15040110)	7.07437 (15040110)
160.0	9.82435 (15040111)	11.08803 (15040111)	9.65940 (15040111)	7.98804 (15040111)	6.57436 (15040111)
170.0	9.03147 (15040113)	10.25147 (15040113)	9.22244 (15040113)	7.75581 (15040113)	6.47570 (15040113)
180.0	7.04725 (15062409)	8.53855 (15102311)	8.44717 (15102311)	7.51300 (15102311)	6.48536 (15102311)
190.0	7.02487 (15102210)	9.35033 (15102210)	9.30894 (15102210)	8.26528 (15102210)	7.01672 (15102210)
200.0	8.45456 (15040710)	9.70349 (15102209)	9.80428 (15102209)	8.70860 (15102209)	7.50450 (15102209)
210.0	11.40300 (15040710)	12.62492 (15040710)	11.00956 (15040710)	9.07019 (15040710)	7.48088 (15040709)
220.0	18.95791 (15030514)	16.50658 (15030514)	12.48176 (15030512)	9.85784 (15030512)	7.89021 (15030512)
230.0	19.38493 (15030515)	17.36497 (15030515)	13.20522 (15030515)	11.81218 (15030518)	11.97904 (15030518)
240.0	11.83437 (15030516)	11.32335 (15030516)	9.42374 (15030510)	8.38465 (15030518)	8.49133 (15030518)
250.0	7.52351 (15092610)	8.15911 (15101010)	7.12975 (15101010)	6.11228 (15092610)	5.25674 (15031713)
260.0	6.09458 (15041909)	6.73270 (15040311)	6.49055 (15040311)	5.69291 (15040311)	4.84232 (15040311)
270.0	11.21373 (15032511)	12.44713 (15032511)	10.80006 (15032511)	8.91183 (15032511)	7.34034 (15032511)
280.0	10.50117 (15032512)	11.66244 (15032512)	10.20404 (15032512)	8.45425 (15032512)	6.98659 (15032512)
290.0	10.11370 (15032510)	11.32196 (15032510)	9.95306 (15032510)	8.17338 (15032510)	6.70135 (15032510)
300.0	8.48118 (15032509)	10.68588 (15032509)	10.35276 (15032509)	8.96142 (15032509)	7.61445 (15032509)
310.0	5.84967 (15091710)	6.57290 (15091710)	6.04160 (15091710)	5.19692 (15091710)	4.40318 (15091710)
320.0	5.97706 (15091709)	5.84580 (15091709)	5.23411 (15091709)	4.57472 (15091709)	3.96471 (15091709)
330.0	5.29080 (15091709)	5.13740 (15091709)	4.55624 (15091709)	3.94164 (15091709)	3.45808 (15021511)
340.0	5.48758 (15032010)	5.38384 (15040411)	4.81262 (15040411)	4.17183 (15032010)	3.61637 (15032010)
350.0	5.40724 (15062209)	5.53832 (15040411)	5.25399 (15022113)	4.70420 (15022113)	4.08806 (15022113)
360.0	6.14508 (15040210)	6.05435 (15041510)	5.38151 (15041510)	4.56389 (15041510)	3.87696 (15040210)

*** AERMOD - VERSION 18081 *** *** Pilot *** 10/09/19

*** AERMET - VERSION 18081 *** *** *** 10:17:33

PAGE 10

Figure 52. First highest 1-hour average concentration

PILOT_AERMOD - Blocco note di Windows

File Modifica Formato Visualizza ?

** CONC OF OTHER IN MICROGRAMS/M**3 **

DIRECTION (DEGREES)	DISTANCE (METERS) 350.00	400.00	500.00	750.00	1000.00
10.0	3.16625 (15040412)	2.71138 (15101309)	2.23783 (15101309)	1.47581 (15101309)	1.18565 (15011611)
20.0	3.70182 (15030210)	3.20269 (15030210)	2.47679 (15011713)	1.49245 (15011611)	1.49131 (15011611)
30.0	4.58493 (15030210)	4.00392 (15030210)	3.11887 (15030210)	1.86603 (15030210)	1.57159 (15121811)
40.0	4.43632 (15091715)	3.81374 (15091715)	2.86196 (15091715)	1.63560 (15011716)	1.52331 (15111610)
50.0	3.94446 (15091714)	3.40522 (15091714)	2.62857 (15030215)	1.66717 (15050108)	1.46404 (15111610)
60.0	4.39093 (15072709)	3.75216 (15033113)	2.84854 (15030215)	1.75117 (15042708)	1.53448 (15112010)
70.0	5.74202 (15011112)	4.94078 (15011112)	3.76035 (15011112)	2.17024 (15011112)	1.53448 (15112010)
80.0	5.11875 (15011113)	4.37120 (15011113)	3.25334 (15011113)	1.83209 (15013009)	2.18818 (15013009)
90.0	5.11304 (15011115)	4.48056 (15011115)	3.48593 (15011115)	2.03664 (15011115)	1.48403 (15062507)
100.0	4.65998 (15020413)	4.02066 (15020413)	3.05961 (15020413)	1.74170 (15020413)	1.62976 (15020810)
110.0	4.94228 (15112211)	4.30227 (15112211)	3.35540 (15112210)	2.01489 (15112210)	1.84685 (15112910)
120.0	5.34352 (15092409)	4.61903 (15092409)	3.54365 (15092409)	2.07557 (15092409)	1.68150 (15112910)
130.0	5.17391 (15101109)	4.51931 (15101109)	3.58737 (15012310)	2.22568 (15012310)	1.65493 (15122611)
140.0	5.53046 (15092410)	4.68647 (15092410)	3.47857 (15092410)	2.06879 (15022310)	1.39091 (15022310)
150.0	5.86014 (15040110)	4.89630 (15040110)	3.53097 (15040110)	1.93240 (15013011)	1.55452 (15111910)
160.0	5.44017 (15040111)	4.54788 (15040111)	3.28423 (15040111)	1.76578 (15031011)	1.71414 (15122811)
170.0	5.49584 (15013012)	4.71416 (15013012)	3.56934 (15013012)	2.04069 (15013012)	1.52262 (15111410)
180.0	5.52541 (15102311)	4.71198 (15102311)	3.48852 (15102311)	1.90039 (15102311)	1.58538 (15010711)
190.0	5.90666 (15102210)	5.02319 (15102210)	3.75002 (15102210)	2.09269 (15102210)	1.46262 (15010711)
200.0	6.41145 (15102209)	5.49054 (15102209)	4.13475 (15102209)	2.31789 (15102209)	1.96502 (15112716)
210.0	6.26997 (15040709)	5.28954 (15040709)	3.88995 (15040709)	2.78853 (15112616)	2.53944 (15040707)
220.0	6.52736 (15030610)	5.54994 (15030609)	4.55766 (15030522)	3.36852 (15030521)	2.66767 (15030521)
230.0	11.35950 (15030518)	10.43655 (15030518)	8.51501 (15030518)	5.70969 (15030522)	4.03533 (15030522)
240.0	8.03942 (15030518)	7.37312 (15030518)	5.99184 (15030518)	3.92101 (15030608)	2.68523 (15030608)
250.0	4.55960 (15031713)	3.94124 (15031713)	2.98625 (15031713)	1.78991 (15020909)	1.32753 (15020909)
260.0	4.11339 (15041911)	3.51199 (15031712)	2.63034 (15031712)	1.50176 (15041909)	1.18079 (15022610)
270.0	6.08844 (15032511)	5.10341 (15032511)	3.71067 (15032511)	1.95049 (15032511)	1.18340 (15032511)
280.0	5.81237 (15032512)	4.88444 (15032512)	3.56451 (15032512)	2.17485 (15032508)	1.49002 (15032508)
290.0	5.53566 (15032510)	4.62373 (15032510)	3.34141 (15032510)	1.73584 (15032510)	1.24217 (15021610)
300.0	6.43767 (15032509)	5.46707 (15032509)	4.06354 (15032509)	2.23292 (15032509)	1.42312 (15032509)
310.0	3.73044 (15091710)	3.18984 (15091710)	2.40200 (15091710)	1.35653 (15091710)	1.23537 (15091708)
320.0	3.44819 (15091709)	3.02000 (15091709)	2.36870 (15091709)	1.50882 (15091708)	1.50080 (15091708)
330.0	3.04008 (15021511)	2.68869 (15021511)	2.14028 (15021511)	1.33947 (15021511)	1.24200 (15032009)
340.0	3.14445 (15032010)	2.75385 (15032010)	2.15906 (15032010)	1.32010 (15032010)	1.28570 (15032009)
350.0	3.52223 (15022113)	3.04364 (15022113)	2.32785 (15022113)	1.34454 (15022113)	1.30137 (15021510)
360.0	3.32935 (15040210)	2.88401 (15040210)	2.27136 (15101310)	1.39823 (15101310)	1.25808 (15011711)

*** AERMOD - VERSION 18081 *** *** Pilot *** 10/09/19

*** AERMET - VERSION 18081 *** *** *** 10:17:33

Figure 53. First highest 1-hour average concentration

In figure 52 and 53 we can see predicted concentrations regarding the highest 1-hour avarage concentration predicted at 100, 150, 200, 250, 300, 350, 450, 500, 750 and 1000 m from the emission source spacing around 360°.

We found the highest value of about **19.4 µg /m^3 at 100 m** far from the source with an angle of 220°, as predicted by our tool.

*** THE SUMMARY OF MAXIMUM PERIOD (8760 HRS) RESULTS ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

GROUP ID		AVERAGE CONC	RECEPTOR (XR, YR, ZELEV, ZHILL, ZFLAG)					OF TYPE	NETWORK GRID-ID
PILOT	1ST HIGHEST VALUE IS	0.41652 AT (	-75.00,	-129.90,	125.00,	125.00,	0.00)	GP	PILOT
	2ND HIGHEST VALUE IS	0.41364 AT (	-96.42,	-114.91,	125.00,	125.00,	0.00)	GP	PILOT
	3RD HIGHEST VALUE IS	0.39232 AT (	-100.00,	-173.21,	125.00,	125.00,	0.00)	GP	PILOT
	4TH HIGHEST VALUE IS	0.38783 AT (	-128.56,	-153.21,	125.00,	125.00,	0.00)	GP	PILOT
	5TH HIGHEST VALUE IS	0.38199 AT (	-51.30,	-140.95,	125.00,	125.00,	0.00)	GP	PILOT
	6TH HIGHEST VALUE IS	0.37640 AT (	-50.00,	-86.60,	125.00,	125.00,	0.00)	GP	PILOT
	7TH HIGHEST VALUE IS	0.37604 AT (	-64.28,	-76.60,	125.00,	125.00,	0.00)	GP	PILOT
	8TH HIGHEST VALUE IS	0.36871 AT (	-114.91,	-96.42,	125.00,	125.00,	0.00)	GP	PILOT
	9TH HIGHEST VALUE IS	0.36010 AT (	-68.40,	-187.94,	125.00,	125.00,	0.00)	GP	PILOT
	10TH HIGHEST VALUE IS	0.34744 AT (	-34.20,	-93.97,	125.00,	125.00,	0.00)	GP	PILOT

Figure 54. Highest predicted period concentrations

Moreover, in figure 54 we find the summarizing of all highest predicted period concentrations.

If we compare results provided by Aermod and those provided by HARP we can as they as exactly the same.

	AERMOD OPENSOURCE			HARP		
	100m	*150m*	*200m*	*100m*	*150m*	*200m*
10°	0.153	0.144	0.126	0.153	0.144	0.126
20°	0.169	0.162	0.142	0.169	0.162	0.142
30°	0.185	0.179	0.159	0.185	0.179	0.159
40°	0.194	0.190	0.169	0.194	0.190	0.169
50°	0.197	0.192	0.171	0.197	0.192	0.171
60°	0.198	0.194	0.173	0.198	0.194	0.173
70°	0.200	0.196	0.174	0.200	0.196	0.174
80°	0.195	0.190	0.169	0.195	0.190	0.169
90°	0.186	0.179	0.158	0.186	0.179	0.158
100°	0.184	0.176	0.154	0.184	0.176	0.154
110°	0.195	0.188	0.166	0.195	0.188	0.166
120°	0.211	0.208	0.185	0.211	0.208	0.185
130°	0.224	0.224	0.201	0.224	0.224	0.201
140°	0.230	0.232	0.209	0.230	0.232	0.209
150°	0.233	0.237	0.215	0.233	0.237	0.215
160°	0.240	0.247	0.225	0.240	0.247	0.225
170°	0.253	0.264	0.242	0.253	0.264	0.242
180°	0.275	0.291	0.270	0.275	0.291	0.270
190°	0.309	0.334	0.312	0.309	0.334	0.312
200°	0.347	0.382	0.360	0.347	0.382	0.360
210°	0.376	**0.417**	0.392	0.376	**0.417**	0.392
220°	0.376	0.414	0.388	0.376	0.414	0.388
230°	0.338	0.369	0.345	0.338	0.369	0.345
240°	0.285	0.308	0.288	0.285	0.308	0.288
250°	0.247	0.265	0.248	0.247	0.265	0.248
260°	0.230	0.247	0.232	0.230	0.247	0.232
270°	0.225	0.242	0.229	0.225	0.242	0.229
280°	0.219	0.236	0.223	0.219	0.236	0.223
290°	0.203	0.217	0.204	0.203	0.217	0.204
300°	0.179	0.187	0.174	0.179	0.187	0.174
310°	0.155	0.156	0.143	0.155	0.156	0.143
320°	0.139	0.135	0.120	0.139	0.135	0.120
330°	0.131	0.125	0.110	0.131	0.125	0.110
340°	0.130	0.122	0.107	0.130	0.122	0.107
350°	0.134	0.125	0.109	0.134	0.125	0.109
360°	0.141	0.132	0.115	0.141	0.132	0.115

Table 8. Period concentration values [µg/m^3] obtained by Aermod in the first columns and HARP in second columns

In table 8 we find a summary of values obtained focusing on the range 100m/200m, in which we find the highest concentrations.

As we expected, results provided by two software are the same concerning both the intensity and the direction (almost **0.42 µg /m^3 predicted at 210°** with respect to emission source).

This is confirmed also in the results, so we can deduce that our input data file is written in a correct way.

Figure 55-56 shows results from the third module of HARP, regarding the **cancer risk assessment.**

We remind that as input data we used the resulting predicted concentration provided by the first module, that are the same provided by our software.

HARP2 - Risk Assessment Standalone Tool (dated 19044)

File Help

Enter Pollutant Concentrations | Select Risk Scenario & Calculate Risk | View Risk Results

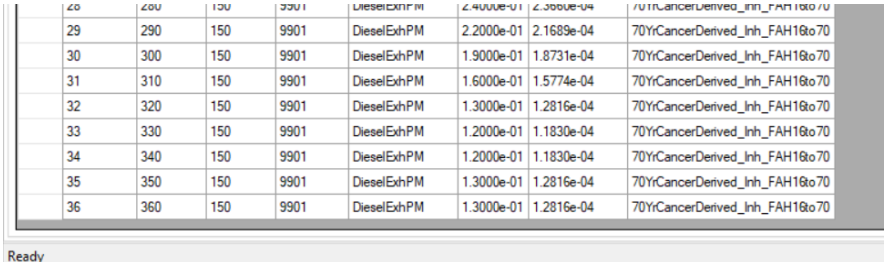
Cancer | Chronic | 8-hour | Acute

Load File | Group Risk By | View | Export

INDEX	GRP1	GRP2	POLID	POLABBREV	CONC	RISK_SUM	SCENARIO
1	10	150	9901	DieselExhPM	1.4000e-01	1.3802e-04	70YrCancerDerived_Inh_FAH16to70
2	20	150	9901	DieselExhPM	1.6000e-01	1.5774e-04	70YrCancerDerived_Inh_FAH16to70
3	30	150	9901	DieselExhPM	1.8000e-01	1.7745e-04	70YrCancerDerived_Inh_FAH16to70
4	40	150	9901	DieselExhPM	1.9000e-01	1.8731e-04	70YrCancerDerived_Inh_FAH16to70
5	50	150	9901	DieselExhPM	1.9000e-01	1.8731e-04	70YrCancerDerived_Inh_FAH16to70
6	60	150	9901	DieselExhPM	1.9000e-01	1.8731e-04	70YrCancerDerived_Inh_FAH16to70
7	70	150	9901	DieselExhPM	2.0000e-01	1.9717e-04	70YrCancerDerived_Inh_FAH16to70
8	80	150	9901	DieselExhPM	1.9000e-01	1.8731e-04	70YrCancerDerived_Inh_FAH16to70
9	90	150	9901	DieselExhPM	1.8000e-01	1.7745e-04	70YrCancerDerived_Inh_FAH16to70
10	100	150	9901	DieselExhPM	1.8000e-01	1.7745e-04	70YrCancerDerived_Inh_FAH16to70
11	110	150	9901	DieselExhPM	1.9000e-01	1.8731e-04	70YrCancerDerived_Inh_FAH16to70
12	120	150	9901	DieselExhPM	2.1000e-01	2.0703e-04	70YrCancerDerived_Inh_FAH16to70
13	130	150	9901	DieselExhPM	2.2000e-01	2.1689e-04	70YrCancerDerived_Inh_FAH16to70
14	140	150	9901	DieselExhPM	2.3000e-01	2.2674e-04	70YrCancerDerived_Inh_FAH16to70
15	150	150	9901	DieselExhPM	2.4000e-01	2.3660e-04	70YrCancerDerived_Inh_FAH16to70
16	160	150	9901	DieselExhPM	2.5000e-01	2.4646e-04	70YrCancerDerived_Inh_FAH16to70
17	170	150	9901	DieselExhPM	2.6000e-01	2.5632e-04	70YrCancerDerived_Inh_FAH16to70
18	180	150	9901	DieselExhPM	2.9000e-01	2.8590e-04	70YrCancerDerived_Inh_FAH16to70
19	190	150	9901	DieselExhPM	3.3000e-01	3.2533e-04	70YrCancerDerived_Inh_FAH16to70
20	200	150	9901	DieselExhPM	3.8000e-01	3.7462e-04	70YrCancerDerived_Inh_FAH16to70
21	210	150	9901	DieselExhPM	4.2000e-01	4.1406e-04	70YrCancerDerived_Inh_FAH16to70
22	220	150	9901	DieselExhPM	4.1000e-01	4.0420e-04	70YrCancerDerived_Inh_FAH16to70
23	230	150	9901	DieselExhPM	3.7000e-01	3.6476e-04	70YrCancerDerived_Inh_FAH16to70
24	240	150	9901	DieselExhPM	3.1000e-01	3.0561e-04	70YrCancerDerived_Inh_FAH16to70
25	250	150	9901	DieselExhPM	2.7000e-01	2.6618e-04	70YrCancerDerived_Inh_FAH16to70
26	260	150	9901	DieselExhPM	2.5000e-01	2.4646e-04	70YrCancerDerived_Inh_FAH16to70
27	270	150	9901	DieselExhPM	2.4000e-01	2.3660e-04	70YrCancerDerived_Inh_FAH16to70
28	280	150	9901	DieselExhPM	2.4000e-01	2.3660e-04	70YrCancerDerived_Inh_FAH16to70
29	290	150	9901	DieselExhPM	2.2000e-01	2.1689e-04	70YrCancerDerived_Inh_FAH16to70
30	300	150	9901	DieselExhPM	1.9000e-01	1.8731e-04	70YrCancerDerived_Inh_FAH16to70
31	310	150	9901	DieselExhPM	1.6000e-01	1.5774e-04	70YrCancerDerived_Inh_FAH16to70

Ready

Figure 55.Results from HARP risk assessment



29	290	150	9901	DieselExhPM	2.2000e-01	2.1689e-04	70YrCancerDerived_Inh_FAH16to70
30	300	150	9901	DieselExhPM	1.9000e-01	1.8731e-04	70YrCancerDerived_Inh_FAH16to70
31	310	150	9901	DieselExhPM	1.6000e-01	1.5774e-04	70YrCancerDerived_Inh_FAH16to70
32	320	150	9901	DieselExhPM	1.3000e-01	1.2816e-04	70YrCancerDerived_Inh_FAH16to70
33	330	150	9901	DieselExhPM	1.2000e-01	1.1830e-04	70YrCancerDerived_Inh_FAH16to70
34	340	150	9901	DieselExhPM	1.2000e-01	1.1830e-04	70YrCancerDerived_Inh_FAH16to70
35	350	150	9901	DieselExhPM	1.3000e-01	1.2816e-04	70YrCancerDerived_Inh_FAH16to70
36	360	150	9901	DieselExhPM	1.3000e-01	1.2816e-04	70YrCancerDerived_Inh_FAH16to70

Ready

Figure 56. Results from HARP risk assessment

For simplicity sake, we focused on the worst case scenario distance, corresponding to 150 m and the relative values found at 360° around the emission source at that distance, spacing with an angle of 10°.

Maximum value is found corresponding to the point of maximum exposure, at 210° with respect to emission source and a health risk of 4.14×10^{-4}.

By setting an exposure time at 70 years, results show a cancer risk that is in the range **$1\text{-}4 \times 10^{-4}$**, indicating values with relatively high risk.

3.3) Comparison between flat and elevated Aermod model setup

During our study, we compared results provided by Aermod in flat mode with that obtained by applying elevation mode.

To do this, we use the software “Aermod View version 9.7.0” of Lakes Environment, available at the Department of Industrial Engineering and Mathematical Science of Marche Polytechnic University.

Since Aermod view is the complete version of the software, it is possible through it to have a scenario for which also the elevation in included.

The elevation model used was in the form of a DEM file, with a resolution of 3 arcsecond, corresponding to 90 m.

Obviously, the input data are the same and are that shown in table 6.

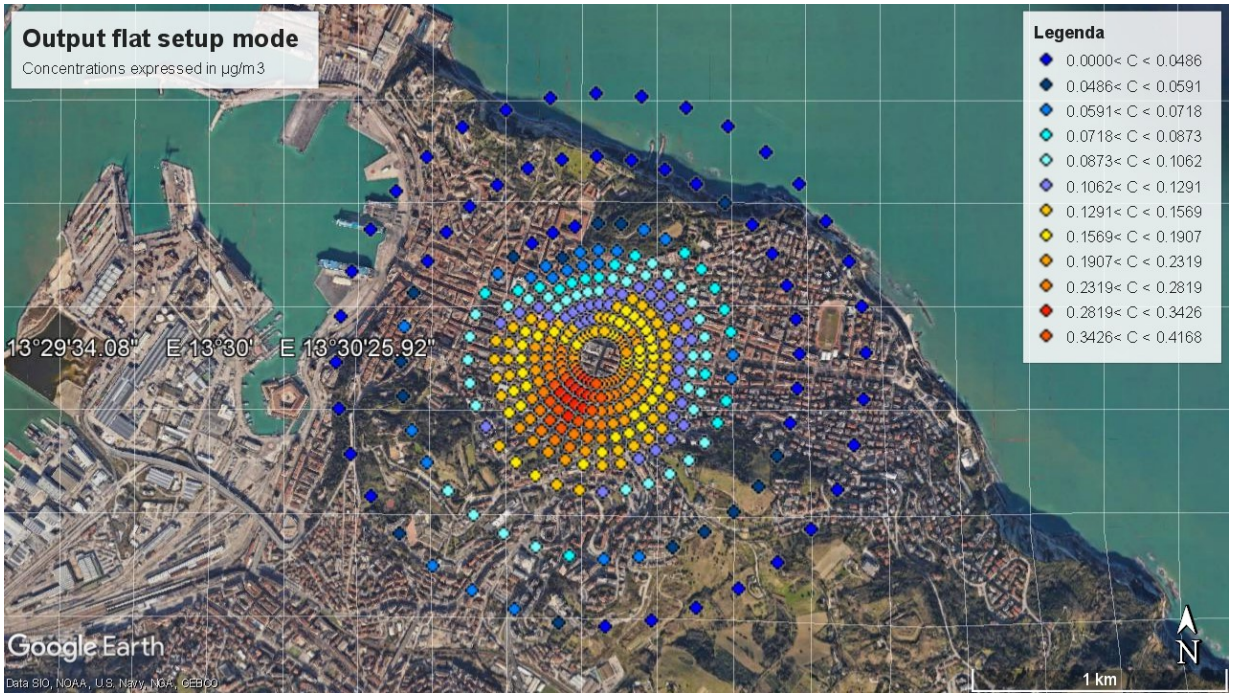


Figure 57.Output of period concentration from Aerplot, using flat model setup

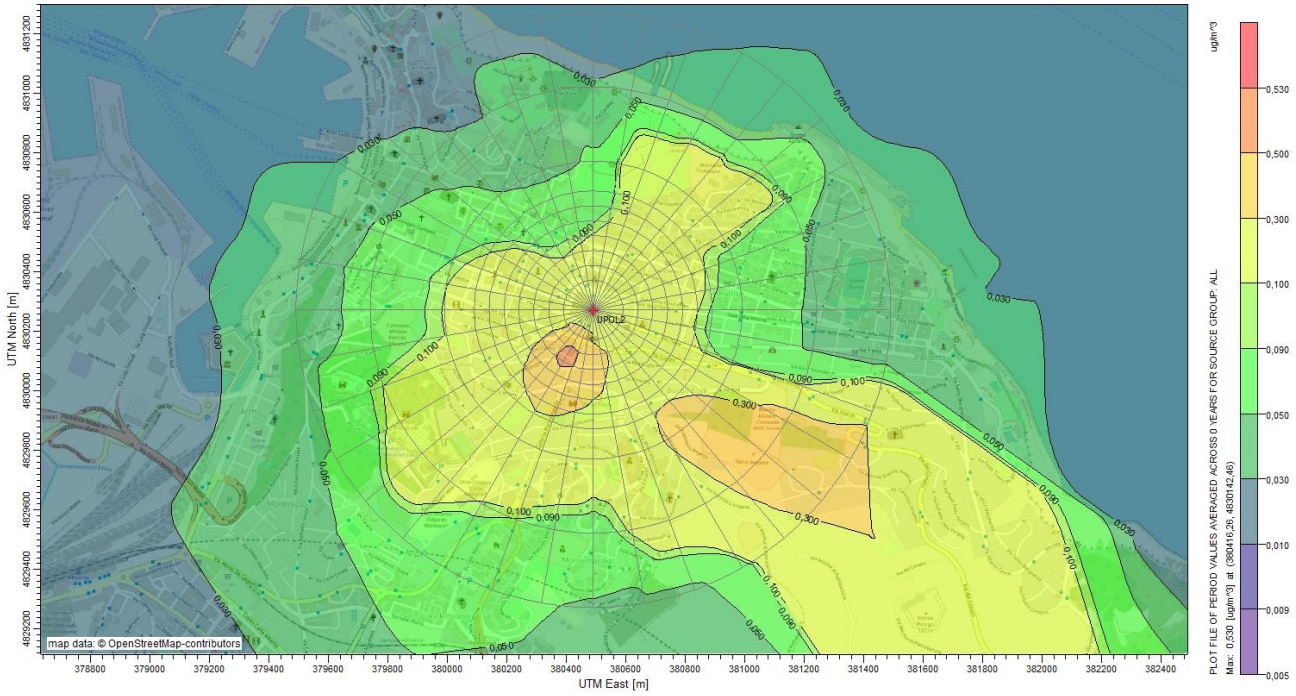


Figure 58. Output from Aermodview, using elevated set up

Figures 57-58 show the plots of the two different scenarios, the first by using flat setup with Aermod opensource and the second using elevated setup using Aermod view.

The trend is quite respected, both speaking about intensity and location.

The peak concentration, trough the elevation model setup, in estimated around **0.50 µg /m^3** against a values for the flat setup of **0.42 µg /m^3**, so in the same order of magnitude.

Moreover, the locations of the predicted maximum concentration are almost the same, in fact, Aermodview predicts a peak concentration at a distance within a range of **150-200m**, instead of the one predicted by our software (**150m**).

Apart of the peak concentration, both softwares estimate a period concentration in a range **0.1-0.3 µg /m^3** in a radius range of 500 m around the emission source.

A notable difference stays in the southern east part of the considered area, where Aermodview estimates an area with concentration over 0.3

µg /m^3, while our software around 0.05 µg /m^3. This is probably due to of the orography of the area. The orography of the studied area, the city centre of Ancona, is quite complex with relatively high elevation gradients.

In the scenario proposed by AermodView there is area where pollutants are concentrated, represented by the yellow colour in the southern east part of the map.

Based on the comparison between figures 45 and 46, we observe that the orography plays a role in the deposition of pollutants in the area under study. Therefore, considering the flat scenario introduces limitations to our study.

Furthermore, it is important to underline that the elevation model has a resolution of 90 m and the peak concentrations found in a range between 100-250 m. This brings to some uncertainties related to the exact evaluation of the orography of the area, the resolution of the elevation model file should be surely lesser (at least at 30m) to have a precise characterization of the area and to relate it with the dispersion of pollutants.

Further, in the considered area, that is an urban area, there is a strong presence of buildings that affect a lot the dispersion of pollutants but it is not considered.

This last should be considered in a scenario similar to that of our study because, more than the orography, it is the building downwash that affect the dispersion.

We remind that the chimney height considered is 10m and also this data is to be related with the results.

Concentrations found are almost near the emission source because of the limited height of the chimney, but surely, if we have been considered a higher release height, the peak concentration would have been found farther and also the orography would have been had a stronger influence.

3.4) Risk analysis

	C. (ug/m3)	Distanza. m	Pm ISS_IRIS RfC. mg/m3		HQ		Esposizione EC
	0.1526		5.0E-03		2.9E-02		1E-01
	0.1687				3.2E-02		2E-01
	0.18462				3.5E-02		2E-01
	0.194				3.7E-02		2E-01
	0.19693				3.8E-02		2E-01
	0.19871				3.8E-02		2E-01
	0.19951				3.8E-02		2E-01
	0.19454				3.7E-02		2E-01
	0.18607				3.6E-02		2E-01
	0.18423				3.5E-02		2E-01
	0.19475				3.7E-02		2E-01
	0.21112				4.0E-02		2E-01
	0.22375				4.3E-02		2E-01
	0.22931				4.4E-02		2E-01
	0.23281				4.5E-02		2E-01
	0.23972				4.6E-02		2E-01
	0.25277				4.8E-02		2E-01
	0.27523				5.3E-02		3E-01
	0.30892				5.9E-02		3E-01
	0.34744				6.7E-02		3E-01
	0.3764				7.2E-02		4E-01
	0.37604				7.2E-02		4E-01
	0.33807				6.5E-02		3E-01
	0.28492				5.5E-02		3E-01
	0.24704				4.7E-02		2E-01
	0.23019				4.4E-02		2E-01
	0.22513				4.3E-02		2E-01
	0.21936				4.2E-02		2E-01
	0.20328				3.9E-02		2E-01
	0.17914				3.4E-02		2E-01
	0.1551				3.0E-02		1E-01
	0.13852				2.7E-02		1E-01
	0.13118				2.5E-02		1E-01

Ris_CONC_50m_10km_Cu | Input_Output_Hg | R ...

Figure 59. Results of the risk assessment analysed through an excel paper

Figure 59 shows results of the risk assessment.

We used an excel paper in which per each concentration found around the emission source is calculated the corresponding hazard quotient, so the toxic risk for exposure population.

In this way we calculated the risk for 324 values, corresponding to predicted concentrations at 9 different distances (100-150-200-250-300-350-400-500-750 m) and every 10°.

In figure 55 are show results by using a plot over the studied area.

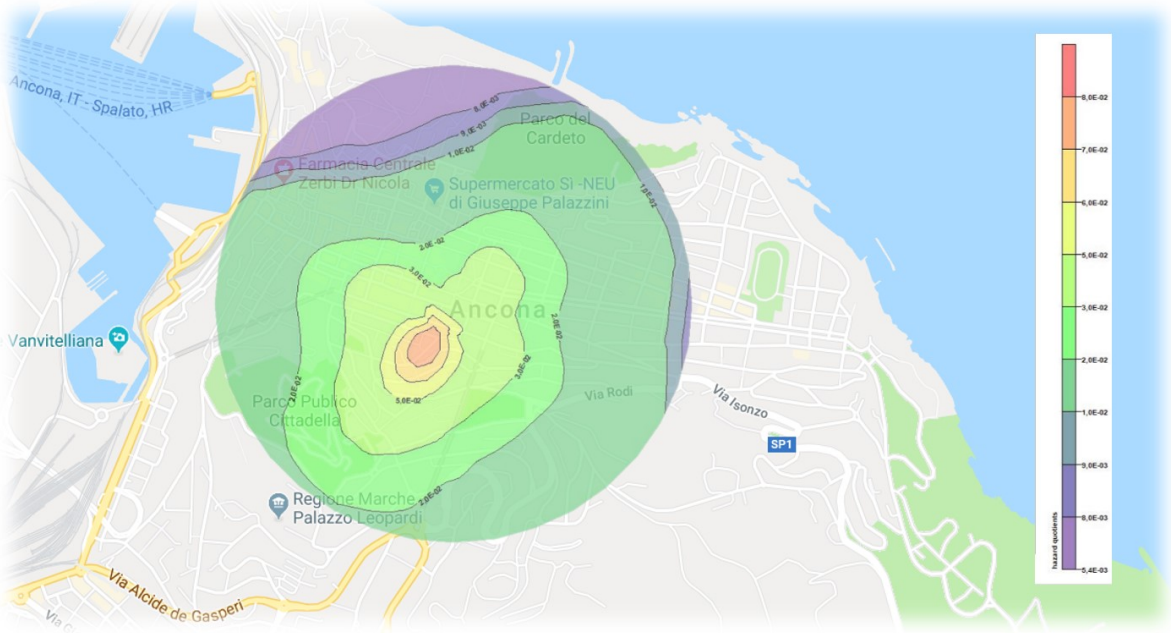


Figure 60. Risk assessment concerning the hazard quotient for the considered pollutant

Figure 60 show results of the toxic risk analysis obtained by use of Aermap. The input file PLT was modified in order to be read by software and to have a visual view of the results.

Results are in a range of 750 m around the emission source, where is concentrated the maximum exposure.

Peak values, corresponding to the area in which there is the peak predicted concentrations, are around $8x10^{-2}$.

More in general, we found a range value between **0.005-0.08**.

Therefore, based on the input data referring to diesel particulate matter and hypothesizing the emission source placed in the centre of the city of Ancona, risk assessment shows values always much lesser than 1, from which we can observe that there is no probability of toxic risk.

Conclusions

The goals of our study were to implement a software for the airborne pollutants dispersion analysis and the consequent association between the results and the health risks, building on the experience of the HARP project of California.

Our first aim was to find a software able to evaluate the dispersion of pollutants into the atmosphere through the definition of few input data. We tested some tools such as AERSCREEN. This software is a screening model, so there is not the possibility input specific meteorological data. For this reason, we choose the Aermod open source code.

By using Aermod, there is the possibility of managing the code regarding the hourly weather conditions and the orography. However, we considered a flat scenario.

Based on the results and on the comparisons between our model and HARP, it is possible to state that our software gives reliable exposure scenario concerning a preliminary simulation about the ambient level of airborne pollutants.

We found the same values between our software and HARP (with a peak value of 0.41 $\mu g / m^3$ of PM10), confirming that the input file was written in a correct way.

Further, we evaluated the hazard quotient and the cancer risk considering the above exposure scenario. We considered the reference concentration value and inhalation unit risk of diesel engine exhaust. The input file PLT was modified in order to be read by AERMAP to have a graphical representation of the results. The hazard quotient was plotted in the studied area. This enables to assess the potential health risk for the considered emission scenario.

Based on the hazard quotient we found that there is no concern ($HQ<1$) for toxic risk in the studied area. The preliminary analysis of the risk

assessment shows a range value for HQ between 0.005-0.08 in the studied area.

Based on risk assessment standalone tool by HARP, the inhalation cancer risk is up to 10^{-4}.

Moreover, we compared the flat setup of Aermod opensource and a setup with the orography data using AermodView. This comparison confirmed the importance of the presence of the elevation model file into the database when dealing with an area characterized by a complex orography. In particular, this is the case of Marche region.

Although, we found peak concentration with the same order of magnitude between the flat setup (about 0.41 µg /m^3) and the elevated setup (about 0.52 µg /m^3).

Considering particulate matter, this difference is almost negligible because the annual limit for ambient concentration is 40 µg /m^3. For other pollutants, whose limit is in the order of ng /m^3, difference could be relevant.

The greatest strength in the use of this software is that through only 5 input data it is possible to create a plausible exposure scenario, with low computational resources.

Limitations and future perspectives of the present study

Our study is still at a preliminary stage in which some aspects still need to be improved.

First of all, it is necessary to insert within the database the territorial component, that is a digital elevation file thanks to which it will be possible to refine the simulations.

This is because, especially in the Marche region, orography plays an important role in that because of its no-homogeneity, made of considerable height differences even at short distances.

This fact will surely have an impact on the exposure assessment and will be the first next step in our study.

The type of file that will be given to our software database will be in SRTM format, an acronym for shuttle radar topography mission, which is a type of file compatible with the software, and this is in a elaboration phase. Moreover, from results we exposed it is possible to state that the elevation model file should have a small resolution, at least at 30m to have a satisfactory characterization of the orography.

A subsequent step will be the assessment of the actual risk to human health.

To do this, for health impact assessment, different information components need to be acquired regarding the exposed population, such as the exact number of deaths or hospital admissions that have occurred in a given area, for a given year.

Subsequently this data will be interpolated with the expected exposure for the area under study and therefore the result will be risk values relative to a given pollutant and a precise geographical area of reference.

However, this is not possible yet, because information on the adverse health outcomes are often considered sensitive or even missing.

Finally, an important step will be the creation of a user-friendly interface to ensure that our tool is going to be very useful in risk analysis. At the moment, it can only be used having some computer skills.

In conclusion, it is possible to state again the validity of the software developed with regard to a preliminary estimation of the exposure.

Bibliography

1. “L’inquinamento atmosferico” – G.Miserocchi, 2019 docente.unife.it/giovanna.miserocchi/dispense-del - corso/L2019inquinamento%20atmosferico%20def.pdf
2. “Inquinamento dell’aria: normativa italiana” - inquinamento-italia.com/inquinamento-dell-aria-la-normativa-italiana-leggi-decreti- legge-qualita-aria-limiti-emissioni-inquinanti/
3. “Norme in materia ambientale” – Camera dei deputati – 2006 - camera.it/parlam/leggi/deleghe/06152dl5.htm
4. “Inquinamento atmosferico: quali effetti sulla salute?” – Dott.ssa Stefania Russo,2018 - anteritalia.org/inquinamento-atmosferico-quali-effetti-sulla-salute/
5. “Data and statistics” – WHO, 2019 - euro.who.int/en/health-topics/environment-and-health/air-quality/data-and-statistics
6. “Domande frequenti sull’inquinamento dell’aria”- Lenntech.it - lenntech.it/faq-inquinamento-aria.htm#ixzz5yNUj52Vx
7. “I quaderno della formazione” – ISPRA,2006 isprambiente.gov.it/files/pubblicazioni/quaderni/educazione-e-formazione-ambientale/3948_Quaderni_formazione_ARIA.pdf
8. “URBAN AIR POLLUTION: DATA INTERPRETATION AND NOWCASTING BY NEURAL NETWORKS” – Francesca Liguori, 1996/1997 - istitutoveneto.org/venezia/documenti/tesi_laurea_dott/tesi_liguori/cap2_intr_par1e2.PDF
9. Picture 2 - zo.utexas.edu/faculty/sjasper/images/airpolsources.jpg
10. Picture 1 - s3.amazonaws.com/user-media.venngage.com/7cfc887906dd4105fffede85627f607a.png
11. “La direttiva 2008/50/Ce sulla qualità dell’aria: applicazione e prospettive di revisione” – Gasparinetti,2014 - regione.emilia-romagna.it/affari_ist/Supplemento%20_2015/Gasparinetti.pdf

12. “Aria”- ArpaLombardia, 2010- arpalombardia.it/Pages/Aria/Inquinanti/Inquinanti-in-sintesi/Principali-parametri.aspx?firstlevel=Inquinanti
13. “Valori limite” – ChiamaMilano.it - chiamamilano.it/valori-limite.html
14. Particolato: Cos'è? Come si forma? Che problematiche crea? – Tecnosida -tecnosida.it/4133/particolato-e-combustione
15. Picture - activesustainability .com/media/560206/effects-air-pollution-health.jpg?width=900&height=2054
16. “Gaseous emissions and treatment plants slides” G.Buguna,2018
17. “Particolato sulla salute” – Wikipedia - https://it.wikipedia.org/wiki/Particolato#Sulla_salute
18. Picture - cdn.shopify.com/s/files/1/0580/1421/files/everything-you-need-to-know-about-the-respiratory-system.jpg?6074
19. “Ossidi di zolfo”, Trezzo – Università degli studi di Parma - .dsa.unipr.it/trezzo/uni_parma/capitoli/inquinanti/ossidi_di_zolfo.htm
20. “Ossidi di azoto”, ArpaLazio - arpalazio.net/main/aria/doc/salute/NOX.php
21. “Ossidi di carbonio” – Trezzo, università degli studi di Parma - http://www.dsa.unipr.it/trezzo/uni_parma/capitoli/inquinanti/ossidi_di_carbonio.htm
22. “Ossidi di carbonio” – De Munari, Pessina – Arpa Emilia Romagna - arpae.it/cms3/documenti/_cerca_doc/aria/ossidi_carbonio.pdf
23. Wikimedia.org upload.wikimedia.org/wikipedia/commons/thumb/9/99/CO_toxicity_symptoms_%28en%29.jpg/290px-CO_toxicity_symptoms_%28en%29.jpg
24. Picture - desktopclass.com/wp-content/uploads/2017/01/Effect-of-oxides-of-nitrogen-on-lungs.jpg
25. “Linee guida per la valutazione del rischio sanitario determinato da fonti di inquinamneto ambientale”, Regione Veneto -

arpa.veneto.it/temi-ambientali/ambiente-e-salute/file-e-allegati/documenti/ambiente-e-salute/as_linee_guida_rischio.pdf

26. “Confronto tra Health Impact Assessment e Risk Assessment” – Ranzi, Cordioli, 2015 - arpae.it/cms3/documenti/ambiente_salute/Ranzi_Andrea.pdf
27. Picture - sphweb.bumc.bu.edu - sphweb.bumc.bu.edu/otlt/MPH-Modules/PH717-QuantCore/PH717-Module2-ExposureAssessment/VariousExposurePathways.png
28. “Il rischio sanitario correlato all’inquinamento atmosferico Approccio tossicologico e epidemiologico” , Mancinelli Enrico , 2018- Class notes
29. “Valutare il rischio sanitario in campo ambientale” – Ecoscienza, 2014 - arpae.it/cms3/documenti/_cerca_doc/ecoscienza/ecoscienza2014_1/cadum_lauriola_ecoscienza_2014_1.pdf
30. researchgate.net/figure/Individual-carcinogenic-risk-of-carcinogens-in-the-site_tbl4_282520621
31. “Views on the purpose of health risk assessment”- Harris,Roxas , 2008 hiaconnect.edu.au/wp-content/uploads/2012/09/views-on-purpose-of-HIA.bmp
32. “Screenview Freeware”, Weblakes,2018 - weblakes.com/products/screen/index.html
33. “Air quality dispersion modelling – Screening models”, EPA - epa.gov/scram/air-quality-dispersion-modeling-screening-models
34. LA MODELLISTICA AMBIENTALE PER VALUTAZIONI DI RISCHIO SANITARIO- Dott.ssa Giovanna Sacco
35. “Air Toxics Hot Spots Program” – EPA,2015- oehha.ca.gov/media/downloads/crnr/2015guidancemanual.pdf#page=19&zoom=100,0,96
36. “Teoria di base della dispersione di inquinanti in atmosfera” - Sozzi, Bolignano,2011 - arpalazio.net/main/aria/didattica/corso02/Dispersione_1.pdf

37. ARIANET – Presentation slides, 2019 – arianet.it
38. “I modelli di riferimento per la diffusione in atmosfera degli inquinanti: cenni teorici e applicazioni pratiche”- M.Sinesi - isprambiente.gov.it/contentfiles/00001100/1176-michela-sinesi.pdf
39. Picture - vgengineering.com - vgengineering.com/wp-content/uploads/2016/07/VGE-Dispersion-analysis-Using-Modelling-Software-1.jpg
40. Picture - ars.els-cdn.com/content/image/1-s2.0-S1385894718316061-ga1.jpg
41. “AERMOD” , wikipedia - en.wikipedia.org/wiki/AERMOD
42. Pitcure - encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTcLh2wFPVBbpMRt4gjb2k5POPRpBsDj7ituWeyHzo3eHnGzRie
43. Picture - i.ytimg.com/vi/KTRFS6Ja-XM/maxresdefault.jpg
44. Picture-researchgate.net/profile/Emanuela_Pace/publication/325756263/figure/fig5/AS:637318314594305@1528959935475/Le-vie-di-esposizione-delluomo-attraverso-lambiente-Fonte-ECHA-2016.png
45. Picture - previews.123rf.com/images/mikrostoker/mikrostoker1601/mikrostoker160100059/51210429-carboxyhemoglobin-joining-the-hemoglobin-carbon-monoxide-the-inability-to-transport-oxygen-carbon-mo.jpg
46. Cfpub.epa.gov. - cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?substance_nmbr=642
47. https://www.epa.gov/sites/production/files/2016-09/pm2.5_scale_graphic-color_2.jpg