URBAN FLOODING MODELLING STUDY AT PLAYA DE GANDIA

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ABSTRACT

An urban flooding alleviation study for the beach resort Playa de Gandia (Valencia, Spain) has been accomplished. The problems encountered were related to frequent flooding with street inundation of up to 50 cm and pollution of the harbour due to CSOs. The problems originate from an insufficient capacity of the drainage system, which cannot cope with intensive Mediterranean storms.

The drainage area covers approximately 189 ha with up to 80,000 PE in high season. The very flat area is served by a complicated, looped drainage network, with three pumping stations driving the flows towards WWTP. The main CSO points are at the pumping stations.

The study has relied on a combined application of mathematical modelling and GIS. The runoff and flow models were built in MOUSE. A special modelling technique was applied, where a hydrodynamic model built in two layers describes both the underground (pipes) and overland network (streets). The exchange of water between the two systems was secured by a system of weirs, which substituted the street gullies and manhole covers.

The pipe network data was imported directly into MOUSE from an ODBC-compatible database, while the streets were digitised from CAD drawings. The model development (surface storage) and result presentation (flood maps) were extensively supported by the use of digital elevation model (DEM) within GIS (Arc View).

The alleviation scheme comprises a globally controlled system (RTC) of six detention tanks (total capacity 32,000 m3), four pumping stations and two gates. The system eliminates the flooding and CSOs for all frequent events. However, for extreme storms CSOs are accepted and excessive water is evacuated by intensive pumping. The proposed scheme forms a base for the rehabilitation plan being implemented from January 1999 onwards.

KEYWORDS

ArcView, urban flooding, GIS, mathematical modelling, MOUSE, real time control, urban drainage.

INTRODUCTION

Intensive impermeabilisation of urban catchments in Mediterranean coastal areas, often driven by the booming tourist industry, imposes ever-growing storm water loads on usually under-dimensioned and/or outdated drainage systems. This is equally the case in traditional urban areas, as in newer tourist resorts. This deficit in drainage capacity is usually a consequence of underestimating the extent of storm water loads caused by high-intensity storms, which occur more or less regularly in most parts of the European Mediterranean coast.

Apart from urban flooding, excessive storm water loads cause combined sewer overflows (CSO) which are responsible for the intermittent bacteriological pollution of the bathing beaches, along with the aesthetic problems in the coastal areas and harbours. If occurring frequently and during the tourist season, these events induce economical damages in the same range as urban flooding, and as such are unacceptable.

Alleviation measures in such situations are difficult and expensive. Sometimes, old sewer pipes may locally be replaced with a new, high capacity network, or some pump capacity may be increased. But, with such partial solutions, the problems just migrate further downstream, causing even worse situation there. The overall effect is usually doubtful, and sometimes even negative. A search for globally feasible solutions must therefore include a comprehensive hydrological and hydraulic analysis of the entire drainage system, in order to establish correct cause-consequence relations and to understand the dominant drainage mechanisms in the system. It is first then, that technically feasible and cost-efficient solutions can be drafted.

The case study which is the subject of this paper may be considered as a reference study of that category. The paper concerns the urban flooding alleviation study for the urban area of Playa de Gandia in Gandia, Spain, carried by DHI in 1998/99. Urban flooding is a serious problem at Playa de Gandia, with frequencies and intensities far above reasonably acceptable level. The flooding repeats frequently - several times each year - with weighty consequences for local traffic and properties. The study was carried out in order to reveal the real causes of the problem and to identify feasible solutions

DESCRIPTION OF THE SYSTEM

The city of Gandia is located in the province of Valencia (Spain), some 65 km South from the city of Valencia and 3 km from the Mediterranean coast (Figure 1). Playa de Gandia is located 3 km northeast from the city of Gandia.

Figure 1 Location of the city of Gandia

Playa de Gandia is a tourist resort stretched as a narrow urban strip along the coast in 3-km length, with only 600-m width. On the southern side, Playa is delimited by a harbour, while in the north and on the land side is surrounded by agricultural areas and low lying wetlands.

The study has covered the urban area of approximately 189 ha. This area is densely urbanised, but there are only few permanent inhabitants – most of urban capacity is used only seasonally by tourists. The resort is divided in a relatively regular raster of rectangular blocks, with main traffic direction along the sea front, and with numerous connecting streets in transversal direction.

The drainage conditions in the area are not very favourable. The terrain is quite low and groundwater level is high. The area is separated by a high (>3m) sand ridge from the sea, so that storm runoff cannot be drained into the sea. Efficient gravitational drainage is also not possible on the inland side, and practically all loads must be pumped out. Gravitational means of evacuation are very limited, and are only present as overflows, possible only in two places.

The drainage system is of a combined type, with wastewater and storm water being drained in the same pipe system. The layout of the drainage system follows the street layout.

PROBLEM DESCRIPTION

At present, the drainage system shows a serious capacity deficit for timely and environmentally justifiable evacuation of the storm runoff. The urban planners have obviously neglected the seriousness of the storm runoff drainage problem under the given hydrological and topographical conditions, and the consequence is frequent urban flooding, which at extreme rainfall achieves catastrophic extent. The floods cause substantial economical damages and create unpleasant image to this otherwise respected resort. The worst situation is in the south-eastern part of the area (Zone 1), where flood level on the streets exceeds 50 cm for extreme storms, with flood lasting 4-10 hours, depending on the hydrological situation prior to the critical rainfall.

Since practically all sewage and storm water from Playa de Gandia has to be pumped, the evacuation capacity is strictly linked to the available pumping capacities, at present at the pumping stations Pont (900 l/s), Rosa del Vents (2700 l/s) and Tres Anclas (340 l/s). Gravitational evacuation capacity is marginal, and occurs at the P.S. Pont (overflow weir) and at a small overflow at Avd. De la Pau. Locally in peripheral areas, some surface runoff leaves the drainage area by gravity, but these are also marginal volumes.

In the same time, the detention capacity of the catchment surfaces and the pipe network is relatively small. The catchment area is relatively densely urbanised with large paved areas. There are not many areas where significant volumes could be detained without causing damages. Similarly, the pipe network has a relatively small volume and does not contain any important volume. In such conditions and with very high rainfall intensities (measured peak intensity on 29 Sept. 1994 was 12.9 mm/5 min, or 43 my-m/s), extremely efficient drainage is required. In the referent situation (1998), this is not the case and water rapidly accumulates on the catchment surface, causing floods.

Furthermore, only a relatively small portion of the evacuated water, which is a mix of storm runoff and sewage, ends-up in the wastewater treatment plant. By far the largest part of the storm runoff during large rainfalls gets evacuated by two larger pumping stations and by two gravitational overflows into environmentally and aesthetically sensitive recipients.
Apart from the inner harbour, an important recipient is an old drainage canal, which is a part of a very sensitive system of inland wetlands, partially exploited as agricultural area, but treated as a natural reserve.

NUMERICAL MODEL

Detailed hydrological and hydraulic models for the present configuration of the drainage system in Playa de Gandia have been developed using MOUSE – a modelling system for urban drainage and sewer systems. The models have been based on the structural, topographical, hydrological and demographic information supplied by the client.

The hydrological model covers a total area of 189 ha, featuring a detailed catchment sub-division to 320 sub-catchments. Two types of sub-catchments have been created (urban block and street surface), and connected to the pipe and street layer of the hydraulic model, respectively. The hydrological model describes the processes of surface storage, runoff and soil infiltration.

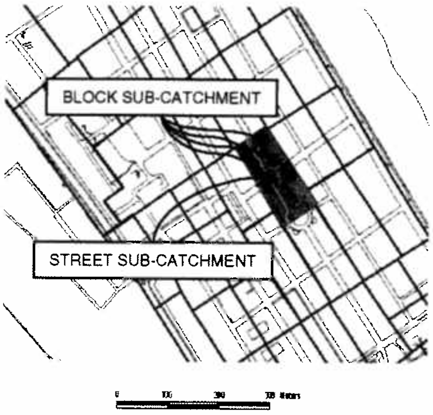

Figure 2 An example of a sub-catchment delineation.

The hydrodynamic model is built in two layers: the sewer network layer and streets layer. The structural, geometrical and topographical information relevant for the model was either available in a directly usable formats, or it was digitised from the maps and subsequently processed into appropriate formats. Digital elevation model of the area was used for the definition of the inundation "cell" volumes. An effort has been made to reduce the complexity of the pipe model, in order to improve manageability of the model. An overview of the model data sets, before and after simplification is presented in Table 1.

Table 1 Overview of the number of principal model elements

Model element	Raw data	After simplification
Pipe network nodes	1446	536
Surface nodes	188	188
Total nodes	**1634**	**724**
Pipes	1456	547
Street conduits	299	299
Total conduits	**1755**	**846**

The hydraulic model takes account of the following processes: sewer flows, street flows, and inundation, flow exchange between the sewer and streets, flood infiltration into the ground and groundwater infiltration. The model of the present system configuration has been extended with Real Time Control (RTC) functionality, in order to simulate a co-ordinated operation of the proposed storage basins and pumping stations.

The MOUSE's standard result presentation facilities have been supplemented by animated absolute and differential flood maps, developed on the basis of a digital elevation model (DEM) of the modelled area.

ALLEVIATION OF THE INUNDATION PROBLEM

The analyses of the present urban flooding problem and the development of the technical solution for the problem alleviation have been carried out based on simulating the system performance under the load of the design rainfall (8-year return period, duration 1 hour), with subsequent check of the system performance during a catastrophic historic rainfall from 29 September 1994 The analyses were performed as a three-step process:

- **Present situation**, where performance of the system in the current configuration is analysed and evaluated;
- **Solution for the Zone 1**, having the origin in the on-going works, including the construction of the storage basin DEPOSIT1 with pumping station and overflow, partial replacement of the sewer network,

separation of the storm- and wastewater system, and modification of the local storm water drainage system;

- **Complete solution,** as an extension of the fully implemented Zone 1 solution (but without storm water separation). This solution includes a number of additional storage basins, pumps and sewer pipes, connected into a globally controlled RTC system. The elements of the system were dimensioned according to the local site conditions or as reasonably proportioned elements of a fully implemented system. Individual optimisation for each element will be required as the implementation of the system progresses.

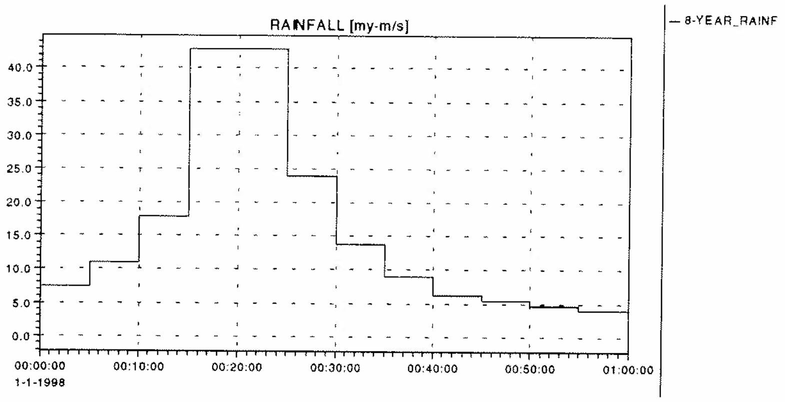

Figure 3 Design rainfall: 8-year return period, duration 1 hour.

Functionality of the Present System

For the design rainfall, the simulations of the present system have shown a pronounced deficit in drainage capacity which results in flooding of large areas in the central and southern part of the system (Figure 4). The simulated flood depth achieves locally (streets La Costera and Atlantic) up to 40 cm, and the inundation lasts approximately 4 hours.

The total hydraulic load on the system during the 24-hour simulation period (storm surface runoff 75000 m3, infiltration 17500 m3, 16500 m3) is partly evacuated to the treatment plant (40%), while the remaining load is discharged into environment (54%) or gets lost as ground infiltration (6%).

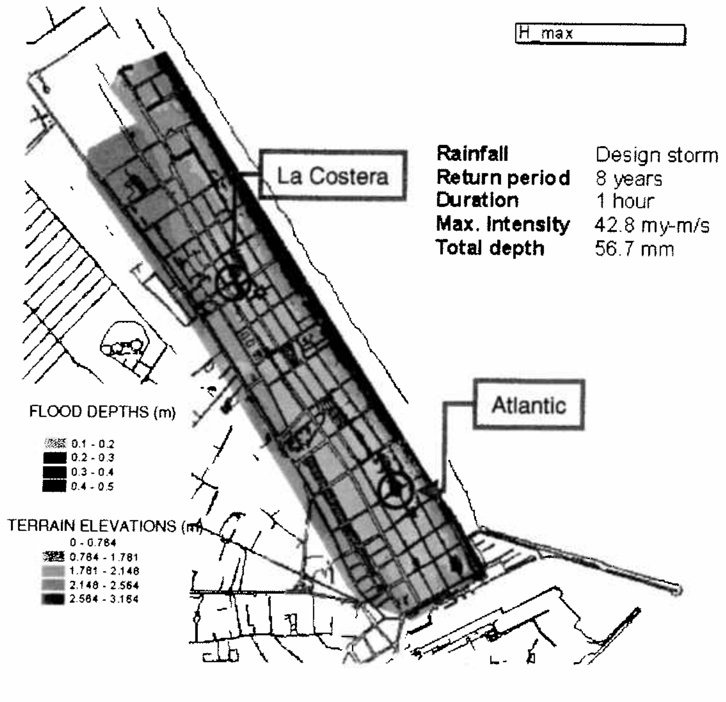

Fig. 4 Present situation – Envelope of the maximum simulated flood extent for design storm

Zone 1 Solution

After the implementation of the solution for the Zone 1, the situation will improve locally in the Zone 1, but in the remaining parts of the system the effect will not be that noticeable. There will still be important areas inundated (Figure 5). The maximum inundation depth in Zone 1 will be reduced by approximately 6 cm and the flood duration will actually be prolonged by 1 hour. The reason for this is that the drainage possibilities for storm water in Zone 1 will actually be reduced by the separation of the wastewater and storm water.

The total effect in the Zone 1 will be relatively small because the inundation water arrives as a street flow from other parts of the system, which underlines the function of the drainage system as an unique system in extreme situations, despite strict disconnection of the local pipe network. The effect of the solution to the maximum inundation at Carrer Costera will be insignificant, while the duration of flood will be shorter there, due to the generally better evacuation possibilities provided by the new infrastructure.

About 45% of the total hydraulic load during the 24-hour period get evacuated to WWTP. The remaining 55% ends up as infiltration (4%) and as overflows into the environment (51%). So, also in terms of environmental performance, the total effect for the design rainfall will not be impressive. However, for all smaller and medium rainfalls which occur frequently, the relative effect will be much more visible.

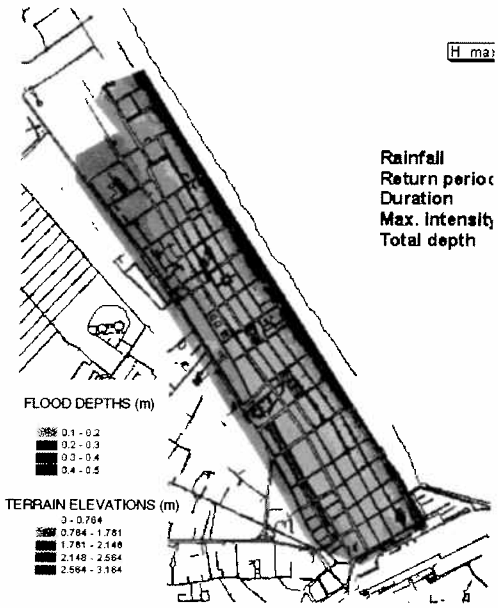

Figure 5 Maximum flood extent after implementation of the solution in Zone 1.

Total Solution

After the implementation of the complete solution, the flooding situation will improve radically in the whole system. However, there will still be some smaller areas inundated (Figure 6), but the flood depths will be reduced significantly and/or large areas will become free of flood (see the flood differential map in Figure 7). Compared to the present situation, the maximum inundation depth in Zone 1 will be reduced by approximately 10 cm, but the main effect actually obtained will be in terms of rapid flood evacuation. Duration of significant inundation (h>15cm) will be reduced by more than 1h30min, so that its total duration will fall under 2 hours. At the other location with locally deep flood (Carrer Costera), a similar improvement is expected, with moderate effect on the maximum flood depth, but with significant reduction of the flood duration.

There are two reasons for relatively small effect of the proposed solution on maximum flood depths. One is related to the system topography, where local depressions represent relatively small volume, but appear with relatively high depths. The second reason is related to a very fast runoff and limited evacuation capacities, which make that despite increased pumping and overflow capacities, storm runoff cannot be conveyed by the existing system (pipes and streets) fast enough towards the points of evacuation. This is the case both with the overflow weirs into storage basins and with the evacuation pumps, where the full evacuation capacity is achieved after the most of the rainfall has already occurred. Therefore, by further enlargement of the storage and evacuation capacities, the effect would be mainly realised as shortening of the flood duration. A significant reduction of the flood depth maximum can only be achieved by improvement of drainage situation locally, i.e. by providing a more efficient drainage (larger pipes and intakes) in each street, along with improving the global storage capacity and evacuation capacity. This, however, requires a different type of analyses, with precise determination of locally contributing sub-catchments and evaluation of the available drainage infrastructure.

In terms of environmental performance, the situation has also radically improved. About 66% of the total hydraulic load during the 24-hour period get evacuated to WWTP. The remaining 34% end up as infiltration (2%) or as overflows into the environment (32%). The significant overflows are concentrated only in two locations. Thus, the overflows are reduced by approx. 40% compared to the present situation, but it should be remembered that for all smaller and medium rainfalls, which occur frequently, the environmental effect will be correspondingly better in relative terms. The frequency of overflow occurrence will be radically reduced, and the total pollution emissions will be accordingly smaller.

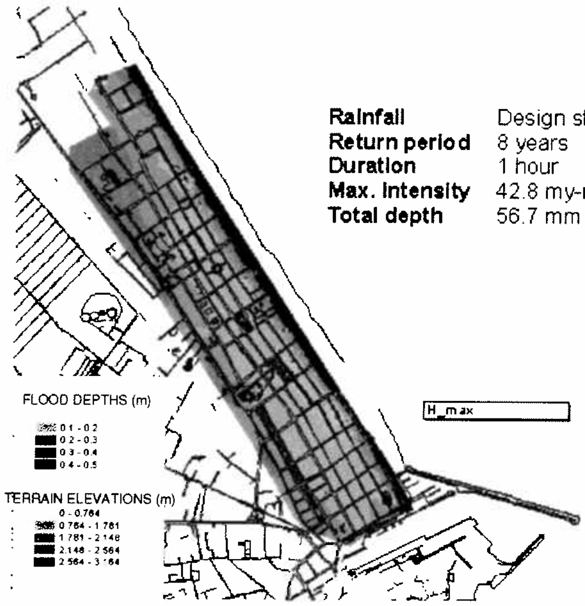

Figure 6 **Envelope of the maximum flood extent after the implementation of the full solution.**

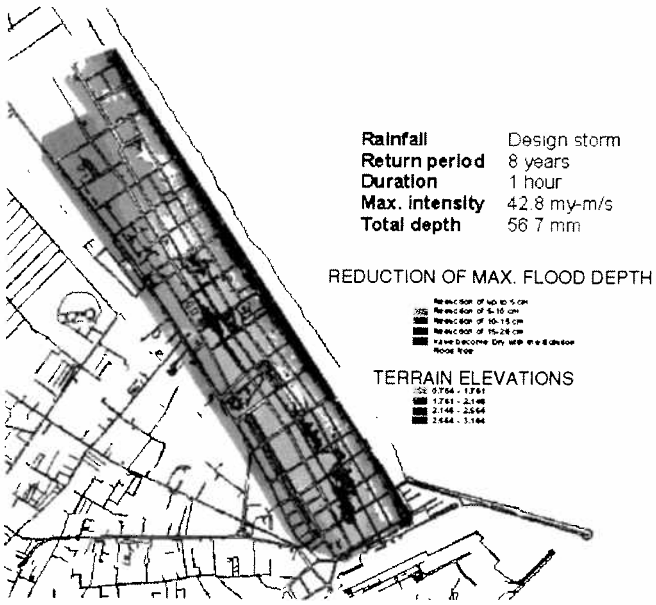

Figure 7 Maximum flood extent reduction: Effect of the full solution relative to the present situation.

RELATIVE EFFECTS OF THE PROPOSED SOLUTION SCHEMES

Flooding

The effect of the proposed solution schemes on the overall flooding situation can be best visualised by a comparison of the flood volume dynamics for the three analysed situations. This is presented in Figure 8.

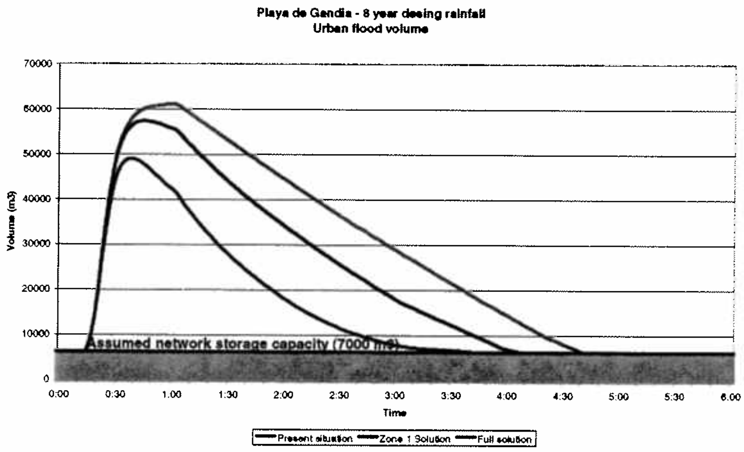

Figure 8 Approximate floods volumes for present situation, Zone 1 solution and Full solution.

In the present situation and assuming a 7,000 m^3 of network storage capacity, the maximum accumulated flood volume achieves approx. 54,000 m^3. This coincides with the end of the rainfall, i.e. approx. 1 hour after the start of the rain. The available evacuation capacities are approximately 16 m^3/s, which results in the full flood removal after 4 hours 40 min after the start of the simulated event.

After the implementation of the Zone 1 solution, the maximum flood volume will be reduced by only 4,000 m^3, but the maximum of 50,000 m^3 accumulated volume will occur already 45 minutes after the event start. Additional evacuation capacities, primarily the pumps at DEPOSIT 1, will accelerate the flood removal, so that the flood will fully disappear some 40 minutes earlier than in the present situation, i.e. 4 hours after the start of the event.

After the implementation of the full solution, the maximum flood volume will reduced by further 8,000 m^3, and the maximum of 42,000 m^3 will occur already 38 minutes after the event start. The added evacuation capacities, primarily overflows into the proposed basins, will accelerate the flood removal, so that the flood will fully disappear already 3 hours after the start of the event.

The early flood volume peak in the last case indicates that the dynamics of the volume accumulation on the catchment surface approaches the dynamics of the rainfall intensity. This early timing indicates that the accumulated volume is spread over the whole catchment surface, rather than in some local low areas. At the time when the runoff starts to accumulate in lower areas, the system has already removed a significant portion of the flood volume. Also, it can be concluded, that it is a local capacity deficit (e.g. too small street gullies or too small local pipes), which prevents a more efficient drainage.

Environmental Performance

The environmental performance of the system can be measured through the statistics on accumulated overflow volume and overflow frequency for a longer historical period with actual rain series. However, this type of analysis was not possible in the Playa de Gandia study, due to too long simulation times required.

Instead, a "snapshot" of the system's environmental performance has been made for a single event - the design rainfall of 8-years return period. Comparison of the volumes evacuated by different means for the three cases (Present, Zone 1, Full) has been made and presented in Figure 9.

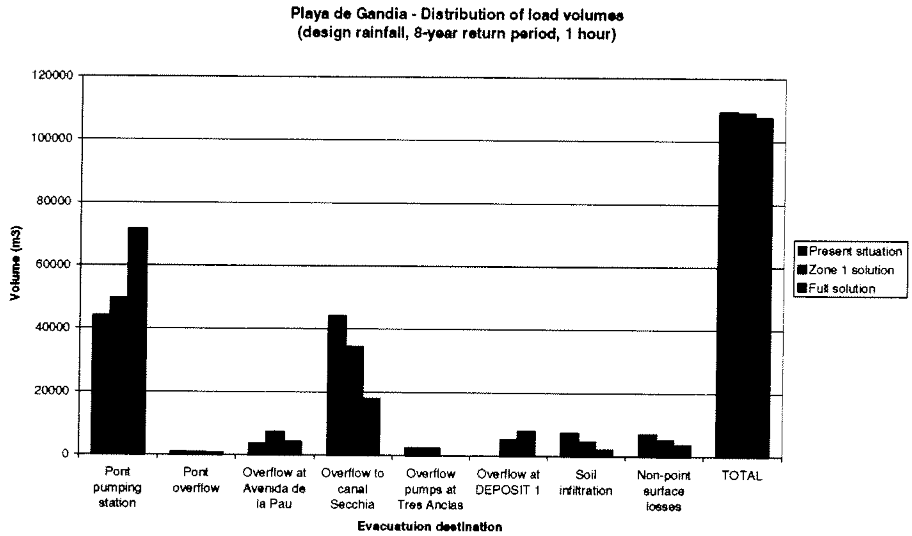

Figure 9 **Comparison of the evacuated volumes per destination for the present situation, Zone 1 solution and the full solution.**

It can be observed that the total system load for the simulated 24 hours is slightly smaller after the implementation of the solutions than in the present situation. This is because high water levels in the network are longer present, due to long-lasting basin emptying flows and consequently the ground water infiltration is smaller.

The most significant effect of the solutions implementation is the increase of the water amount being pumped to the WWTP, with simultaneously reduced amount of the overflows into the canal Secchia (at present P.S. Rosa del Vents).

OVERVIEW OF THE PRINCIPAL NEW INFRASTRUCTURE

As a result of the analysis process a number of structural and operational improvements have been identified, needed for the improved system functionality. The most important elements are storage basins and pumps. An overview of the storage basins and pumps foreseen to be parts of the proposed solution is presented in Table 2 and Table 3, respectively. Figure 10 shows the geographical allocation for principal new and modified infrastructure of the complete solution.

Table 2 Overview of the planned storage basins

Storage basin	Location	Type & Size	Status 1999	Volume (m^3)	
				Nominal	Max.
DEPOSIT 1	Carrer Alcoi - del Grau	Rectangular, net area 1491 m2, Hbott = - 2.87 m	Under constructi on	5000 m^3	5900 m^3
DEPOSIT 2	Parc de la Mota	Rectangular, net area 3000 m2, Hbott = - 3.00 m	Plan	8000 m^3 (incl.connect. tunnel)	9500 m^3 incl.connect. tunnel)
DEPOSIT 3	Carrer Rioja – Vicent Calderon	Rectangular, net area 2500 m2, Hbott = - 3.00 m	Plan	6350 m^3	7850 m^3
DEPOSIT 4	Tres Anclas	Rectangular, net area 1500 m2, Hbott = - 3.00 m	Plan	3950 m^3	4800 m^3
DEPOSIT 5	P.S. Trea Anclas -> P.S. Natzaret-Oliva	Longitudinal, L=1725 m, d=1.20 m + L=95 m, d=2x1.20 m, Hbottom = - 3.00 m	Plan	2200 m^3	2700 m^3
DEPOSIT 6	Carrer Natzaret-Oliva-Carrer Cullera	Longitudinal, L=970 m, d=2x1.50 m + L=270 m, d=1.00m	Plan	3640 m^3	3880 m^3
TOTAL CAPACITY				**29140 m^3**	**34630 m^3**

Table 3 Overview of the pumping capacities

Pumping Station	Status 1999	Function & Status in the Final Solution	Pumps capacity (present vs. future)
P.S. PONT	Existing	Pumping to WWTP	P=F 3x300 l/s
P.S. IGLESIA	Existing	Pumping to P.S. Pont	P=F 3x 170 l/s
P.S. ROSA DEL VENTS	Existing	Wastewater pumps	P=F 2 x 325 l/s*
	Existing	Overflow pumps	P=F 3 x 925 l/s**
P.S. TRES ANCLAS	Existing	Wastewater pumps	P=F 190 + 340 l/s
	Existing	Overflow pump-abandoned	P 340 l/s
P.S. DEPOSIT 1	Under construction	Wastewater pumps	F 2 x 57 l/s
	Under construction	Storm water pumps	F 6 x 425 l/s***

Pumping Station	Status 1999	Function & Status in the Final Solution	Pumps capacity (present vs. future)
	Under construction	Emptying DEPOSIT 1	F 2 x 200 l/s
P.S. DEPOSIT 3	Plan	Emptying DEPOSIT 3	F 2 x 200 l/s
P.S. NATZARET-OLIVA	Plan	Emptying DEPOSIT 5 Pumping to DEPOSIT 6	F 5 x 1000 l/s****
P.S. CULLERA	Plan	Emptying DEPOSIT 6	F 2 x 200 l/s
TOTAL PUMPS CAPACITY (PRESENT VS. FUTURE)			**Present Qtot=5705 l/s** **Future Qtot=14229 l/s**

* To be operated with continuously variable speed control (PID)

** To be refurbished to total capacity approx. 3.5 m^3

*** Possibly increased total capacity of approx. 3.5 m^3

**** Approximate capacity

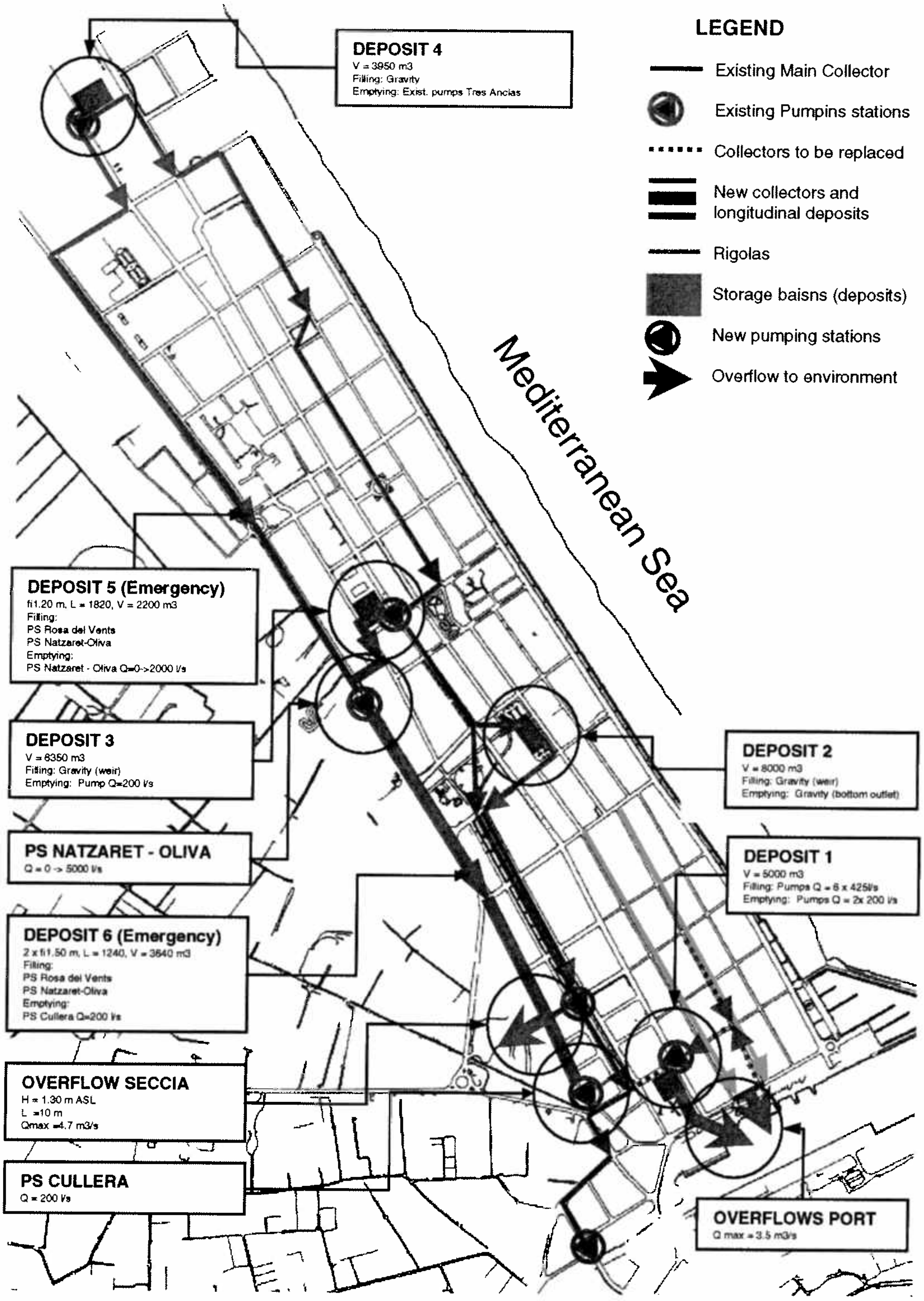

Figure 10. Schematic representation of the new or modified elements of the complete solution.

CONCLUSION

The study of Playa de Gandia has proved the capacity of the modelling system for urban drainage in a combination with GIS as a powerful analyses tool for urban flooding problems. Complex hydrological-hydraulic mechanisms have been encapsulated into the model, and results have been presented as easily understandable animated inundation maps and performance diagrams for individual elements of the drainage scheme. A feasible global solution for a very complex problem has been identified and outlined. Thus, MOUSE has appeared as a part of a comprehensive hydroinformatics system, featuring outstanding both computational and result presentation capabilities. Further integration of mathematical modelling and GIS will contribute to even more cost-efficient and versatile studies in future.