Definition of the main weak points of the investigated test sites
- IT test site -

Final Version

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1. Territorial framework

This report aims at the assessment of the flood hazard in Sant'Antonino basin, that is a strategic area for Ferrara territory.

The site in analysis is crucial and vital for Ferrara territory because it hosts the city hospital pole, named Sant'Anna Hospital. This area is included in a highly regulated hydraulic network, which includes flow regulators, floodgates and water lifting plants, and their smooth functioning is needed for the safety of the hospital site. Given both the regulated hydraulic regime and the strategic importance of the site, the assessment of the hydraulic risk in that area is of major importance and strongly recommended; therefore, this site is chosen as the study site within WP3 of Interreg PMO-GATE project.

Simultaneously, the seismic risk is analysed for the same site and their combination is finally evaluated. It is indeed plausible the increase of flood hazard due to the occurrence of seismic phenomena, which might cause a malfunction in the operation of water lifting plants.

For the following, it is deserved to specify that all the reference documentation has been offered by the authority in charge of the regulation of the secondary watercourses and channels network in Ferrara territory, named *Consorzio di Bonifica Pianura di Ferrara* (hereinafter CBPF)

The catchment area that hosts Sant'Anna Hospital is named Sant'Antonino, and it is 3700 ha wide, whereas the hospital pole covers an area of 50 ha.

Figure 1 shows the CBPF territory. Specifically, the area coloured in pink represents Sant'Antonino catchment area.

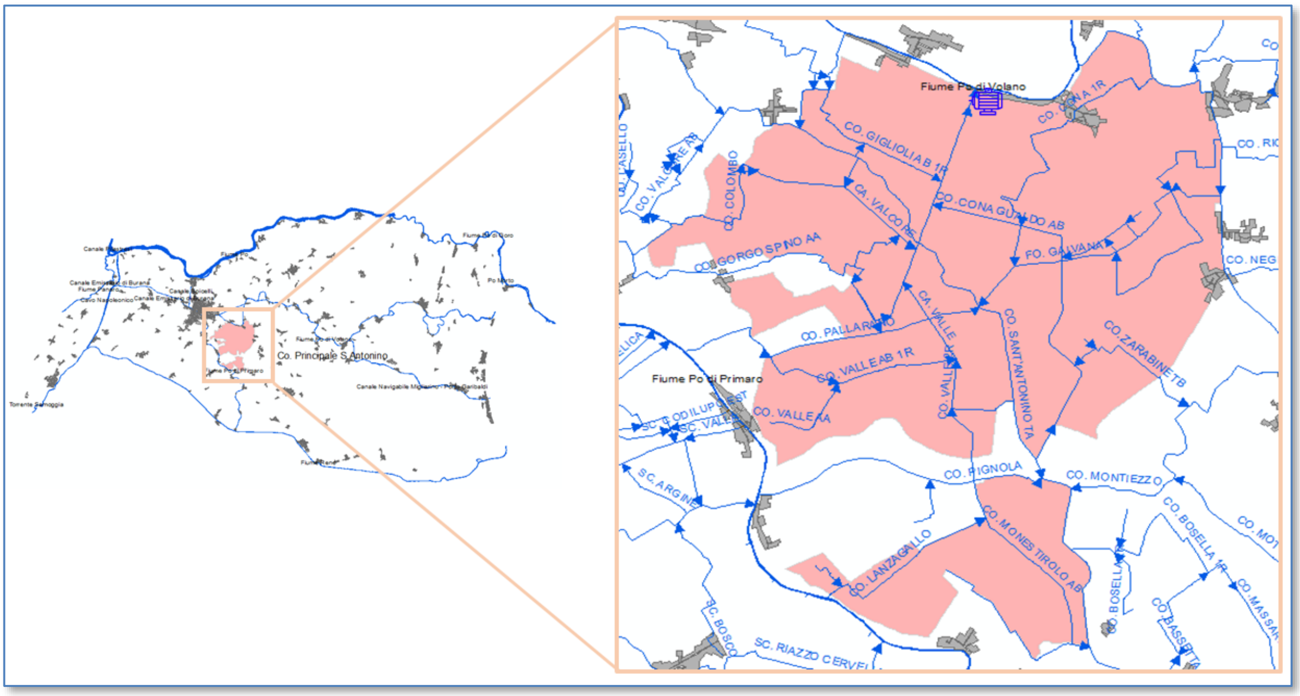

Figure 1. On the left: CBPF territory. It is bordered by Po River and Po di Goro River northward, The Adriatic Sea eastward, the Reno River southward and Panaro River westward. The pink area is Sant'Antonino area. On the right: detail of Sant'Antonino basin.

Sant'Antonino is located few kilometres far from Ferrara. It is surrounded by *Volano River* northward, *Primaro River* westward and southward and *Belriguardo Canal* eastward (Figure 1 figure on the right). Unlike the majority of the CBPF territory, Sant'Antonino area does not present land altitudes under the sea mean-level. In fact, within this catchment area, the lowest altitude is 4 m above sea level, while the highest is 25 m above sea level. Regarding the altimetry of the area, it is important to underline that the Hospital site is located at an unfavourable hydraulic altitude, in fact, it is at a lower elevation than the rest of the basin, therefore its altimetry is unfavourable for the rainfall drainage. To solve this problem, a higher-elevation street is built surrounding Sant'Anna Hospital.

The hydraulic regulation of the basin is now explained. The entire hospital area drains in the channel under the authority of the Consorzio named *Cona AA*, which flows into the *Cona Gualdo AB* duct and it pours out in the *Sant'Antonino Collettore Principale*. This latter hydraulic line is part of the Sant'Antonino basin and it has not a gravity draining system: the entire flow reaches the *Collettore Principale* and it is lifted by the pump station at the end of it, toward the *Po di Volano*. In Figure 1 it is possible to see the previously mentioned channels and the watercourses system of Sant'Antonino basin regulated by the CBPF, as well as the water lifting station downstream the *Collettore Principale*.

2. Sant'Antonino flow regulator

2.1. Object

The hydraulic project for Sant'Antonino catchment area is developed aiming at the adjustment and strengthening of hydraulic infrastructures designated for the hydraulic protection of the basin named Sant'Antonino, location of the new Ferrara Hospital site, under the municipalities of Ferrara and Voghiera. The project consists in the construction of an auxiliary water-lifting plant, next to the initial one that has been working since 1924, and a flow-rate regulator infrastructure.

2.2. The old water lifting plant

The adjustment and development of canals, hydraulic objects and plants were necessary considering their functional inadequacy, caused by their age on one hand, and, on the other hand, by the changed conditions of the land use within the territory. This last aspect considers changes in agricultural processing of the territory, the increase of urban and waterproof areas, and, most of all, the construction of the new Ferrara Hospital Site. Another critical aspect was the insufficiency of the water lifting plant: the initial 5400 L/s were not enough, considering the basin extension. Table 1 shows initial project data.

Total reclaimed area	*3700 ha*
Maximum lifted flow	*5.4 m^3/s*
Hydraulic head	*4.5 m*
Year of construction	*1924*

Table 1. Original water lifting plant data

Figure 2., Sant'Antonino old water lifting plant

2.3. The auxiliary water lifting plant

Given the inadequacy of the old water lifting plant, a new one is built next to the first to satisfy the new hydraulic conditions of the basin. The auxiliary water lifting plant consists in three dewatering pumps with vertical axes, allocated in a structure of reinforced concrete. The purpose of this project is to increase the maximum liftable flow rate from $5.4\ m^3/s$ (the initial one, lifted just by the old plant) to $12.5\ m^3/s$, with an overall increase of potentiality of the old plant of 130%. The entire system works mainly with electric supply: the fuel supply system is based on several transformation substations and on a fossil fuel generator system that guarantees coverage of 65% of the installed power. The project criteria are the division of the lifted flow into different plants and the abundance of supply and control systems, aiming at the complete cancellation of the possibility of a total block of the entire water lifting plant in case of malfunction.

2.4. Sant'Antonino flow regulator

At about 550 m far from the water lifting plan, in the arriving channel, a flow regulator is installed. This is a reinforced concrete structure that allocates three plane floodgates with automatic functioning. This hydraulic infrastructure aims at the regulation of the downstream water height in order to assure a safe condition for the Hospital Site drainage and reclamation networks, assuring the regular discharge from Sant'Anna hospital. Just like for the new water lifting plant, the base criterion for designing the hydraulic infrastructure consists in the abundance of the regulation system (i.e. the three floodgates), and of supply and control systems, to reduce completely the risk of a total block of the floodgates in case of a malfunction.

2.5. The project

The main purpose of the project is to ensure the highest level of hydraulic security for the Hospital Site, given its strategic importance for the community. The requested condition for the optimal outflow from the Hospital Site is that the water height in the emissary canal from the Sant'Antonino reclamation basin must not be greater than 9.90 m. This way, the hospital water discharge can outflow from the site without provoking floods both upstream and downstream. Consequently, the runoff from the 3700 ha Sant'Antonino territory is regulated by the three floodgates, which create the 'Regulator' hydraulic infrastructure. These floodgates limit the flow when it is greater than the maximum flow rate that ensures the safety of the Hospital Site. This latter safety condition depends on the maximum flow rate liftable from the water lifting plant complex in the closing section of the entire area, i.e. the old and the new water lifting systems. Therefore, the entire project is based on the assumption that the discharge from the hospital site must be always received by the emissary canal without generating floods and then lifted in the Po di Volano River.

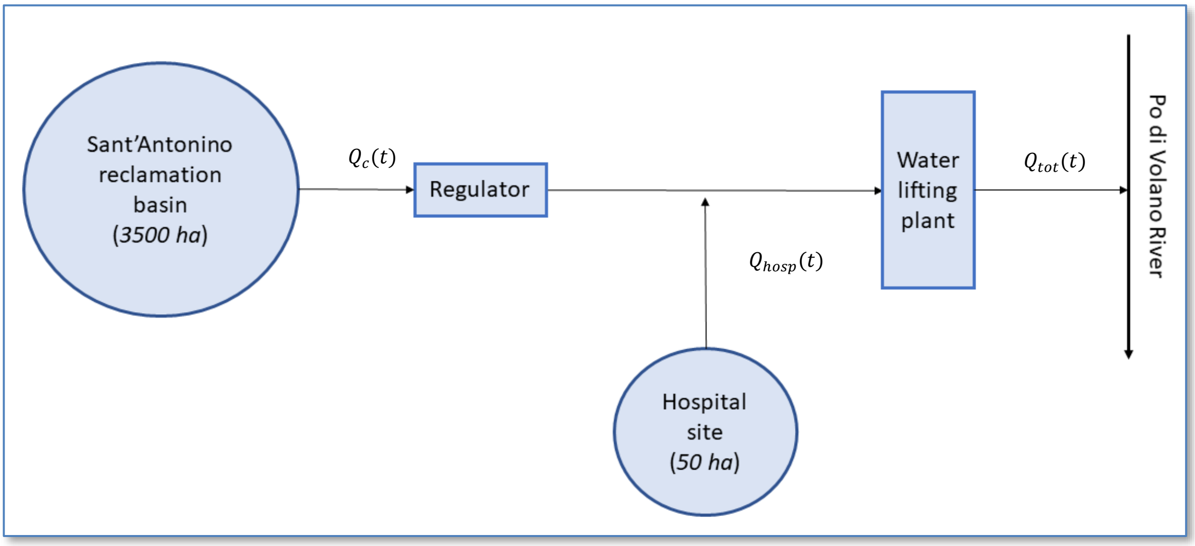

Figure 3. Sant'Antonino reclamation and regulation system.

Figure 3 represents the schematic layout of Sant'Antonino basin and the Hospital pole, indicating discharges directions and the hydraulic infrastructures, i.e. the regulator and the water lifting plant.

With reference to Figure 3:

- $Q_c(t)$ is the outflow rate from the Sant'Antonino reclamation basin, where c stands for *canal*,
- $Q_{hosp}(t)$ is the flow rate produced by the Hospital site,
- $Q_{tot}(t)$ is the maximum flow rate that the water lifting plan can lift, which is $12.5\ m^3/s$.

The system works following the subsequent principles:

- if $Q_c(t) + Q_{hosp}(t) > Q_{tot}(t)$ the Regulator temporarily limits the flow passing through its section, i.e. floodgates are partially open, to have the maximum project flow rate at the water lifting plant section. In particular, the regulator limits the discharge coming from the basin, whereas the flow coming from the hospital can normally outflow toward the water lifting plant.
- if $Q_c(t) + Q_{hosp}(t) \leq Q_{tot}(t)$ floodgates are completely open, and no regulation occurs. Specifically, neither the flow coming from the basin nor the hospital discharge is regulated.

During the period when $Q_c(t) + Q_{hosp}(t)$ is greater than $Q_{tot}(t)$ the Hospital Site is completely safe. This condition is possible thanks to the good retention characteristics of the Sant'Antonino basin; evidently, the drainage conditions of the basin are strongly stressed when the regulator is working.

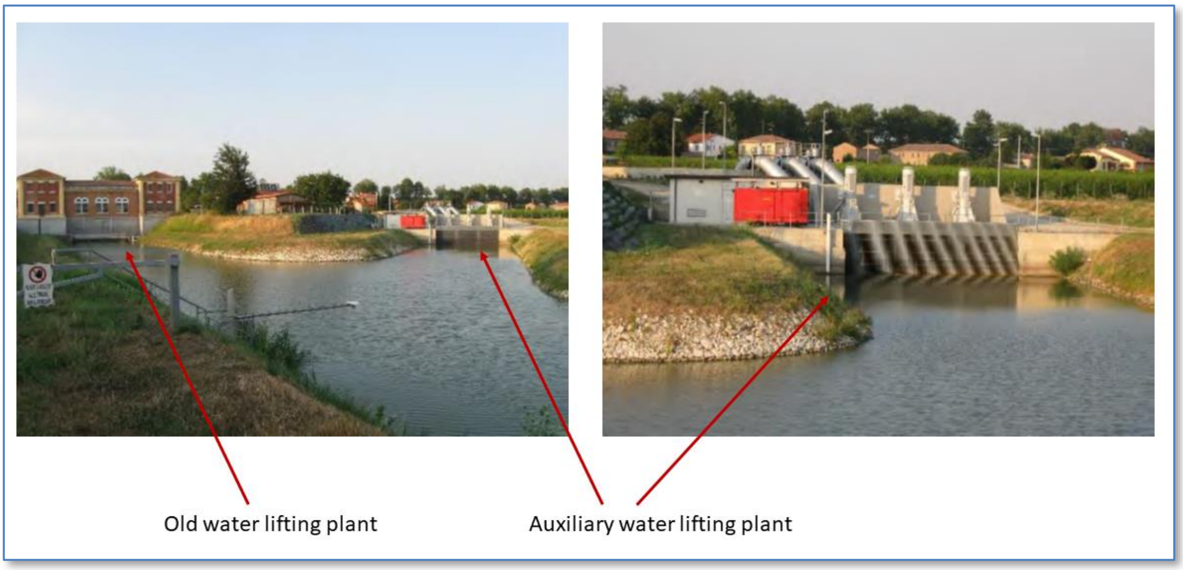

Figure 4. The pre-existing and the auxiliary water lifting plants.

3. Flood hazard for Sant'Antonino basin

All the following information refer to previous analysis carried out by the Consorzio di Bonifica Pianura di Ferrara (CBPF), which gently offered its support for the development of the Interreg PMO-GATE project, in respect of the analysis of the flood hazard for the study site in Ferrara. Given these data, new simulations might be done in order to update previous results. Furthermore, new scenarios of flood hazard might be considered for the evaluation of the combined risk, for example, the critical situation of a malfunction of the water lifting system.

The analysis of flood hazard for Sant'Antonino basin is composed by the following steps:

1. *Hydrological modelling*. Mapping the flood hazard for Sant'Antonio basin would require a detailed process, consisting of the evaluation of flood exposure for every duration of the rainfall event, for different rainfall distributions, for different seasons and different antecedent soil moisture conditions (AMC, in respect of the SCS – CN method). The followed methodology considers just the most significant setup for the modelling: rainfall duration until 48 hours, constant distribution of rainfall event, dry season and a combination of the three AMCs, return period 100 years. The simulation is conducted with the program MIKE 11, which permits the hydrological data processing for a basin.

2. *1D hydrodynamic modelling*. The hydrological data represent the base for the following hydrodynamic simulation. This model is evaluated in MIKE 11 as well. The most critical condition for the basin is identified among the rainfall events produced by rainfall durations of 12, 18, 24, 36 and 48 hours and 100 years return period. Then, the most critical rainfall duration is used to do simulations in face of 200 years return period.
3. *Territory representation*. Using ArcGIS software, the basin is implemented with support of the digital terrain model LIDAR, which is defined by 1 m width cells, spatialised at 10 m. This choice brings some simplification to the model that must be considered in results analysis.
4. *2D hydrodynamic modelling*. The territory model is then used for the bidimensional simulation. This last is carried out using MIKE 21 software, considering the most critical rainfall duration and return periods of 100, 80 and 50 years return period.

3.1. Hydrological modelling

As mentioned in the above, the hydrological characterisation would require several simulations, in order to consider different rainfall duration, different rainfall distributions, different return periods and AMCs (parameter of the SCS – CN method). For simplifying the study, the methodology aims at considering just the most significant situation, which is given by hydrological conditions that most stress the channels network in Sant'Antonino basin.
The most significant condition is given applying the following hypothesis:

- *Rainfall duration*. Only rainfall events with duration by up to 48 hours are considered. Then, the most critical duration is assessed for calibrating the bidimensional model.
- *Rainfall distribution*. The rainfall is described by a Chicago distribution. A constant distribution is considered only when it generates more critical situations.
- *Season*. The western part of the Ferrara territory regulated by the CBPF, where Sant'Antonino basin is located, is characterised by the highest rainfall data during the dry season. Therefore, simulations are carried out considering this period.
- *Soil moisture condition*. In this respect, it is decided to use a combination of the three AMCs (parameter of the SCS – CN method). In fact, the use of one of the three conditions would not be realistic.

- *Return periods*. Return periods considered are 50, 100 and 200 years, aiming at a complete analysis. For the assessment of the flood hazard, it is hypothesised that the flood event has the same return period of the rainfall event that produced it.

- *Micro-basins.* Sant'Antonino basin is divided into several basins to evaluate hydrological information in respect of the channels length of each micro-basins. This is carried out using ArcGIS software and georeferenced cartography.

Rainfall data are gathered from rain gauge stations. They are then corrected using the Areal Reduction Factor (ARF) and all parameters are inserted in MIKE 11 environment for the simulation. This report does not aim at the explanation of the specific setting of the model, therefore, the methodology is only presented in a qualitative way.

3.2. 1D hydrodynamic modelling

For the unidimensional simulation, MIKE 11 is used, and the hydrological modelling results stand for the initial condition. All simulations are carried out considering all floodgates preventively opened, in accordance with the Directive 2007/60/EC, which does not consider flood events imputable to wrong regulations of these hydraulic objects. The geometric information is set up in the model, as well as the shape of the network and all hydraulic infrastructures with their representative parameters, such as branches, points, weirs, culverts, control structures. The hydrological conditions are passed to the hydrodynamic model through the so-called rainfall-runoff links.

When all parameters are inserted in the model, the simulations are run for each of the rainfall durations considered: 12, 18, 24, 36 and 48 hours. Through the comparison among all simulations, results show that the most critical situation is given by an 18 hours rainfall event. Established this, the hydrological and hydrodynamic simulations are carried out for 100 and 200 years return period with rainfall events of duration of 18 hours.

3.3. Territory representation

This step of the analysis is fundamental for the following bidimensional simulation. Land representation is developed in ArcGIS environment. The territory is modelled using both georeferenced cartography of the CBPF, realised by a high-precision point detection, and LIDAR acquisition, which is characterised by 1 m^2 cells. Consequently, buildings, streets, roads and other infrastructures are added to the terrain model. This is then linked to MIKE

Zero software. The terrain model is then cleaned of all points presenting a difference in altitude between the GPS detection and the LIDAR evaluation bigger than a certain threshold. The LIDAR at 1 m resolution is considered a useful tool for terrain representation, it is then spatialised at 25 m (or 10 m in specific cases) in order to reduce simulation timing. This procedure causes the loss of some accuracy, for example, in the altitude of the right and left banks of a channel: since the channel width is completely comprised in a single cell, the spatialised model cannot keep different high information for both banks.

3.4. 2D hydrodynamic modelling

A bidimensional simulation is carried out based on a squared grid land model, and it is combined with the unidirectional one. Using MIKE 21, application of MIKE Zero software, it is possible to evaluate the propagation of water in the transversal direction, not only along longitudinal one. Specifically, the 2-dimentional simulation starts when the water height becomes higher than the level of the channel, so it propagates toward the land. For maintaining the duration of the simulation within acceptable values, the simulation is prolonged until the peak flow-rate is softened. This duration can be assumed about 40 hours.

3.5. Uncertainties related to the study

Lastly, it is important to underline some criticalities, which inevitably affect simulations and, therefore, they must be bore in mind.

- Firstly, flood probabilities scenarios simulated by the CBPF do not consider floods caused by the incapacity of the discharge to reach the channels network, i.e. no sewage flood is considered.
- Secondly, as stated in the above, the return period of the flood event is considered equal to the return period of the rainfall event that caused it; this surely approximates the study.
- Thirdly, all hydrological and hydrodynamic assumptions (i.e. CN method, AMCs, rainfall distribution etc) are other causes of uncertainties, but they are necessary to run the simulation.
- Fourthly, concerning the terrain representation, the land detection with LIDAR has a mean error (compared to a high-precision GPS detection) of ±8cm ÷ ±9cm, with a 68% of probability. The choice of representing the land with a 25 m (or 10 m in some cases)

spatial resolution causes the loss of some information, as the different altitude between the right band and the left bank of the river.

- Fifthly, transversal sections are surveyed at a different distance among each other, and, lastly, despite the roughness coefficient of channels are given with judgment, grass and sediments growth are not evaluable with precision.

3.6. Results: flood hazard maps for different return periods

In this section flood hazard maps are shown. The reported maps are assessed by the Consorzio di Bonifica Pianura di Ferrara; their processing has been directly followed by Doc. Eng. Laura Montanari.

Maps are assessed for different return periods (RP hereinafter): 50 years, 100 years and 200 years. Simulations date back to September 2017.

3.6.1. Flood hazard map: 50 years RP

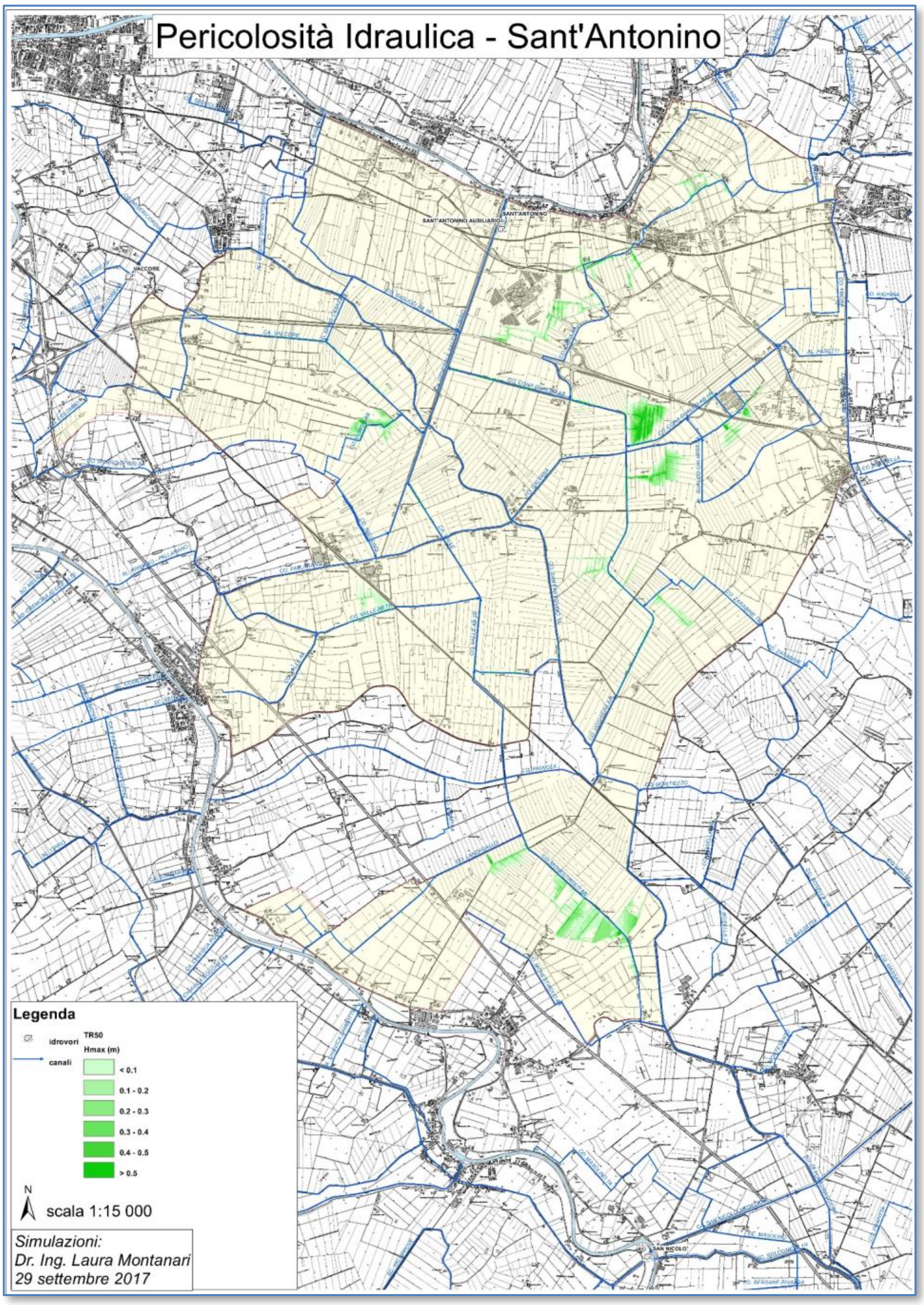

Figure 5. Sant'Antonino flood hazard map, 50 years return period

3.6.2. Flood hazard map: 100 years RP

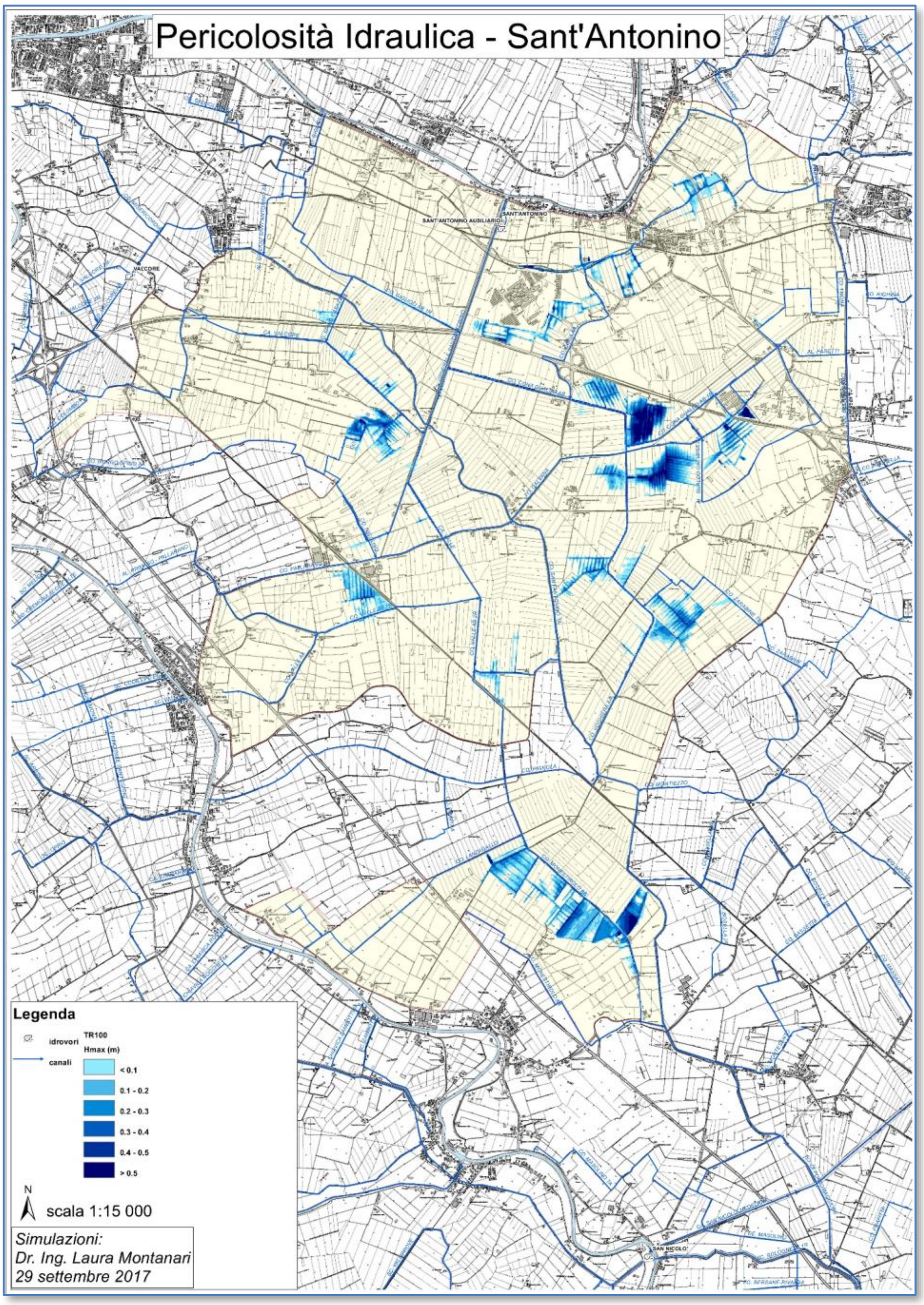

Figure 6. Sant’Antonino flood hazard map, 100 years return period

3.6.3. Flood hazard map: 200 years RP

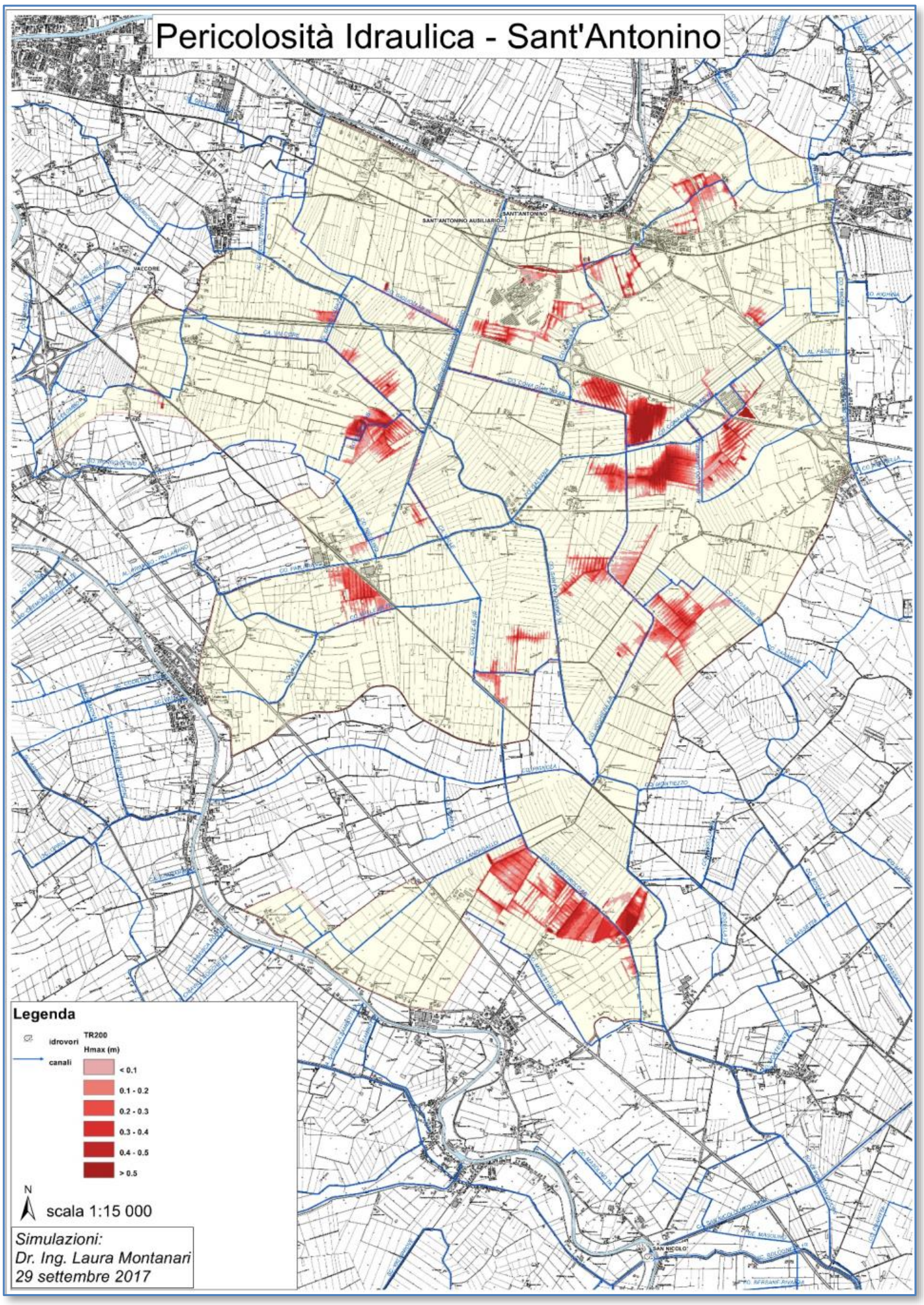

Figure 7. Sant'Antonino flood hazard map, 200 years return period

3.6.4. Flood hazard map: comparison

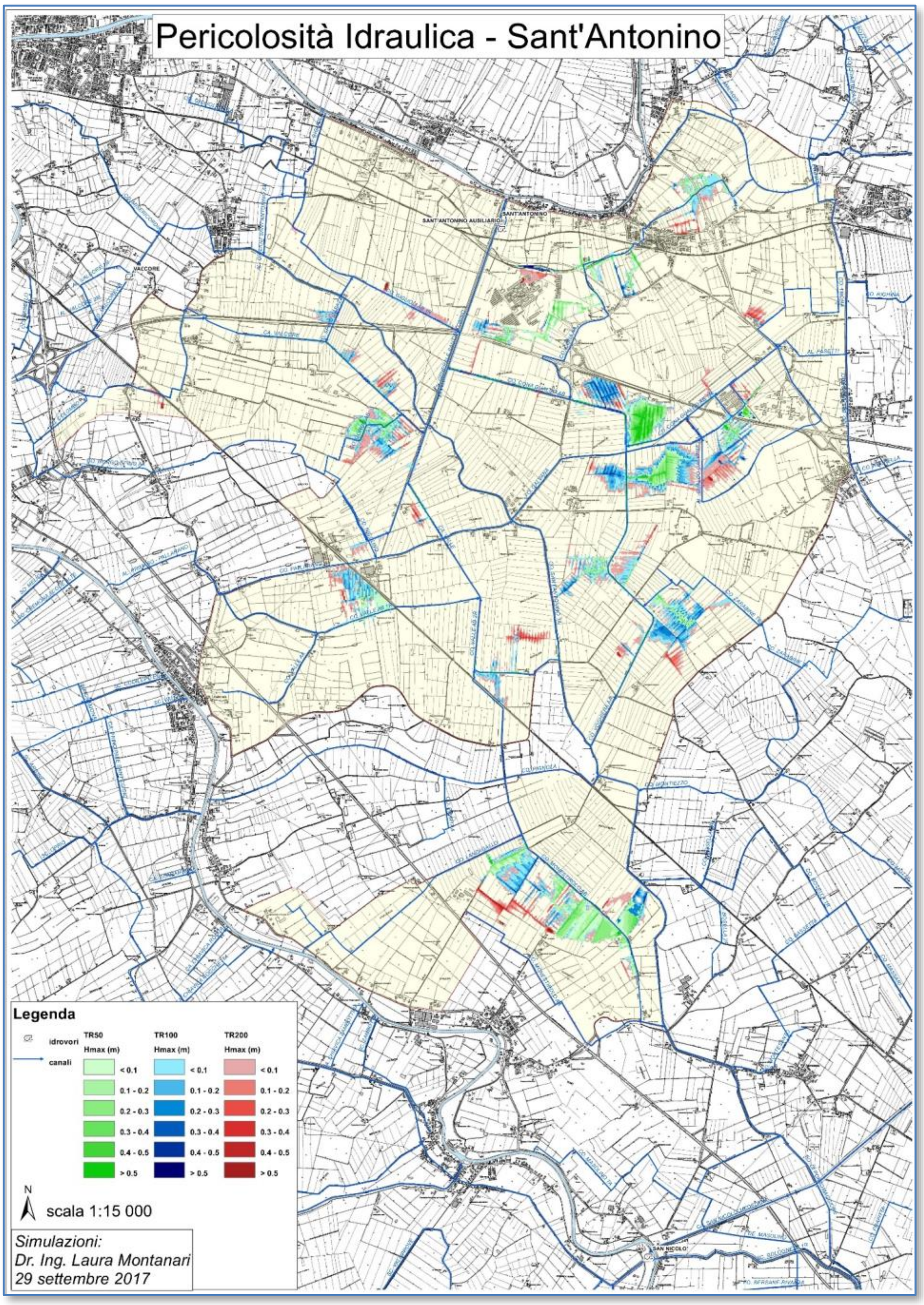

Figure 8. Sant'Antonino flood hazard map, 50 (green), 100 (blue) and 200 (red) years return period

4. The hospital site

Sant'Antonino basin is important for Ferrara territory due to the presence of Sant'Anna hospital. Therefore, it is the aim of this work to assess the flood hazard not only for the entire basin but also for this specific site.

As mentioned earlier, the hospital has been built in an unfavourable position for the hydraulic security: the altitude of this area is in fact lower than the mean land-level of the basin. To solve this problem, a street at a higher quota has been built.

In

Figure 9 it is possible to see that the hospital is protected from 50 years RP floods and 100 years RP floods. Specifically, the south, the east and the west part of the building are not influenced either by 200 years RP floods. On the contrary, the north part of the hospital area is exposed to 200 years RP floods. It is important to remind that the hydraulic security of the hospital area strongly relies on the functionality of the flow regulator and the water lifting plants, both the old and the new one. Therefore, the hazard map might change significantly in face of another scenario, i.e. with a malfunction of the water lifting plant.

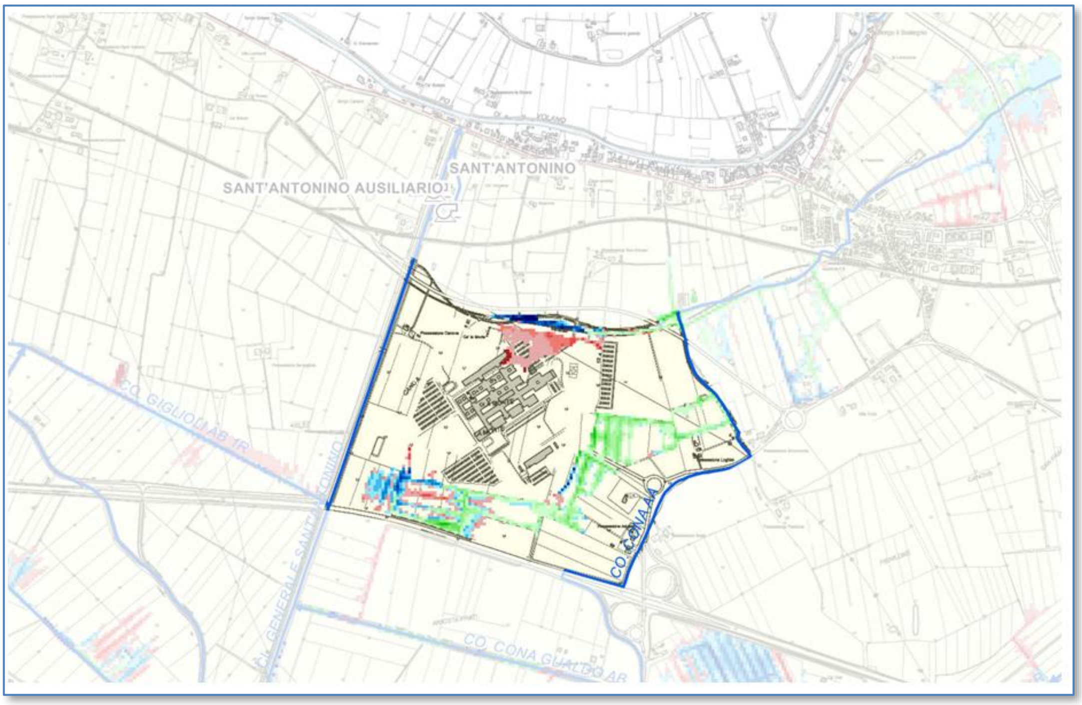

Figure 9. Hospital site in Sant'Antonino and flood hazard map for different return periods:
50 years (blue), 100 years (green) and 200 years (red).

The hospital site in Sant'Antonino basin (represented in Figure 9) has been object for a specific project aiming at a smart and efficient drainage system. In 2008, the Municipality of Ferrara involved the Consorzio di Bonifica Pianura di Ferrara for the definitive regulation of rainfall drainage in Cona area, that is the city where the hospital is located. Therefore, different hypothesis have been designed and introduced for the hospital site, considering different configurations of the channel rounding the hospital. The definitive project sees a new hydraulic line within the area that the original urban planification had disposed for reforestation and naturalisation, using it as hydraulic damper. For the implementation of the project different hypothesis of urban expansion and the capacity of Sant'Antonino reclamation system to drainage rainfall discharges are considered. In fact, the project has been thought to be efficient also in face of a future urban expansion of Cona city, assuring a hydraulic security to the hospital.

4.1. The new hydraulic line

After a careful examination of the different hypothesis presented for the hospital site, the best one consists in the realisation of a new channel, divided into two parts: the canal is characterised by a composed section without floodplain in the upstream part and with floodplain downstream, which is able to contain high discharges, related to the greatest return periods. The overall length is 1675 m. Figure 10 shows the project for the new hydraulic line.

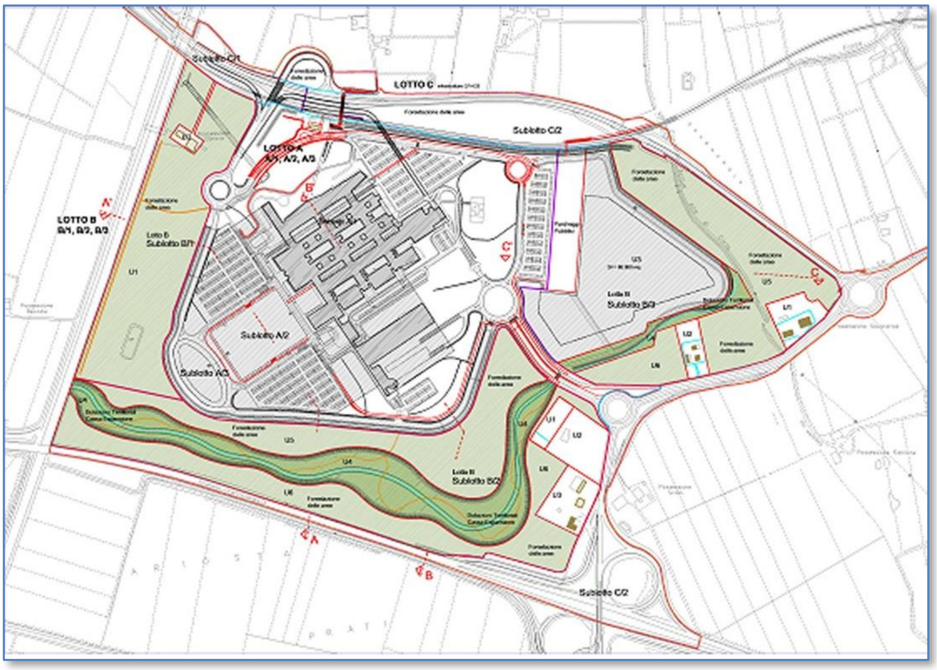

Figure 10. New hydraulic line project

The project of the new hydraulic line followed an analytical process, starting from the evaluation of the “state of affair” condition to the assessment of the proposed hypothesis. In order to assess flood probability in the hospital area, a complete hydrological and hydrodynamic study was carried out: from the rainfall study to a bidimensional simulation of the flow-rate propagation along the new hydraulic line. Before the realisation of the hospital, the land was prevalently characterised by a rural use. Therefore, the project of the new hydraulic line, which works as a drainage system for the area, must consider the hydraulic invariance criterion, for which the peak flow discharged into the receiver watercourse cannot compromise the hydraulic security of the area. This means that it must be kept within limited values, which are suitable for the hydraulic capacity of the receiver. Specifically: the increase of the urbanisation causes, on one hand, the increase in the discharged volumes into receiving watercourse, and, on the other hand, the decrease of the concentration-time in the formation of peak hydrographs. The hydraulic line must be designed to avoid the failure of the receiving system, overcoming these latter hydrological problems, and assuring safety conditions for the hospital.

In Italy exists a Directive concerning the hydraulic invariance that defines the maximum discharge that can drain in the receiving watercourse, depending on the largeness of the urbanised basin. For the realisation of the hydraulic line within the hospital pole, these volumes are respected but, to assure the hydraulic security of the area, they are re-defined: the maximum dischargeable volumes is even decreased from the value reported in the Directive for safety conditions.

The assessment of the flood hazard within the hospital pole follows the same methodology of the evaluation of flood hazard for the entire Sant'Antonino basin:

- Rainfall study
- Hydrological modelling
- 1D hydrodynamic modelling
- Representation of the land
- 2D hydrodynamic modelling

In the following, the methodology is reported, according to the documentation provided by the Consorzio di Bonifica Pianura di Ferrara. Since the procedure is really like the one presented in section 3, this section reports only different simulation approaches or noteworthy expedients.

4.1.1. Hydrological modelling

Firstly, it is important to gather reference rainfall events to design the hydraulic line, it is therefore important to characterise the rainfall regime. Sant'Antonino basin is designed considering a return period of 20 years. On the contrary, the Hospital site, given its vital and strategic importance for the city, is protected from more intense rainfall events. In fact, the canal rounding the hospital is made up of a compound section designed for a 20-years return period, with an engraved channel always filled by water, and it is located in-between a floodplain designed for a 100-years return period. Consequently, different rainfall occurrences must be considered: rainfall events with short RP for the inner channel and longer RP events for the floodplain. Therefore, the events taken into consideration for the analysis of the hydraulic risk of the Hospital site in Sant' Antonino basin have 20, 50 and 100 years return period. All analysis has been conducted considering the most critical season for hydrological conditions, which is the dry season.

Consequently, the reference hyetograph is assessed. With this regard, both constant rainfall distribution and Chicago hyetographs were used. The first typology permits to evaluate the infiltration capacity of the basin during long events; while Chicago hyetograph permits to assess the capacity of the drainage system during storm-like events, characterised by a strong peak. The use of both hyetograph was necessary to assess the behaviour of the basin and, in particular, of the new hydraulic line, in face of its different characteristics: on one hand, the basin has some rural areas that have a greater infiltration capacity, therefore, runoff formation time is longer than for a urban area, on the other hand, the urbanisation of the basin causes the decrease in peak time, but an increase in the peak volume, which often is not even supported by the receiving channel. Given these differences, the rural area is more vulnerable with long rainfall duration; on the contrary, the urbanised part is weaker in face of short and intense events.

Within the hydrological study, several rainfall events are simulated, considering different durations and a duality of rainfall distribution in time, as already stated. Among all durations considered, for designing the entire system, it is important to assess the critical rainfall duration and the consequent hydrograph. Basing on this latter, it is possible to size the hydraulic network and all the structures present in it. For every rainfall event there is a different runoff, and it changes depending on the duration of the event. The assessment of the most critical duration consists in the evaluation of the greatest discharge at the closing section of the new canal for all simulations with 20 years return period.

The determination of the runoff is carried out by the application of the SCS – CN method. To do this, the basin is previously divided into different sub-basin. For each of them, hydrological parameters are evaluated, such as hydraulic lengths of channels, concentration time, lag time etc. Moreover, for the application of the method the land is characterised to assess its infiltration capacity.

For the new hydraulic line, the critical duration results 15 hours, with a peak discharge at the closing section of the basin of 1.077 $m^{3/}s$.

4.1.2. 1D Hydrodynamic modelling

Hydrographs obtained with the hydrological modelling are inputs for the hydrodynamic modelling.

It is important to underline that Sant' Antonino reclamation system has marked rural characteristics, that influence the creation of the runoff; moreover, it satisfies both the drainage and irrigation functions for the basin. All these proprieties must be preserved also after the realization of the project, called New Canal. The New Canal is aimed to fulfil both drainage and lamination functions.

The new hydraulic line is designed to satisfy flow-rates given by different return periods: the inner part of the canal permits the regular discharge of runoff given by 20 years RP, while the consecutive floodplain, present on both sides of the inner channel, can maintain runoff provoked by 100 years RP events. Normally, the floodplain is usable and destined to be a public green area. This part of the canal aims at satisfying the lamination of big discharges, assuring hydraulic security of the hospital site.

From the hydrographs obtained with the 1D hydrodynamic simulation, it is clear the efficient lamination effect that the new hydraulic line operates on great discharges. With 20 years RP flow-rates the maximum volume dischargeable in the receiving channel is respected. On the contrary, with 50 and 100 years RP flow-rates the volume is greater than the threshold given by the Directive, but it is anyway accepted because the watercourses network of the CBPF has been designed for 20 years RP events and so this threshold must be considered valid only in face this RP. Anyhow, even for centennial flow-rates, the hospital site is safe from floods (see
Figure 9).

Concluding, this project of the new hydraulic line is the best solution for the context in which it is introduced. Indeed, on one hand, it respects the constraints of the hydraulic invariance criterion, and, on the other hand, it fits perfectly with the surrounding environment and it recalls Ferrara territory, which is characterised by a crammed open-channels network.

4.1.3. 2D hydrodynamic modelling: flood exposure

In order to assess the flood exposure for the hospital site, a two-dimensional simulation is needed. This simulation combines with the 1D simulation: it consists in the flooding of the lateral land when the water height surpasses the maximum height of the channel.

The first step for the evaluation of a flood exposure map, is the definition of a digital terrain model (DTM), which is a bidimensional model of the terrain that comprises all important land characteristics from a hydraulic point of view. The two-dimensional simulation starts when the water height becomes higher than the level of the channel, so it propagates toward the land.

Simulations consider returns period of 50 and 100 years; the hydrological boundary conditions are the same used for the unidimensional simulation: rainfall events with constant distribution and duration equal to 15 hours. The simulation with 50 years RP event sees the partial inundation of the floodplain next to the inner channel, which grows with the propagation of the incoming wave. In
Figure 11 it is possible to see the simulated flood in face of an event with 50 years return period. The downstream part of the channel sees a wider inundation that is mitigated by the floodplain. Specifically, the maximum water height in the downstream part of the New Canal is 25 cm, and it is always included within the floodplain. The upstream part of the channel is partially flooded, specifically it seems that only the final part of it is vulnerable to these events. The maximum height is about 20 cm and it remains within 5 m from the channel, without interesting the urbanised area.

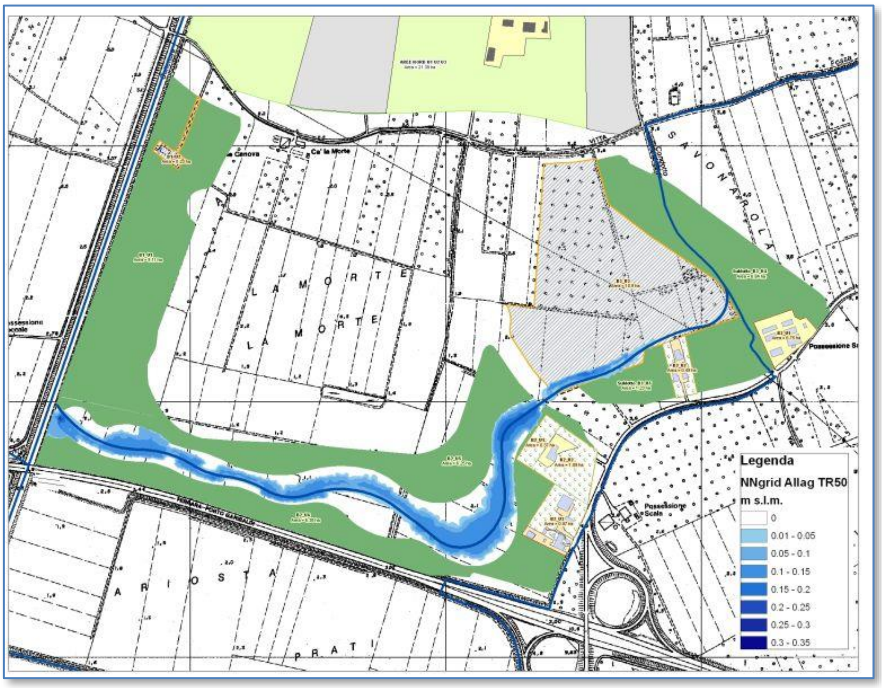

Figure 11. Maximum water heights reached within the floodplain area, with 50 years return period evet.

In contrast with the rest part of the secondary watercourses network, i.e. the channels network regulated by the CBPF, which is designed to protect the land from flooding event with RP of 20 years, the New Canal protects the hospital site from events of 50- and 100-years RP. This is noticeable also looking at
Figure 12.

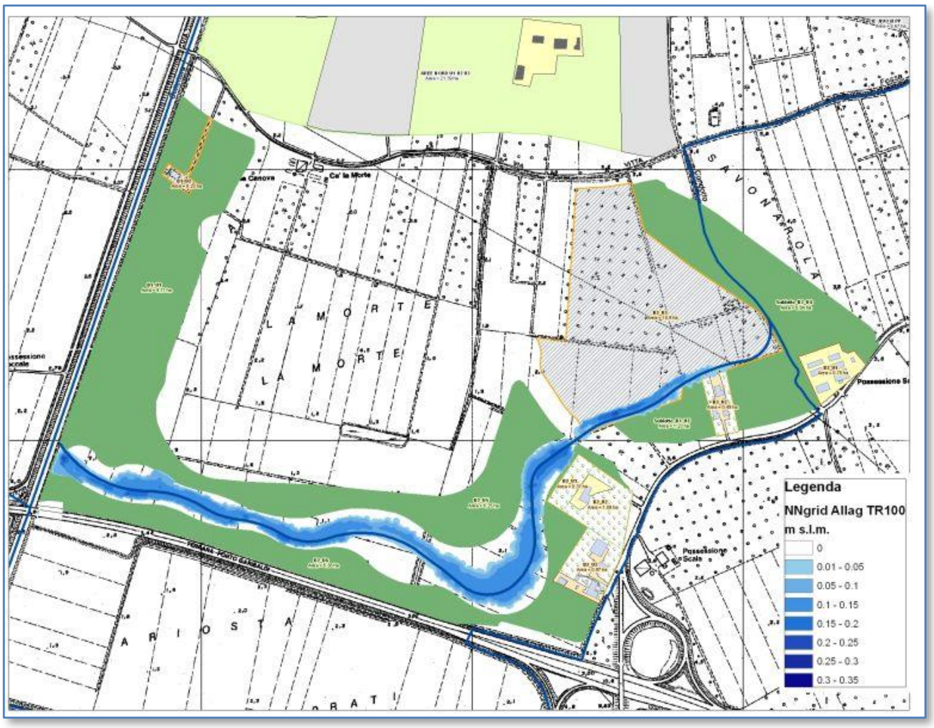

Figure 12. Maximum water heights reached within the floodplain area, with 100 years return period evet.

As well as for 50 years RP events, even in face of 100 years RP the hospital site is safe. Even though the flooded area is slightly bigger, in the downstream part of the canal the flooding area is completely included in the floodplain, whereas in the upstream part of the canal it does not reach the urban area.

To visualise the dispersion of maximum water heights along the canal it is possible to look at the following figures (
Figure 13 and
Figure 14), which represents scatter points of water heights. These figures show the maximum simulated water levels for 50- and 100-years RP, represented from downstream to upstream. As it is noticeable, the maximum water height is almost the same in both simulations, while in the 100 years RP case the flooded area is more spread upstream along the channel axes and the mean water height is overall greater.
Figure 13 and
Figure 14 represent the maximum water height in the floodplain for 50 years RP and 100

years RP, respectively, and
Figure 15 shows their comparison.

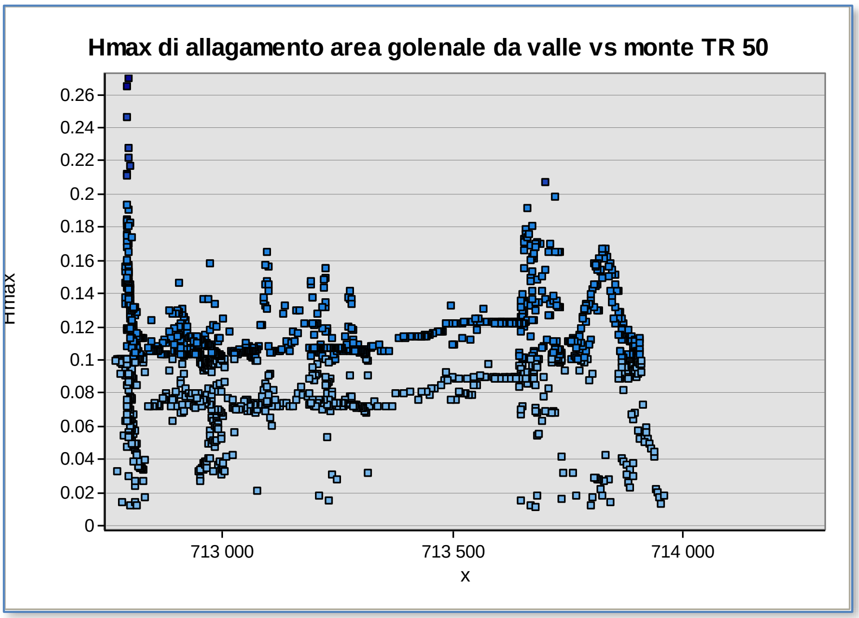

Figure 13. Scatter points of maximum water height reached in the floodable area of the canal, for 50 years RP events

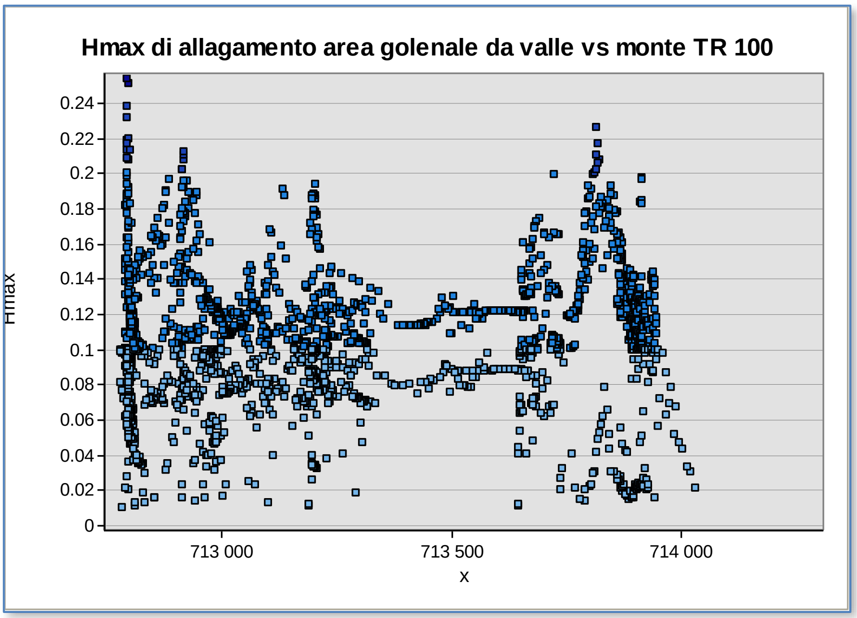

Figure 14. Scatter points of maximum water height reached in the floodable area of the canal, for 100 years RP events

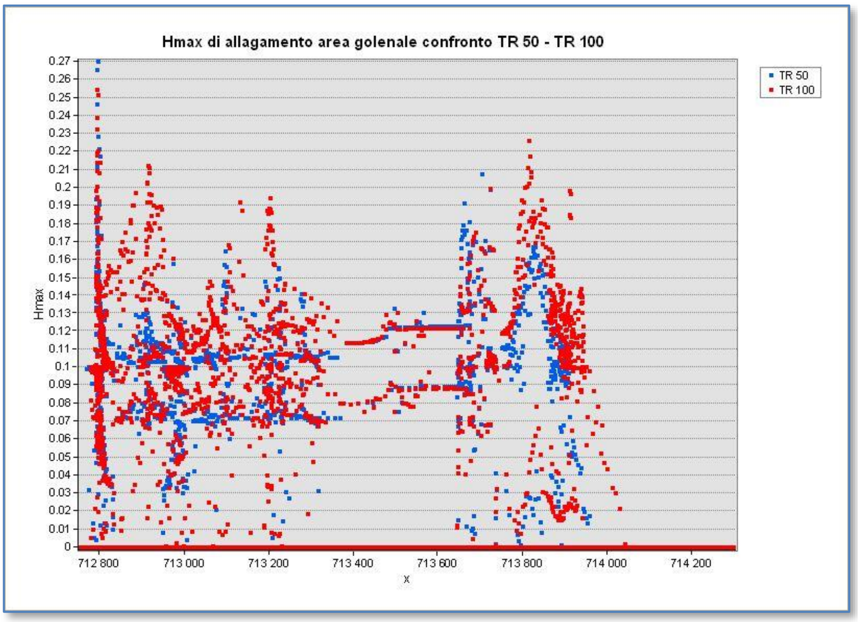

Figure 15. Comparison among scatter points of maximum water heights for 50 years RP (blue) and 100 years RP (red) in the floodable area, reported from downstream to upstream.

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Consorzio di Bonifica
PIANURA di FERRARA