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Development of an early warning system to predict sewer overflow

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Introduction

Flash flooding in our city is still a fairly common phenomenon. Usually the cause is the occurrence of a particularly intense precipitation that may cause the overflowing of rivers, channels or, in many cases, the overloading of the sewers. Damages caused by flooding are affecting communities, busyness, properties and environment.

The defense of urban areas from flooding must start from understanding the dynamics of runoff propagation. This knowledge is particularly important to limit the damage associated with each critical event.

Unfortunately, the development of a flash flood forecasting system in urban areas is not a simple and unambiguous procedure. There are several factors that compete to the realization of this system. The complexity of overflow pathways and the rapid response times are the main difficulties to overcome. Also the choice of the most suitable system must also take into account the sensitivity of the population to this issue and the technical and financial resources of public administration.

Thus the aid made up of all knowledge that public administration and scientific community can provide is extremely important in the study, in the comprehension, and finally in making decision about the actions for safeguard life and property of citizens.

It is clear that this cannot be done by a single person. Technical and relationship skills are part of different people. Citizens themselves are called to collaborate. All people must work together to build a safe space, of which is known the extension.

But how can be defined the extension of an area, or a drainage system? The problem of drawing the boundaries of a living space is secularly known. According to Leibnitz space has no boundaries. It can be represented by a hand in which the extension of the fingers is the distance between people and things that compose a space. Therefore boundaries are relative and only depend on the relationships we choose to adhere to. In the same way the boundaries of a drainage system cannot be defined but it is possible to choose only one extension. If the water exceeds this extension we are in an emergency situation where measures to mitigate risk have to be put into practice. If water does not exceed this limit, the distance between this situation and the limit one takes the name of *resilience* in a drainage system. In recent years, most of the hydraulic studies in the urban area, tries to understand how a city can expand or change with a different contour force before drainage system crisis will happen.

Goals

While attending the PhD course in Civil and Environmental Engineering, research activity has been given to realize an urban overflowing prediction system that was best as possible suited to the drainage network of the city of Palermo.

In the past and recent years the city of Palermo has shown signs of hydraulic failure, very useful for understanding the dynamics of water drainage.

This document is the synthesis of that training and research period. The issues analyzed will be described below.

The first Chapter is devoted to analyzing the causes of flooding in urban areas, with greater attention to the phenomenon most frequently recorded in the case study basin: the overflowing due to sewage network overload. To properly define this argument, some information regarding the current state of Italian and European laws about design, correct operations and management of failure of a urban drainage system have been added.

The next Chapter explains the analysis of risk mitigation systems, focusing mostly on a method of identification of the risk levels based on the principles of hydraulic resilience.

Analyzing the structural and non- structural urban flood mitigation system it was decided to present a brief summary of alert systems in real time, including their function and module of which they are composed in Chapter 3.

The analysis of early warning systems and their fundamental components was useful for the choice of an early warning system suitable for the city of Palermo. Chapter 4 is dedicated to show the early warning system chosen for this city.

Chapter 5 explains the activities aiming to write and implement the early warning system. Due to problems related to the complexity of the system, only the procedures that led to the definition of the hydraulic model and data assessment will be described in the following. The detailed definition of the management systems aiming to a real-time application are postponed to a further stage of research. So this chapter describes the techniques needed to calibrate the hydraulic model in order to obtain the resilience map of sewage network.

Last Chapter contains the balance about the work carried out. Of course to be a balance, each item must be supported by the results obtained. In particular all faults and benefits that the proposed methodology shows are declared.

It is recommended to read the last paragraph concerning the future development of this topic.

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Chapter 1

Flood in urban areas

A *flood* is defined by the Oxford English Dictionary as "*An overflowing or irruption of a great body of water over land in a built up area not usually submerged.*" Hence flooding represents the phenomenon of water accumulation in a usually dry area. Frequently the term is used as a synonym of inundation. In urban areas, it is more correct to talk about sewer overflowing, because of the presence of two runoffs, inside the sewers and over the streets.

Sewer overflowing is a natural phenomenon, but it becomes a cause for serious concern when it exceeds the coping capacities of affected communities, damaging lives and property. A sewer overflow can spill raw sewage into basements or out of manholes and onto city streets, playgrounds and into streams, before it can reach a final receiving point.

Sewer overflowing are affecting and often devastating more urban areas, where unplanned development in floodplains, ageing drainage infrastructures, increased paving and other impermeable surfaces, and a lack of overflowing risk reduction activities all contribute to the impacts experienced.

Figure 1.1 shows in the left the growth in direct monetary impacts resulting from flood events, while since the 1950s there has been a marked reduction in human lives losses.

Economic losses above are intended as direct losses. Indirect losses are equally important, such as disease, reduced nutrition and education opportunities, and loss of livelihoods, can also erode community resilience and other development goals, as does the need to constantly cope with regular, more minor, flooding. Such indirect impacts can be hard to identify immediately and harder still to quantify and value.

In terms of disaster management, it is necessary to understand urban flood hazards during overflowing emergencies in order to allow for mitigation, preparation and damage reduction activities. The management of overflowing risk requires knowledge of the types and causes of overflowing. This understanding is essential in designing measures and solutions which can prevent or limit damage from specific types of overflowing. Equally important is the knowledge of where and how often overflowing events are likely to occur.

This is a critical step in understanding the necessity, urgency and priority for overflowing risk mitigation.

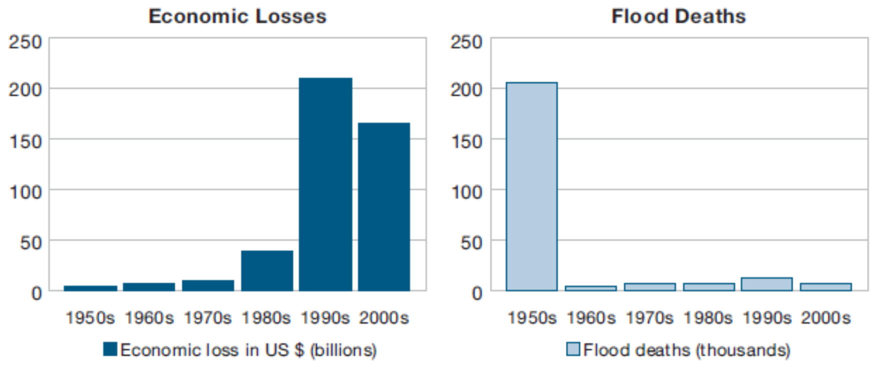


Figure 1.1: Economic and human life losses in the world due to urban flooding events.

1.1. Types and causes of urban flooding

Floods usually result from a combination of meteorological and hydrological extremes, such as extreme precipitation and flows. All floods can have severe impacts on urban areas – and thus be categorized as urban floods.

Urban floods are a growing issue of concern for both developed and developing nations. They cause damage to buildings, utility works, housing, household assets, income losses in industries and trade, loss of employment to daily earners or temporary workers, and interruption to transport systems. The damage caused by urban floods is on the rise.

Urban floods typically stem from a complex combination of causes. The urban environment is subject to the same natural forces as the natural environment and the presence of urban settlements exacerbates the problem. All precipitation and other flows have to be carried away as surface water or through drainage systems, which are usually artificial and constrained by the competing demands on urban land. High intensity rainfall can cause flooding when drainage systems do not have the necessary capacity to cope with flows. Sometimes the water enters the sewage system in one place and resurfaces in others. This type of flood occurs fairly often in Europe, for instance the floods that affected parts of England in the summer of 2007.

In other places, such as Mexico City, constant urban expansion has reduced the permeability of the soil in groundwater recharge areas. This factor, combined with significant land subsidence due to over-exploitation of groundwater during the last century, has increased the risk of flooding. It is now common that floods in low-lying areas consist partially of sewage fluids.

Urban floods are also caused by the effects of deficient or improper land use planning. Many urban areas are facing the challenge of increased urbanization with rising populations and high demands for land. While there are existing laws and regulations to control the construction of new infrastructures and the variety of building types, they are often not enforced properly owing to economic or political factors, or capacity or resource constraints. This leads to obstruction in the natural flow path of water, which causes floods.

Decision makers and city managers may also be influenced by such issues before revealing the actual level of risk applying to an area to the public, which sometimes has much bigger negative impacts on the flood risk situation of the area. Unless there is awareness amongst residents and proper cooperation between decision makers, risk management authorities and the public in the process of flood risk management, it will be very difficult to control the deterioration of the global urban flood risk situation.

Thus it is important to understand both the cause and speed of onset of each type of urban floods to understand their possible effects on urban areas and how to mitigate their impacts.

Firstly based on the speed of onset of flooding, floods are often described as *flash floods, semi-permanent floods, and slow rise floods* (Jha et al. 2011) (**Table 1.1**).

Furthermore based on causes of flooding, floods can be generally characterized into *river (or fluvial) floods, pluvial (or overland) floods, coastal floods, groundwater floods or the failure of artificial water systems*.

Table 1.1: Types and causes of urban flooding based on speed of onset and duration.

Types of flooding	Causes Naturally occurring	Human induced	Onset time	Duration
Flash flood	Can be caused by pluvial or coastal systems, convective thunderstorms, glacial lake outburst flood	Catastrophic failure of water retaining structures. Inadequate drainage infrastructure.	Rapid	Usually short often just a few hours
Semi-permanent flooding	Sea level rise, tide, small river and land subsidence	Drainage overload. Inappropriate urban development and groundwater management.	Usually slow	Long duration or permanent
Slow rise flood	Large river, climate changes	Land use changes.	Slow	Permanent

Table 1.2 summarizes the type and causes of flooding and they are further described below.

Table 1.2: Types and causes of urban flooding.

Types of flooding	**Causes Naturally occurring**	**Human induced**	**Onset time**	**Duration**
Pluvial and overland flood	Convective thunderstorms, severe rainfall, breakage of ice jam, glacial lake burst, earthquakes resulting in landslides	Land used changes, urbanization. Increase in surface runoff.	Varies	Varies depending upon prior conditions
Coastal-Tsunami and storm surge	Earthquakes Submarine volcanic eruptions Subsidence, Coastal erosion	Development of coastal zones. Destruction of coastal natural flora (e.g., mangrove).	Varies but usually fairly rapid	Usually a short time however sometime stakes along time to recede
Groundwater	High water table level combined with heavy rainfall, Embedded effect	Development in low-lying areas. Interference with natural aquifers.	Usually slow	Longer duration

River or fluvial floods occur when the surface water runoff exceeds the capacity of natural or artificial channels to accommodate the flow. The excess water overflows the banks of the watercourse and spills out into adjacent, low-lying floodplain areas. Typically, a river such as the Mississippi in the United States (**Figure 1.2 (a)**) or the Nile in North Africa floods some portion of its floodplains. It may inundate a larger area of its floodplains less frequently, for instance once in twenty years, and reaches a significant depth only once in one hundred years on average. The flow in the watercourse and the elevation it reaches depend on natural factors such as the amount and timing of rainfall, as well as human factors such as the presence of confining embankments, like levees or dikes. River floods can be slow, for example due to sustained rainfall, or fast, for instance as a result of rapid snowmelt.

Pluvial floods also known as *overland floods* are caused by rainfall or snowmelt that is not absorbed into the land and flows over land and through urban areas before it reaches drainage systems or watercourses. This kind of flooding often occurs in urban areas as the lack of permeability of the land surface means that rainfall cannot be absorbed rapidly enough. Pluvial floods are often caused by localized summer storms or by weather conditions related to unusually large low pressure areas. Characteristically, the rain overwhelms the drainage systems, where they exist, and flows over land towards lower-lying areas. These types of floods can affect a large area for a prolonged period of time: the 2007 floods in the Hull area in the UK were the result of prolonged rainfall onto previously saturated terrain which overwhelmed the drainage system and caused overland flooding in areas of the city outside the fluvial floodplain (**Figure 1.2 (b)**). Pluvial floods may also occur regularly in some urban areas, particularly in tropical climates, draining away quickly but happening very frequently, even daily, during the rainy season.

Coastal floods arise from incursion by the ocean or by sea water. They differ from cyclic high tides in that they result from an unexpected relative increase in sea level caused by storms or a tsunami (sometimes referred to as a tidal wave)caused by seismic activities. In the case of a storm or hurricane, a combination of strong winds that causes the surface water to pile up and the suction effects of low pressure inside the storm, creates a dome of water. If this approaches a coastal area, the dome may be forced towards the land; the increasing sea floor level typically found in inshore waters causes the body of water to rise, creating a wave that inundates the coastal zones. The storm surge usually causes the sea level to rise for a relatively short period of time of four to eight hours, but in some areas it might take much longer to recede to pre-storm levels.

Coastal floods caused by tsunamis are less frequent than storm surges, but can also cause huge losses in low-lying coastal areas. The 2004 Indian Ocean Tsunami was caused by one of the strongest earthquakes ever recorded and affected the coasts around the ocean rim, killing hundreds of thousands of people in fourteen countries (**Figure 1.2 (c)**).

Water levels under the ground rise during the winter or rainy season and fall again during the summer or dry season. *Groundwater flooding* occurs when the water table level of the underlying aquifer in a particular zone rises until it reaches the surface level. This tends to occur after long periods of sustained high rainfall, when rising water levels may cause flooding in normally dry land, as well as reactivate flows in bourns, which are streams that only flow for part of the year. This can become a problem, especially during the rainy season when these non-perennial streams join the perennial watercourses. This can result in an overwhelming quantity of water within an urban area. Groundwater flooding is more likely to occur in low-lying areas underlain by permeable rocks; where such an area has been developed; the effect of groundwater flooding can be very costly.

Groundwater flooding can also occur when an aquifer previously used for water supply ceases to be used; if less water is being pumped out from beneath a developed area the water table will raise in response. An example of this occurred in Buenos Aires (**Figure 1.2 (d)**), when pollution of groundwater led to a cessation of pumping. Drinking water was imported instead. The resulting water table rise caused flooded basements and sewage surcharge, which is a greater volume of combined water and sewage than the system is designed to convey (Foster 2002).

(a) **(b)**

(c) **(d)**

Figure 1.2: The Mississippi River flooding in 2011 **(a)**, Hull city during the flooding in 2007 **(b)**, a village in the north of Sumatra in 2004 **(c)**, Buenos Aires province during the flooding in 2002 **(d)**.

Since groundwater usually responds slowly compared to rivers, groundwater flooding might take weeks or months to dissipate. It is also more difficult to prevent than surface flooding, though in some areas water pumps can be installed to lower the water table. Flooding can also therefore occur in the event of the failure of pumping systems and may underlie the phenomenon of semi-permanent flooding.

In many cases groundwater and surface flooding are difficult to distinguish.

Increased infiltration and a rise in the water table may result in more water flowing into rivers which in turn are more likely to overtop their banks. A rise in the water table during periods of higher than normal rainfall may also mean that land drainage networks, such as storm sewers, cannot function properly if groundwater is able to flow into them underground. Surface water cannot then escape and this causes flooding.

Pluvial flooding are those that most frequently occur in Sicily. The Sicily Island is characterized by a Mediterranean climate with short duration and high intensity storm events especially in autumn and spring. Consequently, only stormwater management to mitigate urban flooding risk is described in the rest of the text.

1.2. Urban flooding management

As a result of urban population increase and economic development in some areas, uncertainty about how to quantify and to discern the measures that it must be implemented to mitigate impacts, caused by flooding in urban areas, has grown. This leads to implement strategies for risk mitigation that are flexible and holistic enough. Thus these strategies should be able to ensure sufficient elasticity of the system to different disturbance and understand several aspects that concern not only the structural protection but also the involvement of the exposed population. Consequently, a broad knowledge is necessary for testing mitigation measures, for adapting to the risk that may have a positive impact on the source, on the paths and on the receptors and for understanding the consequences about any flooding event (Langella, 2012).

Stormwater management has been recently married to the criteria of environmental sustainability, due to the application of the concept of *hydraulic invariance*, which states that the peak flow resulting from a flood drainage area should be constant before and after the transformation of the use of the soil in that area. This has resulted in moving from a management based only on the works of regimentation of traditional hydraulic structures to other that employ autodepurative water capacity.

The different established experiences of a holistic and multidisciplinary approach to the use of integrated policies for stormwater, wastewater and drinking water, with the implementation of standardized practices for whole regions, have resulted in significant improvements in water quality and formal solutions, especially in many non-European countries, more sensitive to these issues, even due to harsh outdoor conditions. These experiences have also proved that the use of alternative techniques can reduce costs compared to traditional construction of the sewage networks and helps to protect the environment from landslides.

In particular, the stormwater management in the United States is headed by the Environmental Protection Agency (EPA) and similar government agencies preside in some regions such in Australia and New Zealand, integrating rainwater management into all environmental issues. These agencies produce guidelines used by local communities to implement effective policies and procedures aimed to correctly bring the urbanized areas at having a water balance as near as possible to the one of the pre-existing natural system. In general, the success of the initiatives, carried out with the contribution of the agencies, is based not only on the activities of regulatory and monitoring local organisms, but also - more or less depending on the case - on experimentation, research, sensitization, information, economic incentives, user participation and technical and administrative support, including the production of a rich documentation.

1.2.1.European strategies

While the previously mentioned agencies are designed as organizations to support the local communities, the European Environment Agency (EEA) is more directed to the production of studies. Although the "Towards efficient use of water resources in Europe" report, published on March 2012, highlights the need for integrated water management, originating from better application of existing legislation, it is clear that the EU devotes little attention to rainwater. Indeed this report is mainly directed towards the reduction of waste and it does not generally address the issue of water in an integrated manner between the three types of water (rainwater, wastewater and drinking water) and other environmental issues.

In addition to the absence of a single system that is able to organize and optimize local policies for proper stormwater management, there are not even specific acts on this subject at European level, although there are several documents that affect this subject, such as the *European Charter of water*. This extraordinary precursor declaration was written by "European Committee for the Protection of Nature and Natural Resources" and promulgated in Strasbourg, on May the 6th in 1968 by the European Council. The document consists of 19 statements that will affect all subsequent legislative:

1. fresh water resources must be used in keeping with the objectives of sustainable development, with due regard for the needs of present and future generations;
2. water must be equitably and reasonably used in the public interest;
3. water policy and law must protect the aquatic ecosystems and wetlands;
4. it is up to everyone to help conserve water resources and use them prudently, in conformity with this charter;

5. everyone has the right to a sufficient quantity of water for his or her basic needs;
6. public and private partners must introduce integrated management of surface water, ground water and related water that respects the environment as a whole, takes regional planning into account and is socially equitable and economically rational;
7. integrated management must be based on an inventory of water resources and aim to ensure their protection, conservation and, if necessary, rehabilitation. In particular, any new deterioration and exhaustion of these resources must be prevented, the recycling of waste water encouraged and, where appropriate, limitations placed on certain uses;
8. water policy and law must be based on the principles of prevention, precaution and correction at source as well as the "polluter-pays" principle;
9. underground water resources must be the subject of special protection, and their use for human consumption must take priority;
10. water resources must be regularly monitored and their general state periodically assessed;
11. water concession must be granted for a limited duration and must be subject to periodic review;
12. large-scale consumption of water in agricultural or industrial processes must be carefully assessed and monitored with a view to ensuring better protection of the environment and avoiding unsustainable utilization;
13. at each state level, central, regional and local authorities must adopt and implement water management plans in a spirit of solidarity and co-operation. These plans should be based on the catchment basin;
14. decisions on water must take into account the particular conditions at regional or local level and be implemented by the relevant authorities closest to the areas concerned in keeping with water management plans;
15. States must co-operate, preferably within permanent institutions, to agree on an equitable and reasonable method of managing international watercourses and other shared water resources in conformity with international law and the principles of this Charter;
16. the public must have access to information on the state of water resources;
17. the public must be informed in a timely and appropriate manner of water management plans and projects for the utilization of water resources. It has the right to take an active part in planning and decision-making procedures concerning water;
18. the persons and bodies concerned must be able to appeal against any decision relating to water resources;

19. without prejudice to the right to water to meet basic needs, the supply of water shall be subject to payment in order to cover financial costs associated with the production and utilization of water resources.

The most important rule on water, although not specifically for rainwater, is the *Directive 2000/60/EC*. For achieving good ecological and chemical status of all EU waters by 2015, it establishes a framework for Community action, pursuing multiple targets, such as the prevention and control of pollution, the promoting of sustainable water use, the protection of the environment, the improvement of the status of aquatic ecosystems and the mitigation of the effects of floods and droughts. The Directive involves the identification and the analysis of all European waters, classified by basin to which they belong to, and also the adoption of management plans and appropriate measures for each water body.

A subsequent Directive focused more specifically on the flood risk management. The *Directive 2007/60/EC* on flood risk assessment and management, in analogy to what predisposes Directive 2000/60/EC relating to water quality, wants to create a framework for uniform EU-wide flood management. Therefore, this has been created to reduce the risk of adverse consequences associated with floods, especially for life and human health, environment, cultural heritage, economic activity and infrastructures. The Directive promotes an approach to long-term planning, divided into three stages, which provide for:

- stage 1: preliminary flood risk assessment (to be completed before September 22th, 2011);
- stage 2: development of hazard and flood risk maps (before June 22th, 2013);
- stage 3: preparation and implementation of management plans for flood risk (before June 22th, 2015).

The legislation provides that the elements set out in the flood risk management plan (stage 1, 2 and 3) be periodically reviewed and if necessary updated, even taking into account the likely impacts of climate change on the occurrence of floods. Therefore the updating of the Directive is cyclical, being provided a first review of the preliminary risk assessment to 2019, the hazard maps to 2021 and the management plan in 2021, and thereafter every 6 years.

1.2.2. Laws and institutions for the governance of stormwater in Italy

In Italy, agencies involved in stormwater management are the Basin Authority (Autorità di Bacino) and Land Reclamation Authorities (Consorzi di

Bonifica). The first, introduced by Law No. 183 of 18 May 1989 - Rules for the organizational and functional restructuring of soil conservation - are joint bodies, made up of state and the regions, operating on river basins, considered as unitary systems. Basin Authorities address their actions to protect the soil and the subsoil, to rehabilitate the waters, to use and to management of water resources and to protect environmental aspects, regardless of administrative boundaries. They are delegated to the development of appropriate Basin Plans (Piani di Bacino), that are knowledge, regulatory, technical and operational tools by which actions, aimed at conservation, protection and enhancement of the soil and at correct use of water, are planned, based on the physical and environmental characteristics of the concerned area. Land Reclamation Authorities, which are still regulated by the Royal Decree of February 13, 1933 No. 215, are public bodies responsible for the management of public works, with the aim of making it arable land through irrigation and of making urban areas secure, otherwise subject to flooding or landslides.

To meet the wording of the Water Framework Directive (Directive 2000/60/EC) and those as they're going to fit into the framework it outlined, as the Directive "Floods" (Directive 2007/60/EC), the Italian legislature, with the Legislative Decree 152/06, makes a radical reorganization of the previously set by Law 183/89, dividing the country in just eight river basin districts: Eastern Alps, Po, Northern Apennines, the Serchio (pilot district), Central Apennines, Southern Apennines, Sicily and Sardinia.

The responsible authority is the Basin Authority District and the Regions, in coordination with the National Department of Civil Protection. Because the District Authority has not yet been established, it was determined that the biggest Basin Authorities and the Regions to ensure fulfillment of the obligations the Directive.

From the above it is evident excessive fragmentation and overlapping competencies, with deleterious effects on the implementation of actions for risk mitigation and stormwater management.

1.2.3.Excellences in other member countries

In the UK, the management of rainwater is regulated by several laws, including the recent Flood and Water Management Act of 2010. The law introduces the concept of "flood risk management" instead of "flood defense" and encourages, among other things, the adoption of sustainable drainage systems, introducing the obligation of flood care design for new buildings and redevelopment projects, removing the automatic right to connect to the sewer system. An interesting innovation was introduced in England and Wales with the Code for sustainable homes, introduced in 2008 as a national standard for sustainable design and construction of new houses. The Code measures the sustainability of houses of nine design categories, including runoff of surface waters, and recognizes the value of sustainable drainage techniques to ensure that the drainage capacity of the site must remain unchanged after urbanization, encouraging through this the use of a credit policy. In Scotland, a similar approach was used to ensure that stormwater is effectively managed and the rules applied in a consistent manner: the Water Environment and Water Services (WEWS) Act of 2003 has made mandatory the use of drainage systems sustainable for all new settlements, with the adoption of a partnership that involves planners, local authorities, water authorities, the Scottish environmental Protection agency, the local population and non-governmental organizations.

Germany has always been a pioneer in the regulation of sustainable urban activities, with the enactment by the ATV-DVWK (the association that also takes care of all aspects related to wastewater, waste and soil protection) of some very specific standards, such as the A 105 "Choice of drainage systems" and the ATV-DVWK-M 153 "Recommendations for the treatment of rainwater. “These rules have allowed the realization of paradigmatic interventions such as PotsdamerPlatz in Berlin, considered among the best examples of European technological and formal solutions. The general legislation on water production was national until 2006, when a constitutional amendment made independent the federal legislation on this subject.

Finally, Copenhagen is the first in Europe for environmental policies and rainwater management. It is estimated that the rains on the Danish capital will grow by 30-40% by 2100, while the rise in water level can exceed 60 cm within the next decade. To effectively respond to increased precipitation and sea level rise, for the management of stormwater Copenhagen has developed a specific section within the General Plan climate of the city. This provides various facilities, including catch basins of wastewater and stormwater, drainage and sustainable urban systems that can mitigate the effects of climate change and ensure better resilience in populated areas. In order to slow down stormwater runoff it has planned to distribute permeable areas everywhere, including small gardens and green roofs, which can absorb up to 60% of rainwater, while the coverage of buildings facades through vertical vegetation contribute to the improvement of the air quality and cooling by reducing the heat island effect, and at the same time constitute a useful continuation of the ecological network in urban areas.

Chapter 2

Urban flood mitigation

Hazard mitigation encompasses the range of advance measures taken to avoid, reduce, or eliminate the long-term risk to human life and properties from natural hazards (FEMA 2000a). Mitigation is proactive rather than reactive. Rather than simply waiting for an extreme event and then trying to respond, mitigation planners estimate vulnerability to hazards and take anticipatory actions to lessen risk and exposure.

Traditional hazard mitigation protects people, property, and the environment from the destructive impacts of hazards in a number of ways (Godschalk et al. 1999). According to Jha (2011) it is possible to count almost 200 different types of flood risk mitigation measures. The most common classification divides flood risk mitigation systems into two main categories:

- SAMs (Structural-Hard-Measures);
- NSAMs (Non-Structural-Measures).

The first category belong all hydraulic engineering works such as dams, embankments, drainage systems, stilt houses, flood proofing, etc...While NSAMs are all systems that do not require modification of drainage system such plans, legislation, insurance and social conscience. Furthermore, these two categories can be classified as collective measures, if they aim to protect a specific area, or individual measures, if they defend individual property.

2.1.Flood mitigation measures

In recent years, this classification has been overcome to another one which tends to empower all individuals living in the territory. The principle on which is based this new classification is directly derived from ecology. Especially the urban area is now assimilated to a habitat that although perturbed can return to the status of pre-disturbance or can achieve a new balance with a minimum loss for who lives in it and without significant outside assistance. According to

Bowker, 2007, measures to mitigate flood risk in urban areas can be classified as:

- avoidance measures;
- resistance measures;
- resilience of the existing system;
- forecasting measures.

From this type of scheme some interventions whose function is not primarily flood mitigation are excluded: these are maintenance works. The maintenance of a drainage system can be considered as “extraordinary” if it resets of a structural damage, or as “ordinary “if the drainage system can be restored by cleaning and/or resetting of the components out of place. It has been shown that the only maintenance of the drainage system is able to solve many crises of the drainage system. The major disadvantage of this procedure is still the inability to make the network flexible to floods caused by climate change or by later waterproofing of a basin part. Therefore even if these measures are necessary for the correct operation of the drainage network in many cases are not able by themselves to protect a city.

2.1.1.Avoidance measures

Measures and techniques aimed at mitigating flood risk by building or re-design the drainage system belong to the first category. Construction of a new drainage system is justified for developing cities and for those that still do not have an adequate wastewater treatment system. As other examples, the remediation of wetland or the regimentation of waterways closed to the city can also be considered. In recent years new drainage works to make the system more sustainable through redesign have been also developed. These works are called SUDS (Sustainable Urban Drainage Systems) and aim to:

- partial recovery of soil permeability by placing porous paving or asphalt;
- increase the retention capacity on the surface, with lamination effect of the flood wave by construction of detention basins for stormwater;
- increase the infiltration capacity of stormwater through the establishment of draining trenches or grassy ditches;
- increase the evapotranspiration surface by installing green roofs.

SUDS are meant to keep outflows away from buildings without demolishing the original drainage system. These measures inside already shaped cities are considerable difficult due to the lack of space and the high cost.

2.1.2.Resistance measures

Resistance measures are installed to prevent floodwater from reaching or entering a property. Temporary resistance measures are typically designed to cover building apertures, i.e. doors, airbricks (**Table 2.1**). These measures are able to resist at high water level (up to 1 m) but need to put in place in time. Thus they are not suitable for flash flood events without forecasting measures. Permanent resistance measures are normally of the form of walls which surround properties or communities, or are applications or additions to the fabric of the building (**Table 2.2**). In generally, permanent measures are only used for low depth (less than 300mm) and short duration floods.

Table 2.1: Temporal resistant measures (costs refer to a semidetached house).

Measure	Flood type	Costs (k€)	Benefits	Potential difficulties
Free standing barriers	River flood < 1.5 m, urban flash floods, sewer flooding	7 - 15.0 (detached house)	Community protection, some accredited barriers, prevents floodwater reaching property.	Require adequate flood warning to deploy store and maintain. These are general defenses rather than for individual properties
Door guards and airbrick covers	Urban flash floods, river floods < 1 m, duration hrs – day sewer flooding	2.5 - 5.0	Rapid deployment, bespoke designs.	Temporary, relatively few proven in floods, requires storage, maintenance and deployment by owner, often permanent fittings to building
Flood skirts	Urban flash floods, river floods < 1 m, duration hrs – days sewer flooding, groundwater	12.5 - 44.0	Covers building fabric, permanent housing for skirt, occupant may not need to move out, used successfully with impermeable walls	Suitable for detached buildings only, temporary, sustainability not proven, requires storage, maintenance and deployment by owner, extensive below ground work needed
Sump and pumps	Urban flash floods, river floods < 1 m, duration hrs – days sewer flooding, groundwater	0.06 – 3.0	If fitted correctly and of sufficient capacity can remove floodwater in an emergency.	Must be positioned and sized correctly. May require external or ancillary power supply

Although the resistance measures are important for the mitigation of flood risk in some cases, these systems may not be a winning strategy at all. The main disadvantage is the uncertainty of heights that the barriers must have. Therefore designers and urban planners have recently proposed resilience measures that are based on consideration that a flooding may be occurred but also that in its passage it involves the least possible damage. In the next paragraph basic principles of resilience in hydraulics and the most common interventions are presented.

Table 2.2: Permanent resistant measures (costs refer to a semidetached house).

Measure	Flood type	Costs (k€)	Benefits	Potential difficulties
Automatic barriers (door /gate opening)	River floods < 1.5 m, urban flash floods	10.0 – 22.5	Automatic; unobtrusive, use for flood depths up to 1.5 m, 0.6 m on property level, use for doors, gates or community barriers;	Expensive, may be safety issues for domestic use, requires substantial below ground work, specialist maintenance required
Low bund	River flood<1 m		Community protection, prevents floodwater, reaching property	Require risk assessment and design to prevent breaching, or overtopping, requires below ground work, may increase flood risk
Boundary walls, fences, resistant gates	Urban flash floods, river floods < 1.2 m, duration hrs – day	4.5 – 2.5 3.0 - 5.5	Prevents floodwater reaching property proven in floods, aesthetic designs	May affect flood risk to neighbors
Raised thresholds	Urban flash floods, river flood < 300 mm, duration hrs – day, sewer flooding	1.5- 1.8	Occupant may not need to move out	Disabled access may not be possible
Stormporch	Urban flash floods, river flood < 300 mm, duration hrs – day, sewer flooding	7.0– 7.5	Occupant may not need to move out	Disabled access may be difficult
External wall render and facing	Urban flash floods, river flood < 600 mm, duration hrs – months, sewer flooding	1.5- 2.5	Occupant may not need to move out, prevents floodwater entering property	Good quality workmanship essential wall preparation and regular maintenance essential
Airbrickelev ation	Urban flash floods, river flood < 300 mm, duration hrs – day, sewer flooding	3.0 - 3.7	Proven in floods	Floodwater will enter cavity or beneath floor if used for floods > 300 mm, not to be used in isolation
Integral automatic airbrick	Urban flash floods, river flood < 300 mm, duration hrs – day sewer flooding	1.7 – 2.0	Automatic	Novel, not proven in floods, good workmanship essential
External doors	Urban flash floods, river flood < 600 mm, duration hrs – days sewer flooding	0.9- 3	Proven in floods, aesthetic designs, reduces flood ingress and damage	Access may be a problem during long duration floods, may be difficult to may need maintenance to ensure effective seal

2.2. Urban resilience

Futurist theorist Harold Foster (2002) has proposed 31 principles for achieving resilience. He organized them according to several categories: general systems, physical, operational, timing, social, economic, and environmental. According to Foster, resilient general systems are independent, diverse, renewable, and functionally redundant, with reserve capacity achieved through duplication, interchangeability, and interconnections.

Researchers who have studied the response of resilient systems to disasters find they tend to be:

- *redundant* with a number of functionally similar components so that the entire system does not fail when one component fails;
- *diverse* with a number of functionally different components in order to protect the system against various threats;
- *efficient* with a positive ratio of energy supplied to energy delivered by a dynamic system;
- *autonomous* with the capability to operate independently of outside control;
- *strong* with the power to resist attack or other outside force;
- *interdependent* with system components connected so that they support each other;
- *adaptable* with the capacity to learn from experience and the flexibility to change;
- *collaborative* with multiple opportunities and incentives for broad stakeholder participation.

2.2.1. Resilient city

A resilient city is a sustainable network of physical systems and human communities. Physical systems are the constructed and natural environmental components of the city. They include its built roads, buildings, infrastructure, communications, and energy facilities, as well as its waterways, soils, topography, geology, and other natural systems. In sum, the physical systems act as the body of the city, its bones, arteries, and muscles. During a disaster, the physical systems must be able to survive and function under extreme stresses. If enough of them suffer breakdowns that cannot be repaired, losses escalate and recovery slows. A city without resilient physical systems will be extremely vulnerable to disasters.

Human communities are the social and institutional components of the city. They include the formal and informal, stable and ad hoc human associations that operate in an urban area: schools, neighborhoods, agencies, organizations, enterprises, task forces, and the like. In sum, the communities act as the brain of the city, directing its activities, responding to its needs, and learning from its experience. During a disaster, the community networks must be able to survive and function under extreme and unique conditions.

If they break down, decision making falters and response drags. Social and institutional networks exhibit varying degrees of organization, identity, and cohesion. Just as engineers analyze the fragility of physical structures under stress, social scientists seek to develop ‘‘fragility curves’’ for organizations under stress (Zimmerman 2001). A city without resilient communities will be extremely vulnerable to disasters.

Resilient cities are constructed to be strong and flexible, rather than brittle and fragile. Their lifeline systems of roads, utilities, and other support facilities are designed to continue functioning in the face of rising water, high winds, shaking ground, and terrorist attacks. Their new development is guided away from known high hazard areas, and their vulnerable existing development is relocated to safe areas. Their buildings are constructed or retrofitted to meet code standards based on hazard threats. Their natural environmental protective systems are conserved to maintain valuable hazard mitigation functions. Finally, their governmental, nongovernmental, and private sector organizations are prepared with up-to-date information about hazard vulnerability and disaster resources, are linked with effective communication networks, and are experienced in working together.

Resilience is an important goal for two reasons. First, because the vulnerability of technological and social systems cannot be predicted completely, resilience—the ability to accommodate changes gracefully and without catastrophic failure—is critical in times of disaster (Foster 1997). If we knew exactly when, where, and how disasters would occur in the future, we could engineer our systems to resist them. Since hazard planners must cope with uncertainty, it is necessary to design cities that can cope effectively with contingencies.

Second, people and property should fare better in resilient cities struck by disasters than in less flexible and adaptive places faced with uncommon stress (Bolin and Stanford 1998; Comfort 1999). In resilient cities, fewer buildings should collapse. Fewer power outages should occur. Fewer households and business should be put at risk. Fewer deaths and injuries should occur. Fewer communications and coordination breakdowns should take place.

2.2.2.Flood resilience evaluation

The resilience of a city is absolutely linked to the condition of environment and treatment of its resources; therefore the concept of sustainability is central to study of resilience. An environment stressed by unsustainable practices may experience more severe environmental hazards. For example, reduction of urban green was a factor in increasing the flooding hazard. This approach helps in the selection of variables to be analyzed as indicators of resilience but leaves open the choice of the space-time dimension for resilience evaluation. For example the flooding road can cause a blockage of circulation in a small scale, an interruption of services in a medium scale, a loss of profit in a larger scale. In addition to scale, the rates of onset of the initiating event are another confounding issue in resilience evaluation. In urban areas the rates of onset of the crisis are less than the minimum time of evacuation (about 1-2 hours). So in the evaluation of resilience the variables that take into account forecasting measures of the event are also provided (Cutter et al., 2008).

The majority of assessment resilience techniques are quantitative and use selected indicators or variables as proxies since it is often difficult to quantify resilience in absolute terms without any external reference with which to validate the calculations (Schneiderbauer and Ehrlich, 2006). As a result, indicators are typically used to assess relative levels of resilience, either to compare between places, or to analyze resilience trends over time. Important criteria for indicator selection include validity, sensitivity, robustness, reproducibility, scope, availability, affordability, simplicity, and relevance (Birkmann, 2006b; de León and Carlos, 2006). The most important of these is validity, which answers to the question of whether the indicator is representative of the resilience dimension of interest. Another important criterion is robustness, a characteristic that many of the existing vulnerability indices, for example, exhibit significant shortcomings (Gall, 2007). Several criticisms of the quantitative indicator approach have been noted by researchers, including subjectivity regarding variable selection and weighting, lack of availability of certain variables, problems with aggregation to different scales, and difficulties validating the results (Luers et al., 2003; de León and Carlos, 2006). However, the usefulness of quantitative indicators for reducing complexity, measuring progress, mapping, and setting priorities makes them an important tool for decision makers.

De Bruijn (2004) proposes a method to assess the resilience of the towns near lowland rivers. By describing the system response for rainfall or runoff events the following indicators have been chosen:

- *amplitude* of response;
- *graduality* of response.

- *recovery rate* from flood impacts.

The amplitude of the reaction to flood waves indicates the severity of the expected damage resulting from a certain flood wave immediately after a flood has occurred. To describe the severity of the reaction of a system to a whole regime of flood waves by only one number, the expected annual damage can be used. Hence, quantifying the amplitude requires data on the flood regime and on the corresponding primary direct flood impacts. Primary direct tangible damage can be determined by applying the unit-loss method. This method quantifies damage per unit by using relationships between flood parameters such as flood depth and the damage for typical land use types or properties (Penning-Rowsell and Green, 2000). Instead intangible damage is correlated with the number of casualties (deaths) in the flooded area. Two indicators for amplitude have been developed:

- the expected average annual tangible damage (eq. **[2.1]**);
- the expected average annual number of casualties (deaths) (eq. **[2.2]**);

$$\mathrm{EAD} = \int_{1/10000}^{1} \mathrm{I(f)df} \qquad \textbf{[2.1]}$$

$$\mathrm{EANC} = \int_{1/10000}^{1} \mathrm{C(f)df} \qquad \textbf{[2.2]}$$

with EAD is the expected average damage per year ($/year), EANC is the expected average number of casualties per year (number/year) and f is the annual frequency ($year^{-1}$).

The graduality indicator is calculated by expressing all discharges and damages in percentages of the total range considered. This range includes all discharges from the once a year discharge to the discharge with a probability of 1/10,000 a year and the corresponding damages. The graduality is derived from the relationship between the discharge increase in percentages and the damage increase in percentages (eq. **[2.3]**).When the increase of damage is exactly proportionate to the increase of discharge, the graduality is 1. The graduality will have a value close to zero when damage increases suddenly due to a small discharge increase.

$$\mathbf{G = 1 - \frac{\sum|\Delta Q' - \Delta S'|}{200}} \qquad \textbf{[2.3]}$$

$$\mathbf{\Delta Q'_n = Q'_n - Q'_{n-1} = \left[\frac{100(Q_n - Q_{min})}{Q_{max} - Q_{min}}\right] - \left[\frac{100(Q_{n-1} - Q_{min})}{Q_{max} - Q_{min}}\right]} \qquad \textbf{[2.4]}$$

$$\mathbf{\Delta S'_n = S'_n - S'_{n-1} = \left[\frac{100(S_n - S_{min})}{S_{max} - S_{min}}\right] - \left[\frac{100(S_{n-1} - S_{min})}{S_{max} - S_{min}}\right]} \qquad \textbf{[2.5]}$$

G is the graduality (−),Q is the discharge (m^3/s), $Q_{max}$is the once in 10,000 years discharge, $Q_{min}$is the once a year discharge, S is the damage (M€) as a function of Q, $S_{max} = S(Q_{max})$, $S_{min} = S(Q_{min})$, Q’ is the percentile discharge (−) and S’ is the percentile damage (−).

The third aspect, recovery rate, describes the rate of return from a state where flood impacts are clear to a normal state. Because effects of floods are usually not distinguishable from impacts of other events and trends such as population growth, financial crises, war and diseases (Alberla-Bertrand, 1993) the direct measurement of recovery is not possible. However, some characteristics of society, households and individuals may be regarded indicative for their capacity to recover. These characteristics are studied in so-called vulnerability assessments in social science. The vulnerability of a community to floods depends on its susceptibility to flood impacts and its recovery capacity. Literature on vulnerability and vulnerability assessments can thus be used as a source of information for recovery. Vulnerability assessment can distinguish three groups of factors that influence the recovery rate: physical, economic and factors.

The physical factors determine how fast the water will be gone and when the area dries up again.

The economic factors determine the ability to get hold of enough money for repair and reconstruction, and for returning to pre-disaster or even improved living conditions, as well as to prevent further spreading of effects.

Social factors that determine the ability to organize reconstruction and get access to funds and information are first of all related to the larger social context in which the flood occurs. Examples of such factors are the political structure and the presence of strong social networks.

A qualitative approach is chosen in which all factors are given marks between 1 and 10 after which they are averaged.

However this methodology strongly depends on the types of damage data collected. Moreover the scores attributed to the recovery rate are arbitrary and dependent on the type of town. Finally, it does not solve the problems of spatial scale previously highlighted.

Batica (2013) proposes an approach that analyzes all flood risk management component (relief, resist, response, recovery and reflect) at different spatial scales.

Urban system is divided into four entities: city, district, block and parcel. For each of these entities the FRI (Flood Resilience Index) is calculated. The Index is represented as a level of flood resilience assessment in the analyzed area and for certain flood characteristics. The assessment of FRI on the parcel and block is focused on the building. For these two cases urban functions are evaluated through the assignment of an availability level during and after flood. **Tables 2.3, 2.4** and **2.5** show the meanings attributed to availability levels and the urban functions considered respectively.

Instead on district and city scale the evaluation of FRI is done through five dimensions (natural, physical, economic, social and institutional).A score is assigned to each of these dimensions, the Aggregate Weighted Mean Index or AWMI, calculated using Weighted Mean Index (WMI) method (Rajib Shaw and IEDM Team, 2009), which represents the FRI.

Table 2.3: Availability levels of urban functions.

Availability level	**Description**
0	Not available
1	Poor availability – major interruptions
2	Low availability – interruptions provide minimum availability
3	Medium–small interruptions that are tolerable for small flood durations
4	Medium-high – interruptions that are tolerable for long flood durations
5	Requirement fully provided

Table 2.4: Urban functions for parcel and building flood resilience evaluation.

External services	Energy
	Water
	Waste
	Communication
	Transport
Internal services	Food availability
	Occupation of urban functions
	Access to urban functions

Table 2.5: Types of variables considered for district and city flood resilience evaluation.

Dimension	**Variables**
Natural	Available water bodies, percentage of existing slope or flat areas, drainage density, rainfall duration, existing watershed.
Physical	Structural measures protection, communication network (telephone, internet, transport…), human safety (ex. emergency shelter), equipment for service.
Economic	Employment, wealth, private and public investment.
Social	Health status, knowledge, flexibility.
Institutional	Flood management plans, policies, regulations, evacuation plans.

2.2.3.Flood resilience measures

Resilience measures minimize flood damage, allow faster recovery and lost timeout of a property. Bowker (2007) has shown that although resilience measures could be expensive in many cases, they are comparable to the costs for repairs form flood damage.

The most commonly resilience measures used within properties are:

- tanking;
- concrete floors;
- raised electrical sockets, TV points, etc.;
- horizontal replacement plasterboard;
- plastic skirting boards;
- resilient internal walls (rendered, tiled, coated);
- flood resilient kitchens (plastic, stainless steel, free standing removable units);
- flood resilient internal doors (easily removable).

Tanking basements, cellars or ground floors with water resistant membranes is an effective method of minimizing flood damage but involves specialist fitters and can be very expensive because the whole area has to be fully sealed. Plaster is removed from floor to ceiling before installation. Subsequent care is essential so that seals remain intact. This measure is appropriate for flood depths up to 600mm and would be used in conjunction with other measures such as raised electric sockets, flood boards, flood resistant doors, resilient floors etc. Some systems incorporate plastic barriers or coatings that fit behind sacrificial plasterboard on internal walls and beneath floors. It can often have the appearance of bubble wrap or egg boxes so that any floodwater reaching the inside of the external walls (from outside) or from beneath the floor is directed behind the plastic membrane to a sump at the lowest point in the property and automatically pumped out (**Figure 2.1**).

Ground supported floors with concrete slabs are usually reasonably resilient to floodwater but floodwaters can often ingress through gaps at joints or where seals are not effective. To improve resilience, concrete floors may be coated with an impermeable membrane and finished with ceramic or concrete based floor tiles, wood laminate or even carpets if the adhesives and bonding used in the applications are properly fitted (**Figure 2.2**). Liquid membranes require careful application to avoid cracking. It is always preferable to replace a suspended wooden floor with solid concrete where practical and possible.

Flood damage to any electrical system in a property usually involves not only the electrical sockets, TV points and telephone points but also the consumer units, which may be at low level. It is important that all sockets, home appliances and reservoirs are raised from the floor or placed inside containers that are sealed. In Italy the minimum height of electrical sockets from floor is equal to 17.5 cm. This leads to a slow recovery of the electrical system if water enters.

Figure 2.1: Basement floor and walls covered with plastic render.

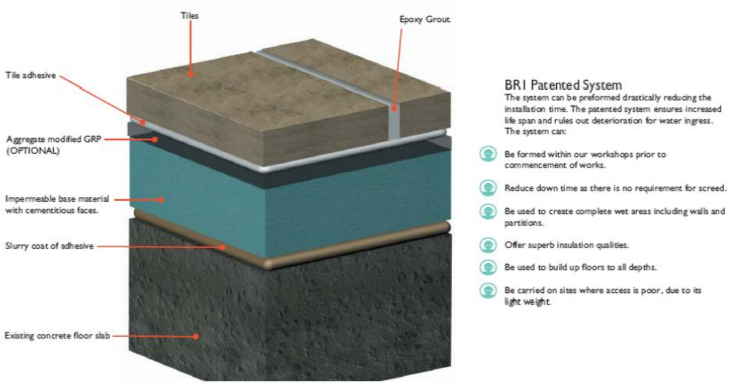


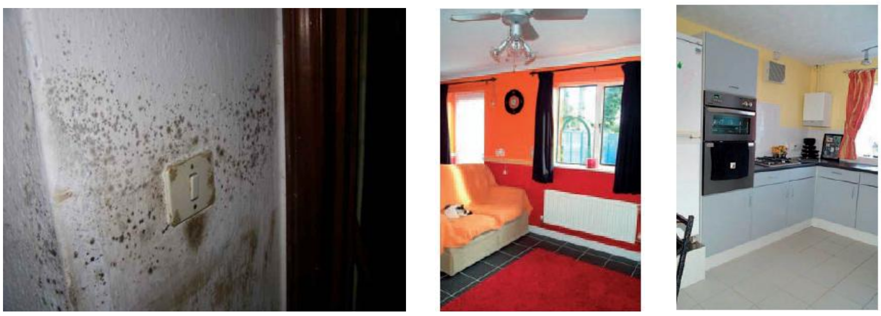
Figure 2.2: Resilient floor arrangement.

Internal cement based renders, preferably with lime content (with good bond),on internal walls are effective at reducing flood water leakage into a building and assist rapid drying of the internal surface of the wall. Standard gypsum plasterboard should be avoided as it tends to disintegrate when immersed in water. Internal lime plaster/render may be a good resilience option.

Even shallow floodwater inside a property is usually absorbed by plaster above skirting boards (**Figure 2.3 (a)**). A practical option to make a wall more resilient would be to apply tanking on the inside of every internal wall up to approximately 450mm by removing plaster, apply water resistant render, apply tanking compound (GRP resin based water resistant), and finish with render on top. Plastic skirting is a good resilient measure to replace standard wooden skirting (**Figure 2.3 (b)**).

The kitchen is a room of particular interest for its function that must be re-established in the shortest possible time. For this reason it is useful to install flood resilient plinths (plastic) on kitchen walls to raise units/equipment. Resilient kitchen units are made of moisture resistant carcasses and doors (plastic, stainless steel) fitted with effective seals (**Figure 2.3 (c)**). Seals should be fitted around all units so that water cannot penetrate behind. Utilities are fitted with double check valves to prevent back flow.

Internal doors could either be fitted with adjustable hinges so that doors may be easily removed before floodwaters enter a property (**Figure 2.4 (b)**). Alternatively, doors may be replaced with water resistant plastic or acrylic doors so that flood damage is minimized (**Figure 2.4 (c)**).Resilient doors would be approximately the same cost as standard doors.



(a) **(b)** **(c)**

Figure2.3: Flood damage on the plaster **(a)**, a room with plastic skirting and raised radiator **(b),** raised house appliances in a kitchen **(c)**.

(a) **(b)** **(c)**

Figure 2.4: Blockage hinges (non-resilient) **(a)** and traditional hinges(resilient) **(b),** PVC doors (Ashish Polymers Company) **(c)**.

2.2.4.Community Mitigation Capacity

Building a disaster resilient city goes beyond changing land use and physical facilities. Effective threat reduction and disaster response require collective action. In addition to traditional physical system hazard mitigation functions, a city that seeks social and institutional resiliency would:

- monitor vulnerability reduction;
- build distributed hazard mitigation capability;
- develop broad hazard mitigation commitment;
- operate networked communications;
- adopt recognized equity standards;
- assist threatened neighborhoods and populations;
- mitigate business interruption impacts.

To track and disseminate progress toward resiliency, city planners and emergency managers would prepare, publish, and update regularly a detailed vulnerability analysis that describes and maps potential hazards and their probable impacts on a neighborhood basis. They would include a vulnerability reduction objective in the comprehensive plan and the capital improvements program, as well as in neighborhood plans and social programs. City elected officials would set annual vulnerability reduction targets with special attention to disadvantaged populations, and would allocate budget funds and program resources to meet these targets.

To create a broad base of mitigation capability, city planners and emergency managers would provide hazard awareness information, funding, and training to new and existing neighborhood and community organizations to enable them to develop capable leaders and carry out hazard mitigation as one element of their program activities. The city government would seek out opportunities to combine hazard mitigation with other functions, such as environmental conservation, economic development, community facilities, and historic preservation.

City staff and leaders would work with public and private decision makers, nongovernmental organizations, neighborhoods, and households to develop a hazard mitigation ethic. They would use incentives and sanctions to move mitigation onto the public agenda, keeping hazards issues before the community and holding leaders accountable for hazard mitigation actions.

City officials would establish and operate a multipurpose community communications system and network with a variety of media and channels to reach all levels from the individual household to the neighborhood, community, region, and state. They would use the network for public announcements, plan reviews, information exchange, and hazard mitigation programs. The network would publish geographic information system maps of hazard areas, programs, contacts, and lifelines.

The city government would adopt standards and benchmarks for achieving equity in hazard vulnerability. They would set aside additional resources to make poor neighborhoods safer from hazards, recognizing that their residents will be the least likely to be able to recover on their own from disasters. City staff would work with residents at the neighborhood level to determine needs and appropriate mitigation programs to remedy inequitable vulnerability situations.

The city government would provide resources and assistance to threatened neighborhoods and vulnerable populations to enhance their survival during and after a disaster. They would operate relocation housing programs to move households out of hazard areas and into safe locations enlist neighborhood leaders in safe neighborhood programs, and combine community learning and improvement efforts with mitigation and vulnerability reduction efforts.

Planners and emergency managers would prepare businesses and financial institutions to cope with disasters by describing potential scenarios in which business is interrupted following a disaster and enlisting business leaders in private sector mitigation programs. The government would establish procedures for providing loans and deferring financial obligations following a disaster, as well as programs to assist workers during periods of business closure duet disasters.

2.2.5.Decalogue for householders

Regarding what has been discussed till now, it is clear that citizens are called to urban flood risk reduction. For this reason scientific community, public administration and protection authorities must promote awareness-raising campaigns in most commonly affected by flooding areas. Urban flood mitigation training would be simple and may be based on this simple Decalogue, to be followed when it was issued an alert signal:

1. turn off gas, electricity and water supplies at the mains;
2. unplug all electrical items and where possible store them up high or upstairs;
3. put plugs in baths and sinks, weigh them down with a sandbag, pillowcase or plastic bag filled with garden soil or a heavy object;
4. keep all important documents in a watertight plastic bag in a high safe place;
5. move as much furniture as possible upstairs;
6. have a list of useful numbers such as the emergency services, local council, your insurer's emergency helpline number and details of the policy;
7. make sure neighbors, especially elderly or infirm ones, know there is a flood on the way;
8. if you can, cover windows, doors and airbricks with plywood, sandbags or metal sheeting;

9. move your car to higher ground so it is not damaged;
10. avoid contact with floodwater as it may be contaminated with sewage.

Chapter 3

Early warning systems

Urban flood mitigation measures analyzed in the previous chapter can be winning strategies by themselves, but sometimes they need a prediction that can make them more efficient. Because of short lead time in an urban basin, systems to predict an overflow event are called *early warning systems*. Since it was decided to develop a risk mitigation system aimed at identifying the best strategies to improve resilience/resistant measures in urban areas, some early warning systems will be analyzed in the follow.

An early warning system is "the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response", and is the integration of four main elements according to the United Nations' International Strategy for Disaster Reduction (ISDR):

1. *risk knowledge*: risk assessment provides essential information to set priorities for mitigation and prevention strategies and designing early warning systems;
2. *monitoring and predicting*: systems with monitoring and predicting capabilities provide timely estimates of the potential risk faced by communities, economies and environment;
3. *disseminating information*: communication systems are needed for delivering warning messages to the potentially affected locations to alert local and regional governmental agencies. The messages need to be reliable, synthetic and simple to be understood by authorities and the public;
4. *response*: coordination, good governance and appropriate action plans are key points in effective early warning. Likewise, public awareness and education are critical aspects of disaster mitigation.

Failure of any part of the system will imply failure of the whole system. For example, accurate warnings will have nonimpact if the population is not prepared or if the alerts are received but not disseminated by the agencies receiving the messages.

The basic idea behind early warning is that the earlier and more accurately we are able to predict short- and long-term potential risks associated with natural and human induced hazards, the more likely we will be able to manage and mitigate a disaster's impact on society, economies, and environment. The nearly warning systems are arranged for ongoing and rapid/sudden-onset hazards. Rapid/sudden-onset hazards include geological threats such as earthquakes, volcanic eruptions, mudslides, and tsunamis. From a scientific point of view, geological events are the result of incremental environmental processes but it may be more effective to refer to them as quick onset. Furthermore most of the hydro-meteorological hazards(such as floods, tornadoes, storms, heat waves, etc.) may be considered rapid/sudden-onset hazards.

In this chapter a review about leading early warning systems for overflow forecasting in urban areas will be showed, by analyzing their functions, their components, their issues and already developed solutions. This investigation was found of considerable importance for two main reasons: allows to simulate case-study basin under overflow perturbation in off-line mode and to design the most suitable warning system for on-line (operative) mode. It is anticipated that this report concerns the use of early warning system in off-line mode and only provides suggestions for the development of the next phase.

3.1. Early warning system components

The structure of an early warning system is susceptible to different research fields. Some people have likened these systems to a modern race car, which requires not only a mechanical but also an electrician, a computer scientist, an Aerospatiale engineer, a pilot, a manager, a financial backer. Each expert must develop his own field and understand the other ones at the same time. This first difficulty can be overcome only through proper training and a strong propensity for teamwork.

A typical early warning system for flood forecasting in urban areas consists of:

- monitoring and processing of rainfall-flooding data;
- urban flow forecasting model;
- alert system.

Each of the techniques used to develop these components must be chosen on the basis of morphological characteristics and climatic conditions of the town, socio-economic conditions of population, interest of public administration.

Next paragraphs show the analysis of all the above-mentioned components. The last section describes some early warning systems already tested in towns.

3.2.Rainfall data

A good system for flood forecasting must be able to predict the meteoric inputs early enough and to use an urban drainage that takes into account the actual interactions with the urban environment. The quality of any flood forecast depends to a high degree on the quality of the rainfall input.

It is generally accepted that a rain gauge network is not able to provide a proper weather forecast. However, a wide and well used rain gauge networks valuable to provide calibration and validation data and can even be used to setup rough warning levels (Hapuarachchi et al., 2011).

When it comes to weather forecast, the main technology used is the radar forecasting, with a resolution which can range from national to local forecast. During the past decade, observation networks (e.g. radar and satellite)have been expanded, and new techniques have been developed for deriving rainfall from multi-sensor observations.

Extensive research has gone into assimilating radar data for producing *Quantitative Precipitation Estimations* (QPEs). In general, radar provides useful information on the spatial distribution of the precipitation field, but QPEs directly derived from radar reflectivity measurements are subject to errors and uncertainties (e.g. Collier, 1996; German and Joss, 2003).

New techniques have been developed for real-time correction of systematic biases in radar precipitation fields, by adjusting radar precipitation to rain gauge measurements (Ahnert et al., 1986; Smith and Krajewski, 1991;Seo, 1998; Anagnostou and Krajewski, 1999; Sinclair and Pegram, 2005; Mazzetti and Todini, 2009).

With the availability of high-resolution remotely sensed data, advanced algorithms for retrieving rainfall from satellite-based microwave and infrared observations have been developed (Sorooshian et al., 2000;Huffman et al., 2002; Kidd et al., 2003; Joyce et al.,2004; Kubota et al., 2007). Consequently, a number of general-use satellite-based precipitation products have emerged (e.g. CMORPH, 3B42RT, PERSIANN, GSMaP) that allow much improved temporal and spatial resolutions and reduced latency. Typically, satellite-based precipitation products provide QPEs of the global area of60 °N–60 °S at 0.1°–0.25° spatial resolution at 1–3 h intervals. Although the accuracy of QPEs varies, they are generally useful for hydro-meteorological modelling, particularly in poorly gauged catchments.

Moreover, advanced techniques have been developed to improve the accuracy of QPEs by blending multiple sources of information (radar, satellite and gauged data) (Seo and Breidenbach, 2002; Gjertsen et al., 2004), thus expanding the limits of hydrological modelling.

Burton and O'Connell (2002) used radar observation fields to continuously update a function to convert from infrared (IR) satellite observations of cloud-top temperatures to precipitation rates. The technique was adapted from the raw histogram-matching technique developed by Turk et al. (2000) and described by Grose et al. (2002).

Instead of using microwave observations of precipitation from satellite to determine fixed relationships between IR satellite observations and precipitation rates, Burtonand O'Connell (2002) used ground-based precipitation radar datasets to estimate an instantaneous relationship. Overall, QPEs produced by blending multiple sources of information have high temporal and spatial accuracy, thus, this approach deserves future research.

3.2.1.Quantitative Precipitation Forecast (QPF)

Accuracy and lead time in rainfall prediction are the most important components of urban flash flood forecasting, and recent developments enable the production of high resolution QPFs with 1–6 h lead times. These techniques include linear regression (Antolik, 2000), quantile regression (Bremnes, 2004; Friederichs and Hense, 2007), logistic regression (Applequist et al., 2002; Hamill et al.,2004), hierarchical models based on prior climatic distributions (Krzysztofowicz and Maranzano, 2006), hybrid approaches that statistically combine radar and Numerical Weather Prediction (NWP) model outputs (Golding, 2000; Ganguly and Bras, 2003; Sokol, 2006), Artificial Neural Network (ANN) applications (Hsu et al., 1997; Kuligowski and Barros, 2001; Ramirez et al., 2005), and statistical methods based on Bayesian techniques (Sloughter et al.,2007).

The spatial (<10 km) and temporal (<1 h) resolutions of NWP model rainfall forecasts have significantly improved in the past few years (e.g. ALADIN, SKIRON).With these developments, the most promising approach for developing QPFs with useful lead times appears tube combining NWP model forecasts with blends of the advected patterns of recent radar, satellite and gauged rainfall data. In the merged product, the contribution of the NWP model forecasts usually increases with increasing lead time. The operational Nimrod system (Golding,1998) in the UK Met Office, designed for 1–6 h QPF, combines radar advection with NWP-based QPF using relative weights (Smith and Austin, 2000).

Recently developed ensemble rainfall forecasting techniques have demonstrated encouraging results that suggest their accuracy for lead times of 1–6 h is sufficient to improve forecasts of flash floods (Kondragunta and Seo, 2004; Yuan et al., 2007; Rezacova et al., 2007).

Pierce et al. (2004) presented a first-step approach to probabilistic forecasting by generating an ensemble of radar rainfall forecasts from a stochastic advection-based scheme. This approach allows the probability of precipitation to be derived from an ensemble of forecasts for several hours ahead. It has been further improved by Bowler et al. (2006) as the Short-Term Ensemble Prediction System (STEPS), which merges an extra extrapolated nowcast with downscaled NWP model forecasts. The ensembles can be used to generate forecasts of the probability density function of areal and temporal averages of precipitation. However, accurate model forecasts of higher rain rates are limited to a 6-h lead time.

Ebert (2001) discussed a different technique to produce ensemble rainfall forecasts, called Poor Man's Ensemble (PME) in which the components are obtained from independent NWP model forecasts from several different operational forecasting centers. The PME then forecasts the probability and distribution of rainfall in the short-term (1–2 days), although the accuracy of the forecasts rapidly declines with increasing lead time. To date, PME has been applied on coarse resolution models (i.e. 100 km).

Nonetheless, these improved QPF techniques have increased the potential for more accuracy and lead time in flash flood forecasting.

3.3.Flooding data

There are different ways to obtain flooding data for the study in urban areas. The choice of one method or another depends not only on the availability of financial resource and technical tool but also on the amount of collectible data. In order to obtain good statistics data set must be consistent and as reliable as possible.

Flood event data includes flood characteristics describing the probability of a certain flood event and related consequences. Typical flood variables are the frequency of occurrence, duration of the flood, water depth, flood extent, flow velocity and whether or not flood waters contaminated (Spekkers et al, 2011). Related consequences of pluvial flooding mainly consist of economic losses such as damage to buildings and their contents and to infrastructure and intangible damages due to traffic delays, road and public and commercial function closures, and evacuation of people (Hauger et al., 2006).

Two different groups of flood event data are distinguished, based on definitions proposed in econometrics (e.g. Angrist and Pischke, 2009). The first group is data based on *natural experiment*: data collected 'by nature' which contain useful information on pluvial flooding. The second group consists of data related to *real experiment*: data collected by conducting a controlled experiment with the purpose of collecting required flood data. This section discusses four data sources, namely insurance databases, call databases, remote sensing observations and data from flood monitoring. The first three fit into the group natural experimental data, the fourth is a case of real experimental data.

3.3.1.Insurance databases

In most European countries, people can insure their property and content for the damaging consequences of pluvial flooding. The databases of insurance companies typically cover tens of years of information on flood damage and can therefore potentially be used for quantitative research. Homeowners can insure both their property and their content; renters can only insure their content, while property damages in that case the responsibility of the landlord. Generally the causes of pluvial flooding which are covered by property and content insurances are:

1. direct rainfall on property;
2. flooding from sewer systems;
3. flooding from regional watercourses.

In addition, the damage should be directly and solely related to local extreme rainfall for a claim to be accepted. Flooding from rivers, sea or groundwater is not usually insurable and therefore if pluvial flooding coincides with other flood types, the damage is not insured. Furthermore, in some cases the rainfall event should have a minimum intensity to be considered as ‘extreme’. The reasoning behind this is to prevent reoccurring claims of damaged buildings that are built on very vulnerable locations. However, it is often unclear on what data this condition is based and how fulfillment is examined. Nevertheless, it is likely that some flood damage is not recorded in insurance databases because they do not fulfill the policy conditions.

Damage data from insurance companies are difficult to collect. Based on a questionnaire, only4 out of 48 insurance companies in Germany were willing to provide damage data for scientific research (Busch, 2008). The Association of British Insurers presently only aggregates national damage data and does not hold local damage data (Lawson and Carter, 2009). An explanation for this is that the databases contain private information of insured which insurers are not willing or able to share. Another difficulty is that insurance premiums are based on the statistics of historical records and insurers do not want to publish much information about the reasoning behind their premiums.

Nonetheless, insurers show an increasing interest in scientific research as climate change poses challenges to future insurance arrangements. They want to know if the predicted increase in rainfall extremes will cause more and/or higher damage claims.

The damage records must not or only limitedly describe the flood cause. Inclusion of the causation could provide a more useful record. Damage data can be used to analyze explanatory variables for damage by correlating the damage data with precipitation data, building properties, digital elevation models and urban drainage characteristics. Insurance databases can also be a source of information on claim frequencies and can be used to map vulnerable locations. A similar database as those for private flood damage to buildings also exists for damage to businesses; however, those are not available yet.

3.3.2. Call databases

Other sources of flood event data are call databases held by water authorities and emergency services. These databases cover several years of flood observations that can improve decision making on how to effectively solve observed problems. In some European Countries citizens can call a call center when there is a dysfunction of urban drainage systems, for example if rainwater cannot be transported because of debris blocking the drainage infrastructure. The call is stored as a short text message describing the observation. The records include a date of the event and a street name and sometimes a house number. The messages contain information on causes and, to a lesser extent, consequences of the event. Occasionally, the database contains a small report of findings and solution after an on-site check. The text messages need to be categorized to make the database suitable for quantitative research, for example categories based on a number of defined causes or consequences. Municipal call databases have proven to be a suitable data source for quantitative flood risk analysis. Recent studies show that these text messages can be used to identify failure mechanisms of pluvial flooding (Ten Veldhuis, 2009; Caradot et al., 2010).

The database can potentially be used to map vulnerable locations which are frequently flooded. Although the text messages are subject to interpretation and classification errors, the database holds valuable information because of the large number of database records. The drawback of the data is that probably not all flooded locations have an entry in the database. Other data sources can be used to validate the calls and to estimate what percentages of events is represented in the call database, for example by comparison with results from flood monitoring campaigns. At the present, databases are scarcely used by municipalities themselves to actually study pluvial flooding. Municipalities often do not have the time or resources for extensive data analysis. Another lack of the data source is that no flood depth, duration or extent is recorded. This makes it hard to judge the severity and magnitude of the event.

In addition, police and fire brigades keep track of flood events. In case of an emergency, for example to drain a flooded basement, a call is registered in the emergency database. Temporal and spatial resolutions are often limited to a date (and time) and locations by means of just street name; they do not contain descriptive text messages of the observations like call databases and are limited to flooded buildings and do not describe street flooding. Lawson and Carter (2009) argue that by not recording the cause of the event, the usefulness of a potential valuable data source is reduced. Another drawback is that when extreme rainfall causes large number of calls in short time period, it is likely that not all the events are recorded or that multiple calls are combined in one record (Busch, 2008). Police and fire brigade records can be used to cross-check with municipal call data.

Call and emergency record databases can provide more useful information in the future if flood causes and consequences are systematically recorded, for example, by improving and automating a classification system for calls. In addition, registration of flood characteristics (e.g. flood duration, flood depth) in the database can help to determine the severity of the flood event. This implies the need for additional measurements of flood characteristics.

3.3.3.Remote sensing

Remote sensing is the acquisition of information of an object or phenomenon, in this case the earth surface, from satellites or airplanes. Remote sensing can be used to gather flood data during or right after a flood event.

There is a wide range of remote sensing techniques. The most promising technology in relation to flood data collection is synthetic aperture radar (SAR) (Mason et al., 2010). Other remote sensing techniques cannot be used either because the spatial resolution of the data is too coarse (e.g. satellite infrared) or the method requires daylight and/or good weather conditions (e.g. satellite photography) or the technique has low or irregular measurements frequencies (e.g. airborne photography).

SAR is a technique which is used to make high-resolution radar images of the earth surface and its properties. SAR is applied in a wide range of different applications from military to environmental sciences. There are many other potential applications and flood detection in urban areas is one of them. SAR measures time delay between emission and return of radar pulses, establishing the location and height of the surface. The radar pulses are processed into a single radar image. Flooded areas would generally appear black on radar images due to specular reflection and therefore the radar images are a potential source of flood extent data. Flood extents have been successfully determined from SAR observations for major fluvial floods in rural areas. Observed flood extents are, for example, used to calibrate flood models.

In addition, it is possible to estimate flood depths if flood extent maps are combined with high-resolution ground elevation data. Application of this technique is far more complicated for flooding in densely built-up areas; however, a recent study by Mason et al. (2010) shows promising results.

Mason et al. (2010) studied the SAR observations (3 m^2 resolution) of the flood near Tewkesbury (UK) in 2007.Of the flood water that was visible on SAR image, 76% were correctly detected, with an associated false positive rate of 25%.

They concluded that because of the side-looking nature of SAR, substantial areas of ground surface is not visible due to shadowing and unwanted reflection caused by buildings or taller vegetation. Another limiting factor is the frequency of flyovers by a satellite. Typical frequencies are once every 11 days to once every month. This questions the availability of measurements that coincide with the flood peak, in particular for pluvial floods with flood duration of only a few hours or a day. Another complicating factor is the micro climate in urban areas. Temperature, rain and wind affect the reflective properties of water surfaces and thus the way flood water appears on radar images. For rural areas where climate characteristics are relatively homogenous in space a distortion can be corrected easily, whereas urban areas with a more heterogeneous climate pose new challenges to correct climate effects.

Over the last decade the resolution of radar images reached higher levels of detail. Currently, a small number of satellites is equipped with SAR with resolutions $\leq 3\ m^2$. Wide streets and gaps and large public spaces can clearly be seen on current radar resolutions ($3\ m^2$), whereas none of this was visible on previous radar observations ($12.5\ m^2$) (Mason et al., 2010). In the near future the resolution will reach even more detail ($\leq 1\ m^2$). With increasing radar detail it will be more likely that also smaller flow and pools will be detected. Nevertheless, radar shadowing and unwanted reflections continue to exist, and an increasing spatial resolution will not solve this.

3.3.4.Monitoring

If a certain flood phenomenon is subject of study, but is not captured with natural experimental data, a monitoring campaign can be carried out to measure flood characteristics systematically, such as flood extent, depth and duration. For example, municipal call databases do not register flood depths and extents, which can be used for model development and calibration. In addition, measurements can be used to validate existing data and models. For example, measurements of flood locations can be used to check to what extent call databases cover flood events and to calibrate overland flow models.

Sensor technology can be effective to measure flood characteristics at predetermined locations. Nowadays, sensors can be very cheap and small and have relative low-energy consumption (Akyildiz et al., 2002), making it possible to deploy a dense network of ‘water’ sensors for years. The ‘water’ sensors detect the presence of water at a specific location or measure the local water height. Sensors can be installed virtually everywhere, for example, on streets or near vulnerable object to monitor the flood frequency, duration and extent. They can be modified in such a way that the sensor is most of its time in a standby modus and only measures when triggered. A wireless interface can be installed in the sensor for data communication between sensors. The network as a whole can be connected tithe internet for easy data collection through a web interface.

Examples of such monitoring networks for flood detection are scarce, although they show promising results in collecting flood data (See et al., 2009; Chang and Guo, 2006). Monitoring is particularly sensible in areas where pluvial flooding occurs frequently throughout the year. This is a complicated factor because pluvial flooding is often very localized and unpredictable. A challenge is therefore to select suitable sensor locations and to keep some flexibility in the experimental set up.

A less static way of monitoring can be the use of citizens as *dynamic sensors*. Nowadays most mobile phones are equipped with internet, GPS and photo camera, enabling people to participate in data collection. Participants can send photos admit data (e.g. their location and time) to a central database were 'calls' are systematically stored. Social networks especially in urban environments allow a good collection of these data in the form of videos, photos and comments.

3.4. Urban outflow models

Another important aspect concerns the choice of suitable model for the processing of the outflows, their propagation up to final delivery, and description of the urban environment.

Models play a vital role in any engineering operation. Modeling of any system can help in evaluating and reducing risk. The significance of modeling is being able to look at scenarios before they occur in reality. Therefore modeling is one recommended approach to analyze extreme conditions such as urban flooding.

Water modeling describes the behavior of waters under a wide variety of conditions. The application of computer simulation in water modeling involves:

- drainage sewer modeling;
- water supply and distribution modeling;
- river modeling.

An urban drainage network model consists of representation of closed pipes, opens channels, and ancillary structures such as weirs, orifices and pump (lift) stations. To simulate flooding in a realistic way, urban drainage models must couple the larger (runoff) and the minor drainage system (outflows in sewer) in what is commonly called *dual drainage system*. There is much software that already applies this concept.

It has been wrongly led to believe that a more realistic physical modeling such as 3D spatial model can provide results more appreciable than 1D models. Instead the choice between the use of 1D or 2D surface model is greatly influenced by the case study and the parameters to be considered. Indeed these determine the accuracy of the results and the processing time. It has been shown that the 1D models allow obtaining a good approximation of the results in the moment in which the water remains inside the road path. When the water overflows the road boundary, runoff can change direction. In this case a 2D surface model type would be preferable. This result is reached by Paquier that compared a 1D model, REM U, with a 2D model, RUBAR 20, in urban areas and concluded that the 1D model is to be preferred in the modeling of the outflows that follow the road pathway. The study suggests the necessity of developing 1D/2D coupled models, where the 1D model should be used on streets, while the 2D on specific conformations, such as, crossings, parking areas and other type of areas. Lhomme et al., 2006, compared a 1D model based on GIS solving the kinematic wave equation with a 2D model and concluded that the former is more suitable for steep roads but falls into error for the flat ones. Depending on spatial and temporal scale and related issues, 1D models could demonstrate to be more realistic than 2D models (Horrit and Bates, 2002).2D models are computationally more demanding than 1D models; Paquier reported 4 hours of simulation for a 2D, RUBAR 20, Lhomme 20 min for a 1D versus some hours for a 2D.

Overflow propagation models have mainly developed since the 1970's, when computers allowed more computing speed. A short review about much using and tested software in the literature is reported below.

3.4.1.SWMM

Introduced in 1971, Storm Water Management Model (SWMM), developed by Environmental Protection Agency(US-EPA), is considered as the basic model for the analysis of urban hydrology (Rossman, 2010). SWMM is a distributed, dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. This model takes account of spatially and time varying rainfall, evaporation of standing surface water, snow accumulation and melting, interception from depression storage, infiltration into soil layers, percolation into shallow groundwater, interflow between groundwater and channels and nonlinear routing of overland flow, various conduit shapes as well as irregular natural channels, pumps, regulators and storage units. It also allows external inflows from runoff, groundwater, Rainfall-Derived Infiltration and Inflow (RDII), sanitary, Dry Weather Flow (DWF), and user-supplied time series and models various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding. In recent years some modules for the assessment of water quality and for the modeling of SUDs have also been added.

However this tool is now not applicable to large-scale non-urban watersheds. Also it cannot be used with highly aggregated (e.g., daily) rainfall data. Finally it has been noted that SWMM does not allow the representation of the overload that dated from the manholes to the surface. The overload flow was retained in the manhole and released when the capacity of the collector was available again. The next generation models were able to remedy this flaw by connecting the major drainage system with the minor one.

3.4.2.MIKE STORM

MIKE STORM (DHI, 2004) is link-node pipe and channel model which is suitable for application to standard stormwater networks using the traditional approach, and for the sub-surface component of the urban drainage network when using the linked 1D/2D approach. The 2D overland flow simulation engine can either be the MIKE SHE (DHI, 2004) or MIKE 21(DHI, 2004) depending on the type of problem to be analyzed.

MIKE SHE is a deterministic multi-layer catchment model which simulates the following processes in a 2D/3D framework:

- overland flow with an unsteady non-uniform 2D finite difference diffusive waver solver;
- overland flow interacts with the unsaturated zone and saturated groundwater zone;
- spatially-variable precipitation, infiltration and evapotranspiration;
- two-layer water balance in the unsaturated zone;
- groundwater flow.

MIKE SHE is therefore most suited to partly urbanized catchments with no downstream backwater effects and where there are groundwater issues which create baseflow in the stormwater networks.

MIKE 21 is a fully dynamic 2D hydraulic solver that can accommodate backwater effects and fine temporal-scale hydraulic behavior. MIKE-21 is therefore more suited to complex overland flow problem areas for example low-lying coastal urban areas.

The connection between the surface and pipe network is via a weir/orifice combination which represents the pit network. The catchment model and the pipe model are executed together and dynamically link flows on a time step basis. Backwater effects and reversing flows are accommodated in the linking, so that if the pipe capacity is exceeded in the pipe model, then the surface model will route the flows overland and cause surface flooding if channel or overland flowpath capacities are insufficient.

Catchment rainfall runoff and overland flow accumulation is determined by applying rainfall directly to the 2D digital elevation model of the catchment surface. The surface model allows distributed, physically based approach to rainfall runoff, with rainfall time series applied directly to a two dimensional grid representation of the catchment surface. Rainfall losses are accounted for either by using the infiltration processes in the MIKE SHE model or by an initial and continuing loss technique approach when using the MIKE-21 solver.

A critical aspect of model setup is that detailed information around each pit is necessary in order to route the flows correctly. This requires that each pit and its detailed configuration be inspected and measured as part of the study so that the details can be incorporated into the model.

LIDAR-generated terrains can be provided either with buildings included or removed, which means that the sensitivity of the results to obstructions by buildings can be investigated if required, with effort in model setup time and cost.

3.4.3.Delf –FLs

Delf FLooding system (Delft-FLS) is a 2D finite element raster based flood simulation package developed by WL/Delft Hydraulics (Duinmeijer, 2002). It is especially suited to simulate overland flow over initially dry land. The model is based on full 2D shallow water equations. These equations are solved following finite difference techniques on rectangular grid and always guarantee positive water depth (Stelling 1998).

Among the raster based 2D hydrodynamic model, Delft FLS widely used in dike breach studies in Europe, especially in the Netherlands. Its numerical techniques are capable to simulate continuity and mass balance for rapids flows with hydraulic jumps and dam breaks. In addition it has been widely used in simulating dynamic behavior of overland flow due to rising water level over initially dry land. The model requires a good topographical data set as a raster Digital Terrain Model (DTM) or other means.

However the Delft-FLS version 2.47 allows only 500 rows and 500 columns of raster cells. Surface roughness enters as a raster layer indicating Manning’s n for each pixel. The model cannot represent the 1D feature with required accuracy if the pixel size of the input DTM is big. The other major limitation of this software is the computation time. Computation time depends on several factors including the terrain slope and the discharge vs. water surface elevation. In general, an area represented by 497 by 497 pixels for on –hour real time simulation may take about 4 to 60 minutes of computation time in the latest Pentium IV 1300 MHz processor. Therefore simulation of a flood event of duration one dry may take 90 minutes to 24 hours of computation time.

3.4.4.Infoworks CS

InfoWorks1M CS is a commercial drainage network model (Infoworks Softwares, 2014). The software was produced by Wallingford Software Ltd.in 1997.Applications include urban flooding and pollution prediction and the modeling of water quality and sediment transport throughout the network. The software incorporates a number of modules, including InfoWorks 2D Module. This produces surface flood modeling, which is better for modeling flows through complex geometries such as urban streets and buildings, road intersections and other transport infrastructure. InfoWorks 2D uses a finite volume approach and a triangular irregular mesh. All of this 2D functionality is integrated with the baseline 1D engine so a single simulation is all that’s needed to analyze the interaction of underground and above ground flows in the urban environment. One major disadvantage with Infoworks is that it has no mechanism for dealing with antecedent moisture content or seasonal variation in infiltration, which raises the question of its applicability for continuous simulations.

3.4.5.TUFLOW

TUFLOW is a computational engine that provides one-dimensional and two-dimensional solutions of the free-surface flow equations to simulate flood and tidal wave propagation (Tuflow software, 2007).TUFLOW is originally the product of a joint research and development project between WBM Pty Ltd and The University of Queensland completed in 1990. The project's objective was to develop a 2D modelling system with dynamic links to a 1D system. Up until 1997 it was used extensively by WBM Pty Ltd for estuarine and coastal studies, with the occasional flood study. In recent years it has been merged with XP Solution's XPSWMMM 1D engine and GUI for the xp2D product (known as XPSTORM in Europe), and Halcrow's ISIS 1D engine using ISIS-TUFLOW or ISIS-TUFLOW-PIPE. The TUFLOW engine interfaces with GIS software such as MapInfo, ArcGIS or SAGA and/or via the Aquaveo SMS GUI.

Some phenomena are neglected in the 2D model. Hydraulic jumps and surcharging against obstructions are not modelled by software. There is no momentum transfer between 1D and 2D connections when using the sink/source connection approach.

3.5.Communication and alert systems

Even the best forecast quality is useless if the system does not communicate the proper information to the right people. Early warning information empowers people to take action prior to a disaster. Early warnings may be disseminated to targeted users (local early warning applications) or broadly to communities, regions or to media (regional or global early warning applications) (UNEP, 2012). When monitoring and predicting systems are associated with communication systems and response plans, they are considered early warning systems (Glantz 2003). Commonly, however, early warning systems lack one or more elements. In fact, a review of existing early warning systems shows that in most cases communication systems and adequate response plans are missing.

To be effective, warnings must be timely so as to provide enough lead-time for responding; reliable, so that those responsible for responding to the warning will feel confident in taking action; and simple, so as to be understood. Timeliness often conflicts with the desire to have reliable predictions, which become more accurate as more observations are collected from the monitoring system (Grasso 2006). Thus, there is an inevitable trade-off between the amount of warning time available and the reliability of the predictions provided by the Newsman initial alert signal may be sent to give the maximum amount of warning time when a minimum level of prediction accuracy has been reached. However, the prediction accuracy for the location and size of the event will continue to improve as more data are collected by the monitoring system part of the EWS network. It must be understood that every prediction, by its very nature, is associated with uncertainty.

Because of the uncertainties associated with the predicted parameters that characterize the incoming disaster, it is possible that a wrong decision may be made. Two kinds of wrong decisions may occur (Grasso 2006): Missed Alarm (or False Negative), when the mitigation action is not taken when it should have been or False Alarm (or False Positive), when the mitigation action is taken when it should not have been.

Finally, the message should communicate the level of uncertainty and expected cost of taking action but also be stated in simple language so as to be understood by those who receive it. Most often, there is a communication gap between early warning specialists who use technical and engineering language and the early warning system users, who are generally outside of the scientific community. To avoid this, these early warnings need to be reported concisely, in layman’s terms and without scientific jargon.

Early warning communication systems have two main components:

- *communication infrastructure hardware* that must be reliable and robust, especially during the disaster;
- *appropriate and effective interactions* among the main actors of the early warning process, such as the scientific community, stakeholders, decision makers, the public, and the media.

Many communication tools are currently available for warning dissemination, such as Short Message Service (SMS) (cellular phone text messaging), email, radio, TV and web service. Information and communication technology (ICT) is a key element in early warning, which plays an important role in disaster communication and disseminating information to organizations in charge of responding to warnings and to the public during and after a disaster.

Today, the decentralization of information and data through the World Wide Web makes it possible for millions of people worldwide to have easy, instantaneous access to a vast amount of diverse online information. This powerful communication medium has spread rapidly to interconnect our world, enabling near-real-time communication and data exchange worldwide. According to the Internet World Stats database, as of December 2011, global documented Internet usage was 2.3 billion people. Thus, the Internet has become an important medium to access and deliver information worldwide in a very timely fashion.

In addition, remote sensing satellites now provide a continuous stream of data. They are capable of rapidly and effectively detecting hazards, such as transboundary air pollutants, wildfires, deforestation, changes in water levels, and natural hazards. With rapid advances in data collection, analysis, visualization and dissemination, including technologies such as remote sensing, Geographical Information Systems (GIS), web mapping, sensor webs, telecommunications and ever-growing Internet connectivity, it is now feasible to deliver relevant information on a regular basis to a worldwide audience relatively inexpensively. In recent years, commercial companies such as Google, Yahoo, and Microsoft have started incorporating maps and satellite imagery into their products and services, delivering compelling visual images and providing easy tools that everyone can use to add to their geographic knowledge.

Information is now available in a near-real-time mode from a variety of sources at global and local levels. In the coming years, the multi-scaled global information network will greatly improve thanks to new technological advances that facilitate the global distribution of data and information at all levels.

Globalization and rapid communication provides an unprecedented opportunity to catalyze effective action at every level by rapidly providing authorities and the general public with high-quality and scientifically credible information in a timely fashion.

The dissemination of warnings often follows a cascade process, which starts at the international or national level and then moves outwards or downwards in scale to regional and community levels (Twigg 2003). Early warnings may activate other early warnings at different authoritative levels, flowing down in responsibility roles, although all are equally necessary for effective early warning.

Standard protocols play a fundamental role in addressing the challenge of effective coordination and data exchange among the actors in the early warning process and it aids in the process for warning communication and dissemination.

The Common Alerting Protocol (CAP), Really Simple Syndication (RSS) and Extensible Markup Language (XML) are examples of standard data interchange formats for structured information that can be applied to warning messages for a broad range of information management and warning dissemination systems.

The advantage of standard format alerts is that they are compatible with all information systems, warning systems, media, and most importantly, with new technologies such as web services. CAP, for example, defines a single standard message format for all hazards, which can activate multiple warning systems at the same time and with a single input. This guarantees consistency of warning messages and would easily replace specific application-oriented messages with a single multi-hazard message format. CAP is compatible with all types of information systems and public alerting systems (including broadcast radio and television), public and private data networks, multi-lingual warning systems and emerging technologies. CAP uses Extensible Markup Language (XML), which contains information about the alert message, the specific hazard event, and appropriate responses, including the urgency of action to be taken, severity of the event, and certainty of the information.

3.6. Early warning system examples

Several cities are equipped with early warning systems for the sampling of precipitation, for the prediction of precipitation and for the estimation of the extensions and the damage caused by a flood event. Each system is characterized by a different type of data collection and processing and of warning channel. The rainfall information can come from a national weather forecast system, a rain gauges network and local radar. Data processing can be done by simple comparison with similar events or by real-time processed events. Finally, warning procedures may be different and more frequently dependent on network sharing of critical information.

Hènonin et al. (2010) have proposed a classification of early warning systems for overflow forecasting in urban areas, identifying 4 main categories (**Figure 3.1**). The following paragraphs report the description of these categories and provide some examples.

3.6.1. Systems based only on rainfall information and empirical scenarios

These early warning systems use only a rainfall forecast as input for empirical scenario selection. The scenarios are based on historical events recordings and key people knowledge (network knowledge, emergency services experience, etc…) (**Figure 3.5 (a)**). These systems are “simple” regarding the technology involved but the data assessment is a key issue to define proper scenarios. This kind of system can be difficult to update (not a continuous process) and faces a risk of loss of knowledge and know-how.

An example is the system of flood risk forecasting in Sicily. Forecasting and coordination of assistance for hazardous events belong to the Dipartimento Nazionale di Protezione Civile (DNPC). As part of meteo-hydrological hazard mitigation, every day the National Centro Funzionale publishes a pamphlet with national weather alerts. On the basis of the type of precipitation (long or short, intense and/or persistent, widespread or localized) various alert levels are established. The Sicilian Protezione Civile that has not a regional Centro Funzionale, translates this pamphlet in “risk level” for those areas that in the past have experienced floods or landslides (**Figure 3.1**).

This system can be considered as approximate. However, it is useful for the identification of areas subject to flood risk, since the structure of this warning system empowers municipalities to monitor much its territory.

3.6.2. Systems based on rainfall information and pre-simulated scenarios

This category of systems use a rainfall forecast as input for simulated scenario selection (**Figure 3.5 (b)**). The scenarios are based on a pre-study project involving data recovering and treatment, and hydraulic simulations. Various modeling strategies and levels can be used depending on the available tools and on the kind of flood. The accuracy of the simulated scenarios depends on both the model(s) and the input data quality (including calibration data). The main issues for this kind of system are the update of the scenarios in case of major change in the hydraulic network and the proper setup for scenarios: the “warning levels” have to be selected carefully so that the scenario catalog will cover the whole range of flood events. Thus, the possible climate change effects should be taken into account, at least through a scenario update schedule.

The municipality of Hvidovre is a southwest suburb of Copenhagen, Denmark. During summer 2008, a real-time online warning system has been setup to provide information on the risk of basement flooding. The system is based on local area weather radar (LAWR) rainfall forecast and on hydrological book-keeping model for 22 urban catchments. The high resolution radar pictures are retrieved every 5 minutes to produce and update a forecast for the next hour. This forecast is used by the Decision Support System (DSS) together with historical data to calculate the accumulated rainfall for each sub-catchment and to issue a warning if any of the pre-defined critical levels is exceeded. The Hvidovre citizens can be either warned automatically by the DSS, by SMS and/or e-mail, or access to the current status information through a webpage developed with Dashboard Manager (**Figure 3.2**).

One of the main issues for such a system is the radar proper setup, including location, data validation and calibration. The radar has to be installed where it can get clear pictures, avoiding as much as possible clutter impacts, so a top position is usually required.

This system has been kept “simple” (even though based on high tech tools) as an intermediate solution before adopting the drainage system modernization plan, which is expected to take several years. Besides warning people as long as the drainage system is insufficient, this system is also used to collect experience and knowledge to enhance the flood management strategies.

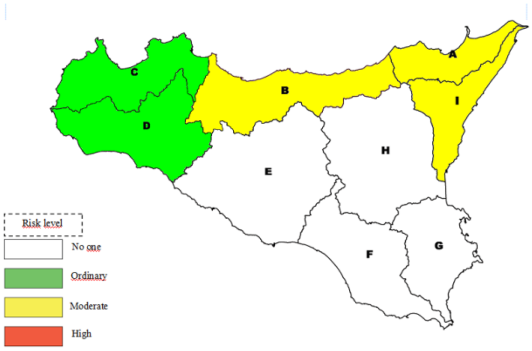


Figure 3.1: Map of risk level for Sicily Island (Regione Sicilia-Dipartimento di Protezione Civile).

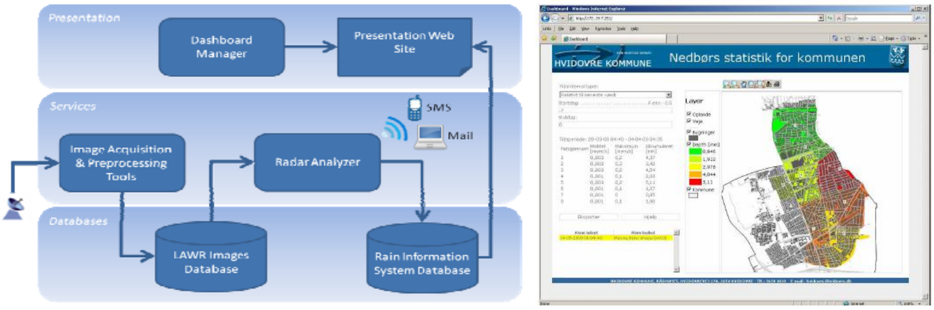


Figure 3.2: System structure and webpage of Hvidovre city warning program.

3.6.3. Systems based on real-time data assimilation

These systems use a rainfall forecast as input for an online modelling system. This kind of system is based on real-time modelling to forecast the behavior of the runoff. The simulation system usually involves a hydrological model connected to a 1D hydraulic model representing the drainage network. Warnings are issued when network overflow is forecasted. Additional historical database storage can be done for off-line simulations and data assessment (**Figure 3.5 (c)**).

The main issues for such systems are the forecast accuracy (depending on the rainfall forecast system, on the model calibration, etc…), the update of the model in case of major change and the whole system maintenance. Besides, automatic and continuous calibration process should be considered to ensure the accuracy of the forecast.

Barcelona is one of the most densely populated cities in Europe, with more than1.6 million people just for the city itself and more than 28000 inhabitants per km^2in half of the city. Barcelona is located in the northeast coast of Spain and has a Mediterranean climate including heavy storm period from August to November with flash flood risk.

The Barcelona urban drainage managing company (CLABSA), in collaboration with HYDS, has developed a flood forecast system called HIDROMET (**Figure 3.3**). This system has been implemented and tested in the Riera Blanca catchment, South-West of Barcelona. The rainfall information comes from both 1 km^2 resolution radar and 7 rain gauges. The rainfall is forecasted for the next 2 hours. The radar data is calibrated using the rain gauge dataset. The system also includes data from 10 water level sensors. The time step for radar data acquisition is 6 min while it is 5 min for gauges and sensor data.

The rainfall forecast is used as input for a MOUSE2 model of the drainage system, including 280 nodes, 300 links and 73 sub-catchments. The real-time and forecast application of the model has been tested off-line, with simulations run every 5 min.

Comparison of off-line predictions with real measurements has proved that such model can work successfully online for overflow forecasting.

Automatic on-screen and on-call warnings can be issued at every level of the system, from exceeded threshold in the rainfall forecast or water level sensors to overflow simulation in the drainage model, or even failure of any item of the forecast system. The phone call alert application ATTELNET has been developed by CLABSA as a stand-alone tool to adapt to various kinds of alert systems.

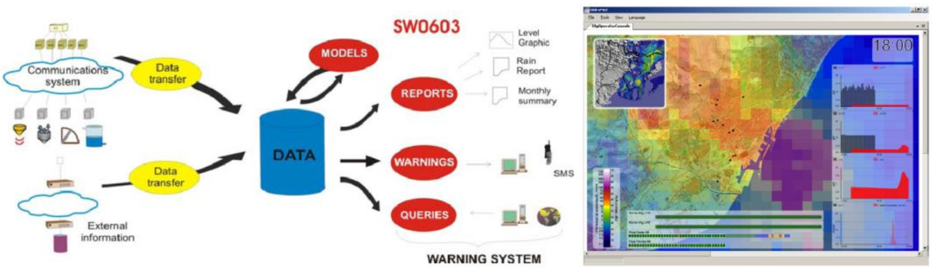


Figure 3.3: System structure and webpage of Barcelona city warning program.

The real-time system has been implemented and tested from June 2008 to December 2008, showing good and reliable results for light rainfall and heavy but non-convective rainfall. Although the forecast reliability is reduced in case of heavy convective rainfall to an optimal prediction of 30 min, the system is now operational since January 2009.

The Barcelona case underlines the importance of the input data reliability and quality, and particularly of the rainfall forecast. Besides, when it comes to flashfloods caused by heavy convective rainfall, the ability of the weather forecast system to detect and predict such event is a major issue, leading to the need of future improvements in forecasting methodologies for this type of rain events.

3.6.4.Systems with active feedback to the drainage system operation

In addition to the previously described online modelling forecast system, this type of systems involves automatic and remote control of the actual network controllable devices based on the model forecast (**Figure 3.5 (d)**). Remote sensors are a key technology for such systems. The main issue (in addition to the issues for the previous type) is the proper setup of the automatic procedures to ensure that the controlled system will behave efficiently (i.e. to avoid overflows) and safely (i.e. not worse than without control). Whatever the kind of forecasting system, it has to be sustainable and ergonomic. The end-user must have easy access and understanding to the forecast.

The City of Quebec opted for a RTC solution in order to control flooding conditions for a centennial storm event (Pleau et al., 2010). The flood protection solution involved the construction of two retention basins (100,000 m^3 each) along the two main tributary creeks (Des Friches and Mont-Châtel), and new pumping stations, as well as the control of flap gates and dykes in the downstream sectors of the Lorette River. The real time control system is implemented at a central station and uses flow monitoring and water level data, rainfall intensity data, radar rainfall images and 2-hour rain predictions (**Figure 3.4**).Weather predictions, along with local flow and water level measurements and alarms, are used by the Csoft™ decision-making system to compute the optimal flow set points to be applied at the local flow regulators. Before being sent locally, these optimal flow set points are displayed on a Human Machine Interface (HMI) along with field measurements. If the sewer system operator acknowledges these set points, they are sent to the local control stations, where local controllers convert the optimal flow set points into gate openings.

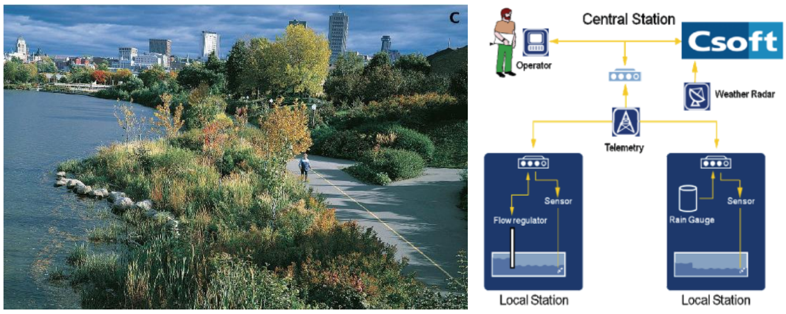


Figure 3.4: The St-Charles retention basin and the architecture of the RTC system implemented in Quebec City.

© (d)

Figure 3.5: Schematic representation of the types of early warning systems.

Chapter 4

Sewer overflow forecasting for the city of Palermo

As a consequence of the foregoing statement, it is clear that a flood forecasting system in urban areas must be designed knowing problems associated with crisis events and socio-economic situation about population. Thus it is important to conduct a careful analysis of the case study. The study basin is that of the city of Palermo. Palermo has been for many years subject to overload phenomena and surface runoff. There are several studies that have dealt with the problem. The University of Palermo and especially the Department of Hydraulic and Environmental Application (Dipartimento di Idraulica e Applicazioni Ambientali- DIAA) has been involved in activities to protect the territory of the city of Palermo many times. For examples in 1999 AMAP (Azienda Municipalizzata Acquedotti Palermo), the company that manages water resources in Palermo, asked to this Department to update and integrate knowledge about sewer network in the historical part of the city. In 2003 the Regional Department for Territory Protection (Assessorato Regionale Territorio e Ambiente – ARTA) has worked with DIAA to make the plans for landslide and flood risk in the Sicily Island. In 2012-2014 a research group has been involved in SESAMO project with other start-up company that deals with sensors design. The project concerned the design of a collecting and sharing system for environmental data near Palermo. It is worthy to note a research work on the costs about integrating some resistance measurements in the city of Palermo (Caltabiano, 2012).

In this chapter an early warning system to protect against damage caused by overflowing for the city of Palermo is described. The chapter begins with a brief introduction about the city, with particular regard to characteristics of the drainage system. Following the same pattern as the previous chapter, techniques and methodologies of each component of the system, the collection and analysis of rainfall data, the hydrologic-hydraulic model of the drainage basin and warning system are shown.

4.1. The city of Palermo

Palermo is a city with 677,854 habitants in the north-east of Sicily Island (**Figure 4.1 (a)**). Founded by the Phoenicians in 734 BC, the city has undergone several changes as a result of the numerous settlements over the time. The city was a plain with many marshy areas. Now the plain is almost completely urbanized and surrounded by mountains with a predominantly limestone. The climate is Mediterranean, characterized by hot – dry summers and cool-rainy winters. The wettest period is from October to January with an average precipitation of 600 mm/year.

Palermo is divided into 8 districts, defined *circoscrizioni* (**Figure 4.1 (b)).** The historic district of the city is called *First-Palazzo Reale-Monte di Pietà*. Over the past 30 years, this district has gone through a radical change of his employment (Busetta, 2013). The lack of building renovation has created a first abandonment of the district and a subsequent repopulation by foreigners. About a quarter of all foreign residents in the city actually lives inside only this district. Except for the commercial and financial building the population is mainly composed of artisans and people who work serving. Then recovery measures for ancient buildings are very scarce. The population density is still very high, about 8000 ha/km^2 compared to average population density in the city, about 3000 ha/km^2.

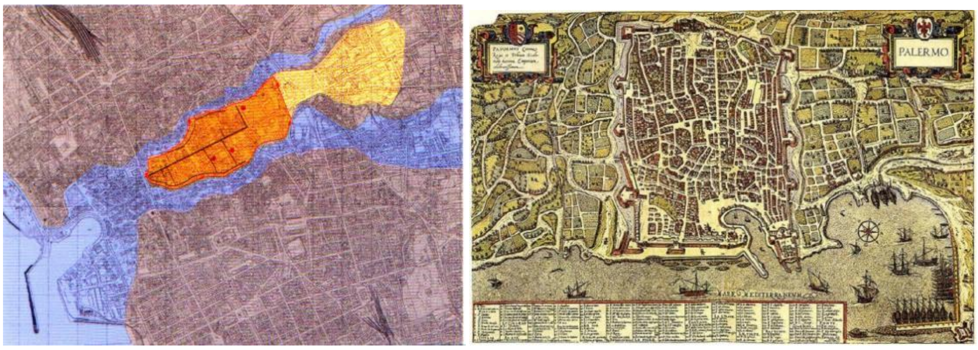
(a) **(b)**

Figure 4.6: Geographical location of the city of Palermo in the Mediterranean sea **(a)** and administrative borders **(b)** (in green the district of the old town).

4.2. Historic information of Palermo sewer system

The construction of the sewage of Palermo has gone hand in hand with the evolution of the city. During the Arab settlement, the city was enclosed by two rivers called "Kemonia" and "Papireto" who received all discharges of the city and representing a perennial danger hygienic (**Figure 4.1 (a)**). Felice Giarrusso writes that as a result of epidemics and floods caused by the Kemonia River in 1557 and 1575, the Senate dealt with the problem of drainage of the two streams by adopting the following solutions (**Figure 4.2 (b)**):

- about the Kemonia River it was decided to divert the water coming from the mountain regions, corresponding to the avenues today called viale delle Science, corso Pisani and fossa della Garofala into the Oreto River and lowest spring waters were conveyed to the harbor area through a covered channel with a vaulted roof that ran under the old course;
- about the Papireto River it was decided to fill the pit called "Danisinni" from which originated the river with a covered canal that served as a disposer of waters draining to the harbor area.

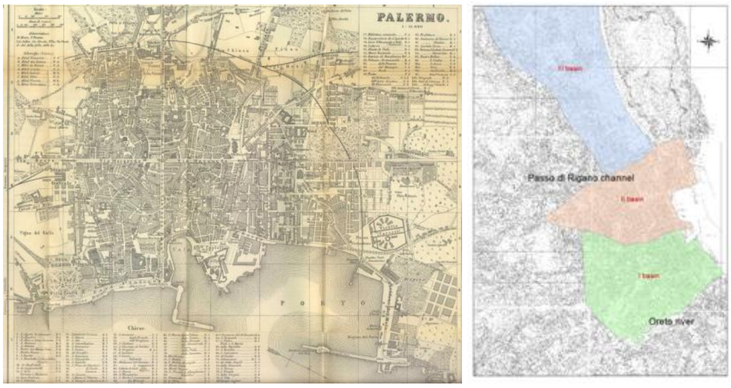


(a) **(b)**

Figure 4.7: In blue the sea and the Kemonia and Papireto rivers, in orange the old town, in yellow the necropolis **(a)** and a Palermo old town map, enclosed in walls without trace of rivers **(b)** (16th century).

However these works were not revealed sufficient to eliminate the dangers of floods, perhaps due to insufficient collectors. In fact, soon after heavy rainfall the filled area is transformed back into the swamp and in the following time intensive rainfall is continued to generate floods with damage and many casualties. It is interesting to note that at that time the roads were built as a cradle, accepting the notion that the road had turned into collector during rainfall event. The drainage system continued to be one of the so-called bells, shafts or pipes, made by individuals without a comprehensive plan, which discharged in two covered streams. These pipes are made of clay. They broke often for brittleness of the material and sewage was going to soak the soil. At the same time many aqueducts, also made of clay, suffered the same fate with constant dangers of drinking water contamination and cholera epidemics, as in 1837 and in 1854.

Meanwhile, the city began to expand, it was realized via Maqueda and extended up to the countryside, a project for the reconstruction of Corso Vittorio Emanuele was written by Torregrossa R. and Ampulla M. in 1858 (**Figure 4.3**). Those engineers renovated the sewer system, providing for the construction of the road with culverts, sidewalks and pronounced slope as to convey the rain water through the culverts. These notions were soon accepted by the Technical Department of the Municipality and implemented in the new city sewers.



(a) **(b)**

Figure 4.8: The city of Palermo in 1890 **(a)** and main drainage areas for sewer system **(b)**.

Before 1886, the city sewer network had a total length of approximately 70 km of canals and 26 outfalls into the sea, 11 discharges to Cala (the harbor), 5 along the beach at the Foro Italico and 10 distributed among Piazza S. Muzzo, in front of the existing commercial harbor, and Piazza Ucciardone. Following the expansion of the city, which extended in principle by the river Oreto to Via Notarbartolo, in 1930 the Municipality of Palermo decided to draw up a general plan of the sewer system.

The city was divided into three basins with independent collection and sewer systems (**Figure 4.3 (b)**). The first one was bounded by the Oreto River, corso Olivuzza, Via Cavour and Via Volturno. The second one was bounded by Via F. Crispi, PA-TP railway, Via Volturno and the Passo di Rigano channel. The third one was bounded by PA-TP railway, Passo di Rigano channel, Via Principe di Scalea and Piazza Libertà-Piazza Leoni. In turn, the city area was protected by appropriate stormwater channels.

4.3. Current assessment

The current sewer system is that drawn in the old project in 1930, but, the urban expansion without adequate extension of sewage, the inadequacy of existing hydraulic infrastructures, the non-realization of part of the channels that allow the diversion of rainwater from the mountains that surround the city, still now amount to situations of discomfort which in some cases can cause severity damage. In fact it can be said that there are fewer rainy days per year and that the rain is torrential.

With the adoption of the Merli law (No. 319/05.10.1976) and the drafting of the new program for the implementation of the drainage system for the city of Palermo (PARF-Programma di Attuazione della Rete Fognaria) by the Division of Public Works, after approved by the Land and Environment Regional Department in 1987, problems related to the disposal of rainwater, even if partially, find a proper solution. In summary, the characteristic features of the solutions outlined by the PARF can be summarized as follows:

- subdivision of the entire urbanized area into two basins:
  a) a main basin called the South - Eastern with an expected population equivalent of 880,000 inhabitants gravitating to the water treatment plant located in Acqua dei Corsari area;
  b) a secondary basin called North - Western with an expected population equivalent of 100,000 people gravitating to the water treatment plant located in the Fond Verde area;
- construction of two main pipes (South - Eastern and North – Western pipes) at the service of the two mentioned above basins;
- realization of the two named wastewater treatment plants serving the two basins;
- elimination of all discharges inshore with the exception of those emissaries in relation to surplus flows and stormwater for the areas served by separated system;
- building of an offshore pipes to carry the water from the two wastewater treatment plan;
- reuse of treated water for irrigation or for groundwater recharge;
- reorganization of the main stormwater channels to protect urban area.

Currently only some works, mentioned in the PARF, have been parceled. The 5 lots already banned are shown below, pointing out the state of realization of the work.

4.3.1. Separate system and pump station inside shipyard area

This first lot deals with the reorganization of Cantieri Navali discharge area with separation of wastewater, (up to a dilution equal to 3 times the average flow rate Q_m) from stormwater, the removal of stormwater through a channel, out of the shipyard area and the building of a pump station lifting for wastewater (**Figure 4.4** in red). It is finding its achievement in the work that the Port Authority has going. From technical point of view limited executive changes must be made to connect these works with the sewage pumping station. Its final design is almost ready, because most of these works are realized during the intervention funded by the Portual Authority Agency.

4.3.2.Pipe connecting shipyard area to the second pump station

It connects to lot n.1 and concerns the wastewater flow. It consists of feeding the “Acqua dei Corsari” wastewater treatment with a channel from harbor area to sewage pump station of Porta Felice (**Figure 4.4** in light green). For this work the municipality of Palermo and the company which deals with water management have already prepared the preliminary project but nothing has been realized.

4.3.3.Removal of discharge to the sea

This program work concerns the interception of pipes, the sewage pumping in Porta Felice plant and the adduction to the South - Eastern collector of the group of discharges present along the Foro Italico, the South Quay and within the Cala area (**Figure 4.4** in blue). The works for the construction of the pumping station and its pipes were made in 2007. However, it was expected a updating of this system due to the construction of other works included in the PARF, which will bring additional flows: the construction of a pipe through piazza della Pace, corso Scinà, Via Quintino Sella and via Puglisi and the construction of another pipe, which will pass under via Roma and via Cavour to reconnect to the Cala pipe.

4.3.4.Building of sewer networks

As part of this lot two interventions aimed at the elimination of secondary discharges are grouped here (**Figure 4.4** in yellow), with less importance than in harbor area, but with strategic importance for the achievement of coastal waters quality:

a) construction of the sewer network for Arenella and Vergine Maria suburbs, with adduction to the shipyard. This intervention aims to regulate discharges of 9,500 residents in Arenella and Vergine Maria that currently end up into the sea and puts them in the sewer network. The work has been completed in 2012;

b) interception of discharges from Via Diaz to the Oreto River and adduction to the South - Eastern Emissar. The South-Eastern emissary has been realized only for the final path between the right bank of the Oreto River and the sewage treatment plant. It is long 6.5 kilometers and has a circular diameter of 3.7 m. For now it collects the wastewater from Sperone, Ciaculli, Brancaccio, Oreto, Guadagna, Villagrazia, Bonagia, Falsomiele and part of Villaggio Santa Rosalia. So that it may come into operation lacks the construction of approximately 3100 m of new pipeline near via Uditore and the area between Piazza Principe di Camporeale and via del Vespro. A spillway system and a siphon in correspondence of the Oreto River are also provided. The realized works have been financed because have been included in the three-year program of public works of the Palermo Municipality (2007-2009).

4.3.5. Wastewaters Treatment Plants

These interventions on the Acqua dei Corsari wastewater treatment plant bring the capacity from the current 440,000 population equivalent to the capacity provided for PARF (**Figure 4.4** in purple). This expansion is necessary because with the implementation of the measures referred to lots no. 2, 3 and 4 is to complete the adduction to the purifier of the whole wastewater for SO basin required by PARF. About this it should be noted that the wastewater treatment plant was built with the general hydraulic parts sized for its final structure (880,000 habitants) and the enhancement involves the construction of new tanks for grit removal, primary and secondary sedimentation and oxidation. However these new contributions of wastewater will allow the completion of the overall project of re-use of treated water for irrigation, which was first funded a lot of 300 l/sec potential in 1997 (**Figure 4.4** in dark green).

The Fondo Verde wastewater treatment plant has been completed and is currently in operation at full load. It is located in via Olimpo and treats the wastewaters flow down Mondello, Valdesi, Partanna Mondello, ZEN I, Z.E.N. II, Pallavicino and Villaggio Ruffini. However the purified wastewater is fed back into the sewer system that revolves on the South-Eastern basin because of not completed North-Western Emissary and the offshore pipe in Cala D'Isola. In fact, the North-Western Emissary has been achieved without the final stretch between Tommaso Natale and Cala D'Isola.

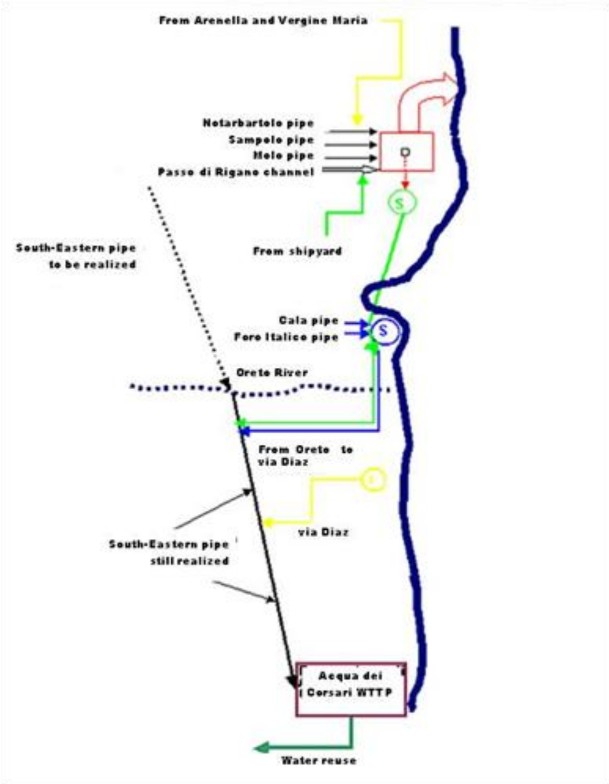


Figure 4.9: Scheme about recovery plan to clean Palermo coast.

4.4. Recent flood events

In the city of Palermo phenomena of overflowing were always recorded, mainly due to flood of underground channels. To alleviate these episodes additional infrastructure for preservation of the town and in particular the old city center were built. The first measure, which was adopted as a result of flooding in 1931, during which the city was fully involved, was the construction of the Passo di Rigano channel. Although it is now transformed in a sewer pipe, this work has proved useful in preventing flood damage effects of previous centuries. However the construction of the channel Passo di Rigano was not sufficient to salveguard certain areas of the city, especially the deeper ones in the old town that became flooded for events with very low return period, equal to 2-3 years (Freni, 1996).

Following further investigations, even by the local Civil Protection Agency, the channel that collects the Papireto River has been designed, in order to prevent any rising during rainy periods. Even this action has improved the efficiency of the drainage system in the old town of Palermo, but overflowing continue to occur.

Gathering information on frequency and distribution of overflowing in the city (par. 5.1), it is possible to note that since 2007, the year in which the last major changes to the sewer system were made, overflowing events mainly occur along the coastline, from Sferracavallo to Acqua dei Corsari and along the surrounding highway areas, nearby the axes of the main crossing (Viale Michelangelo, viale Lazio, via Pitrè, corso Calatafimi, via Oreto). The causes of these inefficiencies, resulting in traffic inconveniences of course, because they involve the principal street of the long-distance traffic, are difficult to understand, although some assumptions can be done. For example, it can be assumed that the waterproofing of additional areas below the hills of Palermo has caused a higher flow rate to discharge. This is very clear in at least two critical events. The first event was the construction of a large shelter for emigrate in Via Belmonte Chiavelli. The impermeable surface has created a slide, almost a preferential channel, with the outlet in a narrow street. The result has been to channel the water directly in the residential area. The second recently occurred example is a major quantity of water in the pipes along the streets viale Michelangelo and viale Lazio. Also in this case it is expected a growing urbanization in that areas.

4.5. QPE

For the city of Palermo it is possible to collect information on rainfall data using two possible sources: gauge network and weather radar.

Rain gauges within the city belong to:

- sicilian agro-meteorological information service (Servizio informativo Agro-meteorologico della Sicilia- SIAS);
- observatory for waters (Osservatorio delle Acque);
- University of Palermo.

The SIAS is a regional Agency that deals with the monitoring of climate variables in order to provide the ideal conditions for crops. It has a gauge network with 96 on line stations, scattered throughout Sicily. Unfortunately, in the city of Palermo, there is only one rain gauge, which is part of the station called *Uditore* (coordinates UTM ED50 353448E, 4221667N, 50 m a.s.l.). Rainfall data are provided as 10 minutes cumulative rainfall or 3, 6, 12, 24 hours cumulative rainfall.

Another rainfall data source is the Osservatorio delle Acque. The Osservatorio is also a regional Agency but deals with the monitoring of water resources for drinking and irrigation in Sicily. His network consists of 255 rain gauges. The city of Palermo currently has three rain gauge: *Osservatorio delle Acque* (coordinates UTM ED50 354093E, 4220253N, 57 m a.s.l.), *Istituto Zootecnico* (coordinates 351007E, 4220156N, 110 m a.s.l.) and *Osservatorio Astronomico* (coordinates UTM ED50, 355705E, 4219648N, 80 m a.s.l.). Temporal resolution about rainfall data is related to the type of rain gauge. Base available product of this Agency is 1 hour cumulative precipitation but it is possible to access at row data.

Both of these agencies are created to provide statistics on rainfall data: they do not have the aim of protecting the city center from flood risks.

Finally, the Department of Hydraulic Engineering and Environmental Applications, part of University of Palermo, has also a rain gauge network that will be recently updated. The network consists of 18 pluviographs of which 8 are installed inside the city (**Table 4.1**). Temporal rainfall data resolution is 1 minute.

Table 4.1: Raingauge installed by Department of Hydraulic Engineering.

Name	E	N	m a.s.l.
Department of Hydraulic Engineering	355147.670	4218796.818	58
Via Gubbio	353831.024	4220150.933	68
Borgonuovo	350259.181	4221475.129	111
Scuola Media Quasimodo	357486.842	4217780.948	29
Istituto Majorana	353155.646	4225534.390	75
Circolo del tennis	354924.027	4223559.855	38
Istituto Nautico Gioeni	357154.661	4220364.170	29
Mondello	352814.911	4228809.941	25

Therefore the best available rain gauge network, using only own University rain gauge, has a density of 1 rain gauge per 19.86 km^2. If it is chosen to enter into an agreement with the regional Agencies, it might be got a density of 1 rain gauge per 13,24 km^2. In reality this rain gauge network, in accordance with Berne et al., 2004, is insufficient. For urban basins of the order of 10 ha they recommend a temporal resolution of 2-3 minutes and spatial resolution of 2 km.

However, rain gauge data, albeit insufficient, it is very important to estimate the spatial distribution of precipitation, working as a feedback on the ground. In this sense remote sensors become an important source of information for QPE. To obtain a time series precipitation maps a weather radar can be used.

The weather radar, also called weather surveillance radar, is a type of radar used to locate the precipitation, to estimate the intensity of precipitation, to calculate hydrometeors movements and to identify the type of precipitation (rain, snow, hail, etc. ...). The weather radar sends directional pulses of radiation in the microwave, order of a microsecond, using a magnetron or a klystron tube connected by a waveguide to a parabolic antenna. Wavelengths usually range between 1 cm and 10 cm. Shorter wavelengths are useful for smaller particles, but are subject to greater signal attenuation. So wavelengths of 10 cm (S-band), are applied on the most used radar, but are also more expensive than those with wavelength of 5 cm (C-band). The radar characterized by wavelengths equal to 3 cm (X-band) are only used for very short distances, and weather radar with a wavelength of 1 cm (Ka-band) are used to trap smaller particles, such as rain and fog phenomena. The weather radar registers the back-scattering power from the intercepted particles. According to the Rayleigh theory and knowing the mechanical characteristics of the radar, to this back-scattering power corresponds a reflectivity, as shown in the radar fundamental equation:

$$p_r = \frac{C_2 Z}{r^2} \quad \textbf{[4.1]}$$

where p_r is the bask-scattering power, C_2 is the "radar constant", because summaries all radar characteristics, Z is the reflectivity and r is the distance between radar and precipitation target. Thus back-scattering power is proportional to radar reflectivity and inversely proportional to the square of the distance.

The reflectivity Z is measured in dBZ, which stands for decibels relative to a reflectivity of 1 mm^6/m^3. So the values of the radar reflectivity factor are:

- (-30 – 0) dBZ barely detectable signal;
- (0 – 10) dBZ for very light rain and light snow;
- (10 – 30) dBZ to moderate rains and heavy snowfall;
- (30 – 55) dBZ to heavy rains;
- up to 55 dBZ for hailstorms.

One of the purposes of radar-meteorology is to estimate the intensity of precipitation. To do this, an equation that converts the measurement of the reflectivity Z in rainfall intensity R has to be used. Z and R are related to drop size distribution of precipitation N(D) and drop speed v(D), according with this relation:

$$Z = aR^b \quad \textbf{[4.2]}$$

It is possible to estimate a and b parameters (dependent variables by N(D)) by using of a disdrometer. Alternatively a rain gauge can be used, paying attention to problems of signal attenuation.

The **Table 4.2** shows some typical values of these coefficients obtained in different studies and for different conditions of precipitation.

The Department of Hydraulic Engineering installed an X-band radar in one of the hills surrounding Palermo in February 2013 (coordinates UTM ED50 347836.32 E, 4209205.159 N, altitude 789 m a.s.l.).

The radar SUPERGAUGE was built ENVISENS the company and tested at the University of Turin. This radar allows getting radar maps with a resolution of 1024 x 1024 pixels, covering an area with a diameter of about 60 km. Temporal resolution is 1 minute.

Table 4.2: Values of the coefficients a and b for the Z-R relationship for different types of precipitation.

Source	Type of precipitation	a	b
Joss and Waldvogel (1970)	Different type	300	1.50
Marshall and Palmer (1948)	Stratiform	200	1.60
Atlas and Chmela (1957)	Stratiform	255	1.41
Fujiwara (1965)	Stratiform	205	1.48
Jones (1956)	Thunderstorm	486	1.37
Fujiwara (1965)	Thunderstorm	450	1.46

Maps are in .png format and are subjected to a first transformation in reflectivity, according to an equation tested in laboratory. Maps are characterized by a high percentage of clutter, equal to 60 %, but the visibility of the city on the left hand side of the Oreto River is assured (**Figure 4.5**). Other sites with greater visibility, even at 100%, were identified. Unfortunately, each of these sites has shown some problems, such as difficulty of access, lack of electricity, landscape and environmental restrictions, landlords not available for installation of the equipment. Nowadays maps are available on line on the site: http://147.163.48.110/sito_prova/.

(a) **(b)**

Figure 4.10: Radar clutter map (www.meteoradar.polito.it) **(a)**, radar SUPERGAUGE **(b)**.

4.6.QPF

The storm advection estimation (Austin and Bellon, 1974) can be chosen among the various Quantitative Precipitation Forecasting techniques using weather radar data. Advection plays a fundamental role in determining the evolution of the rainfall. The Lagrangian persistent model aims at performing the forecasting by taking into account the storm advection, while still neglecting the Lagrangian dynamic component. Therefore momentum equation for precipitation field can be written as:

$$\frac{\Delta h_t(x,y)}{\Delta t} + U_x(x,y)\frac{\Delta h_t(x,y)}{\Delta x} + U_y(x,y)\frac{\Delta h_t(x,y)}{\Delta y} = 0 \quad [4.3]$$

where the first term represents the variation of the precipitation field h_t over time, the second and third term take into account storm advection, $U_x(x,y)$ and $U_y(x,y)$ are the components of the storm velocity vector in the pixel of coordinates (x,y).
In detail, the method requires the preliminary estimation of the storm velocity vector, which is assumed here to be uniform over the whole radar map. Subsequently, the future radar image is forecasted by repositioning downwind the current image accordingly to the storm shift occurring in the next time step, under the assumption that the storm velocity vector remains unchanged in the future.
The storm velocity vector is estimated here by using the correlation method, which consists in identifying the components U_x and U_y that maximize the pixel by pixel correlation between the last two observed maps. Let us denote with t the forecast time and with Δx and Δy the shifts of the radar maps between time t-1 and t, along the x and y directions. Then, the value of Δx and $\Delta y$are found that maximize the correlation coefficient *(*Pegram and Clothier, 2001*):*

$$\rho = \frac{1}{(n\cdot m-1)\sigma_t\sigma_{t-1}}\sum_{x=1}^{n}\sum_{y=1}^{m}[h_t(x,y)-\mu_t]\cdot[h_t(x-\Delta x)-\mu_{t-1}(y-\Delta y)]$$
[4.4]

where $h_t(x,y)$ is the rainfall depth at time t in the pixel of coordinates (x,y); μ_t and σ_t are the mean and standard deviation, respectively, of the rainfall data comprised in the map observed at time t; n and m are the number of pixels along the x and y direction, respectively. The search for the optimal values of Δx and Δy is done by using a sequential algorithm. As mentioned before, the storm velocity vector is assumed to remain unchanged during the lead time of the forecast. Therefore, accordingly to the Lagrangian persistent model the rainfall in each pixel at time $t+1$ is obtained through the relationship:

$$h_{t+1}(x,y) = h_t(x-\Delta x, y-\Delta y)$$
[4.5]

In this way it is possible to obtain a 15 minute forecasting precipitation field, while the 30 minutes ahead forecast is obtained by applying a downwind shift of 2Δx and 2Δy.

In fact the term forecasting is not correct because with forecasts to under an hour talking about nowcasting is more correct. Nowcasting approach could be useful for the early warning system of Palermo to implement real time control measures in some parts of the drainage system or to interrupt traffic in some areas. With the tools on Sicilian territory a lead time of 3 days through can be reached through SIAS forecasting models. SIAS has developed two numeric prevision models:

- DALAM (Data Assimilation Limited Area Model), with a spatial resolution of 30 km and temporal resolution of 3 hours;
- SILAM (Sicily Limited Area Model) with a spatial resolution of 5 km and temporal resolution of 3 hours.

The numerical prevision model SILAM is a hydrostatic mesoscale numerical model which, through mathematical equations describing the physics of the atmosphere, simulates the temporal evolution of weather conditions, starting from an initial situation (fields of analysis at 00:00 UTC) and boundary conditions (forecasts every three hours) developed and daily provided by DALAM. In turn this carries out the weather forecast on the evolution from an initial situation and boundary conditions provided daily by the ECMWF (European Centre for Medium Range Weather Forecasts) in Reading (UK).

The model SILAM produces daily forecast maps of temperature at 2 m, cloudiness, precipitation cumulated, speed and wind direction at 10 m a.s.l., atmospheric pressure, global solar radiation, relative humidity, starting at 00:00 UTC of the current day up to 72 hours.

There is also another version of this model: the GFSS (Global Forecast System for Sicily). SILAM GFSS is a numerical model that works on the output of SILAM GFSE (Europe operating on the domain). This, in turn, carries out the weather forecast on the evolution from an initial situation and boundary conditions provided daily by the GFS (Global Forecast System) implemented and managed by the National Center for Environmental Prediction (NCEP) of NOAA (National Oceanic and Atmospheric Administration) (USA).

SILAM GFSS model, recently implemented by the SIAS on a grid of approximately 7.5 km, daily produces forecast maps of temperature at 2 m, accumulated rainfall, wind speed and direction at 10 m a.s.l. atmospheric pressure, geopotential height at 500 and 850 hPa, starting at 00.00 UTC of the current day up to 144 hours later.

Coarse spatial resolution can be refined by application of downscaling technique as the Random Cascade Model (Foufoula-Georgiou et al., 1996). This statistical technique has long been known and applied to radar images to reduce spatial and temporal resolution. It is based on the concept that the fluctuations from average rainfall are scale - invariant and therefore they are easily parameterized. Flow diagram in **Figure 4.6** shows the procedural steps.

1. **Start**. Input data are composed of rain intensities at coarse scale and sampled radar reflections for CAPE (Convective Available Potential Energy) values.

2. **Parameter evaluation**. Model parameters H and σ_i are estimates based on equations:

$$H = 0.0516 + 0.9646(CAPE * 10^{-4}) \quad \textbf{[4.6]}$$
$$\sigma_i = 0.3811 + 0.6029(CAPE * 10^{-4}) \quad \textbf{[4.7]}$$

3. **Standardized fluctuations generation.** Three Gaussian spatially independent N x N fields, clipped between -1 and 1, with mean zero and standard deviation equal to $\sigma_m = 2^{(m-1)H}\sigma_i$ were used to generate standardized fluctuations $\{\xi_{m,j}\}_{j=1,2,3}$.
4. **Precipitation fluctuations estimation.** Precipitation fluctuations $\{X'_{m,i}\}_{i=1,2,3}$were obtained as the product of the fluctuations standardized $\xi_{m,j}$ and the corresponding average rain intensities $\overline{X_m}$.
5. **Precipitation reconstruction.** To reconstruct precipitation fields at a more reduced scale (m-1), using the inverse of the transform, generated fluctuations $X'_{m,i}$were add to the corresponding average rainfall $\overline{X_m}$. The algorithm for rain reconstruction is based on the two-dimensional inverse transform developed by Mallat (1989).
6. **Further downscaling:** if additional downscaling of precipitation fields is required, it is possible to start from the first step keeping in mind that the starting field is that obtained in the fifth step.

Temporal scaling algorithm or *dynamic scaling* has been written and shown by Venugopal et al. 1999.In particular, they have shown that the speed of evolution of the rain remains constant according to a transformation that follows a power law:

$$\boldsymbol{t \propto L^z} \quad \textbf{[4.8]}$$

where t is the temporal scale and L is the spatial scale. z can be estimated from a statistical analysis on the differences of logarithms of precipitation intensity at different spatial and temporal scales.

In Incontrera, 2011, a test of downscaling spatial data when it was available only DALAM model has been reported Considering now that the minimum spatial resolution is 5 km and that it is possible to proceed to the spatial scaling of 4 orders of magnitude, maps with a resolution of 30 m per pixel could be obtain. Regarding temporal downscaling, it depends on the value of z parameter that can only be evaluated through analysis of a long time series.

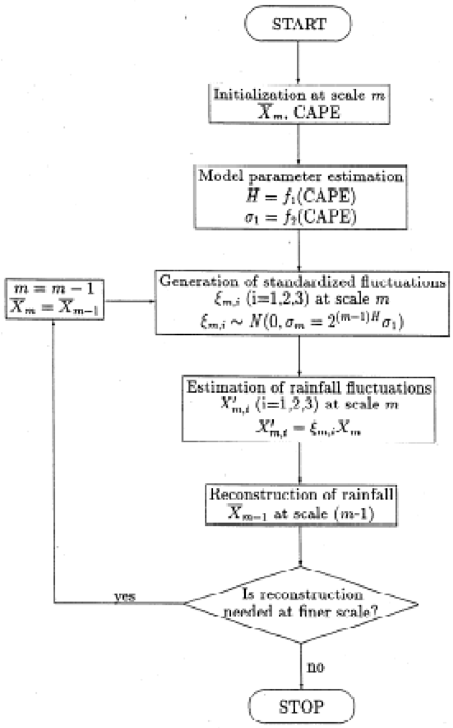


Figure 4.11: Flow diagram for downscaling technique.

4.7. Hydrologic and Hydraulic model

The choice of hydrologic and hydraulic model was made reaching goals of efficiency and quickness to output production. A research was carried out by contacting the major software production houses in the field of hydrology and hydraulics. Some of them are already producing software capable of integrating the entire process of an early warning system, from radar or numerical prediction model image acquisition to management of alert devices or sensors control inside the drainage system. These models are clearly general and require a phase of training to adapt early warning system to city.

Regarding the hydrologic and hydraulic model, all the software are equipped with hybrid models 1D-2D or 2D-2D models (i.e. Inforworks CM 2D, Vflo, PCSWMM, etc…). Taking an average of model prices a cost for the only software equal to 3,000 € for 1,000 nodes of a network has been estimated. This price can naturally increase if it is chosen to have more control systems or server data storage.

Since in this analysis funding did not allow using commercial software, free software that performs 1D-1D and 2D-2D model was used. The use of a 2D-2D model is justified by the fact that such models are inherently self-calibrating. It has been many times demonstrated that their use is also recommended for basins in which were not possible to get sufficient measurements (Leandro et al., 2011). This is precisely the case of Palermo.

Thanks to a partnership with the University of Exeter it was still possible to use a 2D-2D model: the SIPSON-UIM (Simulation of Interaction between Pipe flow and Overland flow in Networks- Urban Inundation Model). This agreement has allowed the verification of the feasibility about times and costs of an early warning system for the city of Palermo.

4.7.1.SIPSON

SIPSON model (Djordjević et al. 2005) calculates flows in drainage pipes and over the ground surface by 1D flow direction on the surface and 1D sewer network. UIM model (Chen et al. 2005) integrates SIPSON with a 2D overland flow. Both models use different numerical schemes and time steps with the discharge through manholes adopted as model linkages. The drainage runoff and surcharge effluents were calculated by SIPSON for every time step and treated as point sinks and sources, correspondingly, in the UIM model within the same time interval. Discharges are determined by weir or orifice equations by taking account of the hydraulic heads at manholes and ground surface.

SIPSON calculates storm flow into the sewer system according to the rational method, assuming that the time of concentration is equal to the rain duration. Dry weather flow is also taken into account through a coefficient pattern.

The hydrological model component regards retention on surface and infiltration, that are considered important in urban study compared to others phenomena that contribute to decrease sewer flow (**Figure 4.7**).Retention on surface is calculated via the Linsley empirical formula:

$$h_e(t) = h_i(t) - h_d\left[1 - exp\left(-{}^{h_i}/_{h_d}\right)\right] \quad \textbf{[4.9]}$$

whereh_e is the effective rainfall depth, h_i is the total rainfall depth and h_d is the surface-dependant empirical parameter denoting the equivalent thickness of the layer of water equally distributed over the entire pervious or impervious area.

Instead infiltration model is based on Green-Ampt equation:

$$H = H_s + h_c ln\left(\frac{h_c+H}{h_c+H_s}\right) + \frac{k_s}{\varepsilon_0}(t - t_s) \quad [4.10]$$

where H is the depth of the wet front reached at time t, , H_s is the wet front reached at time t_s, h_c is the capillary height, k_s is the Darcy coefficient for saturated soil, ε_0 is the effective porosity, t_s is the time from the beginning of rainfall to total surface soil saturation. This model assumes knowledge of initial conditions about soil saturation and the time in which saturation occurs.

Overflow rate is calculated by dividing sub-basin area into two rectangles that flow in one direction toward lower node. This one-dimensional flow model assumes a constant slope for each sub-basin. 1D mass and momentum equations are solved on the surface in the form of the kinematic wave:

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = i_e \quad [4.11]$$

$$-ghI_0 + \frac{\tau_b+\tau_i}{\rho} = 0 \quad [4.12]$$

where h is the water level on the surface, q is the discharge per unit width, i_e is the effective rainfall intensity, g is the gravitational acceleration, I_0 is the slope, ρ is the water density, τ_b is the bottom shear stress and τ_i is the additional shear force due to the influence of the inertial force of rain drops.

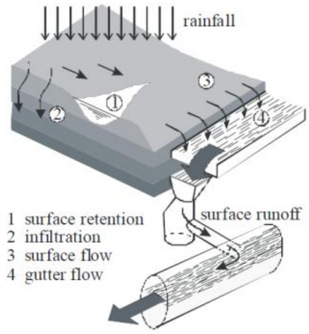


Figure 4.12: Scheme about SIPSON model component.

Flow in a sewer system can be simulated with:

- SIPSON, based on full dynamic-wave equations;
- BEMUS (BElgrade Model for Urban Sewer), based on simplified procedures including kinematic-wave equations.

1D hydraulic model regards the solution of a system of four equations:

- the full dynamic-wave (de St. Venant) equations:

$$\frac{\partial z}{\partial t} + \frac{1}{B}\frac{\partial Q}{\partial x} = 0 \qquad \textbf{[4.13]}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \qquad \textbf{[4.14]}$$

where z is the water level, B is the water table width, Q is the discharge, and A is the cross-sectional area and S_f friction slope.

- the continuity equations for nodes (manholes, channel joints and storage elements):

$$F\frac{dZ}{dt} = q + \sum_{m=1}^{M} \pm Q_m \qquad \textbf{[4.15]}$$

where F is the manhole horizontal area, Z is the water level at the manhole, q is the external inflow to the node (surface runoff, waste water or else), M is the number of links joining the manhole and Q_m is the discharges flowing from the link to the manhole and viceversa.

- the energy conservation equations for nodes and channel ends, where is applicable:

$$z + \frac{v^2}{2g} = Z \pm \xi\frac{vv}{2g} \qquad \textbf{[4.16]}$$

where v is the cross-sectional average velocity and ξ is the local energy loss coefficient.

- equations of flow through structures (weirs, pumping stations, inlets, short culverts). Djordjevic et al., 2004 define the weir discharge as a function of four variables $\left(Hs_{K.D}^{j}, Hs_{k.U}^{j}, z_{level}^{j}, w^{j}\right)$. $Hs_{K.D}^{j}$ and $Hs_{k.U}^{j}$ are the dependent variables, water level downstream, and upstream of the link *j*, at the surface nodes. z_{level}^{j} is the crest elevation considered and w^{j} is the weir crest width.

  Leandro et al. 2007 has defined the Multiple Linking Element (MLE). The MLE determines the discharge exchanged based on the flow characteristics. The discharge for a given single-linking element SLE link j at a given time k as a function of five Control Sections (**Figure 4.8**):

1. CS1—from the gutter to the inlet

$$Q_{cs1} = C_d \frac{2}{3} hs_k^j L_i \sqrt{\frac{2}{3} g hs_k^j} \qquad \textbf{[4.17]}$$

2. CS2 and CS4—from the inlet to the vertical pipe and vice versa

$$Q_{cs2} = C_d A_p \sqrt{2g\left(hs_k^j + H_i\right)}$$ **[4.18]**

$$Q_{cs4} = -C_d A_p \sqrt{2g\left(hp_k^j - hs_k^j - H_i - H_{sh}\right)}$$ **[4.19]**

3. CS3 and CS5—from the orifice to the manhole and vice versa

$$Q_{cs3} = K A_p R^{2/3} \sqrt{\frac{\left(hs_k^j + H_i + H_{sh} - hp_k^j\right)}{L_p}}$$ **[4.20]**

$$Q_{cs5} = -K A_p R^{2/3} \sqrt{\frac{\left(hs_k^j + H_i + H_{sh} - hp_k^j\right)}{L_p}}$$ **[4.21]**

where Q_{csi} is the discharge flow through the control section i; hs_k^j is thewater depth at the surface; $hp_k^j$is the water depth at the sewer; L_i is the perimeter length of inlet box (0.8 m); H_i is the inlet box height (0.40 m); H_{sh} is the height of the vertical shaft connecting the inlet box to the manhole (0.60 m); L_p is the length of the horizontal shaft (5 m), A_p is the area of the connecting pipe; R is the hydraulic radius (80 mm of diameter); *Cd* is the discharge coefficient (0.5); and *K* is the Strickler roughness coefficient (80 $m^{1/3}$/ s). The values in parentheses are used as defaults because that information is not available.

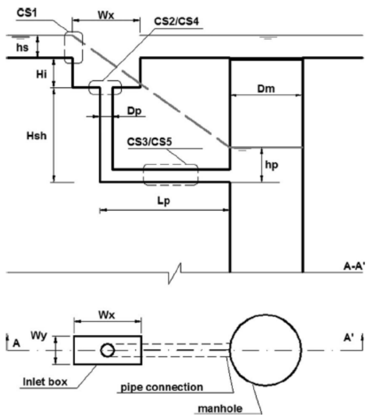


Figure 4.8: The five control section of a SLE.

The discharge Q_k^j of the SLE is determined by:

$$Q_k^j = \min\{Q_{cs1,}Q_{cs2,}Q_{cs3}\}$$ **[4.22]**

$$Q_k^j = \max\{Q_{cs4,}Q_{cs5}\}$$ **[4.23]**

These two equations are selected depending on the flow direction. The first is used if the flow is from the surface to the sewer, and the second is used if the flow is from the sewer to the surface. The MLE is obtained as the product of Q_k^j and the number of connections (SLEs) to each manhole. In sum, the MLE is a function of four main variables $\left(H_{sh}^j, H_{ph}^j, N_{eq}^j, R_{cd}^j\right)$. H_{sh}^j and H_{ph}^j are the dependent variables, water levels at the surface nodes, and at the sewer pipe. N_{eq}^j and R_{cd}^j are two parameters of the MLE, respectively, the number of equivalent SLE and the coefficient to reduce instability (Leandro et al., 2007). The advantage of using the MLE over the SLE is the reduction of the total number of connections between sewer and surface, hence reducing the number of loops in the network.

Figure 4.9 shows the steps for solving previous described equations system. SIPSON uses the Preissmann four-point implicit finite-difference scheme, which is unconditionally stable as long as the time weighting coefficient is greater than 0.5. Systems of difference equations for single channels are reduced to equivalent two-equation in which the discharges at channel ends are expressed in terms of water levels. Equations for weir or orifices link are also discretized in the same form. Node continuity equations are discretized by the Euler modified method, retaining water levels at nodes at the next time step. After converting a sparse node matrix into a row-indexed sparse storage form, system of equations for node levels is solved by the conjugate gradient method. Once water levels at the nodes are known, then the discharges and the water levels at channel ends are computed from energy equations and, at free outlets, from critical/normal depth criteria. Those discharges and water levels are internal boundary conditions by which finally the de St. Venant equations and the equations for other links are solved.

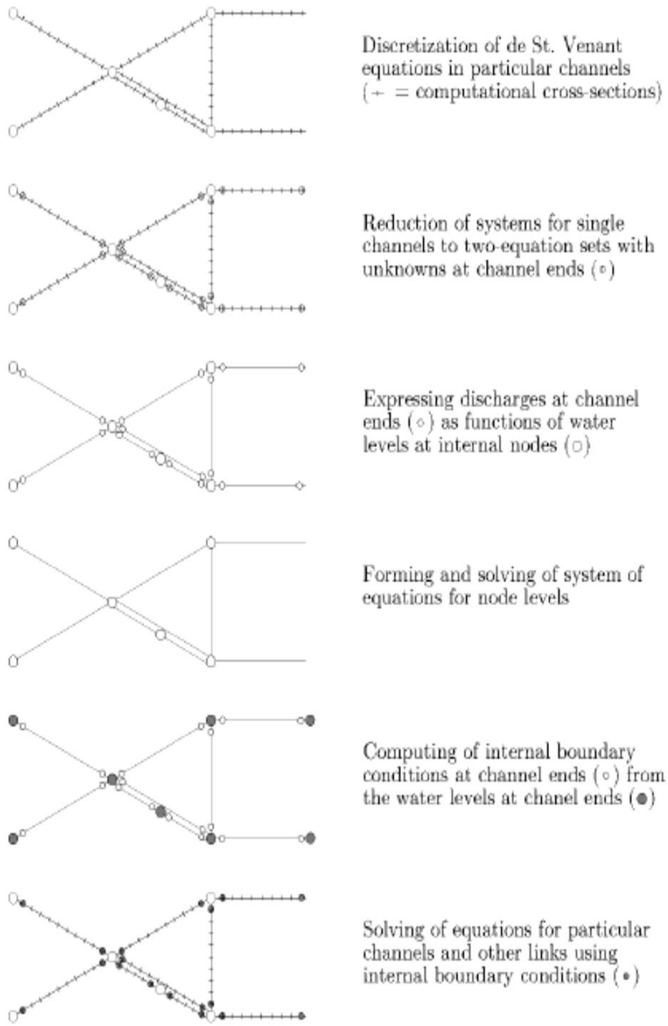


Figure 4.9: Flowchart about the main steps for resolution of equations system in SIPSON.

4.7.2. UIM

UIM integrates SIPSON through the simulation of the flow at surface. The 2D non-inertia flow equations, which are a simplified form of the Saint Venant equations, are adopted in the model. Like many other 2D models, the computing of overland flow is time-consuming when the proposed model is applied to cases with massive number of grids. Consequently, the adaptive time step is introduced to speed up the simulations. The time step in the 2D model is adjusted automatically based on the Courant criterion (Hunter et al. 2005; Yu and Lane 2006) such that larger time steps could be chosen whenever the numerical stability is satisfied.

The time step used in SIPSON is generally larger than the ones used for UIM. The default and upper bound of time steps in UIM are the same in SIPSON, i.e., $\Delta t_{2d_0} = \Delta t_{1d}$. By the end of computation for each time step, the Courant condition is checked based on the latest calculated water depth and velocities for setting the next time step:

$$\Delta t'_{2d_{m+1}} \leq \left(\frac{\Delta x}{\sqrt{gd_{2d_m}}+u_{2d_m}};\frac{\Delta y}{\sqrt{gd_{2d_m}}+v_{2d_m}}\right) \quad \textbf{[4.24]}$$

where, m is the index of the time step; $\Delta t'_{2d_{m+1}}$ is the estimated time step length [s] used in UIM for m+1th step; $d_{2d_m} = h_{2d_m} - z_{2d}$is the water depth [m] of the computing grid at mth step; $u_{2d_m}$and v_{2d_m} are velocity components [m/s] along x and y directions, respectively.

The bidirectional interacting discharge is calculated according to the water level difference between sewer network and overland surface. The upstream and downstream levels h_U and h_D for determining discharge are defined as $h_U = max\{h_{mh}, h_{2d}\}$and $h_D = min\{h_{mh}, h_{2d}\}$, respectively, where h_{mh} is the hydraulic head at manhole and h_{2d} is the water surface elevation on the overland grid.

The free weir equation is adopted when the crest elevation crest z_{crest} is between the values of the upstream water level $h_U$and the downstream water level h_D, as shown in **Figure 4.10**.

The discharge is calculated by using:

$$Q = sign[h_{mh} - h_{2d}]c_w w\sqrt{2g}(h_U - z_{crest})^{\frac{3}{2}} \quad \textbf{[4.25]}$$

where, Q is the interacting discharge, whose positive value meant surcharge flow from sewer toward overland and negative value meant drainage flow from surface into sewer c_w is the weir discharge coefficient, w is the weir crest width, and g is the gravitational acceleration.

The submerged weir equation is used (**Figure 4.11 (a)**) when both water levels at manhole and overland grid are greater than the crest elevation and the upstream water depth above the crest, $(h_U - z_{crest})$, is less than A_{mh}/w, where A_{mh} is the manhole area [m^2].

In this case the equation for calculating the flow has the following form:

$$Q = sign[h_{mh} - h_{2d}]c_w w\sqrt{2g}(h_U - z_{crest})(h_U - h_D)^{\frac{1}{2}} \quad [4.26]$$

If the manhole is fully submerged (**Figure 4.11 (b)**), when the upstream water depth above the crest $(h_U - z_{crest})$ is greater than A_{mh}/w for the submerged weir linkages, the orifice equation is used for calculating the interacting discharge:

$$Q = sign[h_{mh} - h_{2d}]c_o w\sqrt{2g}(h_U - h_D)^{\frac{1}{2}} \quad [4.27]$$

where, c_o is the orifice discharge coefficient.

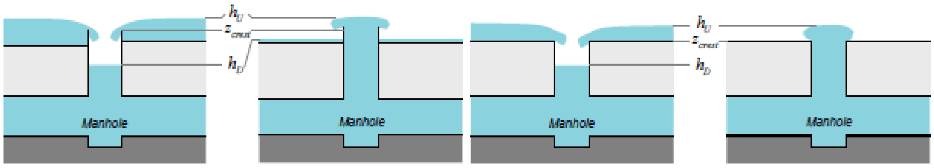
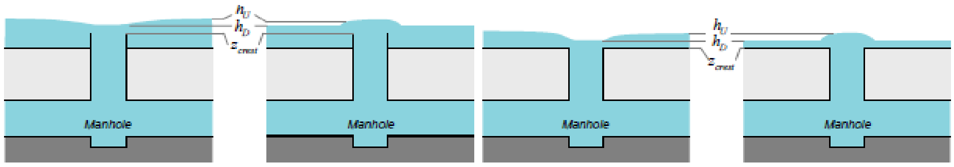


Figure 4.10: Scheme about free weir linkages.



(a) **(b)**

Figure 4.11: Scheme about submerged weir **(a)** and orifice linkage **(b).**

4.7.3.ANN

Prediction of overflow with adequate lead time is essential to provide time for taking safety measures and evacuation of population being endangered by imminent flood (Kia et al., 2011). Artificial Neural Network (ANN) is a powerful computational tool having the capability of capturing underlying characteristics of any physical process from the dataset and is able to extract the relation between the input(s) and output(s) without the underlying physics being explicitly explained. ANNs are widely used for flood forecasting applications because they are simple, accurate and allow high processing speeds (Campolo et al., 2014, Rashid et al. 1992, Lorrai et al., 1995, Pradhan et al. 2009).

The theory and mathematical basis of ANNs are explained in detail by many researchers (Bishop, 1995; Haykin, 1999).As shown in **Figure 4.12**, an ANN includes a number of neurons or nodes that work in parallel to transform the input data into output categories. Typically, an ANN consists of three layers namely input, hidden layers and output. Each layer, depending on the specific application in a network, has some neurons. Each neuron is connected to other neurons in the next consecutive layer by direct links. The input layer receives the data from different sources (e.g., thematic layers). Hence, the number of neurons in the input layer depends on the number of input data sources.

The data are processed in hidden and output layers actively. The number of hidden layers and their neurons are often defined by trial and error (Atkinson and Tatnall, 1997).

Each hidden neuron responds to the weighted inputs it receives from the connected neurons from the preceding input layer. Once the combined effect on each hidden neuron is determined, the activation at this neuron is determined via a transfer function. Many differentiable non-linear functions are available as a transfer function (Bishop 1994; ASCE Task Committee 2000).

Referring to this **Figure 4.12**, the signal flow from inputs x_1, …,x_n is considered to be unidirectional, which are indicated by arrows, as is a neuron's output signal flow (O). The neuron output signal O is given by the following relationship:

$$O = f(net) = f\left(\sum_{j=1}^{n} w_j x_j\right) \qquad \textbf{[4.28]}$$

where w_j is the weight vector, and the function f(net) is referred to as an activation (transfer) function. The variable net is defined as a scalar product of the weight and input vectors,

$$net = w^T x = (w_1 x_1) + (w_2 x_2) + \cdots + (w_n x_n) \qquad \textbf{[4.29]}$$

where T is the transpose of a matrix, and, in the simplest case, the output value O is computed as

$$O = f(net) = \begin{cases} \frac{1 \ if \ w^T x \geq \theta}{0 \ if \ otherwise} \end{cases} \qquad \textbf{[4.30]}$$

where θ is called the threshold level, and this type of node is called a linear threshold unit (Abraham, 2005).

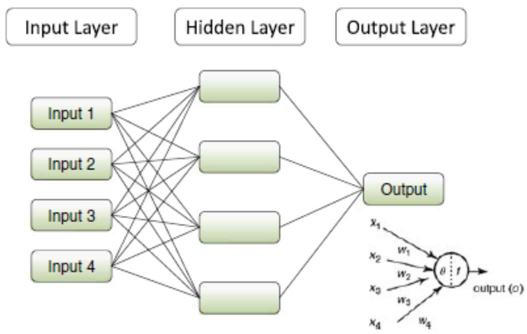


Figure 4.12: Scheme about multi-input Artificial Neural Network.

There are no strict rules to define the number of hidden layers and neurons in the literature. Most researchers have been using the trial and error method to determine them. Although some studies use a single hidden layer in ANN architecture, Sarle (1994) showed that a higher flexibility can be taken using more than one hidden layer and subsequently they used two hidden layers as starting point (Flood and Kartam, 1994; Tamura and Tateishi, 1997). However, the optimal design of ANN architectures depends on the type of problem under investigation.

In this study input layer consists of QPF above each manhole area. One hidden layer contains all transform functions. Output layers is formed by water level above each manhole area. Thus ANN architecture is defined as M-N-M, where M in the number of drainage network manhole and N is the number of neurons in the hidden layer.

Software tool that is able to reply this architecture is the ANN tool inside MATLAB software. Once input variables are acquired as a result of downscaling and QPFs are associated with each manhole area, computer application is responsible for training ANN. Training process deals with minimizing the error between the ANN output and real data, changing values to be given to the weights. Once training process is completed it is possible to use ANN model to generate overflow forecasts in real time.

4.8. Alert system

Each component of the early warning system for the city of Palermo has to be integrated in a server able to:

- capture QPF data, process, and store QPE products;
- run QPF model and ANN model;
- store and post alert maps.

Maps publishing on web is one of warning activities to be used. It is simple but not effective unless accompanied by additional tools to inform stakeholders.

The easiest method of issuing of warnings provides for a program that is setting to some level alert and is able to send a text message to all operators when the water level is higher than level alert. At this stage authorities, who supervise the area, can in turn access to social networks and send instant messages warning. This system is already partly operational by the alert room of the Municipal Police of the city of Palermo. policemen are using Twitter (@PALERMOPM) and Facebook (Polizia Municipale di Palermo) to inform citizens about temporary street interruptions.

4.9. Cost estimation

Any risk management system is considered practicable based not only on technical aspects but also on economic and operational aspects. Thus a rough estimation of installation and management costs for all the early warning system described components was carried on. Each component cost is approximate, that is dependent by the Agency that will take over all system management and by conventions that the same Agency could conclude for correct operation of some components.

For example, to obtaining QPF maps, the cost will depend on the agreements between the managing system Agency and Regione Sicilia, owner of the numerical prevision model by SIAS. It is possible to calculate agreement cost by reference to Annex entitled "List of Air Force Weather Service" (Ministero della Difesa, 2011) to determine before the cost of data originated from ECMWF model. The cost of products is calculated by multiplying the cost attributed to ECMWF service equal to 0.7 € for a parameter function of the number of variables, the time steps and the image resolution. This leads to a value of 0.7 € × 15.7 =11 € per day. However this annex states that if the Regioni want to use the service for other organizations within own territory, all Regioni should ask a fee equal to 15% of the costs to be paid to Air Force, in addition to a charge related to their performance of the service. It was decided to set at 20% the possible cost to use the SILAM products based on ECMWF data. Therefore the total cost for QPF maps is equal to $11\,{}^{€}/_{\mathrm{d}} \times 1.15 \times 1.2 \times 365\mathrm{d} \cong 5550\,{}^{€}/_{\mathrm{y}}$.

A work station on which run the hydrologic-hydraulic model will be also necessary. Since it was decided to use a simple modeling, a machine with high performance does not need. A common PC with a processor speed of 3.2 GHz and 4 Gb of RAM and a memory of 500 Gb has a market price of around 400-500 €. A cost of 80-100 € to take a modem for data transmission should also be added and a subscription for data transmission and alert messaging equal to about 30 €/m.

For ANN overflow model calibration it is recommended the use of a hybrid model to determine with precision flooding areas and a radar to obtain a spatial distribution of precipitation. Based on above exhibited a hydrologic-hydraulic model is priced at about 3000 € for a license large enough to include all city sewer network. The cost of a mobile X-band weather radar is around 50,000 €.

The choice of server size of course depends on the amount of data to be stored. QPF map size is approximately 2 Kb. Whereas downscaling process increases the size depending on wanted resolution, a 2^3= 8 kb size for each input map may be defined. Output maps will have the same resolution of input maps and then the same size. Therefore, as QPF maps are 7 in a day, enough space in the DB should be equal to $(2+8+8)\times 7 = 126\frac{Kb}{d} \times 365\, {}^{d}/{}_{y} \cong 46Mb$. Thus DB should not have a considerable size, being able to use the same machine for data elaboration and storage.

Regarding emergency management three operators will be involved in this service. Job service consists in taking account of drainage system crisis and starting safeguard measures. It does not require an exclusive job service. Therefore, it is reasonable to assume a 10% increase in the salaries for this activity. According to ISTAT data (2013) the average salary of an employee is equal to 1300 €, so $1300 \times 0.1 \times 3 \times 12 \cong 4700\, {}^{€}/{}_{y}$ will be needed.

An estimate of the benefits can be done analyzing the damage caused by overflowing events in previous years. In 2008 an insurance company (SAI) that provided money for house and vehicle restoration was contacted. In 1993-1997 the average annual loss amounted to 1.5 M€. The benefit of an early warning system is consequently indisputable.

In conclusion, in **Table 4.3** start-up and operational costs are reported.

Table 4.3: Start up and management cost for the early warning system of the city of Palermo.

	Service	Cost
Start up cost	PC	400-500 €
	Modem	80-100 €
	X-band weather radar	50,000 €
	Hybrid model software	3,000 €
	tot	**53,600 €**
Management cost	QPF maps	5,550 €/y
	Internet fee	360 €/y
	Operator salary	4,700 €/y
	tot	**10,610 €/y**

Chapter 5

Case study

The aim of Case study is the analysis of critical events and to test the theories previously exposed. This chapter describes all the activities that led to design an early warning system for the city of Palermo. This step of research study involves the application of knowledge, skills, tools and techniques acquired during the years of PhD course in Civil and Environmental Engineering. The main challenge in this research is the achievement of per-set objectives, remaining inside the perimeter formed by constraints of time, cost and quality of results. A secondary challenge, but not less important, is to optimize the allocation of financial resources of the Agency that will manage this early warning system, providing a useful and efficient service to the community. These challenges have been carried out by solving current problems and mitigating errors and inaccuracies that each analyzed component could present.

Testing all early warning system components was not possible, because of the lack of time and the non-implementation of system. Therefore, as previously explained, the attention is focused on processing input data and development of overflowing model.

This chapter describes steps that led to the definition of that component concerning hydrologic-hydraulic modeling inside the early warning system for the city of Palermo. Test events and results have been reported.

5.1. Flood event report

Flooding data is an essential component for verifying tools used to predict flooding. Their retrieval is often not easy for non-instrumented basins. Then, assuming a level of inaccuracy, it was decided to contact local authorities who coordinate emergency activities or dealing with safety measures and redevelopment of damaged areas. None of these public structures have provided the requested information. Some of them have stated that during the remedial measures do not record any information about the flooding height or the amount of damages. Others have explained that the reports contain data too sensitive to be disclosed. Finally, others have no interest to collaborate with University.

Thus to search data on flood events, an alternative channel has been used, simply involving the directly affected component: the citizens of Palermo. Over the past decade, the spread of connectivity and smart technology has contributed to the development of web platforms such as social networks, online newspapers and blogs. Population post photos and videos made from the balcony of their own house. This is equivalent to have many cameras on the city.

At this point it was necessary to define a period for the research. Since, as explained above, the last fundamental change in the historical center drainage network have been in 2007, it was decided to investigate crisis events over the period 2008-2014. Each previous event should be simulated with a drainage network different from the present one.

Further investigation led to the identification of rainfall events that could have generated a crisis of drainage system. Based on the assumption that heavy rain generate substantial flooding in urban areas, tables showing heavy rain days for durations of 1, 3, 6, 12 and 24 hours have been consulted. In this way, 42 dates have been identified as possible crisis events. For each of these dates a research through online newspaper and social networks has been carried out,. In particular the most consulted web sites are the following:

- http://www.palermotoday.it/
- http://www.meteopalermo.com/new/
- http://www.youreporter.it/
- http://www.repubblica.it/
- http://www.ilsole24ore.com/
- https://meteoallertapalermo.crowdmap.com/main
- http://www.youtube.com/
- https://www.google.it/

The selected hashtags are:

- #palermo overflows,
- #palermo rain,
- #palermo flood,
- #palermo venice.

Furthermore, once selected the streets inside the old town of Palermo, a research has been carried using the following hashtag: #address date.

By analyzing distribution and frequency of a set of events recorded in a period prior to the one considered (1993-1997), it was noted that the number of flooding in the city has decreased dramatically over the past 15 years. This means that clean-up and re-sizing works in the Papireto sewer have contributed to decline outflows in the old town. Regarding flooded sites, in some cases these sites remained the same while the new were added: an example is Viale Regione Siciliana underpasses.

In the figures below, maps with synthesis on information about sewer overflowing in the city are reported (**Figures 5.1-5.7**). It should be noted that all events have been not described in order to determine with sufficient accuracy sewer overflowing height, as the news contain only generic data or are not supported by any photo or movie. Therefore each map must be interpreted paying attention to the fact that the red triangle represents the condition for which a flooding event has been documented but it was not possible to determine the value of water height. Moreover, all water levels are expressed in “cm” and they have been determined with accuracy depending on the water level on pavements and cars. By these maps some events, for which the presence of particularly intense storms has not occurred, despite being documented, were excluded, owing to probable failure or malfunction of the drainage network.

Analyzing flooding distribution it can be observed that underpasses and the main upstream street (Viale Michelangelo, Viale Lazio, via Belgio, via Pitrè, via Aloi, via Santa Maria di Gesù, via Giafar) are most frequently subject to sewer overflowing. Thus the local water management agency has recently installed some grids for collecting outflows.

Furthermore some areas of old town of Palermo are affected by sewer overflowing more frequently such as via Imera and Via Cappuccini.

Given that the basin of the old town of Palermo is the most recognized in the academic –scientific area and on which a lot of information about rainfall and sewer structure can be obtained, it was decided to focus only on this part of Palermo drainage system. Modeling of the entire city drainage network still would have been highly complex for the aims of this study.

5.2.Flood events selection

For each area and for each detected event inside old town basin, information about water levels has been retrieved. Any images or any frames have been analyzed to find objects or elements allowing the estimation of water heights with sufficient approximation. The limitation of this type of procedure mainly consists in the difficulty of this operation; there are not always present measurable objects. Moreover, even in the presence of any water level determined in an absolutely correct way, it is still representative of an instant and may not be the maximum reached in that area. However these data types are very useful for the study of event dynamics, for their easy retrieval, and to understand people response to a critical event.

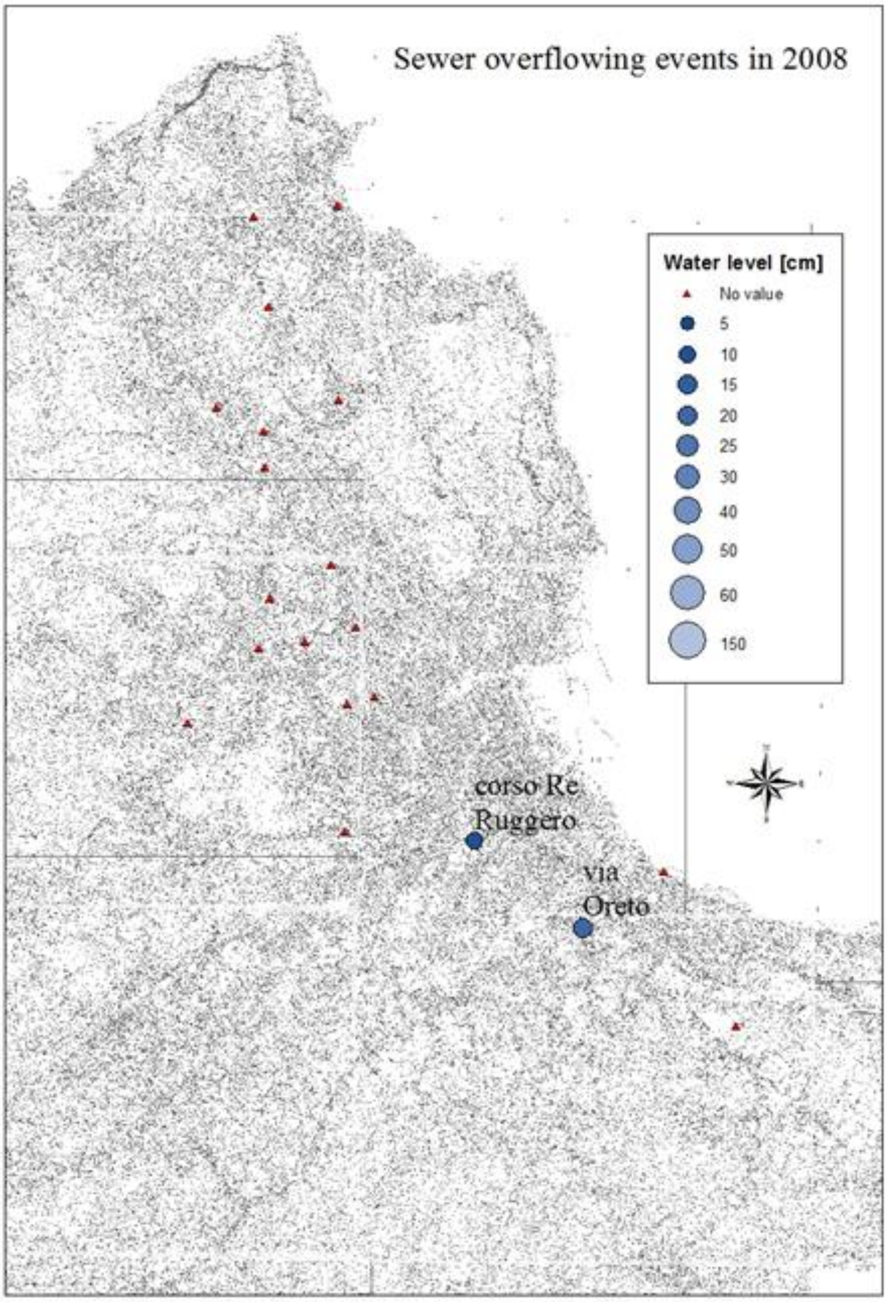


Figure 5.1: Sewer overflowing events in 2008 in the city of Palermo.

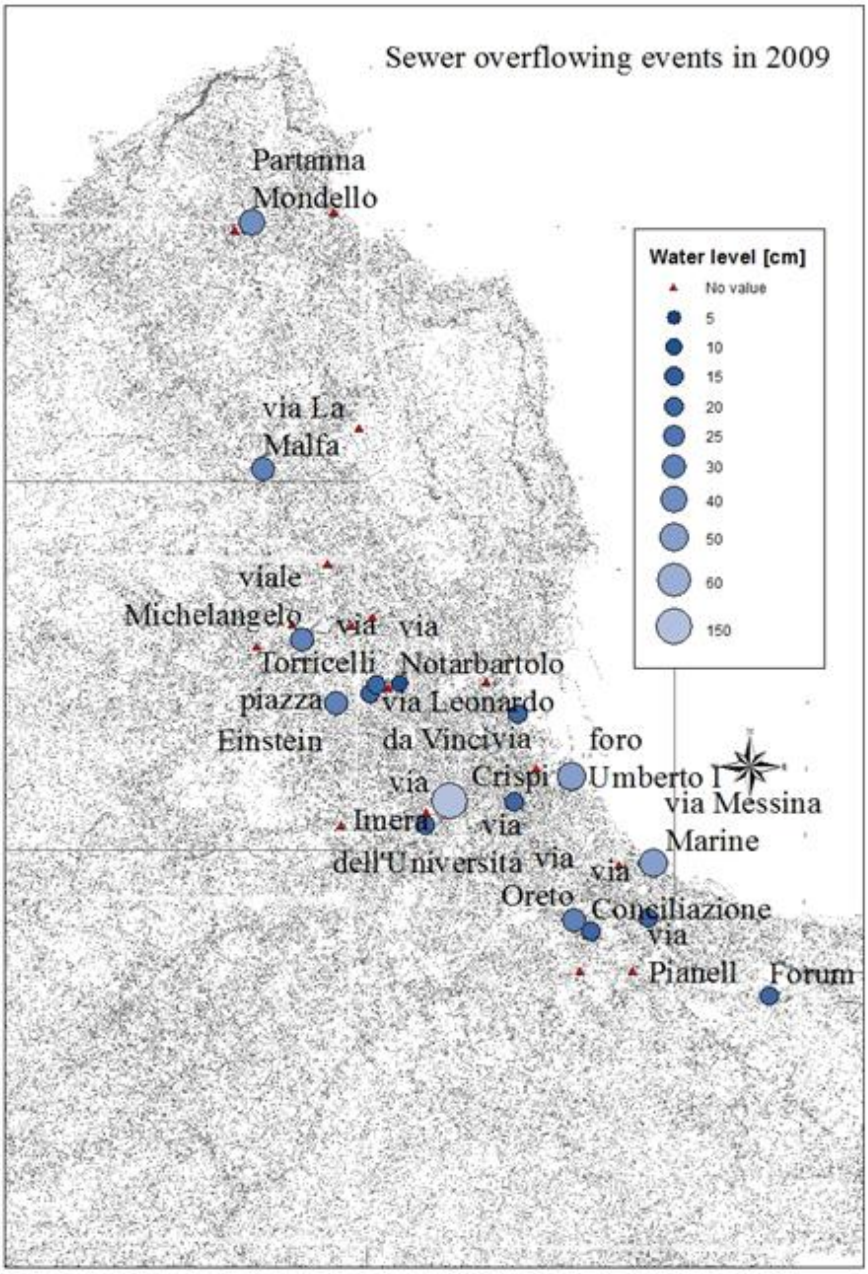


Figure 5.2: Sewer overflowing events in 2009 in the city of Palermo.

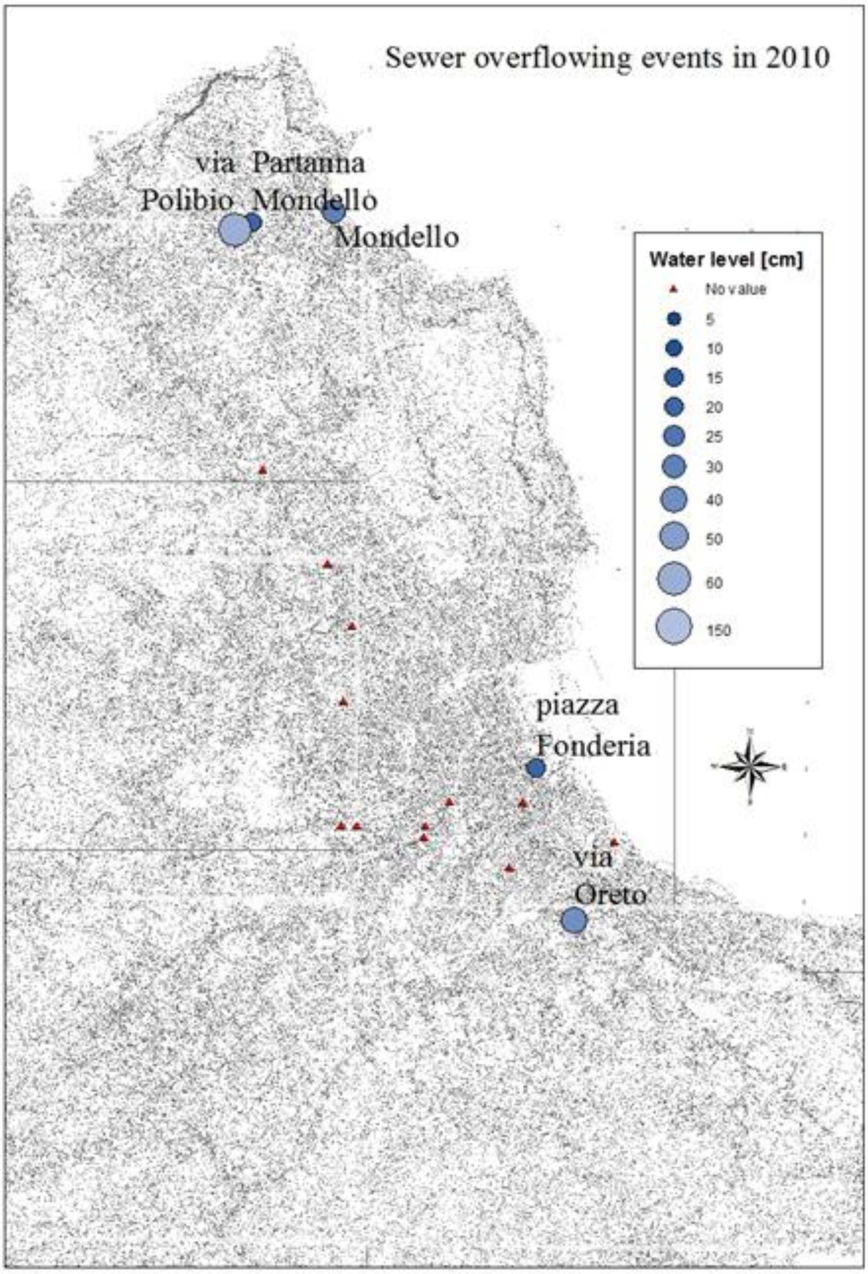


Figure 5.3: Sewer overflowing events in 2010 in the city of Palermo.

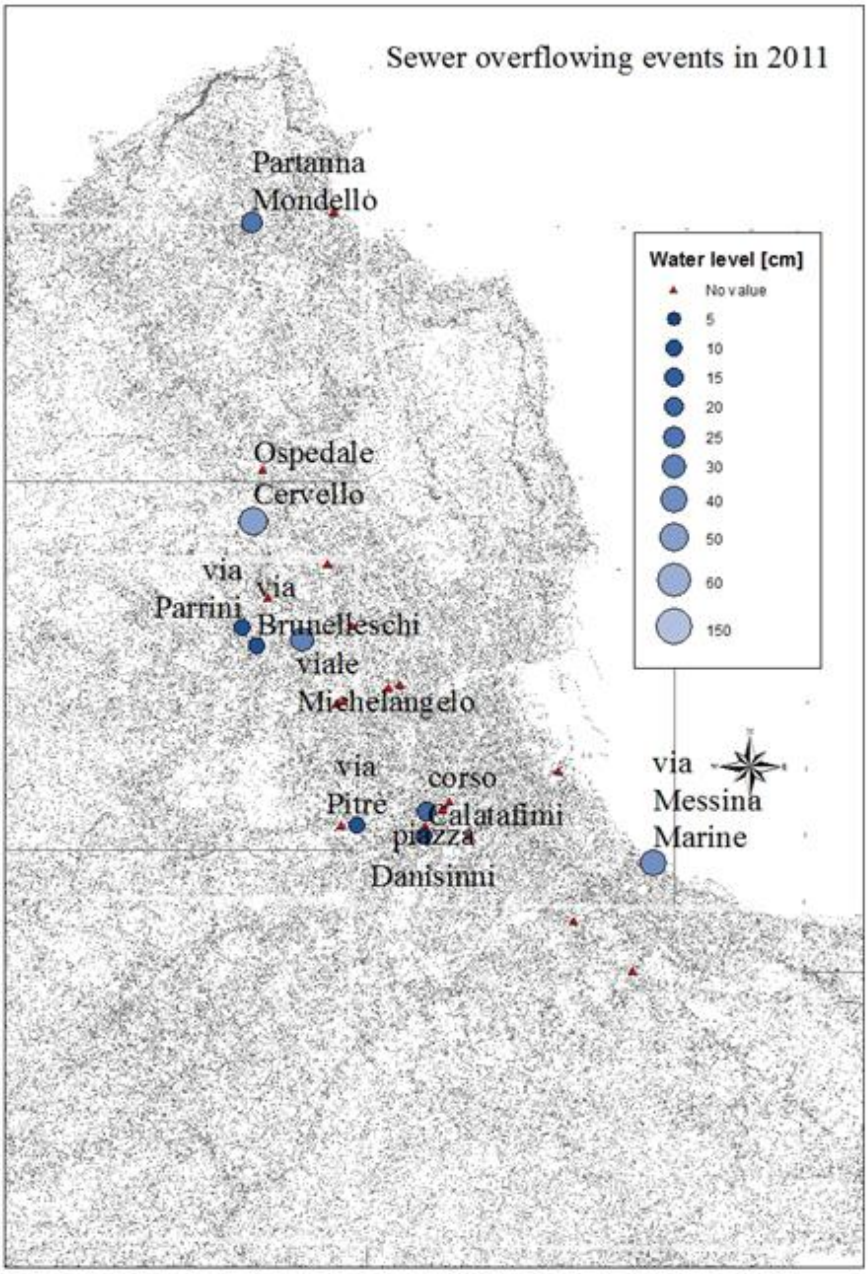


Figure 5.4: Sewer overflowing events in 2011 in the city of Palermo.

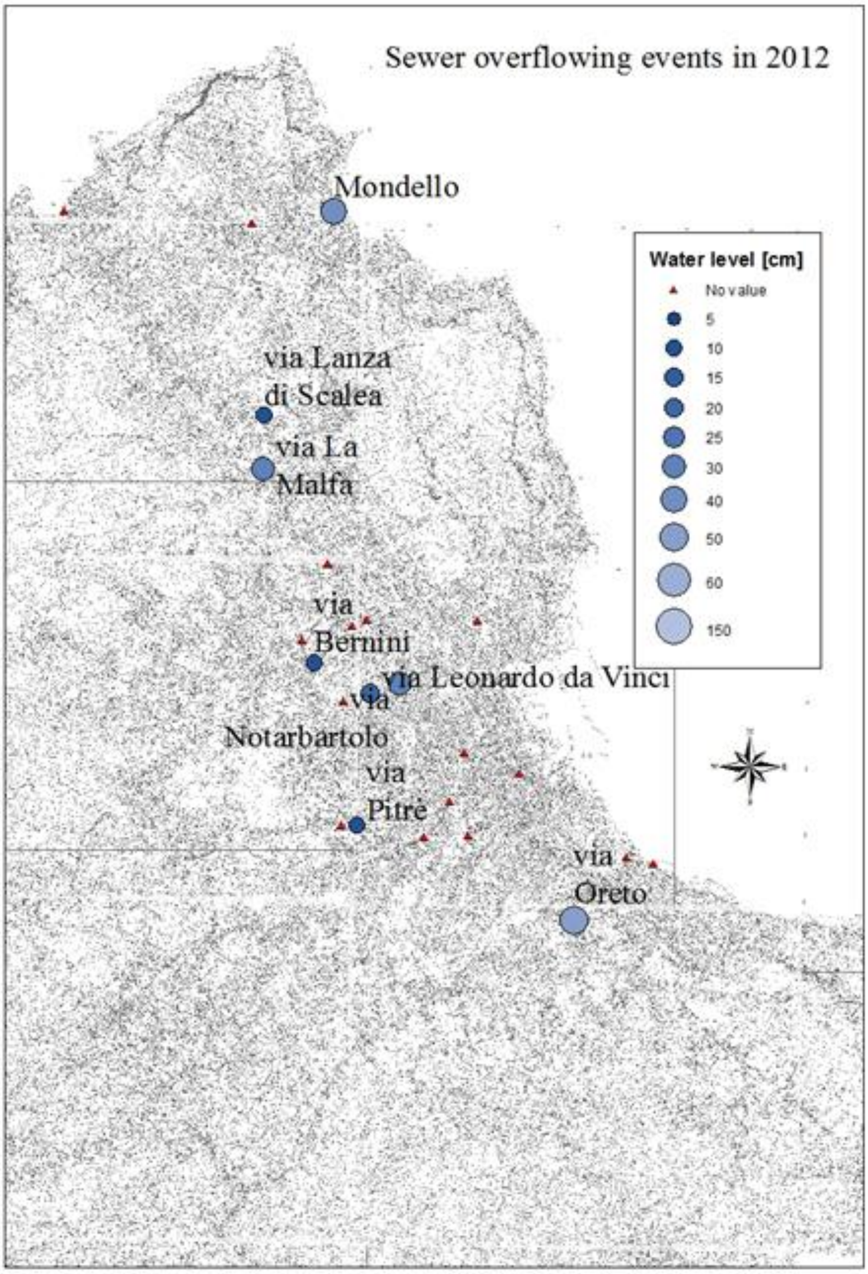


Figure 5.5: Sewer overflowing events in 2012 in the city of Palermo.

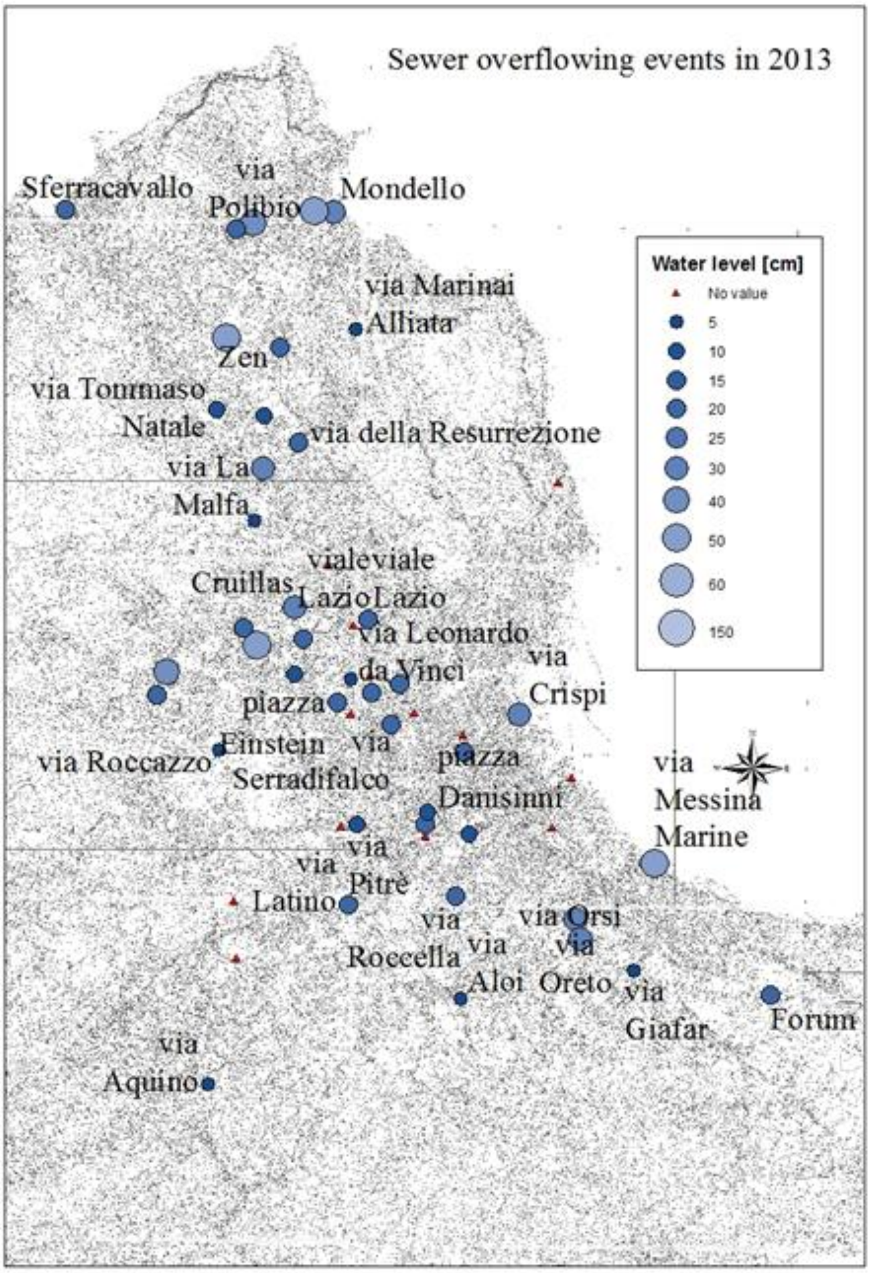


Figure 5.6: Sewer overflowing events in 2013 in the city of Palermo.

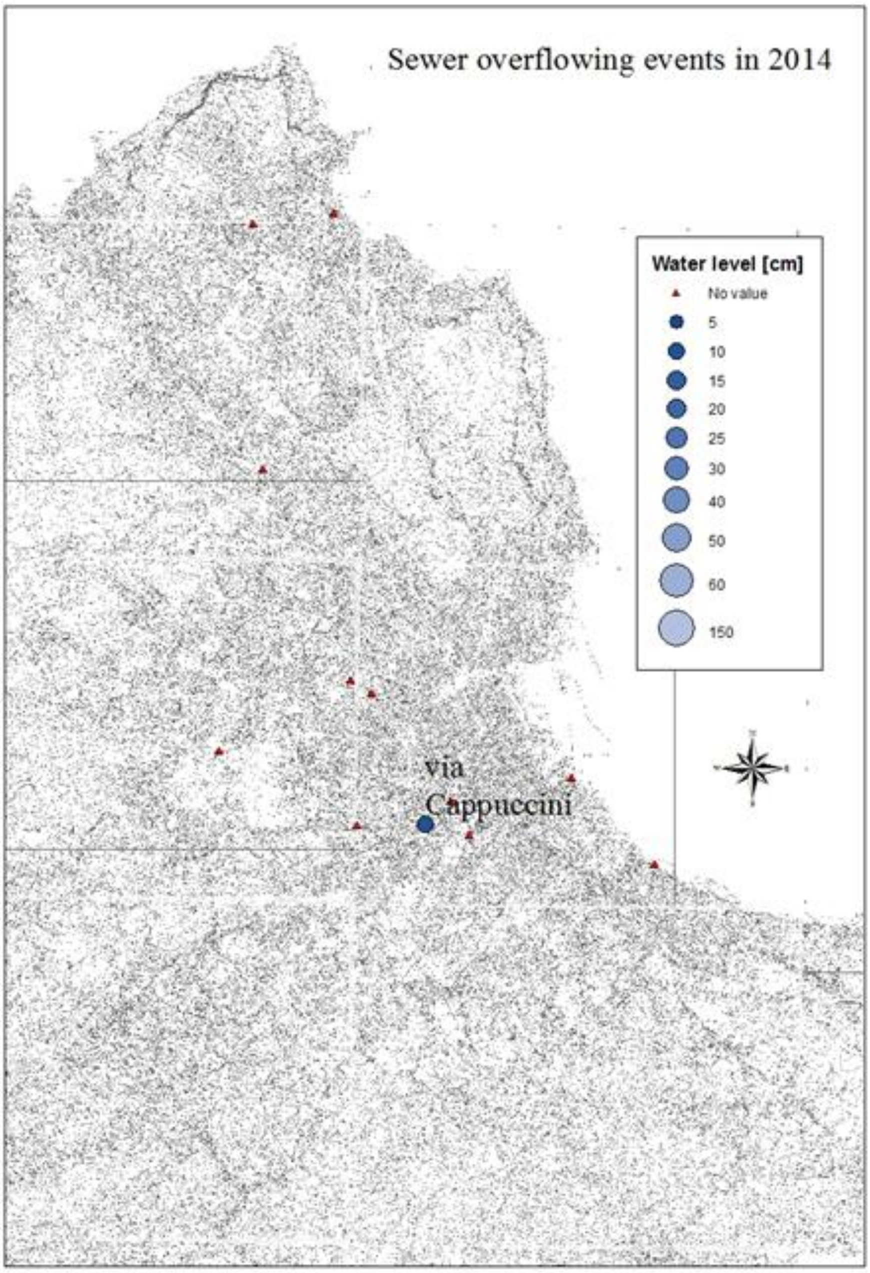


Figure 5.7: Sewer overflowing events in 2014 in the city of Palermo.

Table 5.1 shows information about the date of the event image, the place, the water level, the source and the object that was used as a reference for estimating water level.

Table 5.1: Flood report for the old town of Palermo.

Date	24/09/2008	
Site	Corso Re Ruggero	
Water level	30 cm	
Source	Youtube video: https://www.youtube.com/watch?v=eDhMWJUovro	
Reference object	Bus license plate	

Date	31/10/2008	
Site	corso Re Ruggero	
Water level	30 cm	
Source	Youtube video: https://www.youtube.com/watch?v=b6UXVmwx_cc	
Reference object	Sidewalk on the left	

Date	14/09/2009	
Site	corso Calatafimi	
Water level	< 5 cm	
Source	Palermo today photo: http://www.palermotoday.it/foto/cronaca/primo-acquazzone-la-citta-si-allaga/corso-calatafimi.html	
Reference object	Fiat Punto Tyre	

Date	19/09/2009
Site	via Roma-angolo via Mariano Stabile
Water level	< 5 cm
Source	La Prima Pagina photo: http://www.laprimapagina.it/2011/09/19/allagamenti-a-palermo-a-tutto-c%E2%80%99e-un-perche/
Reference object	Sidewalk on the left

Date	21/09/2009
Site	Via Imera
Water level	150 cm
Source	La Repubblica newspaper article: http://palermo.repubblica.it/dettaglio/ancora-pioggia-ed-e-un-inferno-dacqua/1727232
Reference object	“One and a half meter of water in via Imera, where an amphibious vehicle of firefighters has arrived to clean the road "

Date	1/10/2009
Site	Via Casa Professa
Water level	7 cm
Source	You reporter video: http://www.youreporter.it/video_Fiume_di_pioggia_a_Palermo_01ottobre2009_centro_storico_2
Reference object	Fiat 600 Tyre

Date	1/10/2009
Site	Via Ernesto Basile
Water level	35 cm
Source	Youtube video: https://www.youtube.com/watch?v=0iI1SqmNXco
Reference object	Sidewalk

Date	1/10/2009
Site	Foro Umberto I
Water level	60 cm
Source	Youtube video: https://www.youtube.coc/watch?v=A7K2zw3RRYK
Reference object	Volkswagen Polo and Ford Fiesta tyres

Date	1/10/2009
Site	Corso Re Ruggero
Water level	35 cm
Source	Youtube video: https://www.youtube.com/watch?v=Knr0-1yhCB8
Reference object	Sidewalk on the left

Date	1/10/2009
Site	Via Gustavo Roccella
Water level	10 cm
Source	Youtube video: https://www.youtube.com/watch?v=bsiPQU42dbE
Reference object	Sidewalk

Date	1/10/2009
Site	Via Cappuccini
Water level	10 cm
Source	Youtube video: https://www.youtube.com/watch?v=5ebVyyc3iCI
Reference object	Sidewalk

Date	16/10/2009
Site	Via Imera
Water level	50 cm
Source	You reporter video: http://www.youreporter.it/video_Palermo_allagamenti_per_maltempo_16_ottobre_1
Reference object	Light pole

Date	16/10/2009
Site	Via Colonna rotta
Water level	120 cm
Source	You reporter video: http://www.youreporter.it/video_Palermo_allagamenti_per_maltempo_16_ottobre_1
Reference object	Hole in the wall

Date	16/10/2009
Site	via Roma-piazza San Domenico
Water level	10 cm
Source	You reporter video: http://www.youreporter.it/video_L_incredibile_nubifragio_di_Palermo_1
Reference object	Sidewalk

Date	14/09/2011
Site	via Pitrè
Water level	5 cm
Source	Youtube video: https://www.youtube.com/watch?v=wS127nKUdfU
Reference object	Tyres

Date	19/09/2011	
Site	via Giuseppe albina-piazza Vulpi	
Water level	25 cm	
Source	You reporter video: http://www.youreporter.it/video_nubifragio_a_palermo	
Reference object	Groove in the wall	

Date	10/11/2011	
Site	corso Calatafimi –Albergo delle Povere	
Water level	5 cm	
Source	Youtube video: https://www.youtube.com/watch?v=JcK0ic9yDTc	
Reference object	Sidewalk	

Date	10/11/2011	
Site	piazza Indipendenza	
Water level	10 cm	
Source	Youtube video: https://www.youtube.com/watch?v=JcK0ic9yDTc	
Reference object	Traffic barrier	

Date	10/11/2011	
Site	via Matteo Bonello	
Water level	10 cm	
Source	Youtube video: https://www.youtube.com/watch?v=JcK0ic9yDTc	
Reference object	Tyres	

Date	03/01/2012
Site	corso Re Ruggero
Water level	20 cm
Source	BlogSicilia photo: http://palermo.blogsicilia.it/nubifragio-a-palermo-disagi-in-citta/72611/
Reference object	Garbage trash

Date	01/09/2012
Site	via Giuseppe Pitrè
Water level	5 cm
Source	Youtube video: https://www.youtube.com/watch?v=S9baZzSa3dU
Reference object	Red wall

Date	01/09/2012
Site	via Porta di Castro
Water level	5 cm
Source	Di Palermo Video blog: http://www.dipalermo.it/2012/09/07/che-bello-il-centro-storico-se-ne-stai-alla-larga/
Reference object	Sidewalk

Date	06/10/2013
Site	via Cappuccini
Water level	15 cm
Source	Youtube video: https://www.youtube.com/watch?v=d-pwsKOXhyE
Reference object	Sidewalk

Date	06/10/2013
Site	via Giuseppe Albina-piazza Vulpi
Water level	25 cm
Source	Youtube video: https://www.youtube.com/watch?v=ulQcwZODuas
Reference object	Groove in the wall

Date	06/10/2013
Site	piazza Kalsa
Water level	15 cm
Source	Youtube video: https://www.youtube.com/watch?v=xvDyQLhM9gQ
Reference object	Sidewalk

Date	06/10/2013
Site	Foro Umberto I- via Lincoln
Water level	35 cm
Source	Youtube video: https://www.youtube.com/watch?v=keaqkYunvxY
Reference object	Bench

Date	06/10/2013
Site	corso Re Ruggero
Water level	35 cm
Source	La Repubblica newspaper photo: http://palermo.repubblica.it/cronaca/2013/10/05/foto/forte_nubifragio_a_palermo_strade_allagate_e_telefoni_in_tilt-67969754/1/#5
Reference object	Sidewalk on the left

Date	11/10/2013
Site	Foro Umberto I
Water level	30 cm
Source	Corriere del Mezzogiorno photo: http://corrieredelmezzogiorno.corriere.it/fotogallery/sicilia/2013/10/palermo_allagamenti/palermo-nuova-bomba-d2223466680436.shtml#5
Reference object	Peugeot 108 bumper

Date	11/10/2013
Site	Corso Calatafimi
Water level	5 cm
Source	Il Meteo photo: http://www.flickr.com/photos/ilmeteo/10207300794/in/photostream/
Reference object	Tyre

Date	11/10/2013
Site	via Cappuccini
Water level	10 cm
Source	Youtube video: http://www.youreporter.it/gallerie/allagamento_a_palermo/#1
Reference object	Sidewalk

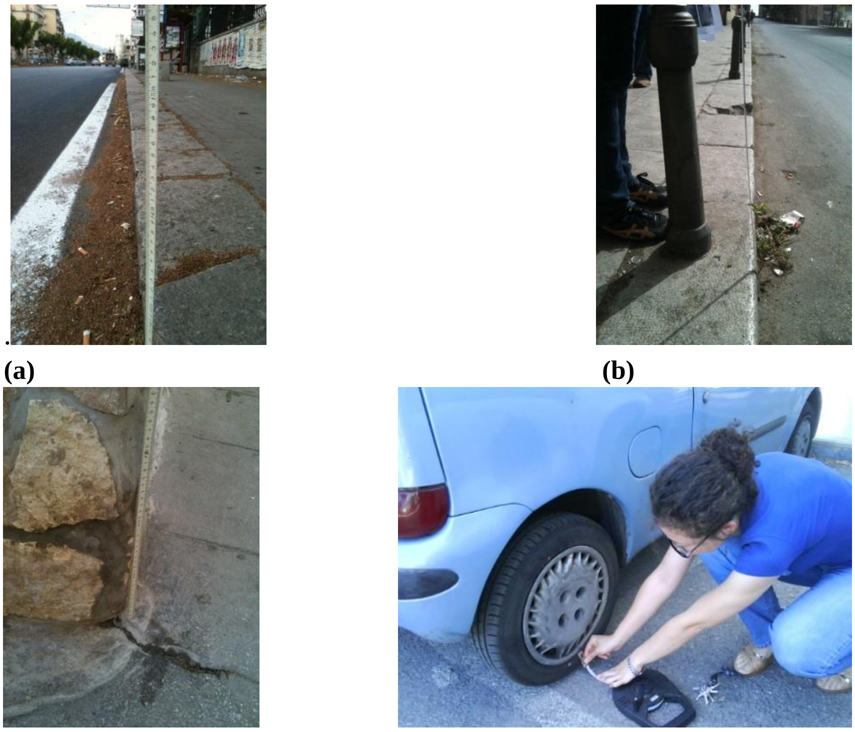
Date	11/10/2013
Site	corso Re Ruggero
Water level	35 cm
Source	BlogSicilia photo: http://palermo.blogsicilia.it/ancora-un-nubifragio-a-palermo-traffico-in-tilt-e-nuovi-allagamenti/213570/
Reference object	Sidewalk on the left

Date	11/10/2013	
Site	via Ernesto Basile	
Water level	10 cm	
Source	You reporter video: http://www.youreporter.it/video_Diluvio_a_Palermo_-_via_Ernesto_basile	
Reference object	Tyres	

Date	11/10/2013	
Site	Corso Vittorio Emanuele- piazza Marina	
Water level	10 cm	
Source	Corriere del Mezzogiorno photo: http://corrieredelmezzogiorno.corriere.it/fotogallery/sicilia/2013/10/palermo_allagamenti/palermo-nuova-bomba-d-acqua-2223466680436.shtml#5	
Reference object	Sidewalk	

Date	11/10/2013	
Site	Via Giuseppe Pitrè	
Water level	5 cm	
Source	Youtube video: https://www.youtube.com/watch?v=vGHo3Lm2sIs	
Reference object	Tyre	

Some examples about water levels estimation by measurements on site are reported below. Often the benchmark was the sidewalk (**Figure 5.8 (a)**) or other objects of urban furniture (baskets, benches, anti-stopping pallet **Figure 5.8 (b)**). The most frequent benchmark was semi-underwater car (**Figure 5.8 (c)**). In some cases signs of flood passage have been found (**Figure 5.8 (d)**).



(a) (b) (c) (d)

Figure 5.8: Water level estimation for sidewalk in via Ernesto Basile **(a)** and in corso Vittorio Emanuele II **(b)**, for a house in piazza Danisinni**(c)** and for a car **(d)**.

Finally a table that reports the number of documented flooding events and available sources of rain is edited (**Table 5.2**). By analyzing this table, the date 11/10/2013 has been chosen as model calibration event, because it has a substantial number of documented sewer overflowing and a source of distributed rain data. Moreover four sewer overflowing events (01/10/2009, 16/10/2009, 10/11/2011, 06/10/2011) are selected to validate model results.

Table 5.2: Flood events report (G and R stands for rain Gauge and weather Radar; selected events have been marked in black).

Date	Number of documented flooding events	Type of rain data
24/09/2008	1	P
31/10/2008	1	P
14/09/2009	1	P
21/09/2009	1	P
01/10/2009	**7**	**P**
16/10/2009	**3**	**P**
14/09/2011	1	P
19/09/2011	1	P
10/11/2011	**3**	**P**
03/01/2012	1	P
01/09/2012	2	P
06/10/2013	**5**	**P**
11/10/2013	**7**	**P/R**

5.3. Rainfall data assessment

Radar precipitation data offer many benefits. They are a source of distributed rainfall data, even at low spatial resolution and with a temporal resolution comparable to modern digital rain gauges. They are an indirect source of rainfall data as radar uses the principle of interference between microwaves and weather targets. Therefore radar maps should be appropriately rearranged before having a tool as accurate as possible.

The X-band radar controlled by DICAM, designed by ENVISENS, provides reflectivity maps on a Cartesian grid of 1024 x 1024 pixels with a spatial and temporal resolution of 60 m and one-minute.

Radar maps cannot be used as recorded because they are subject to many errors (e.g.: obstructions, water melting layer interception, no-interception of hydrometeor, attenuation of recorded signal because of the presence of no-standard atmosphere, radar beam abnormal propagation, interference with other emission systems, uncertainty of transformation from reflectivity values into precipitation intensities, etc ...).

X-band radar has some default filters that correct ground clutter errors. These filters have been determined during a dry day. They do not take into account a different propagation of radar beam due to different atmospheric conditions. Also, with regard to the form of Z-R equation, the default Z-R is a general definition, that is not valid for all types of precipitation.

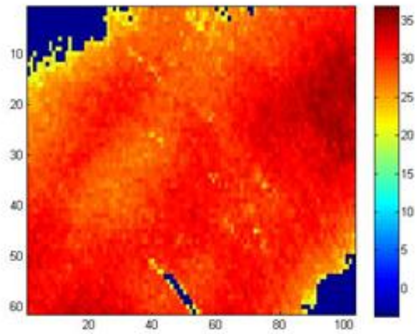
To use a radar map, it is necessary to correct these errors. In this study only obstruction correction and calibration of Z-R relationship have been performed. Ground clutter correction has been carried out by using an algorithm that fills no-value pixels with a reflectivity value. Z-R calibration was made by comparison with some precipitation stations at the same position on the ground (van de Beek et al., 2010).

5.3.1. Ground clutter correction

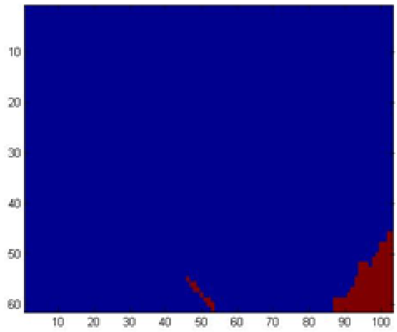
Ground clutter is a phenomenon that occurs when the radar beam is reflected from objects on the ground, such as buildings, trees or mountains. Weather radar is particularly difficult to place for the presence of buildings and interference with other radio frequency instruments in urban environment. It may be generally preferred to place on hills around the city or to use another weather radar with longer sampling radius.

One of the simplest approaches to identify clutter is to create a static map of those areas where clutter is prevalent. Another system is to create a dynamic map that identifies clutter from image to image for each analyzed rain event. In this study it was decided to create a static map of Cartesian grid based on the excess of 90% of the occurrences of recorded precipitation. The corrective chosen method is based on nearest neighbor algorithm. This method has been applied to the map in dBZ, after map processing with instrumental parameters. At each point identified as clutter, the around pixels, which have not been identified as clutter, are averaged and the result is taken as the pixel value for that point. **Figure 5.9 (a)** shows the reflectivity sampled by the radar. **Figure 5.9 (b)** displays the map of clutter obtained for the event (11/10/2013). Red areas at the bottom of the image represent the pixels classified as clutter. Finally **Figure 5.9 (c)** shows the corrective reflectivity map. It may be seen that the nearest neighbor method manages to cover the cluttered areas. Coverage is partial so it would be advisable to extend the resolution of the kernel.

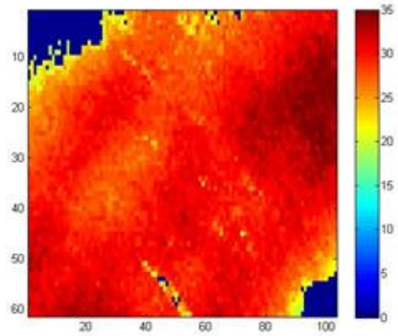
In Appendix A the script that allows operating the real-time correction and the adaptation to hydraulic modeling software is reported.



(a)



(b)



(c)

Figure 5.9 : Radar map in dBZ **(a)**, clutter map for one event (11/10/2013) in which the red areas are classified as clutter **(b)** and no clutter radar map in dBZ **(c)**.

5.3.2.Estimation of Z-R power law

The conversion from reflectivity of a volume of air Z, measured by the radar, and the precipitation intensity R is particularly difficult. As mentioned before, many studies have been carried out to solve this problem. For this research, because of a previous study about spatial distribution of rain drops from which deriving Z-R relation is missing, it was decided to compare the reflectivity measured by the radar and the intensity precipitation measured on the ground. To do this, it is firstly necessary to homogenize Z and R values. Average values of these quantities, according to the sampling interval of the rain gauge, have been calculated, as the rain gauge has a higher temporal resolution. For the event of 11/10/2013 four rain gauges placed on the area of the city of Palermo were available. **Figure 5.10** shows the relations Z-R determined for each one of the rain gauges.

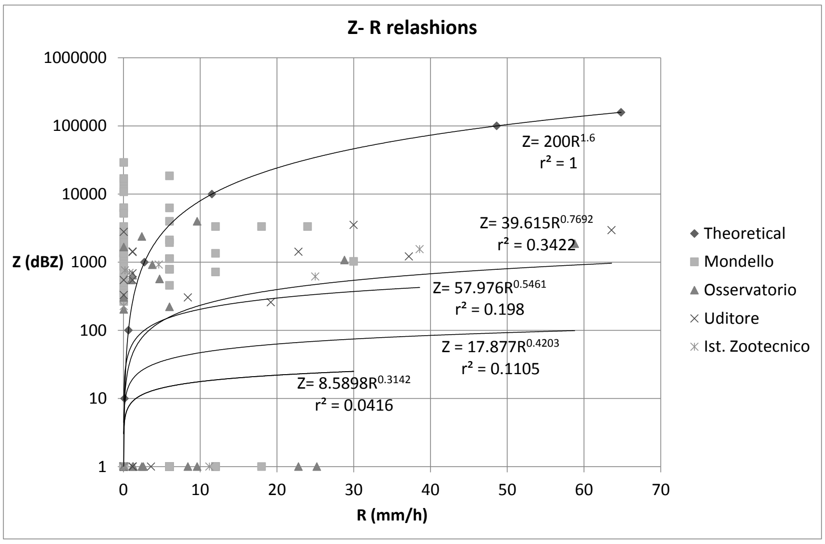


Figure 5.10: Z-R relations determined by comparing radar and rain gauge data.

It is clear that it is not possible to determine a unique relationship. Analyzing rain gauges and radar hyetographs (**Figure 5.11**), it can be seen that the radar underestimates precipitation intensity. It is also not able to represent the peak of precipitation intensity during the event.

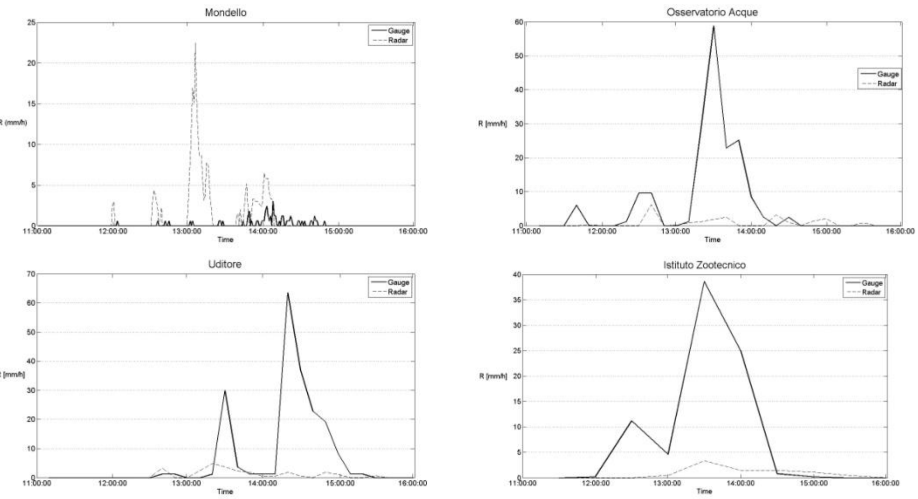


Figure 5.11: Rainfall intensity measured by rain gauge (solid line) and weather radar (dot line).

Moreover it is concluded that the 4 examined pixels are subject to a strong attenuation, so it was decided to use Z-R default relations.

5.4. Model assessment

Sewer network data for the city of Palermo has undergone some changes and some simplifications in order to be used in the chosen hydraulic model.

The first modification work consisted of .inp file conversion (version 4.0 for PCSWMM software), into an .inp file for next software version (version 5.0 for PCSWMM software). This was achieved by using a conversion program provided by EPA (Environmental Protection Agency).

Then a second conversion from .inp file to .mbd file for 3Dnet interface program was done. This conversion was performed through software owned by the research team that developed the hydraulic model.

It was realized that data during conversions had some inconsistency. For example, some variables are renamed. Then all variables were controlled to exclude some variables with same name or nonexistent variables.

Due to several changes in the past, other inconsistencies, such as sewer collectors with same upstream and downstream nodes, or different elevation for the same node, etc ... have been also identified. In this case the network was compared to the original information present in other studies.

Another correction was made on the direction of water flow in sewer collectors. In GIS sewer collectors are plotted with a different flow direction in some cases. SWMM software directly converts downstream node with upstream node when slope is negative. Instead SIPSON returns an error. The same correction was made for those sewers that have zero slope. SWMM automatically assigns a minimum slope equal to 0.0001 while SIPSON reports an error. No slope was corrected outside the program.

At this point, after having corrected transcription and conversion errors, some simplification was operated. Sewer network is too extensive and problematic. A simplification of the network was needed, consisting of unifying very short sewers (less than 10 m) or suppressing secondary sewers with not big size (mostly ovoidal size 200 x 300 mm). SIPSON has been shown to have some problems with such sewers not perfectly coupled with subsequent larger.

The main problem using this program also concerns the inability to solve parts of the network with very steep slopes, typically greater than 20%. In the original sewer network there were about 10 sewers with slopes greater than 20%. These sewers, according to the same practice to solve the problem above, were combined with afterwards sewers in order to make the slope less pronounced or they have been suppressed if they are not critical to study Palermo sewer system. In only one case, it was not possible to apply any of the previous techniques. Sewers that connect Piazza Indipendenza to Danisinni hollow has a slope of about 40%. However, to analyze storm water system, connections with this sewer with others sewers have changed, taking care not to suppress any draining area and respecting connections between sewer network and flooding surface. In fact this area is very important because it is subject to flooding on the side of Piazza Indipendenza and in further downstream areas. Also this part of sewer network belongs to the main area of the network that collects all the sewage from the upper basins and to the old town of the city.

To facilitate fast calibration and to control previous correction operations, a first calibration of 1D-1D model was performed, setting the parameters as in the **Table 5.3**.

Sewer network files have been used for 1D-2D model. SIPSON-UIM runs in DOS commands. Also this program, as SIPSON, was written in FORTRAN computing language. **Figure 5.12** shows the starting simulation file in which the list of other necessary data can be red.

This file contains surface parameters in the first line, represented in this case by a .txt file containing the DEM of concerned area.

The available DEM was derived from LIDAR data, aggregated at a resolution of 2 m. In order to use it, the DEM was later aggregated through a local average, up to a resolution of 60 m per pixel, that is equal to the pixel resolution of rainfall data, provided by the radar. Spatial window size is 1081 x 3090 pixels.

Second line contains simulation parameters, such as start and end of simulation and step simulation for runoff on the surface.

Finally, the last section concerns surface variables and commands for printing obtained results. In particular connections between sewer network and surface drainage, definition of areas with homogeneous precipitation, precipitation series for each area, nodes of sewer network to observe, definition of boundary condition, information about possible interactions with other waterways and some output commands such as printing of variables in float or ascii format for viewing and processing post-analytical can be specified.

In detail, *case_roughness* and dem file contains information about surface roughness and terrain elevation.

Table 5.3: Simulation parameters.

	Description	Value	Units
Surface parameters	Retention capacity of pervious surfaces	2.5	mm
	Retention capacity of impervious surfaces	0.5	mm
	Darcy infiltration coefficient	1	1.e-6 m/s)
	Porosity	0.3	-
	constant-value of capillary rise	0.002	$m^{3/2}s$-$^{1/2}$
	Basin shape factor	0.1	-
	Manning coefficient for pervious surfaces	0.03	$m^{-1/3}s$
	Manning coefficient for impervious surfaces	0.03	m-1/3s
	Percentage of water that flow from roof directly into sewage	1	-
	Percentage of water that flow from roof in impervious area	1	-
	Percentage of water that flow from impervious area into sewage	1	-
General parameters	Initial condition definition	4	Steady flow, plus base flow added in dry conduits
	Base flow system method	0	L/s/ha
	Base flow hydrograph	0	L/s/km
	Total dry flow	200	L/day/PE
	Time starting rainfall and runoff	0	h
	Time ending runoff	600	min
	Time step for runoff	600	sec
	Time starting simulation	0	h
	Time ending simulation	600	min
	Time step for simulation	3	sec
Advanced parameters	Preissman method convergence criterion	0.003	%
	Time weighting coefficient	1	-
	Courant number	7	-
	Max. number of iterations of node level simulation	0.01	-
	Convergence criterion in conjugate gradient method	0.01	-
	Relative width of open slot	1	%
	Velocity distribution coefficient	1	Equal to 1
	Treatment of computational instabilities	1	No automatic action
	Treatment of supercritical flow regime	1	Reducing channel slope

Check-points file, as mentioned above, is used only to specify which parts of sewer network must be printed. In particular, this file contains node identifier and its coordinates.

Link -points file contains information on nodes for which the equations are solved which provide runoff input water flow in sewer network. These points have been chosen so as not to overload the simulation. They have been chosen first during the simulation of linear cascade model, developed in 2008.

Weir.txt file contains boundary conditions to be attributed to outlet nodes. Sewer network ante 2007 had 4 outlet nodes. Two were located on Cala harbor, which represent the discharge of storm water. They were eliminated by this simulation, because full closure of these discharges, in correspondence of such flood event, has been verified.

Another outlet node is located near the harbor and it was maintained for simulation. Another one allows the discharge along Foro Umberto I. According to the restructuring of the final stretch sewer network of Palermo, another outlet node in Foro Umberto was added. It discharges exceeding storm water to protect the downstream pump station.

Consequently, Palermo sewer network has been simulated with this new architecture, inserting three outlet nodes and not imposing any boundary condition because there is no interest in understanding the effects of discharges but only surface runoff in the city.

```
************************
*   BASIC parameters
************************
*       IND         X         Y      LLX      LLY    CELLSIZE
B0        2        103       60    2371559.4798584    4217170.1999512    60.0

************************
*   TIME    related parameters
************************
*         S          E        MM        DT       SEC     RATIO   ADAPTIVE_TIME
T0        0      36000         2         5       1.0         2           1

************************
*   I/O parameters
************************
F0  ELEVATION dem.txt
F0  LINKPOINT LKpoint-stockbridge-detailed-pipe.dat
*F0 ROUGHNESS   case_roughness.txt
F0  GAUGEREGION case_gauge.txt
F0  RAINFALL    RAINFALL.TXT
F0  CHECKPOINT Checkpoints.dat
*F0 WEIR    WEIR.TXT
*F0 STAGE   STAGE.TXT
F1  GLOBAL  INTERVAL_M  1
*F1 FLOAT   INTERVAL_M  6
F1  ASCII   INTERVAL_M  6
*F1 WEIR INTERVAL_M 1
F2  MINUTE
P0  MINDT   5
```

Figure 5.12: Basic parameter file for SIPSON-UIM.

5.5. Results

Analysis of flood forecasting model results is aimed at testing the hypotheses of model accuracy. Thus flooding forecast errors have been analyzed. Errors have been calculated based on differences in percentage and in water height between observed and simulated water levels.

The model provides water level on surface in grid format and water velocity along two directions. **Figure 5.13** shows the map with the highest water level recorded during a simulation of 600 min. Calibration with rainfall radar data has given excellent results in upstream areas. An overestimation of water level has been noted in downstream area near the seashore. In corso Vittorio Emanuele II observed water level is 10 cm and simulated water level is 51 cm. In the other cases the differences between observed and simulated water level remain below 13 cm.

The same simulation has been performed using rainfall data for the same flood event. **Figure 5.14** shows a lower accuracy from previous case. Flood forecast error increases by an average of 25% in the deepest areas, while there is no error (0%) for the flatter areas. Causes about this error are attributable to the less accuracy on spatial distribution of rain gauge data.

For the other four events (1/10/2009, 16/10/2009, 10/11/2011 and 6/10/2013), flood forecasting errors remain with the same percentages (+5%, -32%, -32%, -32%), confirming stability of prediction model (**Figures 5.15-5.18)**. The error for flood event in 1/10/2009 was calculated unless Foro Umberto I site. Also in the coastal area a strong mismatch between observed water level, equal to 60 cm, and simulated water level, equal to 23 cm, is noted.

From the above description, it is clear that the model has excellent results in quite steep areas and underestimates water level in the other areas. Regarding flood forecasting errors in coastal area, it is assumed that these errors can be due to an incorrect determination of water levels or to inaccuracy in terrain representation. Using a DEM with 2 m of spatial resolution could be excluded the second cause of inaccuracy.

Once analyzed the accuracy of used model, it is verified that this hybrid models cannot work in real-time applications. Despite using a spatial resolution of 60 meters for DEM and rainfall data, running time to simulate an event of 10 hours is equal to about an hour. This means that to simulate a weather forecast day, such as that of Sicilian numerical prevision model, a simulation time equal to about 2 hours and a half is needed. 1D/2D model still remains crucial for generating critical events on which design emergency scenarios or for providing high spatial precision data on which train a prediction model based on ANNs.

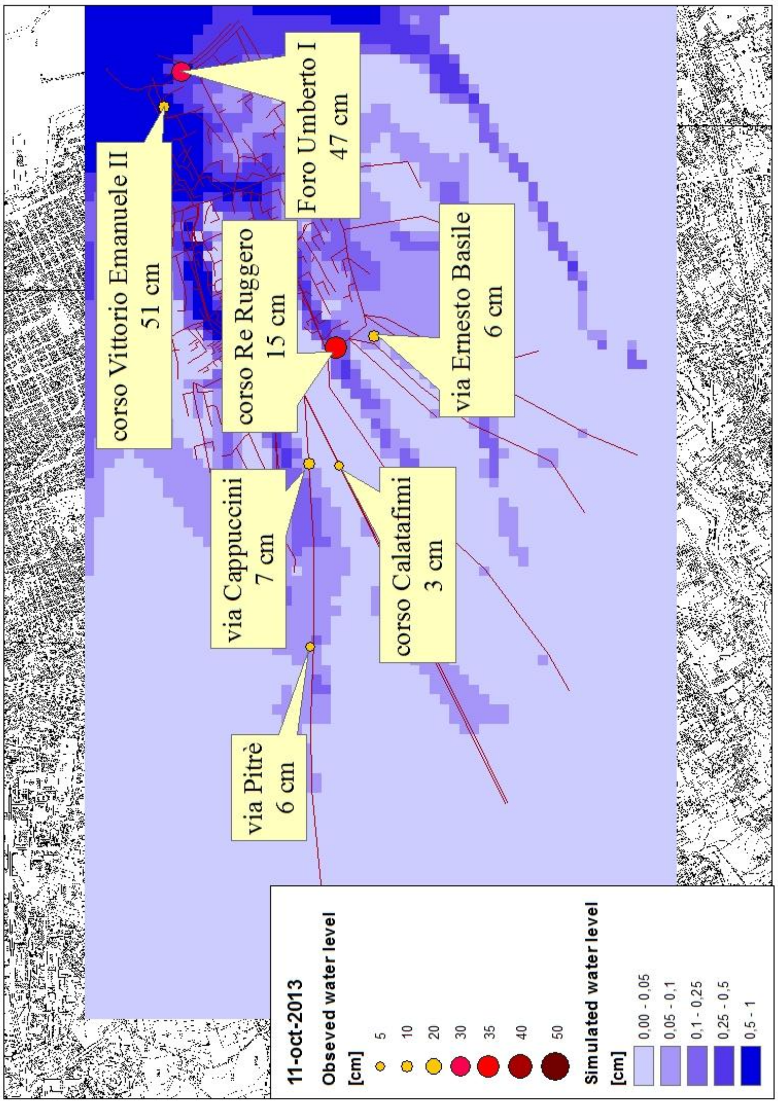
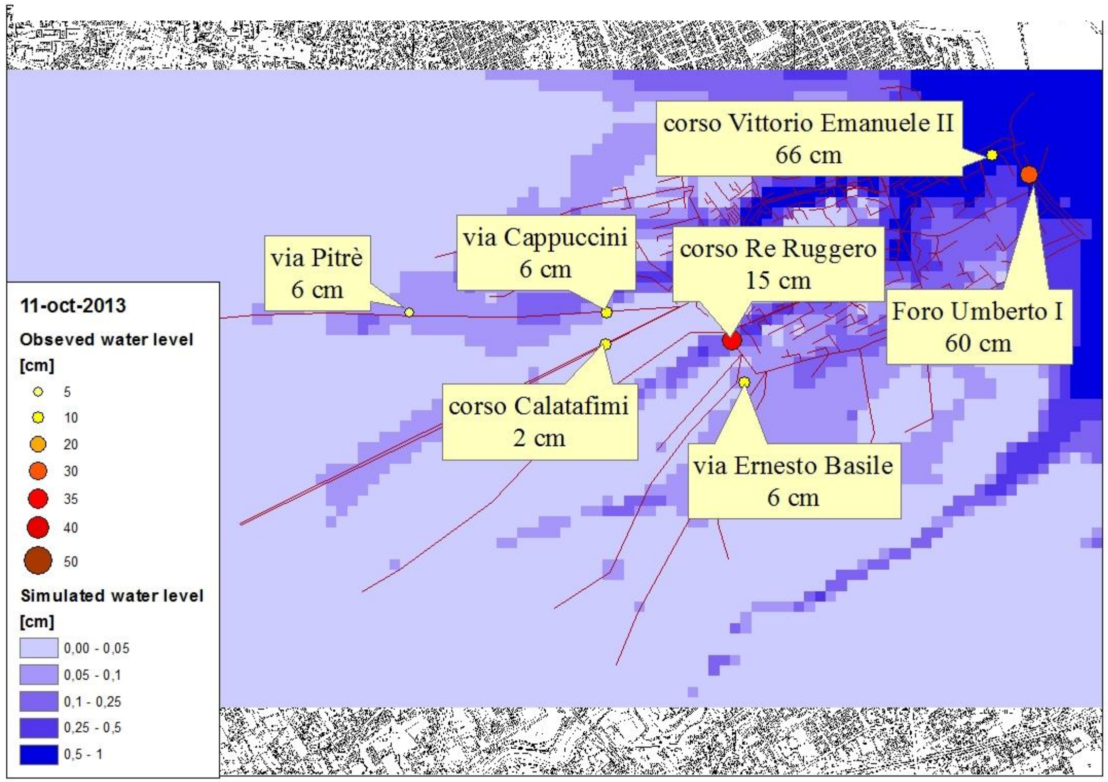


Figure 5.13: Observed and simulated water level in 2013, the 11th of October.

Figure 5.14: Observed and simulated water level in 2013, the 11th of October, using rain gauge data.



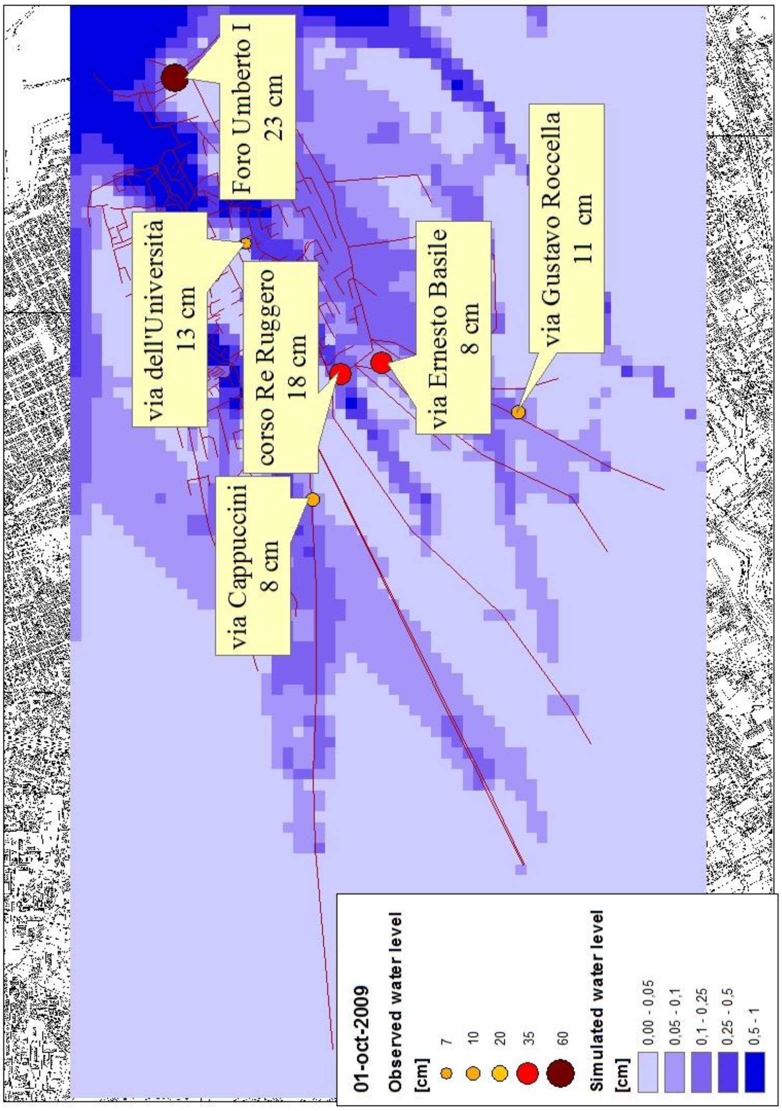
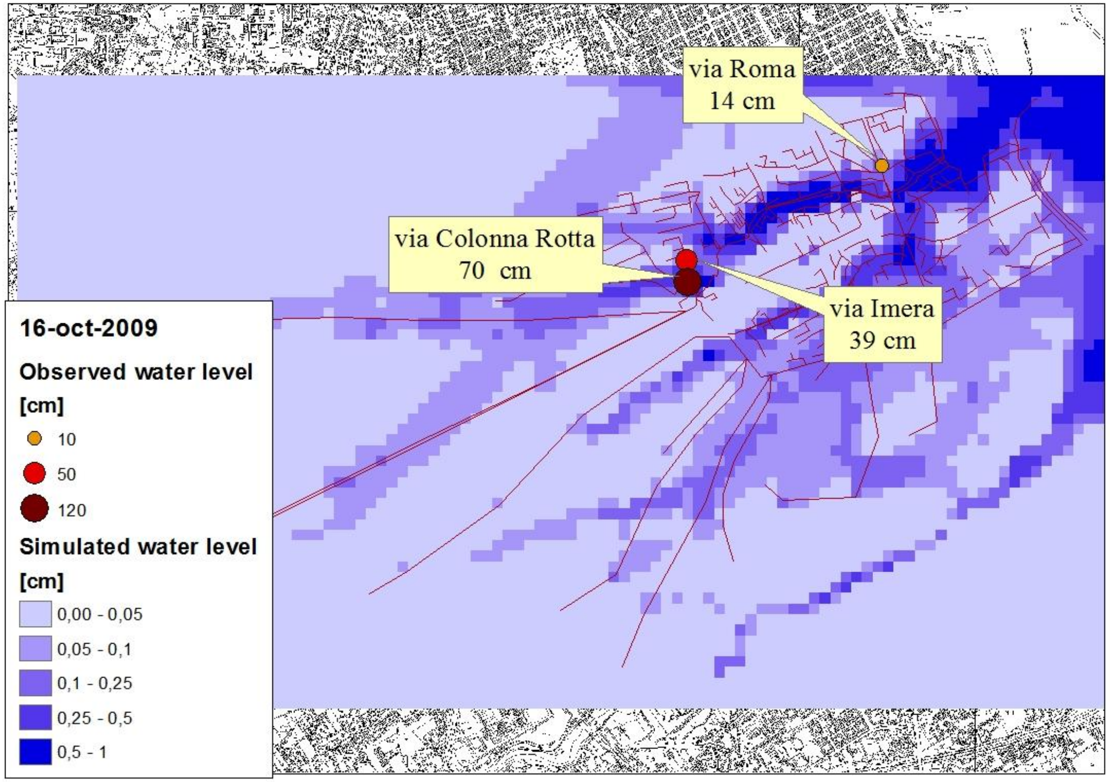


Figure 5.15: Observed and simulated water level in 2009, the 1^{fs} of October.

Figure 5.16: Observed and simulated water level in 2009, the 16th of October.



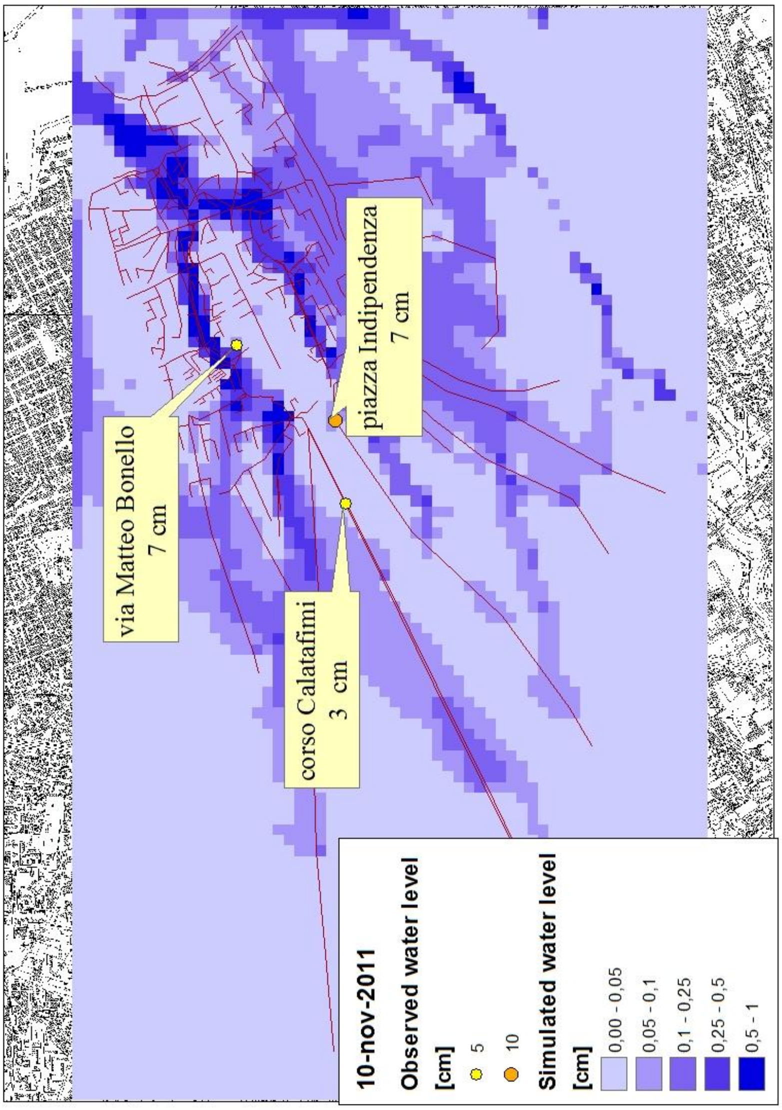
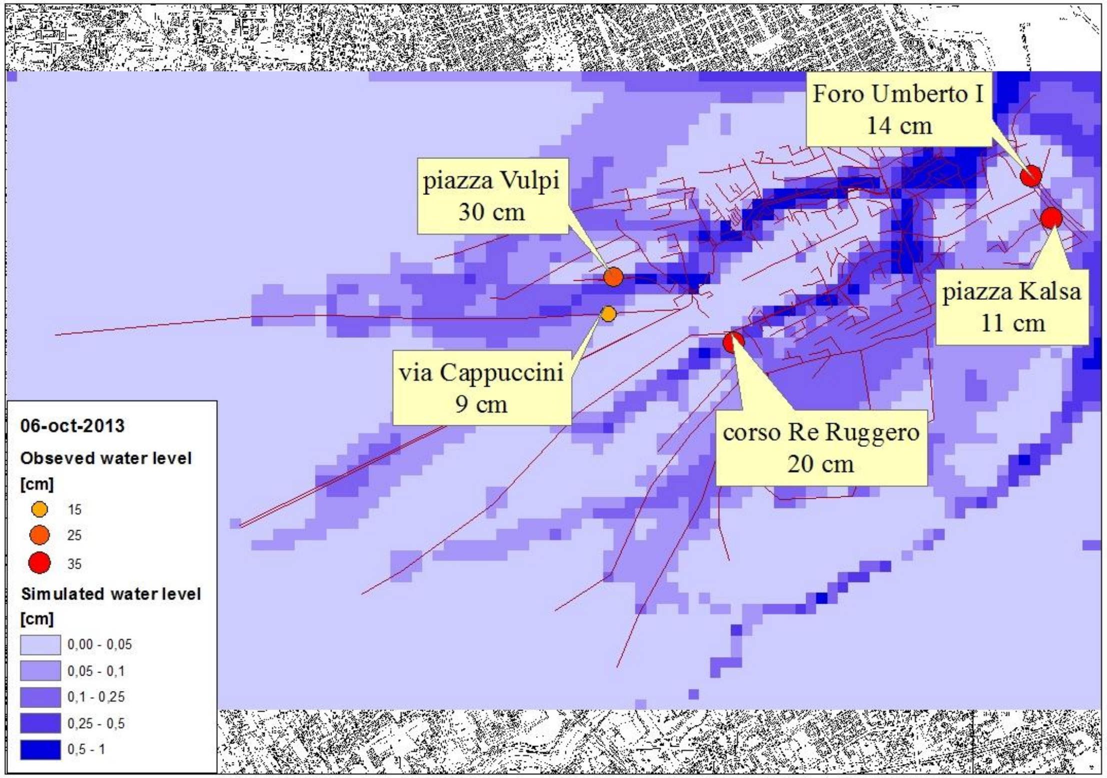


Figure 5.17: Observed and simulated water level in 2011, the 10th of November.

Figure 5.18: Observed and simulated water level in 2013, the 6th of October.



Conclusions

The research activities have been mainly directed to the analysis of extreme rain and floods events in urban areas. The theme of water not perfectly drained is extremely present in the city of Palermo. The causes of these floods are manifold. In this study flooding generated by a flow rate that sewers are not able to be drained in conditions of optimum maintenance has been focused.

Nowadays the flooding risk management in the city is based on closure of economic and social activities, as a result of national forecasting models. Another observed strategy is the closure of roads after flooding happened. Even if there is a regional numerical weather prediction model, for the practical emergencies management, it is not applied any sewer overflow model. To mitigate risks, the only applied interventions are avoidance or resistance measures. No resilience measures, that could mitigate the residual risk in case of impossibility of in time alert, are applied.

The main aim of this research was to assess an early warning system for sewer overflow forecasting. Each early warning system is based on two main components:

- a good network monitoring of principal environmental variables;
- a good flood forecasting model.

With regard to the first component, weather radar has been used as monitoring system. Although it could be affected by many sampling errors, it has been shown that the information of spatial distribution of rain data reduces flood forecasting errors of 25%.

Then runoff dynamics in the basin of old town of Palermo is analyzed, in order to understand the main causes of incidents and to build a valid database for the alert system. Some of public institutions that deal with flood emergencies management in the city have been contacted. More information has been gathered through social networks and newspapers online.

Thus, dual drainage SIPSON- UIM has been tested as flood prediction model. In summary, the model has shown:

- to underestimate flood water level with an average value of 30%;
- to be unreliable in the coastal area;
- to be very reliable in the upstream areas of the city.

It is assumed that such errors can be further reduced by decreasing the spatial resolution of Digital Elevation Model and promoting campaigns to collect data on the most frequently affected sites. This flood prediction model is recommended as a tool for generating scenarios in early warning systems based on comparison of pre-existing scenarios or in those systems based on real time ANN model.

Moreover, research study on so design early warning system could have future developments looking at flood forecasting component. Coming study could involve the effects that the weather forecasting at different lead time could have on flooding heights in the city.

Finally this early warning system could be used to couple with smart technologies that control in real time the drainage system as soon as a level of warning is exceeded.

Appendix A

```
%% PREPARAZIONE MAPPA RADAR
%% estrazione mappe di interesse
data_1=squeeze(double(radar(320:379,574:676,:)));
evento_1=data_1(:,:,542:841);

% DN-mmh
DN=squeeze(double(evento_1));
[x,y,t]=size(evento_1);
dbz=rad2dbz(DN);
%% correzione clutter
%individuazione valori nulli
for i=1:t
    mappa_zero(:,:,i)=dbz(:,:,i)<0;
end
for i=1:x
    for j=1:y
        mappa_sum(i,j)=sum(mappa_zero(i,j,:));
    end
end
%defizione soglia
soglia=0.9*t;
%determinazione mappa clutter
mappa_clutter=mappa_sum>=soglia;
%mappa corretta dal clutter
% for i=1:t
%     c=find(dbz(:,:,i)<0);
%     b=dbz(:,:,i);
%     b(c)=NaN;
%     dbz_1(:,:,i)=b;
% end
[m,n,o]=size(dbz);
a(1:m)=NaN;
for ii=1:o;
mappa(:,:,ii)=horzcat(a',dbz(:,:,ii));
end
mappa(:,n+2,:)=NaN;
bb(1:n+2)=NaN;
for ii=1:o;
dbz_2(:,:,ii)=vertcat(bb,mappa(:,:,ii));
end
dbz_2(m+2,:)=NaN;

for kk=1:t;
    for ii=2:x+1;
        for jj=2:y+1;
            if mappa_clutter(ii-1,jj-1)==0;
                dbz_nc(ii-1,jj-1,kk)=dbz_2(ii,jj,kk);
            else w=[dbz_2(ii-1,jj-1,kk),dbz_2(ii-1,jj,kk),dbz_2(ii-1,jj+1,kk),dbz_2(ii,↙
jj-1,kk),dbz_2(ii,jj+1,kk),dbz_2(ii+1,jj-1,kk),dbz_2(ii+1,jj,kk),dbz_2(ii+1,jj+1,kk)];
                dbz_nc(ii-1,jj-1,kk)=nanmean(w);
            end
        end
    end
end
%% Z-mmh_1
for i=1:t;
```

```
Z(:,:,i)=10.^(dbz_nc(:,:,i)./10);
mmh_1(:,:,i)=(Z(:,:,i)./200).^(1/1.6);
end
% mmh-mm
for i=1:t;
    mm_1(:,:,i)=mmh_1(:,:,i)/60;
end

%eliminazione nan
for i=1:t;
    d=(mm_1(:,:,i));
    e=isnan(mm_1(:,:,i));
    for j=1:x;
        for k=1:y;
            if e(j,k)==1;
                cb(j,k)=0;
                else cb(j,k)=d(j,k);
            end
        end
    end
   mm_2(:,:,i)=cb;
end

%% aggregazioni N minuti
N=15;
aa=1:N:t;
for ab=1:(t/N);
    mm_15(:,:,ab)=mm_2(:,:,aa(ab))+mm_2(:,:,aa(ab)+1)+mm_2(:,:,aa(ab)+2)+mm_2(:,:,aa↙
(ab)+3)+mm_2(:,:,aa(ab)+4)+mm_2(:,:,aa(ab)+5)+mm_2(:,:,aa(ab)+6)+mm_2(:,:,aa(ab)+7) ↙
+mm_2(:,:,aa(ab)+8)+mm_2(:,:,aa(ab)+9)+mm_2(:,:,aa(ab)+10)+mm_2(:,:,aa(ab)+11)+mm_2↙
(:,:,aa(ab)+12)+mm_2(:,:,aa(ab)+13)+mm_2(:,:,aa(ab)+14);
end

% estrazione istogrammi
time_step=N*60;
t1=0:time_step:(t*60);
for l=1:x;
        for k=1:y;
            for i=1:(t/N);
                isto(i,k,l)=[mm_15(l,k,i)];
            end
        end
end
ai=zeros(y);
ai(2:y,:)=[];
for i=1:x;
isto_1(:,:,i)=vertcat(ai,isto(:,:,i));
end

p=1:(((t/N)+1)*y*2);
p=p';
for l=1:x;
r=1;
    for j=1:y;
        for i=1:((t/N)+1);
            s((2*i)-1:(2*i),1)=[t1(i);isto_1(i,j,l)];
```

```
        end
        rr=[r;s];
            r=rr;
            clear s
    end
    clear r
    rr(1)=[];
    count=[p,rr];
    p=count;
    clear rr count
end
istogramma_matrix=p(:,2:(x+1));

fid=fopen('RAINFALL_0.txt', 'wt');
fprintf(fid, '1 0\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %
12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0
f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %
6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n %6.0f %12.3f\n',↙
istogramma_matrix);
fclose(fid);
RAINFALL_0= importdata('RAINFALL_0.txt');
a=1:(x*y);
i=1:((t/N)+2):((((t/N)+1)*y*x)+length(a));
 for j=1:length(a);
     RAINFALL_0(i(j),1)=a(j);
 end
RAINFALL_0=RAINFALL_0';
 fid=fopen('RAINFALL.txt', 'wt');
fprintf(fid, '%6.0f %12.3f\n', RAINFALL_0);
fclose(fid);
```

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