THE USE OF WATER IN THE INCINERATION PLANT OF TORINO

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SUMMARY: The start up of the first incinerator of Torino, a large plant with a capacity of 421,000 tons/yr, is scheduled for 2011. It will make use of a rather large amount of water: 2.73 m^3/ton of MSW. Most of this water (735,000 m^3/year) will be evaporated in six cooling towers of the hybrid wet/dry type. The operation of these towers will have some environmental impacts as a moderate increase of fogging and icing hazards to their surroundings. Visible plumes may occur too, particularly in periods of low ambient air temperature and high relative humidity; in these conditions in towers operation the dry phase should be prevailing.

1. INTRODUCTION

Solid waste management in Province of Torino is still based on landfilling, but the residual capacity of the operating landfills dramatically decreases. In the last few years the total amount of MSW produced in the province has grown almost constant (1,170,000 tons) whereas source separation for reuse and recycling has made important improvements, particularly since *door to door* collection has progressively replaced the disappointing *road* collection. This way the amount of landfilled waste is decreased to 723,000 tons (61.7% by weight) and is expected to decrease further; in fact, according to regional directives, source separation should reach the 50% by weight of MSW produced at the start up of the first incinerator of the province that is due in 2011. Provincial planning schedules for the next years a growth of the total landfilling capacity of only 2,500,000 m^3, that is exactly the volume that is needed to get to 2011. In this situation every effort is made to meet the deadline for the start-up of the incinerator. This report deals with the considerations made to assess the environmental impact of the plant.

2. THE INCINERATOR OF TORINO

The incinerator of Torino (Figure 1) will have the task to dispose of the residual waste of source separation together with the bulky waste; it will be equipped with three combustion lines and is expected to dispose of 421,000 tons/year of undifferentiated or commingled waste.

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Figure 1. The incinerator of Torino. In the background, a little on the left, the six cooling towers.

Considering various combustion systems and various factors as the qualitative and quantitative characteristics of waste which has to be treated, the plant potentiality, the need to guarantee a good degree of reliability, it has been decided to adopt the mobile grate as the most suitable technology for waste combustion and energy recovery. The plant, rather conventional but well-known, versatile and reliable, consists of:

- a pit for the receiving of waste;
- three combustion independent lines;
- a steam plant which converts the thermic energy produced by waste combustion into electric energy and feeds the urban tele-heating;
- a gas cleaning system for the elimination of pollutants from smokes: it consists of an electrostatic precipitator, a dry reactor, a bag filter and a SCR (Selective Catalytic Reduction) reactor;
- a stack;
- a system for cooling, wetting and storage of bottom ashes.

.In particular, the electrostatic precipitator is a three-stage device. Each stage, thanks to corrosion-proof electrodes, generates an independent electromagnetic field that attracts dusts and particulate: they adhere to the precipitator plates which are periodically cleaned by a mechanical percussion system. These ashes are considered dangerous, so they are collected in suitable silos and afterwards they are sent to treatment and inertization plants. The dry reactor allows to eliminate the most part of acid gas, dioxins, furans and heavy metals through the addiction of sodium bicarbonate and powdered active coal to smokes. Afterwards the pulse jet bag filter has the task to remove the remaining dust. It consists of six groups of bags; every group is independent and it can be excluded in case of maintenance. Finally the SCR reactor allows to eliminate the nitrogen oxides (NO_x). It is a catalytic reactor that consists of two parts:

- a mixing part in which gas, deriving from the thermic hydrolyzation of urea and containing NH_3 (3-4%), is added to smokes coming from the bag filter;
- a reaction part in which NH_3 reacts with NO_x on catalysts (WO_3, V_2O_5, TiO_2).

In order to guarantee a good contact among smokes, NH_3 and catalysts, the metallic oxides catalysts are deposited on honeycomb supports. A vibration mechanical system consents to periodically eliminate dusts from supports which are regenerated by a washing system. The system for smokes treatment ends with a suction fan that keeps the whole line under vacuum. At last smokes reach the stack and are emitted into the atmosphere.

3. THE USE OF WATER

Water demand in the plant has been calculated assuming a 24 hours working cycle in three incinerator lines and a load value between 90 and 100% of the continuous maximum load (CML). Water demand is strongly influenced by climatic conditions: in winter is lowest and in summer is highest and it can exceed 300 m^3/hour. Four main water uses must be considered:

- water restoring in the demineralisation plant;
- cooling water restoring;
- service water restoring;
- water in the urea solution (45%) that is used for NH_3 production in the SCR reactor.
- A further water use is referred to the fire-fighting system but this consumption has not been considered because it cannot be linked to waste disposal. Cooling water is recycled after refrigeration in wet/dry towers where an air stream removes sensible heat in a dry section and another air stream partially evaporates water in a wet section.
- Table 1 presents the amounts of water used; these data are referred to the CML condition of the plant (capacity 67.5 tons/hour, ICP 11,000 kJ/kg, thermic load 68.75 MW_t).

Taking into account the capacity of the plant, the flow rate of cooling water and the amount of heat that must be removed, the amount of water lost in atmosphere is remarkable. Of course this value depends strongly on the temperature and on the relative humidity of the ambient air: when the first increases and the second decreases, losses caused by evaporation considerably grow. In wet/dry towers the water of the plant cooling circuit, heated in various equipments, firstly passes through the dry section of the tower, where an air stream removes a portion of the heat. After that, water is cooled in the wet section of the tower, which works like an open tower. Air heated in the dry section is mixed with moistened air coming from the wet section in the upper part of the tower; by this way the relative humidity is reduced and the temperature is increased before the air stream leaves the cooling tower. This allows to decrease the probability of the formation of a visible plume directly above the tower. On this basis, the main differences between a hybrid cooling tower and a conventional one are the lower water consumption (about 20%), the lower power consumption (10-30%) and a higher air flow rate that can be also 100% higher than that of a conventional cooling tower. At last, the water leaving cooling towers in the form of drift

Table 1. Water consumptions referred to several uses.

Use	Water consumption [m^3/hour]		
	Climatic conditions		
	T=20°C H=50% Spring/Fall	T=40°C H=26% Summer	T=5°C H=85% Winter
Demineralised water	2.5	2.5	2.5
Cooling water:			
evaporated in the tower	150.8	204.1	107.1
lost as drips	0.1	0.1	0.1
discharged as blowdown	75.4	102.1	53.5
evaporated for bottom ashes cooling	6.0	6.0	6.0
Water for urea solution	0.04	0.04	0.04
Water for other uses	7.2	7.2	7.2
Total	242.04	322.04	176.44

must be added to the water lost by evaporation. Drift losses are much smaller than those caused by evaporation: at the nominal working condition of the plant it has been evaluated that these losses are lesser than 0.05% of the circulating cooling water. The expected value, 0.03 kg/second, should hardly cause icing in the vicinity of the plant: falling rates exceeding 0.02 μm/hour should not occur more than 2 times every winter.

4. THE EFFECTS OF COOLING TOWERS ON ENVIRONMENT

In addition to the advantages of wet/dry cooling towers previously outlined, it is necessary to analyse their environmental impacts: water use, microbiological contamination, noise pollution and emissions to air with probable plume formation.

4.1 Water use.

Cooling towers, even wet/dry type, emit to air large amounts of water. Taking into account what has been reminded about water use in the incinerator of Torino, the amount of water released into atmosphere will be 735,000 m^3/year. Since plant capacity is 421,000 tons/year, 1.75 litres of water will be released into atmosphere for every kilogram of waste fed to the plant; if water discharged as blowdown (368,000 m^3/year) and water for bottom ashes cooling (47,000 m^3/year) are added to water released by cooling towers, water consumption will rise to 2.73 litres per kilogram. Assuming a constant waste flow rate during all the year, during the worst season (summer, as indicated in Table 1), 2.33 litres of water will be released into atmosphere for every kilogram of waste fed to the plant and the overall consumption will be of 3.58 litres of water per kilogram. These data can be considered from several points of view. Since the average production of waste is 1.43 kg/day/inhabitant, assuming that by the incinerator start-up the source separation will be 50% of MSW, the average amount of water released into atmosphere will be 1.25 litres/day/inhabitant. In summer this data will grow till 1.66 litres/day/inhabitant, while overall consumption will be 2.56 litres/day/inhabitant. Since civil water use in Province of Torino is higher than 200 litres/day/inhabitant, it is possible to consider that water consumption in the incinerator of Torino is not critical. It is possible to arrive to a similar conclusion by considering water consumption for agricultural uses: 500-1500 litres of water for the production of 1 kilogram of wheat or maize and about 2000 litres for the production of 1 kilogram of rice.

4.2 Microbiological contamination

The problems of environmental hygiene related to cooling towers management are focused to the possible proliferation of pathogenic organisms and in particular the *Legionella pneumophila*. Legionellosis comprehends all diseases caused by *gram*-negative aerobe bacteria belonging to *Legionella* genus that reach respiratory apparatus through the inhalation of aerosol drops. Temperature and humidity of cooling towers are perfect for bacteria proliferation; in addition cooling towers radiate aerosol. There is no specific directive about this problem, but, in order to reduce microbiological risks, there are “best practices” that, in general, should be applied to any cooling system with water recirculation. In particular it is important to avoid stagnant zones, to reduce fouling and to remove encrustations and corrosion.

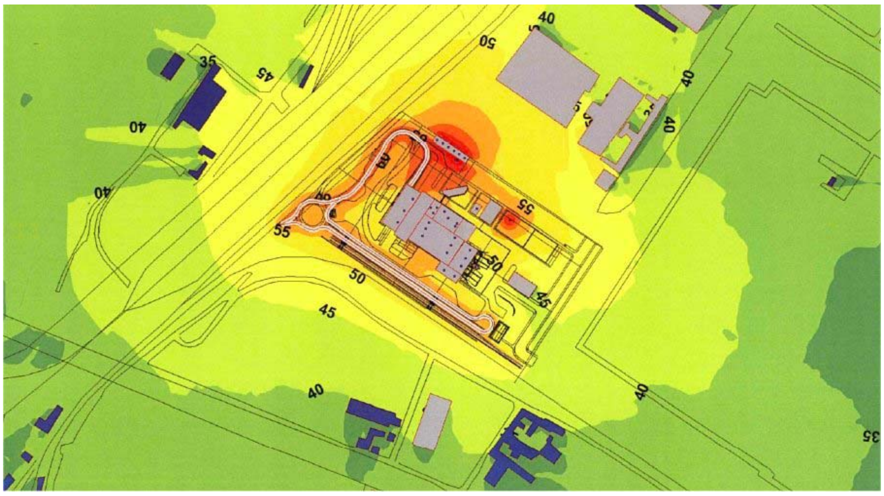

Figure 2. Noise generation: isophonic lines by day (data in dB(A)).

4.3 Noise

The noise level of each fan situated at the top of the six cooling towers results to be high (100 dB(A)) almost irrespective of the kind of fan. It is necessary to consider also the noise caused by falling water inside the towers: its estimated value is 102 dB(A) and so it is even higher than that produced by fans. Figure 2 shows the expected noise pollution situation by day.

4.4 Plume formation

The stream of humid air coming out from cooling towers can be visible when a portion of steam condenses because of low environmental temperature. Wet/dry towers release an air stream which has a temperature higher than that of evaporating towers; so, since saturation conditions are reached at higher altitudes, the plume visibility is delayed. In order to foresee if the plume will be visible, it is necessary to define plume characteristics and to compare them with air temperatures above the immission point.

4.4.1 Evaluation of plume top height

In literature it is possible to find a great number of correlations which allow to calculate the height of a plume emitted by a stack (Stern, 1968; Elias & Siniscalco, 1972; Brunner, 1985). These cases are different from the wet/dry towers because the rise of hot smokes is generally originated by the different density of the smoke itself and it is not due to powerful fans which give smoke velocities that can be higher than 50 m/second. However it can be interesting to consider the results supplied by these correlations; they are presented in Table 2 for summer and winter periods. Table 2 also shows the data used for calculations.

Table 2. Results supplied by some literature correlations: H, B, S, C are for Holland, Bosanquet, Smith and CONCAWE correlation respectively (Holland, 1953; Bosanquet, 1957; Smith, 1968; CONCAWE, 1966).

Period	d	v	u	p	T_n	T	Plume height [m]			
	[m]	[m/s]	[m/s]	[mb]	[K]	[K]	H	B	S	C
Summer	7.93	55.7	1.33	1013	289.9	293.2	394	1351	1479	831
Winter	7.93	146.4	1.59	1013	277.9	278.2	1073	2990	4457	718

The Holland correlation is probably the most well known thanks to its versatility and reliability; in this report the equation that Turner derived in 1969 from the one developed by Holland has been used (Turner, 1969). The Bosanquet correlation used, is the one suggested for cold smokes with high velocity of emission; according to this model, rise of smokes is exclusively due to their momentum. The Smith model, often indicated with the initials of the American Society of Mechanical Engineers, has been used for the case of small volume sources with high emission velocity of smokes and a temperature quite similar to that of the environmental air. Also in this case the rise of the plume is due to momentum of smokes. The CONCAWE (Conservation of Clean Air and Water, Western Europe) correlation has been chosen only as an element of comparison because it considers exclusively the effect due to smokes heat and so it doesn't take into account the emission velocity of gas stream. Considering the characteristics of the released gas stream, results obtained with Bosanquet and Smith correlations should describe in a satisfactory way the plume of the cooling towers of the incinerator of Torino. However the high velocity given to the air by the fans utilized in the towers has suggested to apply to these streams the model of free turbulent jets emerging from submerged nozzles into large volumes of a miscibile fluid (Davies, 1972); in fact, in the past, this approach has already been applied to cooling towers with good results (Kaylor et al., 1972).

4.4.2 The free turbulent jet model

In order to describe the discharge of humid air from the cooling towers of the incinerator of Torino the model of a free turbulent jet emerging from submerged nozzle into a large volume of a miscible fluid has been used (Davies, 1972). According to this model the jet has characteristics which can be described as a sequence of four regions. Naming d the nozzle diameter and L the distance from the nozzle itself, the four regions are:

- 0 < L ≤ 6,4 d: the rise velocity is substantially the same as that of emission and for this reason the jet is practically cylindrical;
- 6,4 d < L ≤ 8 d: it is the transition zone between the cylindrical and the following conical zone;
- 8 d < L ≤ 100 d: the rise velocity gradually decreases and the jet section grows due to the slowdown and the mixing with external air. The outer diameter of the jet D can be estimated as 0.36 L.
- L > 100 d: the rise velocity decreases quickly approaching zero.
- Since d = 7.93 m, the established flow region extends up to an height of about 800 m in both summer and winter because the model doesn't consider the exit velocity from the nozzle and the jet temperature. At this altitude jet diameter should be about 280 m. Figure 3 shows a jet pattern with the average rise velocities which have been calculated by the following equation:

$$v_L = 6.4 v_n \frac{d}{L} \qquad \text{(Eq. 1)}$$

The temperature variation along the jet is rather fast (faster than the drop in velocity) because of the very high nozzle velocity which creates a great deal of turbulence (Davies, 1972). The empirical correlation:

$$\frac{T_{pL} - T_L}{T_n - T_L} = 4.5 \frac{d}{L} \qquad \text{(Eq. 2)}$$

has been used to make a rough calculation of the temperature profile along the jet. Figure 4 shows the vertical ambient temperature gradient in Torino in a typical situation similar to the one taken into consideration for the incineration plant nominal working condition and the average temperatures of the humid air released by the cooling towers calculated by means of Eq. 2. The main working parameters are listed in Table 3. In this situation the relative humidity of the exhaust air is about 77% and the saturation temperature 12.6°C: therefore a visible plume will not take place. Obviously this result is largely affected by the characteristics of the ambient air, in particular its relative humidity: higher values would bring the air in the plume to the saturation at lower altitudes.

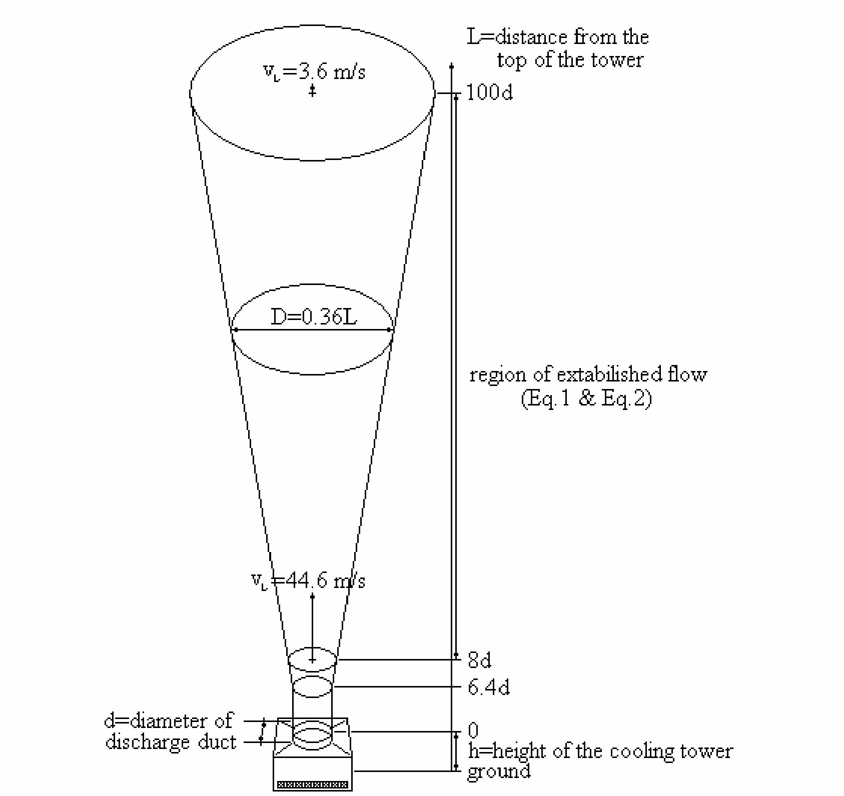

Figure 3. The plume according the free turbulent jet model.

Table 3. Main working parameters for simulations in Figure 4 and Figure 5.

		Nominal working condition (Spring – Fall, Table 1)	Generic Winter condition (Figure 5a)	Critical Winter condition (Figure 5b)
T	[°C]	20	5	5
T_u	[°C]	13.7	2	3.6
H	[%]	50	60	80
T_{wIN}	[°C]	31.3	28.1	28.1
T_{wOUT}	[°C]	21.7	18.5	18.5
W_c	[m^3/h]	11,000	11,000	11,000
W_w	[m^3/h]	150.8	107.1	107.1
T_d	[°C]	25	10	10
H_w	[%]	100	100	100
T_n	[°C]	16.7	4.1	4.7
H_n	[%]	77	79	90

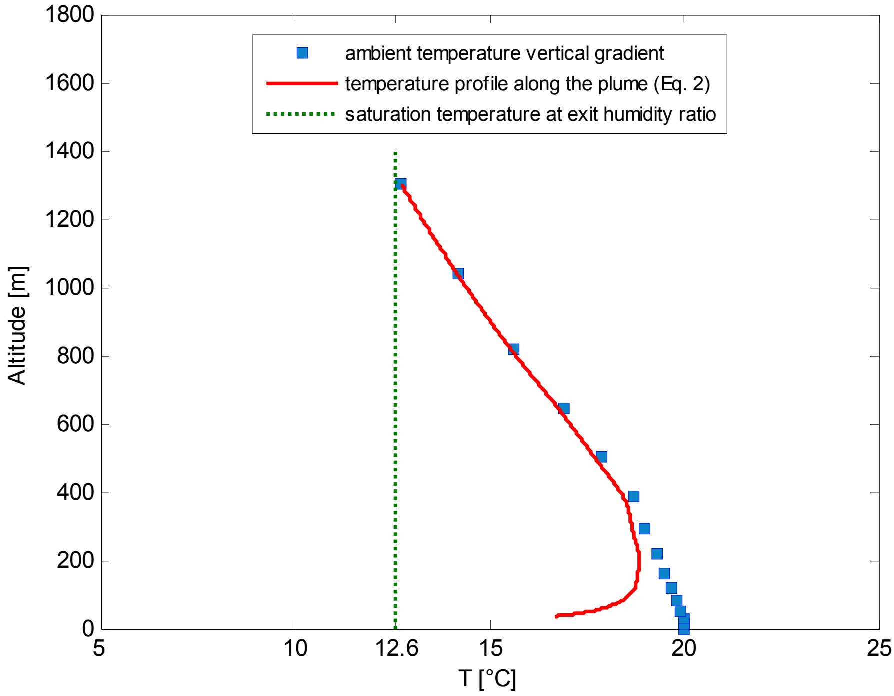

Figure 4. Plume temperatures at nominal working condition according to Eq. 2. The points are the measured ambient air temperatures in a corresponding climatic situation and the dotted line represents the saturation temperature of the air in the plume at discharge conditions.

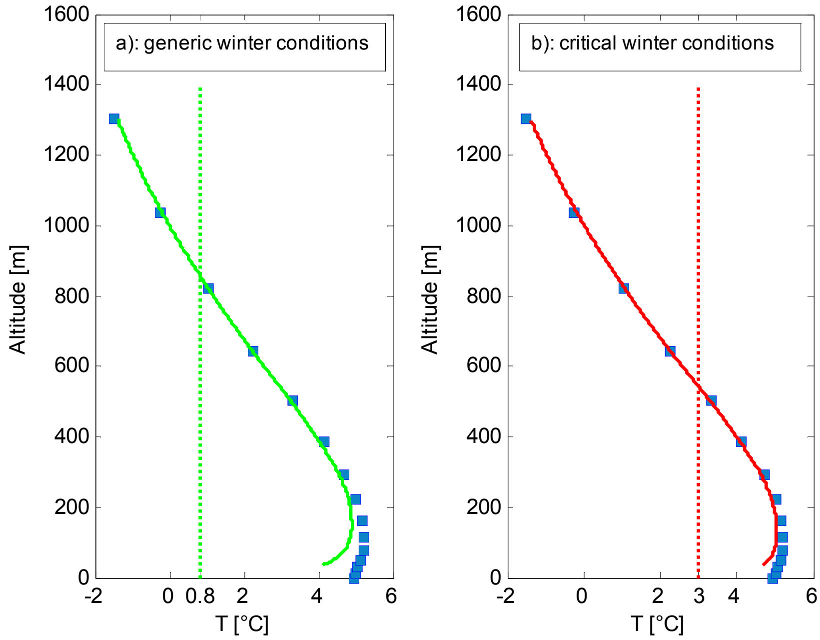

Figure 5. Plume temperatures in winter according to Eq. 2. The points are the measured ambient air temperatures in a corresponding climatic situation and the dotted lines represents the saturation temperature of the air in the plume at discharge conditions.

In the same way in winter, if the relative humidity of ambient air is not very high, the mixed air discharged from the towers will be rather far from saturation and there is little chance that the plume turn visible (Figure 5a). However a worsening of the weather conditions, with an increase of the relative humidity of ambient air, might bring to a critical condition as shown in Figure 5b. In the end a study has been carried out in order to predict the effects of the introduction in the ambient of such an amount of water: the results are shown in Figure 6 and are somewhat reassuring; however the frequency of fog occurrence is expected to increase.

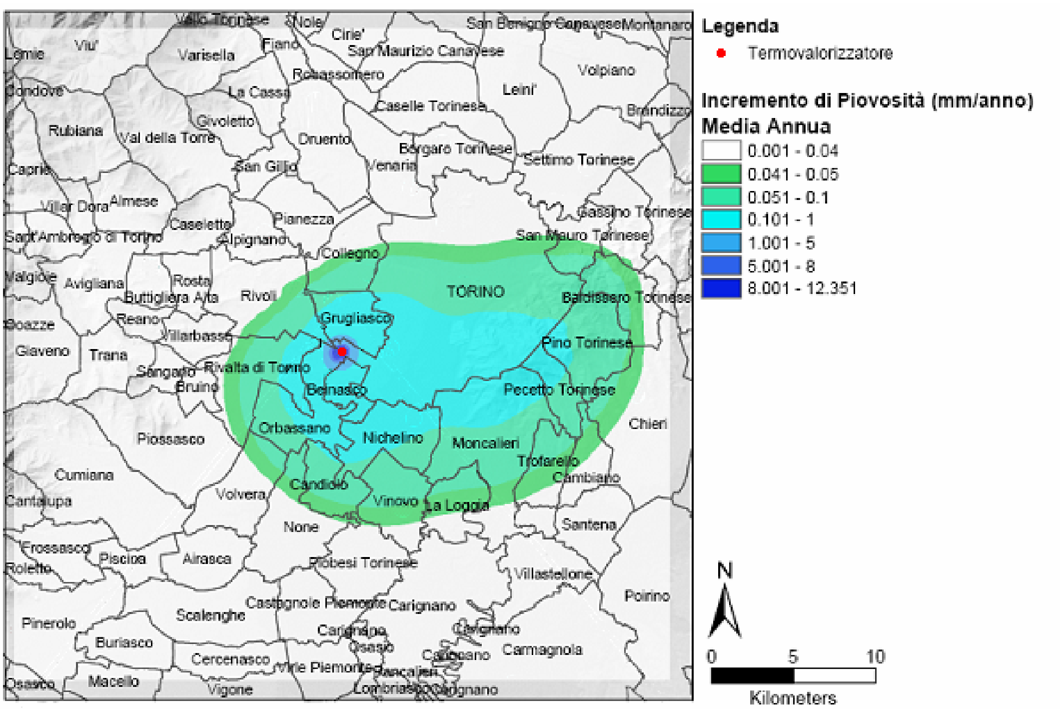

Figure 6. Predicted increase of rainfall.

5. CONCLUSIONS

The incinerator of Torino will have a rather high water consumption which, however, considering the number of served inhabitants and their water use, will not weigh significantly on the daily per-capita use. A significant portion of the used water will be released into the atmosphere as steam, but the wet-dry chosen technology will contain the formation of a visible plume. Anyway it is probable that fogging and icing conditions occur more frequently in the close proximity of the plant.

LIST OF SYMBOLS

d	diameter of the air exit duct of the cooling tower (nozzle diameter in free turbulent jet model)	m
D_L	diameter of the plume at a distance L from the top of the cooling tower (from the nozzle in free turbulent jet model)	m
H	per cent saturation of ambient air (relative humidity)	-
H_u	per cent saturation of the (mixed) air at the exit of the cooling tower	-

H_w	per cent saturation of the air from the wet section of the cooling tower	-
L	distance from the top of the cooling tower (from the nozzle in free turbulent jet model)	m
p	atmospheric pressure	mb
T	ambient dry bulb temperature	°C
T_d	temperature of the air from the dry section of the cooling tower	°C
T_L	ambient air temperature at a distance L from the top of the cooling tower (from the nozzle in free turbulent jet model)	°C
T_n	temperature of the (mixed) air at the exit of the cooling tower (nozzle exit temperature in free turbulent jet model)	°C
T_{pL}	temperature of the plume at a distance L from the top of the cooling tower (from the nozzle in free turbulent jet model)	°C
T_u	ambient wet bulb temperature	°C
T_{wIN}	temperature of the water entering the cooling tower	°C
T_{wOUT}	temperature of the water leaving the cooling tower	°C
u	wind speed	m/s
v_L	air velocity at a distance L from the top of the cooling tower (from the nozzle in free turbulent jet model)	m/s
v_n	air exit velocity from the cooling tower (nozzle velocity in free turbulent jet model)	m/s
W_c	circulating cooling water	m^3/h
W_w	flow rate of water evaporated in the six cooling towers	m^3/h

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