Towards Sustainable Planning and Design of Stormwater Control Solutions in Brazil

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The way to manage stormwater and its discharge in urban areas, is an age-old question. Since recent years the performance of the urban water system should be in line with the preservation or recovery of the system’s quality, quantity and integrity for the system to be sustainable. As a result new approaches for the planning and design of urban water systems are required to be able to provide the demanded services (like flood protection, ecological values and livelihood).

In the last years, research on sustainable urban water management has been undertaken in Netherlands. Michiel Rijsberman and Frans van de Ven focused on concerns regarding planning approaches. While others searched for innovative design solutions, for example around the concept of floating cities. For my internship I was involved in the project ‘Floating Greenhouses’ under the supervision of Chris Zevenbergen. At his counsel Professor Carlos Tucci invited Elwin Bakker and me to come to Brazil for a graduation project.

Brazil is a country passing through a transition phase towards more sustainable urban water management. Some regional capitals have developed management plans for urban drainage together with appropriate legislation, starting from the premise that newly urbanised spaces should not increase natural surface runoff, and that urban drainage must be integrated with planning the urban environment of cities. This master thesis reflects a very interesting moment in the transition, providing insight in some of the most critical issues in the planning and design of Urban Drainage Master Plans.

Most of the experience presented in this report is drawn from the Porto Alegre case, given that I carried out my graduation at the local university. Many people were responsible for providing me an updated and detailed picture of the Urban Drainage Master Plan and the development of its scope and knowledge. Special acknowledgement is owed to Prof. Carlos E.M. Tucci, Adolfo O.N. Villanueva, Daniel G. Allasia, Rutinéia Tassi, Walter Collischonn, Marcus A.S. Cruz, Daniela Bemfica and Adaila de Castro Rechden.

Very special thanks should also go to the members of my graduation committee, Prof. ir. Sanders, Dr. ir. Van de Ven, Dr. ir. Verhaeghe, drs. De Boer, Prof. Dr. Tucci and Dr. ir. Zevenbergen for investing their time and energy in this master thesis.

Also, I gratefully acknowledge the financial support of the Lamminga fund.

And last but not least, I would like to thank all my friendly students from the Institute of Hydraulic Research and the UFGRS, in particular my companion Elwin F. Bakker, for the wonderful time I enjoyed in Porto Alegre.

Delft, May 2005

Berry Gersonius
SUMMARY

The problems of urban drainage in Brazil

Brazil is currently facing widespread problems in the urban environment associated with inadequate systems for drainage of urban stormwater runoff. The PNSB study (2000) identified that out of a total of 5507 municipalities 22% suffered from flooding in the 1998-1999 period. The majority of problems occurred in the southern states, which have higher rates of urbanisation and higher amounts of rainfall. Table 1.1 summarises the main causes of flooding according to the municipalities.

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The problems of urban drainage are compounded by a lack of public awareness and participation, insufficient funds to supply and maintain the basics of sanitation and drainage, weak municipal organisations and a lack of coordination between the different organisations.

Traditional master planning has generally failed to address the problems adequately and the implementation of these plans has tended to rely on large-scale costly infrastructure projects, which in some instances have attributed to the worsening of problems, as the stormwater is drained rapidly resulting in the exacerbation of downstream flooding. As a result of the inadequacies of traditional responses, combined with increasing awareness of the need for integrated approaches, a new generation of management plans for urban drainage is emerging.

Urban drainage management

In recent years some regional capitals have developed an Urban Drainage Master Plan together with appropriate legislation, starting from the premise that newly urbanised spaces should not increase natural surface runoff and that urban drainage must be integrated with planning the urban environment of cities.

Experience with the development of Urban Drainage Master Plans showed that institutional and strategic/communicational aspects are essential for the success of the plan and thus deserve special attention. The plan development process in the city of Porto Alegre is a relevant example of that process. This is the main consideration to select the Urban Drainage Master Plan of Porto Alegre as the case study for this master thesis. Using an assessment framework, focusing on relevant criteria concerning both content and process, this study presents an overview of the policy cycle in Porto Alegre, with a focus on the shortcomings and strongpoints of the followed approach in relation to the concept of sustainable development.

The objective of this study

The overall objective of the study is to improve the approaches for the planning and design of stormwater control solutions in Brazil. From the case study several analyses are possible, which can help to improve the approaches in Porto Alegre and other Brazilian cities. As a first step, critical factors for the success of the plan are identified according to the information and insights that came to light on the basis of the assessment criteria (concept, scope, and knowledge).
Critical factors in the plan development

The application of the framework revealed the aspects that require special attention in the planning and design of stormwater control solutions.

**In concept** – The concept should correspond to the local water system and other relevant systems and it should maintain the system quantity, quality and integrity. The concept in Porto Alegre involves detention in public open spaces. However, because the stormwater is transported through a combined system in the project area, such a concept is less applicable as the facilities get contaminated by the deposition of faecal material, solid waste and pathogenic organisms.

**In scope** – Actors that have a power over or a interest in the relevant issues (at least quantity, quality and amenity) have to be involved in the planning process. In the case study important actors did not participate in the plan development, either because they were not invited or because they did not want to. As a consequence water quality and amenity issues played no role in the planning and design.

**In knowledge** – The development, communication and verification of knowledge seems to be crucial in the acceptance (or at least understanding) of the solution. In that respect the consideration of different aspects and interests is essential. Communication is therefore more than one-way traffic of information from the plan developers to the interested stakeholders. In addition to communication of ideas, verification is important. The case study shows that a perception of unacceptable risks and environmental impacts developed around the concept. The perception could not be disproved, because important assumptions were not verified.

**In aspects** – The importance of the initiative phase is often underestimated. For that matter, a thorough exploration of the scope and the creation of sense of urgency for the actors to join the planning table is indispensable for the success of the plan. However, in practise the negotiation process that is necessary to make the actors participate seems to be difficult. As a result it is tempting to start solving these problems, one by one, in stead of striving for a more integrated and sustainable solution.

Conditions for policy development of Urban Drainage Master Plans

On these critical aspects are based the guidelines discussed below.

(1) Any urban (storm)water policy starts with defining the scope, with its actors, areas and issues. The change of a successful Urban Drainage Master Plan is considerably greater if the planning makers take sufficient time to agree on the issues to be covered, their approach, the actors to be involved and their way of involvement. An important question to be answered is if the sense of urgency to solve the problems is high enough among the various actors.

(2) The involvement of a much larger group of actors to the planning process leads to increased demands to the performance of the urban water system, e.g. with respect to water quality, recreation, and its role in urban landscapes. A broader scope calls for sustainable urban water management. The concept of the Urban Drainage Master Plan should therefore be in correspondence with the 5 key elements of sustainable development:
   - Needs of the present
   - Needs of future generations
   - System quantity and quality
   - System integrity
   - Equity

(3) An important characteristic of the Brazilian situation that makes it more difficult to realise sustainable development is that the population uses to dispute innovative solutions. In view of this practise, the verification of knowledge is essential to defend the solution and to avoid endless discussions on the results. Verification is required in any process phase,
from initiative to use (think of monitoring). Knowledge that needs to be verified are claims, assumptions, ideas and data. Obviously it is most important to test the ideas that are experienced as harmful to the interests of one (or more) of the actors.

(4) A Urban Drainage Master Plan requires enough support among the population and the involved administration. To obtain enough support by all participants it is important that the own administration, involved organisations and the population are properly informed and that ideas that live in the society are used in the plan development. In view of this, elements of a process oriented approach are valuable and useful. Rijsberman mentions four central elements that are a prerequisite for participatory planning processes:

- Openness
- Equality
- Debate and negotiations
- Influence

(5) In conclusion continuity is considered to be a critical condition in the policy development of Urban Drainage Master Plans. In the case study both the concept and the project coordinator supported the progress of the process. The concept should therefore accommodate continued learning and modification of the plan or design. On the other hand it should be reasonably robust in the sense that new information does not mean a rigorous break from the past (Rijsberman, 2004). The project leader, as the dragger of the process, has the important task to inspire the project members, to sufficiently involve stakeholders and to organise the communication and verification of knowledge.
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INTRODUCTION

1.1 Water in urban environment

1.1.1 Urban water system
From a water management viewpoint, there are many important differences between urban and rural areas. An area is classified as urban when it has a predominantly urban land use, as opposed to natural, recreational, agricultural or industrial. The predominant land use has major consequences for local water management, because of its hydrological impacts and the demands to the performance of the water system. Urban areas typically have a high percentage of sealed surfaces (roofs, pavements and the like) contributing to much quicker rainwater runoff, a storm water drainage system to accommodate the runoff, a sewerage system and a drinking water system. The schematisation of the urban water system used in this thesis is that of:
1. a natural water resources system (groundwater and surface water)
2. a storm water system
3. a sewerage system
4. a drinking water supply system.

1.1.2 Social system
No city can function without water: it is a prime condition and an improvement factor for the urban living environment. Interaction occurs between the water system and social system. The social system has an influence on the water system and requires services: demands of functions to be satisfied, interests to be protected. The social system's impact on the water system can be detrimental to the water system: deterioration of water quality, disruption of natural communities and flow regimes, etc. Also, the water system has an influence on the social system and provides services, i.e. facilitates functions (like urban landscape quality, water supply, sanitation), but can pose a threat to certain interests: e.g. extreme rainfall and water levels can result in flood damage.

1.1.3 Management and control
The management and control of the urban water system aims at optimally facilitating the functions and protecting the interests of the inhabitants against minimum cost. Urban water management intervenes in both the social and the water system (figure 1.1). Interventions in the water system are mainly physical. Social interventions include serving societal interests, like drinking water supply, sewerage and safety from flooding, and extend to public behaviour and appreciation. Part of the social aspect is the coordination of water management with spatial planning, urban development, recreation planning, and other fields.

Figure 1.1 Water management in relation to the social and water system

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Of course, there is a relationship between the satisfaction of the needs and demands and its impact on the urban water system and the social system (figure 1.2). To satisfy the demands to the water system, an impact on the water system is intended. Impacts can be negative and positive, direct and indirect, intended and unintended. For instance, certain amounts of rainwater will fall over a period. Part of this water evaporates, another part is temporarily stored and discharged in due time. One basic demand is that a system is in place with an adequate capacity to deal with these flows and volumes effectively. The natural water system is changed in order to ensure no flooding, water logging or other nuisance to inhabitants will follow from foreseeable weather conditions.

Figure 1.2 Impacts in relation to the interventions (Zhou, 1995)

1.2 Urban drainage

1.2.1 Flooding of urban areas

Interaction between natural processes and human activities may create hazards such as floods. An inundation happens, mainly as the consequence of flooding, when water flows where it ought not to flow (Gumbel, 1958). According to Tucci, the main types of flood that may impact urban areas can be classified in the following two types:

**Due to urbanisation:** these are floods related to the increase of the impermeable areas and man-made drainage such as conduits and channels. Usually the land use surfaces in small urban basins are made of roofs, streets and others impervious surfaces. Runoff flows through these surfaces to the storm sewers. It changes the hydrological cycle, increasing the overland flow and decreasing the groundwater flow. Under these circumstances the peak discharge increases together with the flood frequency. In addition, during rainy days the washed urban surfaces increase the pollution load in urban environment and to downstream rivers. Flooding due to urbanisation is the primary focus of this master thesis.

**Due to flood plain occupation:** these are natural floods, which mainly occur in medium and large sizes rivers. When no reliable urban plan and regulation exists, the population occupies the flood plain after a sequence of low flood years, because these areas have a flat topography and are near to valuable city land and have a low cost. However, when a larger flood occurs, flood damage increase and the municipality is requested to invest in flood protection in this area.

Correspondingly, Van de Ven makes a distinction between two main causes of inundation:
1. Due to a too limited discharge;
2. Due to inflow of water from outside.

Flood hazards have major social and economic impacts, and are a threat to human life and property. Flood damages are the result of the physical contact with fast flowing water, or the
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mere presence of the flood/inundation water (e.g. economic activities are hampered due to the flood disruption of transport systems, or diseases are transmitted via routes that can be related to the occurrence of flooding). The composition of flood damages is illustrated in figure 1.3. The level of flood damages depends not only on the characteristics of a flood but also on the characteristics of the properties and infrastructure systems in the floodplain.

![Figure 1.3 Composition of flood damages (Zhou, 1995)](image)

1.2.2 Urban floods in Brazil

The problems of urban stormwater management are widespread throughout Brazil. But there are wide regional differences and the main problems are in the southern states, which are more developed, have higher rates of urbanisation, and have higher amounts of rainfall. The National Research in Basic Sanitation (PNSB, 2000) study, undertaken by IBGE, identified that out of a total of 5507 municipalities 22% suffered from flooding and/or inundation during 1998-1999. The majority of these occurred in the Southeast (539), South (356) and the Northeast (238) regions. Table 1.1 summarises the main causes of flooding according to these municipalities.

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1.2.3 Urban storm water management

To reduce the (impact of) floodwaters many interventions are possible, ranging from technical, to educational, economic and legislative measures. The relations between cause and effect typically are complex and typically, any intervention has many effects. Moreover, not any intervention imaginable is possible, and not all possibilities are feasible, technically, socially, economically or otherwise.

Conventional solutions to urban drainage are to canalise watercourses and to invest in drainage works. These kinds of works increase peak flow and the frequency of storm runoff without addressing the main problem, which is lack of control over storm runoff at source, caused by impermeable surfaces, which prevent infiltration. This kind of thinking is called the sanitary philosophy, in contrast with the sustainable model, in which detention and infiltration works provide control of runoff at source, thereby avoiding both generation of
large volumes of surface runoff and the very high discharges caused by accelerated flow in the storm sewers network of closed conduits and channels.

1.2.4 **Sustainability in urban water management**

From research of the TU Delft (Rijsberman, 2004) appears that a sustainable development not only can hardly be defined because it can differ from case to case (it has to be made to measure), but it also appears that when in a specific situation different people interpret sustainability, different results are produced. This subjectivity in sustainable development is not widely recognised. The subjective character is due to the fact that developing sustainable levels of performance involves trade-offs and choices, because resources and technical possibilities are limited. Often it is not possible to tell if one solution is more sustainable than the other. This certainly is the case when the different solutions are compared not only on environmental aspects only, but for example also on social or spatial aspects.

**People and environment**

According to Rijsberman (2004), the choices made in the elaboration of sustainable development are either people-driven or environment-driven, or weak and strong sustainability. In a people-driven approach, people and their desires, needs and objectives are the driving forces behind the perception of sustainable development. People and their desires, needs and objectives are leading and dominate the interaction with the environment: weak sustainability. In an environment-driven approach the environment (or nature), with its possibilities and limitations, is the driving force behind the perception of sustainability and the elaboration of sustainable development. The possibilities and features of the environment (i.e. of nature) have an intrinsic value that cannot be ignored. The perspective is ‘care for the environment’. Human objectives and conduct are adapted to the properties of the environment, not the other way around. The boundaries and possibilities of the environment dominate human conduct: strong sustainability.

**Norms and values**

Besides the attitude of people towards their environment, the way in which people evaluate this relationship or interaction is important to the approach to sustainable development. Again, two contrasting approaches can be distinguished; (1) a quantitative approach based on norms and standards and (2) a qualitative approach based on values.

The standards-approach assumes that figures can be established to measure the achievement of the system. These standards can be derived from the properties of the environment or from the objectives for the system, dependent on if a ‘men’ or an ‘environment’-approach is used.

Critics of the standard-approach state that these figures are not ‘devoid of value judgements’: standards are always an expression of a desired image of the reality, hence it is subjective. Contrary to the standard-approach the values optic does not exclude not or very difficult measurable objectives or criteria: the objectives being measurable is no condition.

**Basic approaches to sustainable development**

Combining the extremes of the two dimensions results in four combinations, representing basic approaches. The two dimensions are plotted in figure 1.4, showing is a division in four quadrants, each representing a basic approach. These basic approaches are extremes (in practice many gradations exist):

1. norms-oriented & environment-driven: carrying capacity approach
2. norms-oriented & people-driven: ratio approach
3. values-oriented & people-driven: socio approach
4. values-oriented & environment-driven: eco approach
Towards sustainable planning and design of stormwater control solutions in Brazil

1.2.5 Sustainable urban water management in Brazil

Brazil is a country passing through a transition phase towards more sustainable urban water management. Some regional capitals have developed management plans for urban drainage together with appropriate legislation, starting from the premise that newly urbanised spaces should not increase natural surface runoff, and that urban drainage must be integrated with planning the urban environment of cities, instead of being simply an engineering problem.

Municipalities in Brazil have a legal obligation to produce an Urban Drainage Master Plan (Plano Director de Drenagem Urbana). This is the mechanism through which municipalities develop strategies and plans to implement urban drainage infrastructure, and the objective of the urban drainage master plan is to create a mechanism for the management of urban infrastructure related to stormwater drainage and of the natural drainage channels in the city.

Traditional master planning has generally failed to address problems adequately and the implementation of these plans has tended to rely on large-scale costly infrastructure projects, which in some instances have attributed to the worsening of problems, as the stormwater is drained rapidly resulting in the exacerbation of downstream flooding. As a result of the inadequacies of traditional responses, combined with increasing awareness of the need for integrated approaches, a new generation of urban stormwater master plans is currently emerging in Brazil.

Integrated urban drainage management planning is based on the goals and objectives related to the well being of the population and environmental conservation. An Urban Drainage and Flood Control Master Plan (UDMP) is developed in order to reduce flood risks based on urban space, hydrological conditions, hydraulic network and environmental conditions.
The main goals of integrated urban drainage management usually are:
- Regulation of the use of floodplain areas through legislation and other non-structural measures;
- Prevention and relief measures for low frequency floods;
- Improvement in the urban drainage water quality.

For interventions to be effective and sustainable, both structural and non-structural strategies are considered as complimentary elements in the plan development process. The non-structural measures may be included in the county legislation or in the city building code.

1.3 The case study

1.3.1 Introduction
Experience with the development of Urban Drainage Master Plans showed that institutional and strategic/communicational aspects are essential for the success of the plan and thus deserve special attention. The plan development process in the city of Porto Alegre is a relevant example of that process. This is the main consideration to select the Urban Drainage Master Plan of Porto Alegre as the case study for this master thesis. Other criteria are that the main actors in the process were very willing to cooperate, and that a lot of project data was available.

The case study plays an important role in the thesis, because it can help to improve the approaches for planning and design methods of Urban Drainage Master Plans.

1.3.2 Study area description

The urban system
Porto Alegre is the capital city of Brazil’s southernmost state, Rio Grande do Sul (figure 1.5). In 1973 the Metropolitan Area of Porto Alegre was defined. That fact reflected the municipal district’s new situation, whose urban planning started counting an entire area where the centre is the capital. Porto Alegre surpassed the physical and administrative limits and its interaction to the neighbouring municipal districts revealed the need for co-operation.

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Figure 1.5 Location of Porto Alegre, Brazil
Towards sustainable planning and design of stormwater control solutions in Brazil

The Porto Alegre region is surrounded by four geomorphological features. To the north is a plateau (planalto meridional), with a steep escarpment intersected by ravines and altitudes of up to 1,298 metres. To the south, the highlands of the Rio Grande do Sul Shield (planalto do Escudo Sul-Rio-Grandense) has diverse relief formations and heights of up to 599 metres. Between these two highland regions, a narrow fluvial plain (depressão periférica) extends westwards to the Gran Chaco of Bolivia and Paraguay to the north and the Argentine Pampas to the south. To the east is the South Atlantic coastal province (provincia costeira), formed by an extensive sand barrier enclosing the world’s largest lagoon and containing numerous lakes, among them Lake Guaíba, which borders Porto Alegre to the east. The forms of relief from the city county are depicted in figure 1.6.

Porto Alegre is located inside of a river delta basin of about 80,000 km². The city covers 26 drainage basins. It is protected by a system of dykes, storm water and pumping stations designed and constructed before 1970. The city developed from downstream to upstream.

Porto Alegre itself has a population of 1.3 million inhabitants. It covers an area of 470 square kilometres, 40 per cent of which is urban and 60 per cent rural. Porto Alegre and 14 other municipalities make up the wider metropolitan area, which has a population of approximately 3.5 million. Urban development in Brazil concentrated in metropolitan areas; the population grow rates of Porto Alegre are represented in table 1.2. The largest grow rates happened in the 1950 to 1965 period. According to table 1.2 the population of the city is almost totally urban.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total [1000]</th>
<th>Urban [1000]</th>
<th>Rural [1000]</th>
<th>Growth</th>
<th>Period</th>
<th>POA [%]</th>
<th>MA [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>1.125,5</td>
<td>1.114,8</td>
<td>10,6</td>
<td>1960-1970</td>
<td>3,3</td>
<td>4,2</td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>1.263,4</td>
<td>1.247,5</td>
<td>15,8</td>
<td>1970-1980</td>
<td>2,4</td>
<td>3,8</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>1.270,1</td>
<td>1.258,2</td>
<td>12,8</td>
<td>1980-1991</td>
<td>1,06</td>
<td>2,55</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>1.296,1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>1.312,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

May 2005
The drainage basin of Arroio da Areia

The Areia basin is located in the north of the city. It covers an area of 20.85 km², of which approximately half corresponds to the basin of Arroio da Areia, i.e. about 11.7 km² and the rest belongs to the Airport polder. The Arroio da Areia has an extension of 5.4 km and it descends 121 meter to the pumping station Silvio Brum. Figure 1.7 represents the entire Areia basin, the Airport polder included.

As for soil conditions, the planning area can be divided in three parts. The higher grounds on 'Morro Petrópolis' that are a formation of broken granite rocks, the sloping grounds that consist of a matrix of stones combined with silt and mica, and the lower grounds that are a fluvial deposition.

The urban occupation of basin developed from downstream to upstream, being more dense at the top. The lowest part of the basin is a reserved zone for new developments, where the main industrial activities are located. The higher grounds experienced a process of dense urbanisation from the eighties onwards, but there still are some undeveloped areas and lots. Figure 1.8 shows the urban occupation of February 2003.

The basin is naturally drained through the main stream Arroio da Areia that receives water from various smaller canals along its course, among others the Canal Assis Brasil, Carneiro da Fontoura, Menna Barreto and Cerro Azul. The drainage originates from six springs in the mounts Rio Branco and Petropolis. The longitudinal profile of the main water course and the hypsometric curve of the Areia basin are depicted in respectively figure 1.9 and 1.10.
The main drainage network runs in general below the street grid, except for a small part that intersects a housing block and passes under the foundations. The drainage system in the basin of Arroio da Areia can be divided into two distinct systems: one drained on the basis of...
gravity and the other drained by the pumping station Silvio Brum. The areas with a level above 8.13 meter are drained by closed conduits, while the pumping station drains an area of 139.2 ha that is below the level of 8.13 meter. In the end the drainage from the upstream basin flows inside a pressure pipe (which is located below the airport lanes) up to the Jacui Delta. A pumping station serves to drain the lowest basin ('Polder Aeroporto'). The lay-out of the macro drainage network in the basin of Arroio da Areia is represented in figure 1.11 and cross-sections of the conduits in figures 1.12 and 1.13. In the entire basin with the exception of Higienópolis the rainwater as well as the waste water is removed through one system of conduits (figure 1.14).

Figure 1.11 Layout of the macro drainage network in the basin of Arroio da Areia
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Figure 1.13 Cross-section of the circular conduits

Figure 1.12 Cross-section of the rectangular conduits

Figure 1.14 Sewerage water system in Areia basin

May 2005
1.3.3 **Floods**

The actual capacity of the urban drainage in some parts of the Areia basin is not enough to discharge the upstream increase in flood peak and volume as a result of the urbanisation process. The heaviest inundations happen on the intersection of the roads ‘Nilo Peçanha’ and ‘Texeira’. On this point that is the lowest of the region the drainage system, which transports the water to the ‘Arroio the Areia’, overflows and inundation levels can reach one meter. Previous floods had resulted in damage to property and even in the loss of life. In 1986 a flood run off carried away a car occupied by a doctor and his two sons, killing them. Whereas in 1998 a five-year-old child lost his live due to the contact with the fast flowing water. And quite recently, in 2003, another car was dragged along the stream, its occupants fortunately being rescued (figure 1.15).

![Figure 1.15 Flood in ‘Nilo Peçanha’ street (2003)](image_url)

In the Urban Drainage Master Plan of Porto Alegre the occurrence of floods is simulated with the help of the cinematic model IPHS1 and a hydrodynamic model. For that purpose the basin of Arroio da Areia was divided into 11 sub-basins (figure 1.11) and study scenarios were created on the basis of actual occupation and the predicted occupation according to Porto Alegre’s urban development master plan. The simulation of the existing scenario showed that the drainage systems in the Areia catchment is underdesigned in a number of different sections and, as a result, a number of areas were observed to be flooded with design storm of a two year return frequency. Based upon the future growth scenario, the hydraulic limitations of the system will become increasingly critical in future urban development scenarios. Figure 1.16 shows the locations of bottlenecks in the drainage network with insufficient capacity according to the simulation results on the basis of a storm event with a return period of 2, 5 and 10 years and the actual scenario conditions.
1.3.4 The Plan for the Areia basin

Control Alternatives
In order to reduce the occurrence of urban floods a number of drainage solutions is considered and compared. The control alternatives are:
1. Expansion of the pipe capacity along the major drainage system to discharge all the run-off generated by a storm with a return period of 10 years;
2. Construction of reservoirs along the basin to detain the peak run-off from a rainfall event with a return period of 10 years (figure 1.17);
3. A combination of the previous alternatives.

A preliminary cost estimate showed that the implementation of alternative 2 would not be totally satisfactorily due to the high costs involved in the construction of reservoir 06 (sub basin C) as a result of the large difference between ground level and the actual level of drainage network, which implies gigantic excavation volumes. For that reason an
intermediate alternative is developed that foresees only an expansion of the pipe capacity in sub basin C.

Figure 1.17 Possible locations for reservoirs and chosen locations (dark circles)
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Environmental impacts
According to the hydrographs of figure 1.18, the peak flow in conduit 34 would increase up to 140 m³/s for alternative 1. Using detention ponds in the major drainage system (alternative 3) represents a 63% lower peak flow.

![Figure 1.18 Hydrographs for the 3 control alternatives (conduit 34)](image)

Economic evaluation
Table 1.3 shows the costs estimate for the expansion of the pipe capacity along the major drainage system. The costs for expansion of the main stream Arroio da Areia are divided between the sub basins. The total costs for the expansion of the closed conduits of the Arroio da Areia are R$ 16,3 million. The exchange rate of the Brazilian Real Dollar against the Euro is about 1:3.

<table>
<thead>
<tr>
<th>Alternative 1</th>
<th>Works</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expansion of pipes in sub basin A</td>
<td>R$ 7.176.110</td>
</tr>
<tr>
<td></td>
<td>Expansion of pipes in sub basin B</td>
<td>R$ 3.884.015</td>
</tr>
<tr>
<td></td>
<td>Expansion of pipes in sub basin C</td>
<td>R$ 6.186.928</td>
</tr>
<tr>
<td></td>
<td>Expansion of pipes in sub basin D</td>
<td>R$ 16.582.281</td>
</tr>
<tr>
<td></td>
<td>Expansion of pipes in sub basin F</td>
<td>R$ 5.859.943</td>
</tr>
<tr>
<td></td>
<td>Expansion of pipes in sub basin G</td>
<td>R$ 5.735.213</td>
</tr>
<tr>
<td></td>
<td>Expansion of pumping capacity Silvio Brum</td>
<td>R$ 11.269.230</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
<td></td>
<td><strong>R$ 43.105.094</strong></td>
</tr>
</tbody>
</table>

The costs of alternative 2 (implementation of reservoirs) are listed in table 1.4. This alternative does not imply works on the closed conduits of the main stream Arroio da Areia. And it refrains from misappropriate investments in works mainly in the Country Club and on the pumping station Silvio Brum.
Table 1.4 Costs for alternative 2 (price level of December 2001)

<table>
<thead>
<tr>
<th>Alternative 2</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Works</td>
<td></td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin A</td>
<td>R$ 3.304.324</td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin B</td>
<td>R$ 1.258.702</td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin C</td>
<td>R$ 6.269.045</td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin D</td>
<td>R$ 8.429.648</td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin F</td>
<td>R$ 1.121.269</td>
</tr>
<tr>
<td>Diversion of pipes in sub basins G and H</td>
<td>R$ 5.007.530</td>
</tr>
<tr>
<td>Reservoir in Country Club (sub basin E)</td>
<td>R$ 1.602.682</td>
</tr>
<tr>
<td>Reservoir and pipes in pumping station Silvio Brum</td>
<td>R$ 6.739.965</td>
</tr>
<tr>
<td>Total costs</td>
<td>R$ 27.013.753</td>
</tr>
</tbody>
</table>

Alternative 3 that contains works of the two previous alternatives, seeks to utilise the cheapest works of the two alternatives, with minimum alterations to the main stream of Arroio da Areia. Table 1.5 points out the costs involved in this alternative.

Table 1.5 Costs for alternative 3 (price level of December 2001)

<table>
<thead>
<tr>
<th>Alternative 3</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Works</td>
<td></td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin A</td>
<td>R$ 3.304.324</td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin B</td>
<td>R$ 1.258.702</td>
</tr>
<tr>
<td>Expansion of pipes in sub basin C</td>
<td>R$ 2.606.431</td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin D</td>
<td>R$ 8.429.648</td>
</tr>
<tr>
<td>Reservoirs and pipes in sub basin F</td>
<td>R$ 1.121.269</td>
</tr>
<tr>
<td>Diversion of pipes in sub basins G and H</td>
<td>R$ 5.007.530</td>
</tr>
<tr>
<td>Reservoir in Country Club (sub basin E)</td>
<td>R$ 1.602.682</td>
</tr>
<tr>
<td>Reservoir and pipes in pumping station Silvio Brum</td>
<td>R$ 6.739.965</td>
</tr>
<tr>
<td>Total costs</td>
<td>R$ 23.351.137</td>
</tr>
</tbody>
</table>

Recommendations
A first analysis of the costs involved in the 3 alternatives learns that alternative 1 represents a total sum that is 60% higher than alternative 2 and 85% higher than alternative 3. Alternative 2 is about 15% more expensive than alternative 3.

Besides a monetary advantage, it can be observed that alternative 3 has a smaller environmental impact than alternative 1, because it preserves the stream of the Arroio da Areia in its natural conditions and does not transfer the problems to downstream sections.

On the basis of the above-mentioned advantages the implementation of detention ponds as foreseen in alternative 3 is proposed as the recommended alternative.

1.4 Problem description and research objectives

1.4.1 Problem description
Urban floods in the Areia basin led to loss of life in 1986 and 1998. Besides flood damage caused considerable economic loss. A solution for the problem was discussed for many years, without any corrective measures being implemented. Finally in 2002 local mitigative measures were proposed in the Areia Plan that included the implementation of 11 detention ponds. However the implementation of the Plan is currently failing and a complex management problem emerged. As a consequence structural interventions are held up in spite of the tragic impacts of the local floods.

Absence of public support for the Plan seems to be one of the main reasons why the implementation is failing. Public support may be missing for practical reasons and/or because of miscommunication between actors. In order to look after their interests the organised inhabitants of two neighbourhoods have consulted the Public Ministry. Similar actions that
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are opposing to the solution direction are often based on NIMBY (not in my backyard) interests.

Another reason for the failing implementation process seems to be a lack of financial resources. Using detention ponds in the major drainage system would cost US$ 8 million. This requirement is well beyond the financial capacity of the responsible municipal authority (Departamento de Esgotos Pluviais), which works with a total annual budget of about US$ 2 million.

In spite of the fact that detention ponds are already applied in a number of Brazilian cities and that considerable experience on the principle is available from developed countries, the implementation in the Areia basin brings about major questions. Questions that have much significance to the inhabitants as the ponds are planned in public open spaces and multi-objective use of those areas is foreseen. ‘How frequent do the reservoirs inundate? What are recreational or other open space opportunities between storm runoff events?’

The lack of insight in the functioning of the structures creates a perception among the population that unacceptable risks are involved in applying the detention concept. As a consequence many people feel the desire to keep constructing drainage pipes, thereby ignoring the elements of sustainability.

The conflict on the urban drainage solutions became an important topic in the municipal elections of 2004. About 25 percent of the city councillors supported the detention concept and a similar percentage was against.

1.4.2 Research question
A key question in this study is:

How was the policy development in Porto Alegre organised, which factors were detrimental for the unsuccessful implementation of the mitigative stormwater control solutions, and what can be learned from the case study and methods in the Netherlands to improve the approaches for planning and design of Urban Drainage Master Plans?

1.4.3 Approach
In order to find an answer to the research question, this study reviews in the first place the problems that Brazil is currently facing in the sector of urban stormwater management, and the conditions under which it occurs.

Secondly, the main approaches for planning and design will be briefly discussed. A method for ex-post evaluation of the planning and design of urban water systems will be presented and applied to the case study in Porto Alegre. The evaluation should provide information and insights on critical aspects for the success of the Urban Drainage Master Plan.

A third step is to test and assess the functioning of the detention facilities in the study area to allow for a resolution of the problems in Porto Alegre.

The final step of this study is to provide lessons for more sustainable approaches to planning and design of stormwater control solutions in Brazil based on the results of the case study and methods in the Netherlands.
1.4.4 Objectives

The overall objective of this study is:

To improve the approaches for the planning and design of stormwater control solutions in Brazil, through the evaluation of a case study, focussing on both content and process.

The specific objectives of this study are as follows:

1. To identify urban drainage issues in Brazil; socio-economic, institutional, and technological factors in developing countries make it more difficult to solve problems of urban drainage than in developed countries.

2. To evaluate the planning and design of the Plan for the Areia basin. The ex-post evaluation should reveal shortcomings and strongpoints of the followed approach. Rijsberman (2004) has developed a method (3D-bril) that is useful as an assessment framework, focusing on relevant criteria concerning content and process.

3. To allow for a resolution of the problems in Porto Alegre by testing the functioning of the detention facilities in the study area.

1.5 Outline of this thesis

This thesis will be presented in three parts.

Part I (Chapters 1 trough 3) consists of this introduction and a discussion of important background information on urban stormwater management in Brazil.

In part II (Chapters 4 trough 6) an assessment framework for ex-post evaluation of the planning and design of the Areia Plan is presented and applied. On the basis of the evaluation analyses are made that can help to improve the planning and design approaches for the Brazilian perspective.

Part III (Chapters 7 and 8) consists of the testing and assessment of the functioning of the structural measures in the study area. Results for the verification are used to find a more acceptable solution.

Finally, chapter 9 summarises the observations and conclusions of the study resulting in a list of guidelines to improve the approaches for the planning and design of stormwater control solutions.

Figure 1.19 shows the relationship between the different chapters and parts.
Towards sustainable planning and design of stormwater control solutions in Brazil

Figure 1.19 Schematic outline of this thesis
2

URBAN DRAINAGE ISSUES IN BRAZIL

2.1 Introduction
The practice of urban drainage in developing countries such as Brazil encounters more serious problems than those of developed countries, because urban development occurs under more difficult socio-economic, institutional, technological and climatic conditions. Urban drainage management requires in the first place an understanding of these conditions.

2.2 Social aspects

2.2.1 Rapid urban development
Although the rate of urbanization has decreased in recent years, Brazil has undergone rapid urban development over the past 20 years and the country is characterized by one of the highest levels of urbanisation in the world; the percentage of urban population is currently greater than 80% – an increase of more than 15% in the past 20 years (United Nations, 1999). The urbanization process, caused by a large growth in the urban population, has resulted in the growth of larger metropolitan areas, which consist of a main centre and several neighbouring towns, as well as regional centres and many smaller urban centres.

In particular, the pattern of urban growth has been characterised by irregular and haphazard expansion of the peripheral areas, which have paid little attention to existing urban land control and planning regulations. Many cities have grown in a disorderly manner and have developed with insufficient consideration of the impact of urbanization on stormwater runoff. Many developments have been constructed in a way that has ignored natural hydrological characteristics. Urbanization increases the hydrograph peak and overland flow volume, and decreases the time of concentration of runoff. This has resulted in widespread flooding problems in the urban environment caused by inadequate urban drainage systems, which causes localized flooding and the increased runoff from upstream catchments which can result in inundation of settlements on floodplains and riverbanks.

An indirect method of evaluating the impact of urbanisation on drainage is to relate population density with the extent of impermeable cover, which in its turn is directly correlated with runoff coefficients. Figure 2.1, developed for Porto Alegre with data obtained by Silveira (2000) and Campana and Tucci (1994), shows a runoff coefficient that increases to 60% when the population density is approximately 100 inhabitants per hectare, which corresponds to an imperviousness of 50%.

![Figure 2.1 Population density and runoff coefficients](image-url)
2.2.2 Clandestine urban development

Besides the problems of stormwater runoff control in legal settlements, socio-economic problems lead to unregulated developments, invasion of public areas, and occupation of risk areas.

In peri-urban areas of big cities the real estate is low priced. Regulation of these areas requires investments, which have almost the same price as that of the land. As a consequence private landowners develop urban areas without infrastructure, selling it to the low-income population.

Furthermore the homeless often invade public areas that were planned in Urban Master Plans for future parks, public construction and even streets. Due to low income conditions and slow decision making by the public administration these developments are consolidated, receiving water and electricity, and slums are formed with high population density and high rates of impermeable soil surface.

Also, informal settlements develop on marginal land, such as low-lying land adjacent to rivers or steep slopes, which are undesirable for other types of urban development. Due to their location and the topography these areas are either prone to flooding on flood plains or at risk from landslides on hillsides during storm events. Hillsides that are denuded of vegetation contribute towards increased runoff and are also a source of increased pollutant and sediment loads into downstream drainage and receiving watercourses.

2.2.3 Sediment production

Urban areas in developing countries have significant proportions of exposed soil liable to erosion and giving rise to large quantities of sediment that, sooner or later, reaches the urban drainage system. The two main producers of sediments in urban areas are unpaved street surfaces and construction sites. Building sites, whether in areas where the city is expanding or within the developed urban area, do not normally have controls for erosion prevention or for retaining sediment so that it does not reach the streets, storm drains and urban rivers. It is no exaggeration to say that 10 to 15% of urbanised area in developing countries contributes extensively to sediment production and transport.

Based on a table given by Dunne and Leopold (1978), which collected results from a number of studies, sediment production by urban building sites has levels in the range that corresponds to roughly 20.000 - 40.000 m$^3$ km$^{-2}$ yr$^{-1}$. For 10% of building sites without sediment control within an area, the overall production of sediment would be about 2.000 - 4.000 m$^3$ km$^{-2}$ yr$^{-1}$. This is the order of magnitude of sediment production in the best-documented case in Brazil, Lake Pampulha in Belo Horizonte (sediments recorded from 1957 to 1994) calculated as 2.436 m$^3$ km$^{-2}$ yr$^{-1}$ by Oliveira and Baptista (1997), cited by Tucci (2001). The sediment production per capita in the Lake Pampulha basin (95 km$^2$) is equivalent to 2 kg per person per day. More extensive data from areas with greater
population densities suggest a mean rate of uncontrolled sediment production, in developing-country urban areas, of between 0.5 and 1 kg per person per day. The contrast with developed countries is seen by comparing these figures with that given in an example by Schueler (1987), as 67 tons/yr over 106 acre (~ 120 m\(^3\) km\(^{-2}\) yr\(^{-1}\)).

### 2.2.4 Solid waste production

One of the main causes of flooding in urban drainage is the decreased hydraulic capacity of stormwater drainage due to trash filling conduits and channels during periods of intensive rainfall. Solids entering the drainage network are mainly due to garbage washed away from urban surfaces. The washoff of total solids is a function of the garbage accumulation in the streets and the rainfall intensity. The amount of garbage that can accumulate in the streets depends on the public disposal of garbage, the frequency of garbage collection and cleaning of street surfaces, and the rain frequency. Garbage production in Brazil is about 1.0 kg/person/day, of which a part is dumped on the streets. This is a result of the lack of knowledge and care about the environmental impacts by most of the population, because of insufficient environmental education. Other problems related to total solids are a lack of a reliable garbage disposal system or a lack of street cleaning or its low frequency.

In addition, poor people living in areas with run-down public services use the storm-drain network for garbage disposal, as they tend to pay little regard to all that is public. Even where garbage collection is established, if other public services do not exist the situation may not change, with the dumping of garbage in gutters seen as a kind of environmental vandalism in response to the continued urban degradation from other unsolved problems (densely inhabited areas of shacks, lack of drains for sanitation, lack of paved streets and public transport). It can be predicted that many years will be needed to transfer to such communities a proper concern for the environment and for the sustained preservation of streams and public areas.

![Garbage and sediments in main drainage system (Dilúvio basin, Porto Alegre)](image)

**Figure 2.3** Garbage and sediments in main drainage system (Dilúvio basin, Porto Alegre)

### 2.2.5 Lack of public awareness and participation

Within Brazil there is a strong public perception of water issues: in Belo Horizonte the representative of the public in the county budget, selected the Urban Master Plan as the fifth investment among 34 in the city budget for 2000. However the impacts and causes of urban drainage are not clearly understood by the population. Due to current policies in urban drainage the main impact is transferred downstream, and the upstream population, which
creates the source of the impact, is not the one that suffers from the impacts. As a result there is a lack of awareness among the upstream population.

As a consequence of the lack of awareness there is a need for greater participation on the development and implementation of stormwater management plans. The potential benefits of participation are widespread which, at one level may increase awareness about the issues of stormwater management and therefore promote greater public responsibility towards urban drainage problems, and, at another level, the involvement of communities may promote more sustainable solutions and lead to greater impacts of programmes. The participation of communities is especially relevant to the provision of infrastructure and services for informal settlements (Imparato and Ruster, 2003).

Lack of community participation leads to the repetition of earlier errors in solving drainage problems, to the discredit of public action, and lack of concern with environmental questions. It can also bring about low investment in urban facilities. Lack of community participation can be a result of two factors: (a) absence of the desire and ability of people to organise themselves, and (b) absence of channels of direct communication to the municipal administration.

2.3 Environmental aspects

2.3.1 Climatic factors

Brazil is a very large country of approximately 8.5 million km2 stretching from latitude 10° N in the north to 35° S in the South. However, the bulk of the country lies between the equator and 25° S. Convective rainfall, characterized by high rainfall intensity and short durations, is the predominant type of rainfall in Brazil, but there are significant regional and seasonal differences (Tucci and Porto, 2001). Over most of the tropical regions there is a well-defined seasonal cycle of precipitation, with precipitation exceeding combined evaporation and evapo-transpiration, with a less clear range in the temperature field (Dias, 2001). Based upon a rainfall time series of 20 years, figure 2.4 illustrates the significant differences in mean maximum rainfall intensities of one-hour duration between the humid tropics and regions between the latitudes of 20° S and 30° S. From this, it can be seen that the mean values in the Humid Tropics for that duration are approximately 10 mm/h greater than the cities outside of this region. On average, it is observed that the return periods of rainfall in temperate South are 25% more than the tropical areas in the North of the country.

![Figure 2.4 Comparison of mean maximum rainfall intensity in humid Tropics and 20-30° S](image-url)
Towards sustainable planning and design of stormwater control solutions in Brazil

Figure 2.5 shows the average peak 24-hour rainfall intensities recorded in Brasília (16° S), Porto Alegre (30° S) and São Paulo (23.5° S) over a period 1995-2001. This data illustrates the widespread seasonal differences in rainfall in different parts of Brazil. This has significant influences on the design of urban drainage systems as peak intensities are generally the main cause of flooding – although the return period of rainfall events does not determine the return period of floods.

![Rainfall intensity chart](image)

Figure 2.5 Maximum monthly 24-hour rainfall intensities from 1995 - 2001

The most important climatic factor is the high rainfall of the humid tropics, in terms of volume, number of days with rain, and rainfall intensity. The intensities of storms lasting less than one hour (giving runoff events with similar concentration times) are significantly greater than in temperate latitudes, and this greatly increases peak discharges and the volumes flowing into drainage networks during critical periods. Structures are therefore more expensive to build.

The larger volumes of runoff, and greater frequency of days with rain, are such that for some cities in the humid tropics it is not only the extreme rainfall events that determine the size of drainage works, since less-extreme events (which often have rainfall intensities higher than the most intense storms of temperate latitudes) can be decisive in terms of design criteria.

Higher temperatures throughout the year allow the development of many diseases related to water such as malaria, yellow fever, dengue (the host mosquito develops in warm climate in storage without pollution) and schistosomiasis (the host develops in lakes, such was observed in the urban lake of Pampulha in Belo Horizonte).

2.3.2 Pollution of natural environment

Rivers receive high loads of organic and industrial pollution from urban conglomerations and their surrounding regions, due to absence or low efficiency of wastewater treatment. The cities of Brazil show that there can be great variation in levels of treatment, with some large cities without any treatment (Belo Horizonte), others with low treatment levels (Porto Alegre with 15%, São Paulo with 25%), while Brasília stands out with 64% of its sewage treated. These figures do not include treatment in septic tanks because in general such treatment is inadequate in practice. For every 100 thousand inhabitants discharging untreated sewage into the environment, there are 200 or 300 l s⁻¹ of highly polluted discharge.
Groundwater aquifers are polluted via leakage and infiltration from the sanitary drainage system.

2.4 Engineering aspects

2.4.1 Inappropriate approaches to drainage design
The majority of drainage designs are based upon the principle of rapid conveyance of runoff through drainage channels. However, this often exacerbates downstream flood problems. In addition, this technically outdated approach also convinces the population to follow the same ideas in their urban private properties by making their patios and other areas impermeable. The flood problems are further aggravated by the fact that in many cases sanitary concept is poorly implemented through bad design, bad construction or deficient maintenance. In the cities, for example, it is common to see drain gratings that are badly positioned and blocked, and eroded gutters: all of which contributes to inadequate drainage management and design (figure 2.6).

![Figure 2.6 Partly blocked stormwater inlet (Porto Alegre)](image)

2.4.2 Contamination by foul sewage
Pollution of urban streams and of the storm-drain network by foul sewage results from the diffuse contribution from areas without sewers and from discharge from foul drains where these do not lead to a treatment plant. The former case is common in slums or poor districts, while the second occurs in any part of the city. Some of the sewage network is commonly linked to the storm-drain network either with or without official recognition. There are also cases where storm sewers are used for domestic waste disposal. Many cities with separate sewers succeed in passing on the pollution to areas outside city limits (the sea, or large rivers) but even so areas without foul drains or with combined sewers (collecting overflow from heavy rains) end up by polluting rivers within city boundaries. In general it is expected that storm runoff in developing countries has higher pollution indices in terms of organic material and coliforms. The contrast between Porto Alegre (Ile, 1984) and American cities (USEPA, 1983) is remarkable: Porto Alegre had a BOD of 32 mg/L and 15,000 thousand coliforms per 100 ml, whilst on average American cities had BOD of 9 mg/L and only 21 thousand coliforms per 100 ml.

2.4.3 Lack of data
In urban areas of Brazil hydrological data are usually not available, and the existing information consists mainly of rainfall data, level and discharge, but water quality and sediment records are rare. This situation is mainly due to the following.
- The hydrological networks are designed for major rivers and for water resources development such as energy.
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- Costs for a systematic water quality record are high.
- Urban drainage management is usually done by the counties administration, which does not have the funds and capability to deal with a hydrological network.
- Most investments in developing countries come from international funds that usually have short-term goals. These projects usually do not invest in information, which could give support to better projects and decisions.
- Urban basin flows present high variation in time, which requires appropriate equipment and special operational procedures to obtain rating curves and water quality sampling.
- Land use change is very rapid and requires a continuous update of the basin cover and drainage networks.
- Operational costs of an urban network hydrological network are very high due to environmental modification.
- Environmental changes in the basin and in the networks could closedown or move hydrological gauges.

A lack of sufficient data of adequate quality can cause urban drainage systems to be under-designed, resulting in lack of sufficient capacity, or over-designed, resulting in projects with higher costs.

2.5 Economical aspects

2.5.1 Lack of funding

Urban drainage management is done by the municipal government. Municipalities are autonomous from the federal and state governments. The autonomy has an administrative, a financial, and a legal dimension. The municipality's legislative council and executive are directly elected; the municipality has the right to levy specific revenues and has freedom in allocation of resources; it also has the right to make its own arrangements for the internal organisation and the provision of services, such as sanitation and drainage. However, in practise municipal autonomy is threatened by local financial weakness. As a result of high personal costs and large expenditures on urban poverty reduction, municipalities usually do not have sufficient funds to supply and maintain the basics of sanitation and drainage.

2.5.2 Large differences in population income

The distribution of a city's income in Brazil is extremely unequal and marginal neighbourhoods developed in the cities, especially in the outlying areas. The phenomenon is due to the incorporation of new production technologies, which resulted in a drop in employment opportunities at specific product levels and a call for substantially greater knowledge and higher qualifications for employment candidates. A vicious circle was thus developed between unemployment and limitations to the access of knowledge, which is the principal growth factor of marginal neighbourhoods in large cities, where housing, sanitary and environmental conditions are extremely precarious.

For example, in Porto Alegre, a relatively wealthy city, the per capita income in 1991 was US$ 369 per month. But the distribution of the income is rather unequal, though less than in other parts of Brazil. In 1990 8.6% of Porto Alegre's population received an income up till one minimum salary, and 27.9% up till two minimum salaries. On the other hand, 5.3% received more than 20 minimum salaries. The population living under the poverty line in Porto Alegre was estimated to be 22.5% in 1985 (Mirjam Zaaijer, 1995).

Large differences in population income lead to illegal occupation of public or private areas (see paragraph 2.1.2). And no or insufficient education resulted in lack of awareness and participation (see paragraph 2.1.5).
2.6 Efficiency aspects

2.6.1 No coherent policies

Often stormwater management plans are not implemented and operated effectively, because a supportive institutional environment is lacking or because policies for both structural and non-structural drainage strategies are inappropriate. Results from a recent research study undertaken in the State of Minas Gerais (Gomes et al., 2003), involving 85 municipal districts with populations from 20,000 till 2 million, (with diversified socio-economic levels which are considered to be representative of Brazilian conditions) showed that 35% of the municipalities do not possess any technical agency with the responsibility for the urban drainage. In addition to this, less than 40% of the municipal districts consider that they have the technical capacity and resources to tackle the problems effectively. Concerning management arrangements, Pompêo (2000) recognises that independent from the institutional arrangement, it is necessary to recognize that urban drainage is part of a management system and not only sparse flood control engineering works defined after a problem arises.

2.6.2 Ineffective institutional frameworks for implementation

In Brazilian cities there is a widespread lack of resources for regulation or unrealistic regulation. For example, in metropolitan areas several townships use to cover a water catchment area. In general those townships that are in the upstream areas of a river system or catchment area have no interest in exerting any rigid control, because the impact occurs downstream of the city and beyond its jurisdiction. In this case there is a need for state or federal intervention.

An example of unrealistic regulation, which failed to take economic pressures into consideration, is the legislation on water-collecting basins in the city of Curitiba. Urban development had, to a certain extent, encroached on preserved areas for urban water supply and increased their real-estate value. The law that sought to preserve basins from population settlement so as to safeguard the water resources did not allow water-collecting basins to be settled and obliged the owner of the land to pay tax on it. What happened was total civil disobedience, since an owner would simply abandon his land, which would be invaded by low-income families. Sometimes an owner would even organize the invasion himself in order to break down the regulations and sell the land to the municipality as a social solution (this usually occurred during election years, when the political pressure was greater). The result was the worst possible, since clandestine settlements, without any structure, would occupy water catchment areas, causing contamination of the water. And there was no law enforcement by the administration since the process was very quickly when started.

2.6.3 Lack of coordination between different agencies

Other institutional problems relate to a lack of coordination between different agencies and organisations with vested interests in urban drainage. Research undertaken by Gomes et al. (2003) showed that 75% of the municipal authorities considers the importance of integration of urban stormwater management with other aspects of urban infrastructure. To integrate the management of solid waste collection and disposal services under the same institutional authority, which is responsible for urban drainage is considered to be particularly important as stormwater drainage systems are frequently blocked by solid waste. This has been carried out in the municipality of Santo André, which has assigned responsibility of management of all the services for water supply, sanitation, solid waste management and urban drainage to one municipal agency (SEMASA).

For example, simulation of urban flooding in the city of Porto Alegre following from the storm rainfall with a 25-year return period showed that the floods were mainly due to flow obstruction by bridges (Campana and Tucci, 2001). This scenario is the result of a lack of coordination between municipal authorities. Figure 2.7 is an illustration of the scenario.
2.6.4 Absence of integration between administrational and hydrological boundaries

Another institutional constraint to overcome is the definition of the administrational boundaries, which are often different from hydrological boundaries. In an ideal situation, urban flow control is developed at sub-basin level and regulated by modules that are defined by a political division, but this is often hard to achieve in practice. Therefore there is a need to have overall coordinating agencies for stormwater management whose boundaries are defined by physical hydrological boundaries as oppose to political, administrational boundaries.
3  CONCLUSIONS PART I

3.1 Introduction
This chapter comments on the objective and the related observations and conclusions based on the literature study. The objective for this part is:

1. To identify the urban drainage issues in Brazil; socio-economic, institutional, and technological factors in developing countries make it more difficult to solve problems of urban drainage than in developed countries.

3.2 Conclusions
In summary, factors that make it more difficult to solve problems of urban drainage are:

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<td>• Solid waste production</td>
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4 PLANNING AND DESIGN APPROACHES

4.1 Introduction
In this chapter approaches for planning and design are discussed and an assessment framework for ex-post evaluation of a plan development process is presented.

4.2 Two families of approaches for planning and design\(^1\)
In policy sciences, generally two main families of methods are distinguished, a content (or product) oriented approach and a process oriented approach. Quinn (1995) uses the terms 'formal systems approach' and 'power-behavioural approach', respectively. The formal systems are scientifically tested, well-documented methods that prevail in conventional policy analysis. The power-behavioural relates to the behaviour actors display in strategic planning processes and the power they have to influence the course of that process. In a 'power-behavioural approach' much more attention is given to opinion, bargaining and negotiation, and reaching consensus. Hence, it includes most participatory approaches.

4.2.1 The content oriented approach
Formal policy analysis follows from the tradition of Technical Rationality, which has its roots in the second half of the 19th century. Policy analysis has a strong focus on the content of a plan to be developed. Rational policy choices follow from analysis, which selects the policy option from the alternative packages of measures available that returns maximum (societal) benefit against the lowest (societal) costs. Policy analysis in this context is seen as a technical process that takes place within or parallel to political decision-making. The policy analyst uses advanced methods and techniques to establish and compare the effects of policy options. Risk is dealt with as much as possible by quantification and presenting the result to the administrators along side the other results of the policy analysis, using techniques like sensitivity analysis.

Content oriented approaches like policy analysis are based on the following three separations:
1. Between objectives and means – Problem solving can be seen as a technical procedure of which the effectiveness can be assessed using preset objectives.
2. Between research and practice – Practice consists mostly of the application of scientific theory and technology.
3. Between thought and action – In the sense of 'think first, act later'; practice after planning is only the execution of (technical) decisions.

4.2.2 The process oriented approach
The process oriented approach chooses interactive involvement of stakeholders as a departure point for plan development. Within the plan development process openness is an important condition for the learning process. Openness does not only mean that the participating actors are open for each other and each other's points of view, but also to be open with respect to the content. In the process oriented approach, the final content of a decision depends on a value and interest decisions made in a process of negotiations, not strictly on the basis of scientific of technical considerations, like those following from formal planning systems. Process steps, decisions to be taken and the agenda are set according to the progress in the decision making process, not by technical considerations. Holding interaction between the actors is the core of this approach.

\(^1\) 'Sustainable Urban Water Systems; Planning and design' (M.A. Rijsberman, 2004)
4.2.3 Choose or combine
A choice for a certain approach implies automatically that certain aspects of other approaches do not or to a lesser degree come forward. Research on design and planning of sustainable urban water systems (DusWat, 2004) executed in the Netherlands showed that it is not significant to choose for one approach or for the other. Instead, the various approaches can complete each other and the way in which that can best happen depends on the planning situation. But also within one planning situation several aspects of both approaches are useful and necessary. For example, because those are appropriate for certain actors and at certain plan phases. It is thus advisable to consider at the beginning of each new phase – from initiative through the implementation and monitoring – which elements from the other approaches are useful.

4.3 Planning and design approaches in Brazil
The commonly used approach for planning and design in developing countries (Brazil) is content oriented. Arguments to choose a content oriented approach are that the problems, e.g. urban flooding, are clear and widely felt, and that there is a lack of sufficient budget so that a transparent and rational assessment of what can and cannot be realised is necessary. A lack of attention for process aspects did not use to lead to serious problems in the past decades. That situation changed however when conventional solutions to urban drainage, i.e. to canalise watercourses and to invest in drainage works, were abandoned in favour of more sustainable solutions.

The process of the Plan for the Areia basin showed how a plan can fail in practise as a result of a strongly content oriented way of policy development that is not suited to deal with the subjectivity, interdependent choices and dynamic preferences involved in sustainable water management. Such situations lead to increased frustrations, especially for those who want to see fast results or if large interests are at stake.

As a result there is a need to consider which elements from a more process oriented approach are useful for the planning and design of more sustainable storm water systems.

Therefore an assessment framework is necessary, aimed at the question if the obtained solution is integrated and sustainable. Within the framework of his research into sustainable urban water management Rijsberman (2004) developed the method 3D-bril. The method is useful as a support tool for planning and design of urban water systems, by systematically bringing up important aspects. The broad character of the method, discussing both contents and process, makes it also suitable as an assessment framework and that is the role in which it is used in this thesis.

4.4 3D-bril: framework for planning and design of sustainable urban water systems

4.4.1 About the framework
The framework exists of three dimensions: concept, scope and knowledge. Within these dimensions some aspects are of specific importance, as continuity and the phase in which the process is itself. The framework has been developed on the basis of an extensive literature study and on experience with, among other things, making urban water plans. The method 3D-Bril is elaborately described in Vroege (2004) and the doctoral thesis of Rijsberman (2004). The framework with three tracks and four aspects is represented in figure 4.1. The three tracks are folded on to each other to stress their mutual influence.
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- **concept** - four key elements of sustainability
  - process phases
  - continuity
  - system perception
  - basic approach

- **scope** - actors, issues and areas
- **knowledge** - dialogue, verification, documentation

Figure 4.1 Three related tracks of planning and design, with general aspects

The different facets and aspects together form the tool for evaluation - all facets and aspects should have received sufficient attention; relevant questions should be answered and choices justified in the course of the process. The facets and their aspects are explained shortly below.

**Concept** - The notion behind the plan or design. The concept can be 'central problem x will be solved using y and z type strategies', which is typically the case in (pseudo) single-issue water plans. The concept can also be a rather more complex but coherent set of principles and values, which is typically the case in multi-issue water plans. Evaluation of the concept can take a huge effort if it is carried out in detail, including all consequences, for material flows and concentrations, hydrological consequences, and other ecological, social and economic impacts.

**Scope** - The actors involved or ignored, the issues treated, and the areas or geographical boundaries under consideration define the scope of the study, planning or design effort. During the process the scope typically changes: actors join and leave, issues come up and are dealt with, for instance. Any inclusion or exclusion should deliberate and motivated. Of course, any limitation in time (i.e. planning horizon or effect horizon) should be justifiable as well.

**Knowledge** - The label of knowledge encompasses all things to do with knowledge, information and results. Important aspects are dialogue, which is the essence of a process approach, verification of information and discussion results and the documentation of any progress and agreements. Different forms of communication, sharing and creating knowledge between different actors are applicable for different purposes. Process results (agreements, plans, designs) should be verified to avoid 'negotiated nonsense'. The way the process is documented is an indicator of the process's efficiency; a good 'collective memory' will hold agreements and share understanding of problems and their solutions. Especially verification of the plan or design can encompass a huge effort, e.g. assessing all claims and assumptions made in the process.

Aspects of these facets important to urban water planning and design are:

- **Process phases** - Concept, scope and knowledge evolve in the different phases of the process, like vision formulation, functional or technical design, or implementation.

- **Continuity** - Continuity is necessary to prevent efforts in the process to be wasted. Even if a process yields concrete results eventually, support for a plan or design is lost and participants demotivated. All three facets have a great influence on the continuity.

- **System perception** - The way the system is perceived, with respect to its separate components and their relative importance should fit the circumstances and the facets. For
instance, in a system defined as having only a small number of very generic components, studying problems, processes and impacts on a very detailed scale will not be possible.

**Basic approaches** – Basic approaches of actors, i.e. the position in relation to dealing with uncertainties and to the environment, influence the view of the concept, scope and knowledge facets.

### 4.4.2 3D-bril as an assessment framework

The method 3D-Bril is described in the following paragraphs on the basis of topics for each dimension. A rigorous discussion of these topics should provide insight into the plan process. At each topic a characteristic question has been asked. An important consideration in formulating the questions is that it is hard or impossible to provide specific, quantitative criteria for assessment of the different dimensions, but that an answer should be found to the questions if the assessed is appropriate in its context, if the assessed fulfils the intended function effectively (and offers insight), if the assessed is relevant for the observations in the process (and does not result only from theory) and if the assessed is consistent (and therefore shows no conflicts with other (sub)processes).

#### Concept

*C*<sub>1</sub> – **Correspondence**

Does the concept correspond to the local water system and other relevant systems such as the spatial system and the socio-economical system of the plan area?

*C*<sub>2</sub> – **Insight**

Does the concept offer insight in for example nature of problems, solution directions or relations within and between systems?

*C*<sub>3</sub> – **Relevance**

Is the concept relevant with respect to the goals and the issues?

*C*<sub>4</sub> – **Consistency**

Is the concept consistent? Are there no contradictions?

*C*<sub>5</sub> – **Sustainability**

Does the concept fit the (intersubjective) concept of sustainable development? Does it correspond with the five key elements of the concept?

#### Scope

Of importance to the **relations** in the scope:

*S*<sub>0</sub> – **Internal consistency**

Do the actors, issues and areas fit?

Of importance to the **issues** in the scope:

*S*<sub>1,0</sub> – **Pertinence to central problem** (in the case of a problem driven plan)

Do the issues targeted in the plan fit the problems and the concept?

*S*<sub>1,2</sub> – **Potential contribution to the plan or design** (in the case of a vision oriented plan)

Which relevance have the issues for the plan or process? Does this relevance appear from the process?

Of importance to the **actors** in the scope:

*S*<sub>2,1</sub> – **Power**

Does an actor has the power to influence the process and its outcome? What is the role of this actor in the process?

*S*<sub>2,2</sub> – **Resources (like personnel, monetary, knowledge)**

Does an actor has resources to contribute to the process? Are those resources used in the process?

*S*<sub>2,3</sub> – **Moral right to be involved in decision making**

Does an actor have the moral right to be involved in the process? Did this actor participate?

*S*<sub>2,4</sub> – **Organisation of the process**

How is the process organised? Does the organizational structure fit the tasks and issues of the actors?

*S*<sub>2,5</sub> – **Positions of and relations between actors**
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What are the respective positions of the actors? Are the relations between actors of a sufficient nature and are they safe? Are the positions and relations a threat to the process? Did the positions and relations change as a result of the process?

Of importance to the areas (and their subdivision) in the scope:
S_{3.1} - Subdivision of planning area
Does the subdivision of the planning area fit the diversity of the area?
S_{3.2} - The geographical boundaries and the (water) system
Do the geographical boundaries fit the water system and other relevant systems, such as the administrative system, the socio-economic system or the spatial system? Which system has the largest influence on the geographical boundaries?
S_{3.3} - The geographical boundaries and the territories of the actors
Do the geographical boundaries fit the territories of the actors?
S_{3.4} - Relevance to the issues
Do the geographical boundaries fit the problems?
S_{3.5} - Relevance to the actors
Do the geographical boundaries fit the interests of the actors?

Knowledge
K_{1.1} - Fitting communication style
Are the discussions dialectic or constructive? Is the communication integrative or distributive?
K_{1.2} - Openness
Is the process open with respect to content? Is the process open to the entrance of participants and in the behaviour of those participants? Is the process open with respect to the procedures and different steps in the process?
K_{1.3} - Internal inspiration
Does inspiration, leading to new ideas, come from exploring and combining each other's points-of-view?
K_{1.4} - External Inspiration
Does inspiration, leading to new ideas, come from input by experts from outside the process?
K_{1.5} - Incremental or consecutive steps
Are the steps in the process incremental or consecutive? How does this influence the outcome?
K_{1.6} - (Non) negotiables
Which knowledge can be negotiated? When is knowledge considered as 'non-negotiable'?
K_{1.7} - Structure of the discussions
How are the discussions in the process structured?

K_{2.1} - Verification
Is knowledge gained in the process verified? If yes, how, by whom and when?
K_{2.2} - Dealing with uncertainty
To what extent do the actors accept uncertainties in the process?

K_{3.1} - Documentation of progress
Are the progress, discussions and outcomes documented in the process?
K_{3.2} - Documentation of agreement
How are the outcomes and agreements documented? Is this documentation technically and organisationally useful?

Aspects
Process phases
- Does the concept change during the process?
- When does an actor have influence, resources or the moral right to be invited to the process?

Continuity
- How is the progress supported by the concept?
• Do changes occur in the scope during the process? How does this influence the process?
• How is the progress during the process? Is knowledge continuously developed?

System perception
• Which system perception is used in the process?
• Which perception of the system has an actor?
• What is the role of the system perception in the documentation?

Basic approaches
• On the basis of which basic approach does an actor act?
• Which basic approaches come forward in the outcome of the process?
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5 ASSESSMENT OF THE PLANNING AND DESIGN OF THE AREIA PLAN

5.1 Introduction
The plan development process of the Areia Plan is evaluated in this chapter. Data sources for the assessment are document analysis, observation and (semi structured) interviews with participants.

5.2 Concept

5.2.1 Description for the UDMP of Porto Alegre

Objectives and goals
The Urban Drainage Master Plan (UDMP) serves as a planning mechanism to integrate the development of the urban drainage infrastructure in harmony with the occupation of the urban areas by the population. The objective of this plan is to create management practices for the urban infrastructure related with the drainage of storm waters and rivers in the urban area of the city of Porto Alegre. The planning aims to prevent economic losses and to improve the conditions for health and environment in the city, within the economic, social and environmental boundaries defined in the Urban Master Plan.

The UDMP has as goals:
- To plan the control and distribution of the drainage system in time and space, based on the trend of urban occupation, making compatible the urban development and the planning of infrastructure in order to prevent economic and environmental losses;
- To control the occupation of the flood risk areas through restrictions in the areas of high risk;
- Living with floods in the areas of low risk.

Products
The plan was developed in three stages:
1. *Policies of drainage control* - That deals with the conceptual elements of the UDMP, the proposed regulation and the vision on all aspects of urban drainage and flood control (Volume I, May 2000).
3. *Plans for the basins* - That elaborate on the planning of the structural interventions for control of the urban drainage in each basin, minimizing the actual impacts (Volumes III through V, March 2002).

Concept
The concept of the UDMP of Porto Alegre is based on the following components (Volume I, 2000):
- Urban drainage control principles
- Strategies for plan development
- Norms and standards for control variables
- Definition of scenarios for urban development and flood risk
- Economic feasibility of the measures
Set of principles
The urban drainage control principles are necessary to prevent continued increase of urban floods and wasting of resources. Control principles characterised in the UDMP are:

1. The Urban Drainage Master Plan is part of the Urban Master Plan;
2. No urban user should increase the natural runoff;
3. Flood control measures should not transfer the impact to downstream reaches;
4. The UDMP should anticipate a minimisation of the environmental impact related to urban drainage runoff;
5. The UDMP, in its regulation, must contemplate the planning of the areas to be developed and the densification of the areas already divided into lots;
6. Appropriate emphasis should be given to non-structural measures and urban planning;
7. The control should be carried out for the basin as a whole and not be confined to specific flow sections;
8. Control management should be implemented through the UDMP, the Municipal and State legislation and the Urban Drainage Manual;
9. Flood control is a continues process;
10. Education of engineers, architects, agronomists and geologists, among other professionals, of the population and of public administrators should be developed;
11. The cost of control and operation of the draining system should be transferred to the users proportionally to the impermeable area of the owners;
12. This set of principles is based on the control of the urban drainage at the source;
13. Efficient management in drainage maintenance and law enforcement are essential.

Strategy definition
To fulfil the functional demands of these principles the basic elements of structural and non-structural measures are reviewed in the UDMP. These measures, among other considerations, were used in drawing up two basic strategies for plan development, i.e.:

For undeveloped areas – To develop non-structural measures related to the regulation of the urban drainage and the occupation of risk areas, in order to control the impacts of future developments. These measures seek to transfer the responsibility for the control of the hydrological alterations due to urbanisation to those who effectively produce the alterations.

For developed areas – To develop specific studies for urban macro basins in order to plan the necessary measures for control of the impacts within the basins and not transferring the actual impacts to downstream reaches. The use of temporary storage through detention has priority in the plan development.

With respect to stormwater quality, solid waste and groundwater pollution secondary strategies were proposed:

For the areas where the wastewater sewerage net does not exist or where a great amount of linkages of wastewater effluent exists in the pluvial net, quantitative control measures have priority. This type of measure uses the detention only for the exceeding volume of the current drainage capacity, ergo preventing that the dry weather drainage and the first flush contaminate the detention ponds.

When a wastewater net will be implemented, in the second stage of planning, the drainage system should be modified together with the detentions that as such can also contribute to quality control of the storm water.

In order to control the contamination of aquifers and the amount of solid waste, programs have to be created in the medium term, aiming at the reduction of this contamination by means of measures distributed throughout the city.
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Norms and standards
In behalf of the design and the assessment of drainage systems norms and standards are used, meant for an optimal management.

Quantity control – A return period of 10 years was chosen for the design of the macro drainage, based on a qualitative evaluation of the economic impacts of the control measures. Generally, the highest costs following from damage by inundation result from high-risk floods (low return period), due to the great frequency of occurrence. In this respect use of control measures for low risk floods (high time of return) can represent high costs but do not represent a high average benefit.

Quality/environmental control – The reservoirs are kept the dry during the year and are only used during events with return period above 2 years. In some cases a lower return period was used due the low capacity of the existing net.

Scenario definition
Two aspects need to be considered in the scenarios for the plan development, i.e. the urban development and the implementation of regulation on source control. With respect to the urban development the following scenarios are identified:

Current scenario – Involves the urban occupation of 2000 obtained in accordance with demographic estimates and satellite images;
Current scenario + UMP – Involves the current occupation for the parts of the basin where the UMP was surpassed in its forecast, while for the areas where the UMP was not surpassed, the value of predicted urban density was considered. The Urban Master Plan that was considered established different conditions for maximum allowed urban occupation and was in force until September 1999.
Scenario of maximum occupation – Involves the maximum occupation in accordance with observations in different parts of the city during the study phase. This scenario represents the situation that occurs as a result of clandestine urban development.

With respect to the implementation of regulation on source control the scenario should anticipate a delay in the approval of the regulation. Currently, the implementation is impracticable for properties with an area inferior to 600 m$^2$. As such, the new regulation will only be able to act in the approval of new developments. But, since the studied basins are already for a large part developed, little area remains for new developments and the effect of the new regulation will be small.

The design scenario is the ‘Current scenario + UMP’ in combination with the ‘best degree of interventions’ (structural measures).

Economic feasibility
The economic feasibility of the implementation of structural measures and the urban drainage control along the planning horizon possesses two components: (a) evaluation of the construction cost of the alternative works, and (b) finance mechanisms for urban drainage. The costs related with urban drainage are divided in execution of works, operation and maintenance. The construction cost should be distributed between the hydrographical basins, on the basis of the Plan for each basin. The costs of operation and maintenance can be charged: (a) as part of the master budget of the city, without a specific collection from the users; (b) through fixed taxes on each property, without distinction of impermeable area; (c) on the basis of the impermeable area of each property. The last alternative is the most just one.
The Plan ‘Arroio da Areia’
The elaboration of the structural measures for the Areia basin consisted of a consecutive series of steps, from problem identification to evaluation, as represented in figure 5.1.

Figure 5.1 Approach for the Areia Plan

The Areia Plan is based on the vision and functions of the urban water system, laid down in the policy document (UDMP Volume I). The Plan starts with a problem analysis to identify which bottlenecks exist in the current situation and which bottlenecks could develop as a result of predicted urban developments. For the identification of the bottlenecks, i.e. the occurrence of inundation, the urban water system was simulated with the help of the cinematic model IPHS1 and a hydrodynamic model. The hydrodynamic model was only used for the section of the drainage network where the water is pumped through closed conduits to the pumping station. Input for the models consisted of rainfall parameters, the design of the drainage system, the hydrological parameters of CN and K<sub>s</sub>, and the topography. The CN-value was estimated on the basis of the percentage of impermeable area and the type of soil (figure 5.2). For the latter parameter an intermediate value between the hydrological soil groups C and D according to the classification of the Soil Conservation Service was used. The extent of impervious areas in the existing catchments and the potential future increases due to future urban development was estimated, using the relationship between urban density and impermeable area (figure 5.3).
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Figure 5.2 Relationship between impermeable area, soil type and curve number (SCS)

Figure 5.3 Relationship between urban density and impermeable area

The bottleneck analysis was executed with design storms of a 2, 5, 10, 25 and 50 year return period (figure 5.4). Analysis of the current scenario showed that the main drainage systems in the Areia basin are underdesigned in a number of different sections and that, as a result, a number of areas were observed to be flooded frequency with a design storm of a 2 year return period. Based upon the future scenario, the hydraulic limitations of the system will become increasingly critical.
In order for the drainage system to fulfill the targeted functions and the standards for system behaviour, three technical alternatives were developed that are practically equivalent in terms of effectiveness. Alternative 1 contemplates the expansion of the conduits network without the implementation of detention ponds. Alternative 2 foresees the implementation of 12 detention ponds without expanding the conduits network. The detention ponds are planned in public parks, sport fields and undeveloped lots. They are designed as open reservoirs without lining. An inlet system is to be constructed to take in water from the combined system only when the discharge in the conduits surpasses a determined value. Alternative 3 is in fact a combination of the previous alternatives: one detention pond is left out of the design due to too high excavation costs involved.

Subsequently the three alternatives are evaluated on the basis of their construction costs. The construction costs of the three alternatives are respectively: R$ 43 million, R$ 27 million and R$ 23 million. On the basis of this evaluation alternative 3 is recommended in the plan.

5.2.2 Discussion of topics

C₁ – Correspondence
Detentions ponds are well suited to the spatial system of the Areia basin, where storage volumes can be maximized in the steep (partly) confined valleys (for example, see figure 5.5). Secondly, the designed system depends almost solely on gravity for operation; this corresponds well to the socio-economic system, because it reduces the change of (flood) damage due to human errors and the operational costs are low.

On the other hand the concept does not correspond well to the local water system. In the Areia basin the stormwater is removed through a combined system. In a combined system rainwater as well as wastewater is transported through the same system. A concept involving detention strategies, is less applicable in that case, because the storage will fill with untreated wastewater mixed with stirred up sewerage sludge when the capacity of the conduit system is surpassed. This situation can bring about environmental degradation and causes considerable concern among the population on health issues.
Moreover, the concept should correspond to the large quantities of sediment and solid waste produced in Porto Alegre situation. In the existing design no precautionary measures such as a sediment basin that would need more regularly maintaining, are taken. Similar issues have to be taken into consideration when designing the facilities in the implementation phase.

**C2 – Insight**

The strategy that is leading for the development of the Areia Plan is centred on water quantity. Water quality issues are said to be targeted in the ongoing planning process. The decision to separate the water quantity issues from the quality issues would be of serious consequence: contamination of the public open spaces with sewerage water is observed to be one of the most important reasons for the conflict on the implementation of the detention ponds. Amenity issues (i.e. environmental setting and needs of the local community) will be considered in the operational phase (at project level).

The 2 basic strategies of the UDMP of Porto Alegre are based on the premise that interventions aimed at source control are only possible in the areas that are to be developed. In the areas that are already divided into lots, no source control measures can be implemented because it is legally impossible to ask inhabitants to change their construction. The strategies are strongly related to the set of urban drainage principles, although the link between these is not discussed in the UDMP.

How the principles relate to the natural, socio-economical and administrative and institutional system is briefly discussed as for each principle an explanation of one or a few sentences is presented. For example, principle 5 (i.e. the UDMP, in its regulation, must contemplate the planning of the areas to be developed and the densification of the areas already divided into lots) is justified on the basis legal boundaries. It foresees that prevention measures can only be imposed on new developments and not on existing constructions.

Whether or not the UDMP provides insight into problems identified in chapter 2 and its potential solutions is assessed in table 5.1.
### Urban drainage issues in Brazil

<table>
<thead>
<tr>
<th>Social aspects</th>
<th>Insight in problems and solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid (clandestine) urban development</td>
<td>The plan elaborately describes the impacts of urbanisation on runoff, and the control measures. How to slow down the urbanisation process is outside the scope of the study.</td>
</tr>
<tr>
<td>Abundant sediment and solid waste production</td>
<td>The problem is discussed and somewhat quantified. With regard to the solution it is only mentioned that control programs have to be created in the medium term. There is not yet a clear insight into effective measures.</td>
</tr>
<tr>
<td>Lack of public awareness and participation</td>
<td>Only little attention is given to the issue in that public education is promoted.</td>
</tr>
</tbody>
</table>

### Environmental aspects

| Climatic factors                                  | The available data for Porto Alegre is represented. This is only rainfall data. High temperature and the effects are not studied.                                                                                         |
| Pollution of natural environment                  | There is unfortunately almost no attention for pollution of the ground water and receiving surface waters via the drainage runoff.                                                                              |

### Engineering aspects

| Inappropriate approaches to drainage design        | The issue is the trigger for the plan development process. Modern approaches are presented.                                                                                                                                   |
| Contamination by foul sewage                       | The issue is not dealt with, because solutions are considered to involve too high cost. However avoiding mixture of pluvial and sewerage water should deserve more attention because it can result in valuable economic and environmental benefits. |
| Lack of data                                       | The problem is discussed and some monitoring programs are foreseen.                                                                                                                                                           |

### Economical aspects

| Lack of funding                                    | The problem is not really discussed. How to distribute cost is.                                                                                                                                                            |
| Large differences in population income             | No insight, although the aspect is important for the economic feasibility and from the point of view of equity in distribution of cost                                                                                   |

### Efficiency aspects

| No coherent policies                               | The policy of the plan is based on a clear vision on the urban storm water system. New regulation, maintenance and education programs are proposed. The lack of resources for effective implementation is not mentioned. |
| Ineffective institutional frameworks for implementation | The plan promotes better coordination in that the UDMP is now part of the UMP. It is observed that 4 hydrological basins lie in the municipalities of Porto Alegre and Viamão. No further attention is given to the issue. |
| Lack of coordination between different agencies    |                                                                                                                                                                                                                         |
| Different administrative and hydrological boundaries|                                                                                                                                                                                                                         |

A concept involving detention strategies is relatively unknown in Brazil. Some experience with the concept exists in São Paulo where a program for implementation of 46 detention
basins, called 'big pools', was launched in 1997 as a corrective measure, due to severe problems with urban flooding. In Porto Alegre, only the IPH and the design section of the Stormwater Department could provide knowledge on the concept. At present, local inhabitants of the Areia basin understand the concept and the issues it is focussing on, but not everyone is (yet) being inspired to behave accordingly: especially the richer population in the upstream areas, that experiences no inundation into their houses, is not accepting the solutions proposed in the UDMP.

C3 - Relevance
The planning aims to prevent economic losses and to improve the conditions for health and environment in the city. Therefore, surplus water flowing from the drainage system during high intensity rainfalls is to be temporarily stored in detention ponds. This concept is relevant to prevent economic losses, since the surplus water causes less damage if it is controlled in ponds than if it flows freely in the streets and houses. For the same reason, the concept is relevant to improve the conditions for health and environment in the city.

But, a secondary order effect is that the environmental hygienic conditions of the public areas that are to be used as ponds can decrease. To maintain local environmental hygienic conditions as well as possible the detention was designed to be dry during the year (off-line detention pond) and only to be used for the exceeding volume of the current drainage capacity.

C4 - Consistency
The concept should be consistent, both internally and externally. This means that different parts or elements of the concept should not be conflicting. A potential problem with consistency in the UDMP of Porto Alegre is the scenario definition with respect to the implementation of the regulation on source control. In the design scenario the positive effects of the new regulation on urban drainage (e.g. less storm water entering the drainage system) are not taken into account. This is inconsistent with the concept and the set of urban drainage principles, which is based on the control of the urban drainage at the source.

This inconsistency is recognized by the plan developers and is explained as being the 'worst case scenario'. It foresees that the new regulation is not approved due to political problems or is not enforced properly. A possible consequence of such an inconsistency is that the concept may fail to convince or inspire. Another consequence is that the ponds are more likely to be overdesigned and that valuable financial resources are thus wasted.

The definition of hydrological basins is externally consistent with that of the Sewerage Master Plan of Porto Alegre. And the design scenario (scenario of maximum occupation) is consistent with the allowed maximum population densities by the Urban Master Plan.

Technical elaboration of measures can also lead to inconsistency. For example, the detention pond at "Quintino Bocaiuva" park has been designed as a closed underground reservoir instead of an open one, as it was originally designed in the UDMP. Because its properties hinder easy cleaning and it design is inflexible, it can no longer or only at high cost be converted to function as an extended detention pond. In that respect the measure is inconsistent with the quality control strategy.

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C5 - Sustainability

Sustainable development is an elusive concept: however, Rijsberman (2004) distinguished five key elements from the definitions in literature. These elements constitute the core of the concept of sustainable development: every definition is based on some or (ideally) all of these elements:

1. Needs of the present
2. Needs of future generations
3. System quantity and quality
4. System integrity
5. Equity

The first two key elements are oriented on 'human' factors: the problem in assessing these elements is how to know the needs of the present and in particular the future generations. Different people and generations prefer different solutions to the same problem based on differences in problem perception and in values. For example, in the Areia basin inhabitants of the downstream areas support the concept, while others, living more upstream and not experiencing all consequences, do not. Also, differences in value judgement are a cause for disagreement on the preferred solution: some actors involved hate the thought of sewerage water entering places where children play.

In a sustainable situation, the systems (like water systems, socio-economic systems etc.) and subsystems (like rivers, sewers etc.) are not to be stressed beyond their capacity, both in quantity as in quality. In the present situation, the urban drainage has insufficient capacity to meet the quantity demands by the society, and socio-economic capital is lost due to frequent urban flooding. With the realisation of the detention ponds the quantity problem is tackled, but the quality problem remains. Moreover, the solution can represent certain environmental losses if the amenity issues are not thoroughly taken into account.

In relation to maintaining system quantity and quality the system integrity should also be maintained: this is not the case since only water quantity is considered.

Equity means that problems should not be solved at another’s expense, elsewhere or at another point in time. From the point-of-view of equity the concept is desirable because it prevents a downstream transfer of the impacts and promotes source control. Also in the distribution of costs the concept is just since it claims that the cost of control and operation of the draining system should be transferred to the users proportionally to the impermeable area of the owners.

5.2.3 Reflection on content

The initiative for the development of the Urban Drainage Master Plan came from the Stormwater Department. They felt a need for new management practices for the control and distribution of the drainage system and a need for more integration with urban planning. There is a clear link between this motivation to start the urban water planning process and the content of Volume I of the UDMP. In Volume I ('Fundamentos') the problem definition and vision formulation are elaborated. This plan can be distinguished as being vision oriented.

A central value in a vision oriented process seems to be inclusiveness: Typically, the parties try to include as many issues and actors as are practically feasible. With respect to the plan development process in Porto Alegre, it is observed that the IPH in order of the Stormwater Department was solely responsible for the drawing up of the urban drainage principles and strategies on which the concept is based. A lack of attention for the issues of other actors may be one of the causes of the conflict.

On the other hand, a sense of urgency to intervene in the urban drainage system was widely felt among the population of the Areia basin. Previous floods had resulted in damage to property and even in the loss of life. In 1986 a flood run off carried away a car occupied by a doctor and his two sons, killing them. Whereas in 1998 a five-year-old child lost his live due
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to the contact with the fast flowing water. And quite recently, in 2003, another car was
dragged along the stream, its occupants fortunately being rescued. For this reason the Areia
basin was chosen as one of the first basins in the city to be tackled. The Plan for the Areia
basin can be said to be problem driven. In this type of planning problem definition is far less
of an issue. The concept of the Areia Plan can in fact be characterised as follows: ‘to solve
inundation problems using canalisation and/or detention strategies.’ In comparison with
Volume I the Areia Plan has a much narrower scope that is only aimed at solving the flood
problem.

Here, finding an acceptable solution is complex, due to technical complexity and uncertainty
(in data, cost and effectiveness as well as in impacts). To what extent the actors are
prepared to accept a solution partly depends on how is dealt with this complexity. Uncertainty and the actors will be dealt with in the following chapters.

Additionally, costs and their distribution make it more difficult to find an acceptable solution,
because the Areia Plan is more concrete and close to implementation. The Stormwater
Department had no budget available for the implementation of the projects, mainly due to
too low revenues. Neither did the municipal Planning Cabinet (GAPLAN) have any resources
available for the projects. Besides, the distribution of cost among the inhabitants of the
hydrological basins seemed to be failing due to political reluctance. A plausible reason for the
political reluctance to invest money or to impose taxes is the fear to lose votes, elections
going on at the time of the conflict, in view of the strong opposition against the solutions.
Also the national government is at this moment reluctant to spent money on the projects.
Because of the lack of budget construction cost are recognised to be the most important
selection criterion.

Finally, legislative or organisational aspects determine successful implementation, operation
and maintenance of the measures. To assess if none are forgotten in the plan development
process the BRUHO-template should be used. BRUHO stands for a series of aspects related
to the measures:

- Policy (Beleid)
- Legislation (Regelgeving)
- Execution, implementation (Uitvoering)
- Enforcement, performance evaluation (Handhaving)
- Organisation (Organisatie)

Evaluation of the aspects brings the following to light, respectively:

- In the Areia Plan rapid transportation and mitigative measures are elaborated. Rapid
transportation clearly does not fit the (source control) policy of the Stormwater
Department, aimed at control of urban drainage at the source. Mitigation only partly fits,
being in fact a regional approach.
- National and State legislation on water resources states that in case of a conflict
involving water resources the Hydrological Basin Committee is the authority responsible
for interference. In Porto Alegre, this is the Committee of Management of the
Hydrological Basin of Lake Guaiba. To include this organisation in the planning process
could help to solve the conflict.
- Engineers in the construction section of the Stormwater Department do, at this moment,
not know how to construct a detention pond. Education is thus needed. Also, engineers
in the design section are not educated for the discussions with the public.
- The Stormwater Department lacks the resources for sufficient control of the measures,
being people, money as well as knowledge. For example, the section that has to check if
the execution is in accordance with the design does not even know how a detention pond
has to look.
- The Stormwater Department consists of a design, construction and maintenance section.
All sections encounter their own problems. The lack of hydrological data complicates
the design work. The engineers in the construction section are not yet familiar with detention
concept. And the maintenance section does not know well how and how often to clean
the detention ponds.

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5.3 Scope

5.3.1 On relations

The scope concerns a constellation of issues to do with study and planning areas, the choice of issues and the actors involved. Choices in these three aspects are strongly related (figure 5.6).

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**Figure 5.6** The relations between actors, issues and areas as parts of the scope

**S₀ - Internal consistency**

The consistency of the scope is applicable to the different aspects of the scope as follows:

**Issues ↔ actors**

The central issue within the planning process is the water quantity (i.e. urban flood problems). That issue touches on the (core) interests of the Stormwater Department and the inhabitants. From the point of view of the inhabitants, however, the recommended solution is not compatible with their other issues. Of which the most important is quality of life. They argue that a separated system should be implemented in the project area and that the ponds should not be located in recreational areas.

To design a separated system requires the participation of the Water and Sewerage Agency. Because their cooperation could not be secured, the water quality issue was excluded from the scope. However, the scope is consistent as for the water quality issue, because the exclusion is explicitly named in the strategy formulation.

A last central actor in the process is the municipal Secretariat of Environment. The interests of this actor have altogether no direct relations with the flood problems. But the actor is included in the scope because it is responsible for the public parks and sport fields, in which the detention reservoirs are planned. Environmental, aesthetic and recreational issues are important for the Secretariat of Environment.

**Issues ↔ areas**

The water quantity issue is applicable throughout the planning area. Inundations occur on multiple locations (figure 1.16). The other way around, other issues inside the planning area are also relevant for the water quantity. A good example of that is the rapid urban development through densification and new urban developments. The negative impacts thereof are tackled by the new regulation on source control that is presented in Volume I of the UDMP.

**Actors ↔ areas**

The actors all have a specific task or role in the planning area. But the other way around, not all actors that have a role with respect to the water system are included in the planning process. Inclusion of the Water and Sewerage Agency (DMAE) and the Secretariat of Cleaning (DMLU) in the scope is relevant because the detention ponds get polluted by solid waste and sewerage water. In that respect the scope is inconsistent. Afterwards, it was
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admitted that at time the plan developers did not realize how important the water quality issue would be and that more emphasis would be given to the inclusion now if the process could be done anew. This problem is mainly political/managerial: for example, the municipal Secretariat of cleaning argues that it is not allowed to clean garbage that is in the urban drainage system.

5.3.2 On issues

The Areia Plan is a problem driven or single issue plan (see paragraph 5.2.3).

S1.1 – Pertinence to central problem

In the Areia Plan only the water quantity issue that is off course pertinent to the urban flood problems is targeted. The argument from the plan developers for the thematic delimitation of the scope to water quantity issues is a lack of budget for the inclusion of water quality issues. Besides, it was observed that the participation of two outside actors that have power over the water quality issues and their solution could not be secured. None the less, certain water quality impacts are shallowly studied, but no measures are elaborated. Another issue that is very relevant to the central problem and its solution is the intended multi-objective use of the detention areas. However, the specific conditions for multi-purpose use and whether or not these are met is not considered in the Areia Plan.

5.3.3 On actors

Criteria for organisations to be included in the planning process are:

S2.1 – Power
S2.2 – Resources
S2.3 – Moral right

The role of an actor in the planning process is reflected in table 5.2. For this purpose a distinction is made in their degree of participation. Involvement can be co-decision, but also co-operation, and even staying informed. A second distinction concerns the phases of the policy cycle; this is significant because the openness of the process to participants depended on the phase. The reasons to invite the actors to participate are represented in table 5.3.

Table 5.2 Participants and their role in the planning process

<table>
<thead>
<tr>
<th>Actors</th>
<th>Initiative phase</th>
<th>Vision phase +elaboration</th>
<th>Implementation phase</th>
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<tbody>
<tr>
<td></td>
<td>co-decide</td>
<td>co-operate</td>
<td>inform</td>
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<tr>
<td>Municipality</td>
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<td>DEP</td>
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<td>SMAM</td>
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<td>GAPLAN</td>
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<td>PGM</td>
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<tr>
<td>IPH</td>
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<td>Consultants, hired engineers</td>
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<tr>
<td>Inhabitants</td>
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<td>Organised</td>
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<tr>
<td>Individual</td>
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<td>Ministério Publico</td>
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Table 5.3 Reasons for participation

<table>
<thead>
<tr>
<th>Actors</th>
<th>Reason for participation</th>
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<tr>
<td></td>
<td>Power</td>
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<td>SECAR</td>
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<td>IPH</td>
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<tr>
<td>Consultants, hired engineers</td>
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<td>Inhabitants</td>
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The organisational structure of the municipality of Porto Alegre is represented in figure 5.7. Municipal organisation that are involved in the planning process are the Stormwater Department (DEP), the Secretariat of Environment (SMAM), the Planning Cabinet (GAPLAN), the Secretariat of Extraordinary Resources Acquisition and International Cooperation (SECAR) and the Attorney General’s Office of the Municipality (PGM).

The Stormwater Department, being the central actor, consists of three sections, i.e. Design, Construction and Maintenance. The Design section was responsible for the decision making in cooperation with the managing director. The directors of the Construction and Maintenance sections participated in the plan development.

The Secretariat of Environment owns the public parks in which the detention ponds are planned. By municipal law permission from the SMAM is obligatory before the construction can start. Therefore the SMAM participated by co-operation in the implementation phase.
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The Planning Cabinet is responsible for the financial management of the municipality of Porto Alegre. They were reluctant to allocate any resources to the projects. A second municipal organisation that could provide monetary resources is the SECAR. The mission of this secretary is to look for extraordinary resources. For that purpose the SECAR consulted the World Bank, but they did not succeed in acquiring any money.

The last municipal organisation that participated in the process was the PGM. They provided juridical knowledge to the process.

A notable fact is the role of individual inhabitants in the policy cycle and their power over the solutions. The co-decision making for inhabitants is achieved in Porto Alegre through the participatory budgeting process (figure 5.8). Therefore the control of the prioritisation of municipal expenditure (i.e. monetary power) is passed over to the communities themselves, which influences the decision to invest in urban drainage in relation to other perceived needs. In 2000 the inhabitants voted for the development of the Urban Master Drainage Plan. But, on another occasion, no priority was given to expenditures on the implementation of the detention ponds.

![Figure 5.8 Structures, stages and timescale in the participatory budgeting process](image-url)

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Although the inhabitants could co-decide about the expenditures, they were not invited to participate in the creation of the UDMP. In fact, the plan development process can be described as closed with respect to the participation of other actors, especially during the vision formulation phase and the elaboration of measures. The inhabitants and the Secretariat of Environment were only informed about the measures in the last stage of the elaboration phase and had no influence on the concept.

Inhabitants have the moral right to be invited to the planning table because the solutions affect them. The organised inhabitant of the neighbourhoods of ‘Chacara das Pedras’ and ‘Três Figueiras’ used their ‘hinder power’ to try and stop the implementation of the detention ponds in their neighbourhoods. To voice their disapproval they addressed the ‘Ministério Público’. However, the ‘Ministério Público’ did not approve their complaints and allowed the municipality to proceed with their work.

S2.4 - Organisation of the process
The project coordinator was a representative of the IPH, professor C.E.M. Tucci. Professor Tucci together with the director of the Stormwater Department, A. Damiani, had the most influence on the concept of the UDMP of Porto Alegre. Tucci was responsible for the drawing up of the policy volume. A.O.N. Villanueva was appointed as executive coordinator of the project and was responsible for the review of the design capacity of the system of dykes and pumping stations. Furthermore, a technical group of 13 persons, mainly students at the IPH, played a considerable role in the process. Usually one or two students worked out a Plan for a hydrological basin. Because the IPH could work with students, that already received a scholarship and thus were not or only very little paid, the plan development process was relatively cheap. A benefit for the IPH from the cooperation was that they received data that could be used in varied research projects. Four participants from the Stormwater Department had seat in a supporting group, which had the task to supply input data for the work of the technical group.

The role of the IPH was limited to the vision formulation phase and the elaboration of measures. During the implementation phase an external consultant was hired to work out a technical design for 5 of the detention ponds in the upstream part of the hydrological basin and to make an estimate of costs of those works.

S2.5 - Positions of and relations between actors
The relation between the Stormwater Department and the IPH can be described as being very close. The reason for this is that several of co-operators on the plan development who work now for the Stormwater Department were previously a student at the IPH. Two of them even combined their work with a doctoral study at the IPH.

The positions between the Stormwater Department and the Secretariat of Environment started out as what is described as being ‘opposed’. The Secretariat of Environment did at first not want to hear about the construction of detention ponds in the public parks. The reason why the positions were so opposed is that the Secretariat of Environment did not cooperate in the elaboration phase. As a result they were surprised by the solution. Later on in the process the relation between the two municipal authorities became friendlier, as they began to realise that they needed the co-operation of each other in order to get something done. This is called shaping the policy arena. At all times contact between the two actors was easily set because both are municipal organisations.

The relations between the Stormwater Department and the inhabitants cannot be generalised. The position of the inhabitants of the downstream neighbourhoods is in favour of the implementation of the detention ponds. They experience the urban floods in their houses and on the streets and they reason that they prefer to have the parks inundated than the houses and streets. On the other hand the organized inhabitants of the upstream neighbourhoods of ‘Chacara das Pedras’ and ‘Três Figueiras’ do not support the solutions of the Stormwater Department. An engineer from the Stormwater Department describes the
latter relation as 'very unfriendly' and also pointed out that the inhabitants do not believe the municipal employees. In this respect, the role of the IPH is important since the inhabitants do trust the professors from the IPH.

5.3.4 On areas

A planning area is the area for which the plan is to define a strategy and where measures can be implemented. The study area is the area where impacts of the plan or design or causes for problems in the planning areas are studied. The planning area and the study area of the Areia Plan have the same geographical delimitation that is chosen on the basis of a water system approach. The urban water systems or hydrological (sub) basins of Porto Alegre are defined by the Sewerage Master Plan. In the Areia Plan the Areia basin is studied. However, the planning area does not cover the entire basin but only half of it, since the 'Polder Aeroporto' is not studied. That area has a low degree of urbanisation and urban flood problems do not occur. - A polder is an area that is protected against inflow from water from the outside (until a water level of 5 meter above Datum), delimited by a dike. Pumping stations have the function to keep the polder dry and to remove the sewerage and drainage water.

The planning area is divided in 11 sub areas (A through L) based on water system and urban conditions. A geographical representation of the planning area and the sub areas is presented in figure 1.11.

S3.1 - Subdivision of planning area

The subdivision of the planning area is based on (and thus fits) the structure of the sewerage and drainage system. From the point of view of the problems, this subdivision is explainable. The main stream is the 'Arroio da Areia', which receives water from smaller canals, such as the canal 'Assis Brazil', 'Carneiro da Fontoura', 'Menno Barreto' and 'Cerro Azul'. The drainage system in the planning area can be divided in two distinct systems: one drained on the basis of gravity and one drained by a pumping station ('Casa de bombas Silvio Brum'). The subdivision of the planning area fits these two systems. For the analysis of the two systems two different computational models were used.

As for urban occupation conditions, the whole of the planning area has a similar function that is residential area, with the exception of the 'Country Club', two large shopping centres and a large green area. Although it is not made, a distinction of a shopping area is of importance, because it implies large impervious areas that contribute heavily to surface runoff. On the other hand the presence of impervious areas, e.g. parking areas, offers unique opportunities for the temporary storage of sewerage and drainage water because they limit interaction with the environment and they can easily be cleaned.

A division into neighbourhoods is used for the calculation of the CN-values on the basis of the urban density values per neighbourhood. However, CN-values corresponding to the future situation are based on yet another division that only recognizes categories of maximum allowed urban density. The latter division is somewhat problematic in that it foresees a considerable increase in urban density for some neighbourhoods: in some cases up to more than 3 times as much. This division does not fit the diversity in urban occupation.

Another distinction that is useful for the planning process, but that is not made, is between areas with a combined and a separated system. The fact that in one specific area a separated system is implemented should be of importance for the elaboration and selection of measures.

S3.2 - The geographical boundaries and the (water) system

The boundaries of the Areia basin are determinative for the choice of the planning area. The choice was made to exclude the 'Polder Aeroporto' from the scope. This did not lead to inconsistencies because the polder has relatively little hydrological relations with the water system inside the planning area. The explanation is that the surplus drainage water from the planning area is pumped away, before it enters the polder system, into a separated canal.
leading to 'Rio Gravitai'. With respect to the interaction with 'Rio Gravitai' and 'Lagoa Guaiña', it is supposed that the measures have no considerable impact on the water system, because the amount of water contained there is very large in comparison to the drainage volumes. This assumption neglects water quality impacts (for example, see figure 5.9).

Figure 5.9 Solid wastes washed onto the beaches of a nature reserve at 'Lagoa Guaiña'

A small discrepancy exists between the boundaries of the drainage systems that lead to the pumping station and those of the Areia basin as it was originally defined in the Sewerage Master Plan (figure 5.10). For this reason the boundaries of the planning area were slightly changed.

Figure 5.10 Systems that have an influence on the choice of the planning area

The whole hydrological basin lies inside the administrative boundaries of the city of Porto Alegre.
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S3.3 - The geographical boundaries and the territories of the actors
The geographical boundaries of the Areia basin do not fit the micro regions (figure 5.11): for the participatory budgeting process, the municipality has been divided in 16 'micro-regions', which function as the territorial bases for resource allocation. A micro region consists of one or more neighbourhoods. In each micro-region public hearings are organised in which the priorities for investments for the coming year in that area are discussed and decided upon by the population. These include both thematic priorities (e.g. pavement, transport, education) and public works to be carried out.

In 2003 inhabitants of the neighbourhoods ‘Chácara das Pedras’ and ‘Três Figueiras’ visited a public hearing to demand for expenditures on the implementation of the detention ponds. However no investments were allocated to their issues. Possibly, because the respective neighbourhoods represent only a small part of the concerned micro-region ‘Leste’. As a consequence inhabitants of other neighbourhoods, that are poorer, outnumbered the representation and thus had more weight in the selection procedure.

The fact that socio-economic difference exists between the neighbourhoods is of importance for the participatory budgeting process because poorer people tend to visit the meetings more often. Usually they have more urgent problems and more spare time, as they do not have a day job. Another reason that the drainage project was not chosen is that the construction costs were very high and not corresponding to the costs of other issues that are more generally decided upon in the meetings.

Figure 5.11 The planning area does not fit the division in ‘micro-regions’

S3.4 - relevance to the issues
The geographical boundaries are relevant for the flood problems. Flood problems occur throughout the whole basin and all areas inside the hydrological basin contribute to the causes of the problems. Rains that fall outside the study area do not contribute to the causes of the problems, because the surface runoff is towards other hydrological basins.

The heaviest inundations in the study area (involving loss of life) happen on the intersection of the roads ‘Nilo Peçanha’ and ‘Teixeira Mendes’ (figure 5.12). On this point that is the lowest of the region the drainage system, which transports the water to the ‘Arroio the Areia’, overflows and inundation levels can reach one meter. As a consequence houses are inundated. More upstream, on the intersection of the roads ‘José Gertum’, ‘Teixeira Mendes’ and ‘Luiz Walker’ water accumulates in the streets due to a limited drainage capacity. Upstream neighbourhoods that contribute to the causes of the flood problems are ‘Chacara das Pedras’, ‘Bom Jesus’ and ‘Três Figueiras’. 

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S.5 – relevance to the actors
In the current situation the flood problems of the upstream neighbourhoods Três Figueiras, Chácara das Pedras, Vila Jardim and Bom Jesus are transferred downstream. It is in the interests of the downstream inhabitants that surface runoff from these areas is controlled near the source. Therefore the geographical boundaries fit the interests of the downstream actors. On the other hand the solutions do not fit the NIMBY-interests of neighbourhood associations of Três Figueiras and Chácara das Pedras. Their issues should be contemplated in the process but they do not disprove the relevance of the geographical boundaries.

5.3.5 Reflection on scope
The evaluation shows that the scope can be dynamic. The central issue at the start of the planning and design process was the urban flooding and its solution. The inhabitants of the project area initially agreed to the solution that involved the implementation of detention ponds throughout the basin. However, their priorities changed when they learned about the elaboration of the measures and the recommended alternative. In particular the (organised) inhabitants of the neighbourhoods Três Figueiras and Chácara das Pedras were opposed to the recommended alternative, which foresees the implementation in 4 detention ponds inside the public parks of the two neighbourhoods. Their complaint is that the solution is not compatible with their interests, of which the most important is ‘quality of life’. The argument of inhabitants is that the parks get contaminated by the deposition of faecal material, solid waste and pathogenic organisms. Besides the ponds would produce a bad smell and attract mosquitoes. ‘Detention is a good solution … but not in Brazil’ is the perception of the president of AMATRES (neighbourhood association). The foundation for such statements is the bad maintenance and the lack of interventions and investments in the drainage system by the Stormwater Department in previous years. Moreover, the perception of unacceptable hygienic risks is fed by a lack of inside in the functioning of the detention ponds in urban areas. The Stormwater Department cannot provide information on how often the reservoirs will inundate and what are the key considerations to achieve multi-objective use.

On the other hand part of the complaints is due to lack of awareness and environmental education of the population. The opinion that ‘big cities need big canals’ is illustrative for the way of thinking of the population. In that sense the actual conflict is beneficial because the inhabitants are at last confronted with the results of their own actions (e.g. to make gardens highly impervious or to throw away rubbish on streets).
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And, of course, some complaints are pure NIMBY-interests: ‘Why is no detention pond planned in the other neighbourhood Bom Jesus?’

To include water quality and livelihood issues asks for a review of the scope. Actors that have a strong influence over the water quality issue are the Water and Sewerage Agency and the Department of Cleaning. But it is observed that these actors are not very susceptible to the urban flood problems and as such are not eager to enter the planning table. This problem is a nationwide one (see paragraph 2.6.3). In that case, other arguments need to motivate the intended participants to join the process.

Here lies an important role for the national government. New developments on a national level can provide the necessary arguments for integration of urban stormwater management with other aspects of urban infrastructure (as water supply, sanitation and solid waste management). Such arguments can be the ability from the national government to provide monetary and/or personal resources and/or knowledge to the process, be it that an integrated approach is followed. In this moment the national government is developing a National Stormwater Plan (Plano Nacional de Águas Pluviais). The policy of that plan is just to achieve the intended coordination.

5.4 Knowledge

5.4.1 Discussion of topics

K1.1 - Fitting communication style
Public meetings were organised at the end of the plan development process to inform the people about the urban drainage problems and the recommended solutions and to ask for budget for the implementation of the stormwater control measures. The educational character of the meetings was important because the perception of the inhabitants is usually such that they are ignorant to the causes of the flood problems and to what are modern solutions. In that respect the role of the media (newspapers and television) is important too, because they comment regularly on the flood problems and the solutions. With regard to the second objective, the plan developers have to ask the communities for priority in municipal expenditures as a result of the participatory budgeting process (see paragraph 5.3.3).

Participatory budgeting discussions typically have a distributive character (Van Woekum, 1998), in which parties compete for a share of a limited resource, resulting in closed positions and win-lose situations. In this case, the inhabitants compete for a share of the limited municipal budget. As a result of this scenario no money has been assigned to the benefit of the implementation of detention ponds. It is observed that the participatory budgeting process obstructs integrative discussions.

Another distinction is between dialectic or constructive communication modes. In dialectic discussions, people discuss starting from different points-of-view, exploring their differences. In constructive discussions people look for common ground and try to build a compromise.

A dialectic communication mode was recognizable in the initial discussions between the Stormwater Department and the Secretariat of Environment. Relations were already tense before the start of the discussion, because years before the Stormwater Department had constructed a multi-purpose detention area without the necessary authorisation of the Secretariat of Environment. In the first meetings the Secretariat of Environment was reluctant to accept any detention pond in the public open spaces. At one occasion, the differences between the actors only intensified as the unwitting consequence of different points of view between the actors and untactful behaviour: a co-operator from the IPH had mentioned the public parks as being the only ‘unused areas’.

Nonetheless, after a few years the discussion became more constructive, and the first detention pond can now be build in 'Quintino Bocaiuva' park, approved by both parties. To
achieve that situation the particular pond had to be redesigned in the implementation phase as a closed reservoir instead of an open one, as was proposed in the UDMP. On the other hand, the Secretariat of Environment now demands a similar design for all the other ponds. But, the Stormwater Department cannot afford this since a closed reservoir is more expensive to build and to maintain and thus a serious difference in ideas remains.

**K1.2 – Openness**

*In content* – The objectives for the Urban Drainage Master Plan were made explicit and public. The development of the plan was chosen as a fifth priority among 34 main city projects in the participatory decision-making process. Relevant base data for the elaboration of measures were provided by the Stormwater Department and were available to all members of the technical group.

To potential participants there was a threshold, in the sense that only more or less completed reports were readily available and presented to outsiders. As a consequence, no sooner than during the last phase of the policy cycle it became clear that public support for the plan was lacking. According to a co-operator on the plan development, that was never imagined considering the nature of the flood hazards.

*By participants* – Consciously strategic use of information was non-existent in the technical and supporting group. In the discussion with outsiders, city councillors Beto Moesch and Osório Queiroz played an important role. Both represented a different political party than the one that initiated the plan development, being the workers party 'PT'. The councillors were mentioned to have behaved distributively with the intention to win political votes, municipal elections going on at that time. They presented themselves as environmentalists. As a result of their behaviour the discussions polarized. The UDMP and the solutions that it presented became a political matter and the plan was described as 'PT stuff'. This compromised the position of the representatives of the Stormwater Department in the discussion. As for the role of the media similar political preferences play a part, one regional newspaper that reports regularly on the subject, being owned by the opposition.

Also, the employees of the Secretariat of Environment seemed to take a reserved attitude, stressing their own views, interests and objectives and being less susceptible to the views of others. At the moment they are only considering a variant with closed reservoirs within the public parks, but not the open types.

*To participants* – The design process was not open to participants; all participants were preselected on the basis of either their formal responsibilities (i.e. municipal authorities) or their knowledge (i.e. IPH and hired engineer). Representatives of the Secretariat of Environment and of the neighbourhoods were not involved directly in the project team, and they were consulted only when the plan was completed.

Even when the inhabitants were finally invited to participate, access to information was in some cases limited for them. This is shown by the following example. On a certain moment the Stormwater Department stopped the discussion with the neighbourhood associations on the solution of the flood problem, because the neighbourhood associations were very inflexible. The inhabitants wanted underground reservoirs or none at all. When at last the Stormwater Department decided to build an underground reservoir at ‘Quintino Bocaiuva’ park, they did not inform the inhabitants about the start of the works on this reservoir. Their argument was that the neighbourhood association had already expressed to accept a closed reservoir. The incident caused the inhabitants to consult the ‘Ministério Publico’ in order to stop the construction. Better communication could have prevented interference from the ‘Ministério Publico’.

**K1.3 – Internal inspiration**

In order to secure future law enforcement new knowledge had to be developed during the process. In that respect the development of an equation to distribute cost for operation and maintenance and for construction is a good example. Besides, a relation between the
percentage of impervious area and the necessary storage volume is developed to be able to maintain predevelopment runoff conditions.

A structural measure that is inspired on the local situation is the development of an on-line reservoir with two compartments, the first one executed in concrete for easiness of maintenance of more frequent storms, the second unlined and integrated in the landscape, for example, in the form of sport fields. A similar solution was adopted in the Capivara basin, where due to a lack of physical space no off-line reservoirs could be constructed because the drainage network could not be altered.

K1.4 - External Inspiration
Inspiration for the detention concept came mainly from knowledge in international literature. As for the regulation of the urban drainage and the occupation of risk areas experiences from the USA and France were contemplated.

K1.5 - Incremental or consecutive steps
The planning process for the Areia Plan is characterised by a step-by-step approach (figure 5.1). The plan development started in August 1998 with the drawing up of the conceptual elements that form the basis for the Areia Plan. The conceptual report was finished in May 2000. Partly in parallel with the work on the conceptual elements the technical group executed the planning for 3 hydrological basins of the city. The Areia Plan was finished in March 2002. Knowledge from the conceptual part and the Plans for the sub basins was used in the drawing up of the Urban Drainage Manual. Therefore the work on the manual was done at the end of the planning process.

K1.6 - (Non) negotiables
The policy that was developed by the IPH was discussed with the Stormwater Department. The latter did well accept the policy and no difficulties were encountered in the discussions.

In dealing with the unknowable a point of particular relevance is the scenario definition. The maximum allowed urban densities that are considered in the Urban Master Plan were chosen as design scenario for the future occupation. The maximum allowed density in the neighbourhoods was discussed in a public meeting. However the private interests from real estate developers were more decisive in these discussions than the interests of the local community. As a consequence a very high urban density was allowed. A co-operator from the IPH mentioned that it is undesirable from a water system point of view to plan so many inhabitants in the area.

With respect to the positive effects of the new regulation on urban drainage a conservative solution was chosen for two reasons. It was unsure how long the implementation of the regulation would take. And, if the source control measures would have a positive effect, then the surplus volume in the reservoirs could be used for environmental control.

K2.1 - Verification
As in any planning or design process, there is a need for verification of the notions used in the process. An important pitfall is the emergence of negotiated nonsense: negotiation results that make sense to the parties involved, but are not valid according to science or practical experience. In the process of the Areia plan the idea to control the water quality through extended detention times is considered. If pursuing the idea can lead to valuable results or to a ‘dead end’ is unknown to the policy makers. The same goes for the idea to
allow for multi-purpose use. This of course is an undesirable situation, because it can bring about promises that cannot be fulfilled.

Input data for the simulation of the macro drainage system, such as topography, pipe diameters, position and elevation, were delivered by the Stormwater Department. To obtain or check the data survey teams were used. Data verification by the side of the IPH proved that the survey data from the Stormwater Department was not always correct and measurements had to be redone in some cases.

The results from the hydrological simulations were tested for validity too. A qualitative assessment of the occurrence of inundations under the current scenario was done by expert judgment (through interviews of civil servants and local inhabitants). The verification learned that in some instances inundations were predicted where they did not occur and vice versa. This error could be explained by the fact that no street runoff was modelled, but only transportation through the drainage system. In reality the surplus water above the drainage capacity would be transferred downstream via surface runoff. However, the error was not corrected in the plan documentation. As a consequence of the bad documentation communication to outsiders was incorrect. At the 2003 flooding an employee of the Stormwater Department declared to be surprised by a flood incident that had happened in Nilo Peçanha Street, because the location was not considered as critical for the occurrence of floods in the Areia Plan. That statement strengthened the feeling of distrust from the inhabitants towards the municipality.

Only for the Moinho basin a quantitative verification was done taking into account observed flow velocities during flood conditions, because for this basin that is a sub basin of the hydrological basin of the Dilúvio monitoring has already been undertaken before the development of the UDMP.

K2.2 - Dealing with uncertainty
Uncertainty has turned out to be a precarious issue in the planning process. Sources of uncertainty were the (lack of) data, the knowledge of future developments, and the knowledge of fundamental processes. To understand the influence of uncertainty in related parameters on the final costs of the project a separate study was executed by a student, D.G. Allasia. Information from his master thesis was useful in the understanding of the limits of the design. However, the research outcomes were not documented in the reports, because the study was executed after the actual plan development. The quantitative way of dealing with uncertainty can be describe as a ‘content-oriented’ approach.

K3.1 - Documentation of progress
The IPH was responsible for the reporting of the study. A ‘growth document’ was used to discuss results, adding new results to the document as the process progressed. The growth documents were oriented on technical and scientific progress and were intended to form the final report in the end. The final report was presented in three parts (see paragraph 4.2.1). One part deals with the Plans for the hydrological basins, which were presented as separate volumes. In those Plans the bottlenecks are identified, the management strategies are elaborated, and the construction costs are estimated. Furthermore, a narrow plan of actions is included in the Plans.

The documentation of the progress in knowledge is sometimes insufficient. Some computational methods that are used for the simulation of the hydrological processes in the Areia basin are mentioned, but values that are used for the model parameters are not presented. Input data and assumptions are presented but were observed to be incomplete and inaccurate. For example, with regard to the characteristics of the conduits no roughness parameters and contributing drainage areas are included in the report. Besides it is unclear if the documented pipe diameters represent the total capacity or the increase in capacity needed to fulfil the stormwater control demands. Finally, the results of the verification process are not documented. The consequences thereof are discussed under topic K2.1.
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Better documentation is valuable to avoid discussions over interpretation of earlier results.

**K.2.2 - Documentation of agreement**
The Stormwater Department never documented any agreements from the public meetings, because of a lack of care. On the other hand, the population was more committed in their documentation. The population used the documents for their case against the Stormwater Department by the 'Ministério Publico'. Later on in the conflict the Stormwater Department began to realise the importance of efficient documentation and now it wants to start documenting too.

**5.4.2 Reflection on knowledge**
The planning process for the Area Plan was guided by the detention principle, rapid transportation being the alternative. Knowledge was mainly based on the application of scientific theory on sustainable stormwater control solutions. This meant that technicians played a leading role in the process. They used their knowledge to structure the problem and to solve it effectively and efficiently. The final step of the policy cycle was to announce the study results in the form of two alternative solutions (supposedly one sustainable and one non-sustainable) and to convince the public of the quality of the recommended alternative.

 Though sustainable stormwater control solutions inspired the plan developers, in the end they did not reach a sustainable solution themselves. In the final analysis the stakeholders concerned did not accept the recommended solution. Hence, the solution cannot be considered as sustainable in view of ethical aspects in sustainable development, like democratic values (equity). Additionally, some actors that do not support the solution can influence its implementation. For example, the Secretariat of Environment can withhold its authorisation. That this impedes sustainable development may be clear.

An important factor in the acceptance of and agreement on a solution is the approach followed in reaching that solution. In that respect the consideration of different aspects and interests is essential. Participants to the process should be more open about their interests and objectives, and be more susceptible to other people's interests and views. This lead to increased debate and negotiations, and to increased influence of stakeholders that otherwise would not have had that influence. Communication is therefore more than one-way traffic of information from the plan developers to the interested stakeholders; it is especially to listen to each other and to find acceptable solutions for the problems together. Whether or not this leads to a different technical solution (than in a closed process) in the end, as one of the co-operators to the plan development process in Porto Alegre mentioned, is not important. What matters is acceptance (or at least understanding) of the solution direction and legitimacy of the process.

**5.5 Aspects**

**5.5.1 Discussion of topics**

**Process phases**

*Initiative phase* - The Stormwater Department took the initiative to start the planning process. A need for new stormwater management practices and more integration with urban planning prompted the initiative for the Urban Drainage Master Plan. The plan development was commissioned to the IPH and Professor Tucci was appointed as project coordinator. The two central actors started talks with other municipal organisations that had influence over the problem and its solutions. The stake of the negotiations was to make a more integral solution possible by simultaneously targeting water quantity, water quality and solid waste management issues. But in the end neither the Water and sewerage agency nor the Department of Cleaning could be persuaded to join the planning table. As a result the water quality issue was left out of the plan. In hindsight it was admitted that the importance of that issue on the success of the plan was underestimated.
Plan development phase – The participants from the IPH worked in parallel on the vision formulation and the elaboration. The elaboration of the structural measures consisted of a consecutive series of steps, as represented in figure 4.1. The plans were prepared internally without input from the other municipal organisations or the public. The plan development phase was closed by the approval of the accompanying project documents.

Implementation phase – After the municipality had approved the plans, the reports were made public and the concept was explained in a series of public meetings. Since the respective phases were all but finished at that time, the issues from outsiders could not be incorporated in the process anymore. As a result of the DAD (Decide, Announce, Defend) approach support for the resulting plans was limited, which hindered effective implementation. One adaptation that was possible on the basis of the discussions with the Secretariat of Environment was to change one detention pond to a closed underground reservoir.

Knowledge gained in the discussions with the public would also be taken into account in subsequent plans for other hydrological basins. For one, reservoirs are not likely to be planned in public parks anymore.

Continuity
In concept – The concept should be reasonably robust and on the other hand it should not contain unnecessarily restricting (design) choices. The concept for the UDMP of Porto Alegre was defined at the start of the planning process. This concept was leading for the subsequent elaboration of structural measures and it supported the progress during the process for that reason. The plan developers, in hindsight, described the rate of progress as being satisfactorily.

In progress – No major pauses were observed in the initiative and plan development phase. In that respect, the project coordinator, Professor E.M. Tucci, and the director of the Stormwater Department, A. Damiani, played an important role as draggers of the planning process.

In people – In the discussions with the inhabitants continuity related to persons slowed down the progress. Replacements of the representatives of the neighbourhoods delayed the process, since the newcomers lacked the shared memory as well as the knowledge and insight resulting from the learning process. Reasons for inhabitants to leave the discussions can be that they moved to another neighbourhood or just that they grew tired with the discussions. Moreover, the neighbourhood association changes its president every two years.

System perception
The Stormwater Department is responsible for the protection of the municipality against pluvial floods and floods caused by the inflow of water from the river Gravatai and the lake Guaiba. On the basis of that task the Stormwater Department focuses mainly on physical system components. Besides, they have some attention for social components, like programs for solid waste control and education. This can be explained from their participation in activities, promoting environmental education in order to increase public participation and awareness in relation to the disposal of garbage and the functioning of the natural environment. Also the representatives of the IPH have a tendency to focus on physical components due to their predominantly technical background.

The Secretariat of Environment has a view of the urban system as a part of their control territory, in this case the public parks. The task of this authority is to manage and maintain the equipment placed in the public parks, and to preserve flora and fauna. Therefore they are predisposed to mainly intellectual and biological components, like aesthetic values and local ecology.
In the reporting the system perception of the IPH and the Stormwater Department are determinative. The Areia Plan focuses exclusively on physical and to lesser extent chemical components. Only in the policy volume are social components recognisable too.

**Basic approaches**

In paragraph 1.2.4 four basic approaches towards the management of the urban water system are described. The approach that is followed for the development of the Areia Plan by the central actors can be qualified as a 'ratio' approach. As is typical of the approach, the flood problems are defined as the difference between the present and future situation and the objectives set by the Stormwater Department. And the technical solutions to those problems are based on an evaluation and by considering the objectives. The method weighs the solutions on economic aspects in order to find the (supposed) optimum solution. The effectiveness of the solutions is solely determined by the capacity of the drainage network in relation to the maximum discharge. Ecological and socio values, which may not be quantifiable, like aesthetic values, play no role in the process.
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6 CONCLUSIONS PART II

6.1 Introduction

This chapter comments on the objective and the related observations and conclusions based on the evaluation of the planning and design of the Areia Plan. The objective for this part is:

2. To evaluate the planning and design of the Plan for the Areia basin. The ex-post evaluation should reveal shortcomings and strongpoints of the followed approach. Rijsberman (2004) has developed a method (3D-bril) that is useful as an assessment framework, focusing on relevant criteria concerning content and process.

The method 3D-bril that is used in this thesis as assessment framework is developed mainly on the basis of experiences with the urban water plans in the Netherlands. This study showed that the aspects discussed in the method 3D-bril are just as relevant for the Brazilian perspective. From the evaluation of the planning and design for the development of the Areia Plan several analyses are possible, which can help to improve the approaches for urban drainage planning in Porto Alegre and other Brazilian cities. However, before such analyses can be made it is necessary to discuss a few basic differences between the Dutch and Brazilian situations. These differences are a consequence of different institutional and cultural histories.

The Netherlands constructed their water management system from a basis of established institutional foundations, some of them centuries old. The system is characterised by a long tradition of democracy and decentralisation, and a strong consensus culture. Authoritative solutions and hierarchical decision-making are not very popular, in stead there is a strong urge to appease, reach agreement and prevent conflicts.

Brazilian independence was only recognised in 1822 by the Portuguese government (for background information on Brazilian history see appendix B), and as such the country had far less time to construct its administrative and institutional system. Moreover, for the greater part of the twentieth century Brazilian politics were characterised by repression of rivals in political disputes, corruption, bureaucracy and centralisation. As a result of that tradition a fair part of mistrust still exists between the population and the governments nowadays. The latter explains why governments and community organisations often see each other as adversaries, not as partners. Another relevant characteristic due to historical reasons is that Brazilians are more prepared to defend their individual rights, acting collectively if necessary, than their community rights. This cultural feature explains, for example, why nepotism has been politically tolerated for a long time.

When seeking to improve the methods for plan development in Brazil on the basis of the evaluation of a case study, it must be recognised that the evaluation framework 3D-bril is based on a context that is distinct from the Brazilian perspective. Nonetheless, the assessment criteria were illustrative indicators to reveal shortcomings and strongpoints of the planning and design process of the UDMP of Porto Alegre. Observation of these shortcomings and strongpoints will suggest important guidelines about how to improve the methods for plan development in Porto Alegre and other Brazilian cities. On the basis of these guidelines the policy makers should find out workable planning and design approaches for themselves, founded on existing institutional and cultural traditions adapted to the prevailing resources (power, personnel, monetary and knowledge).
6.2 Conclusions

Brazil is a country passing through a transition phase towards more sustainable urban stormwater management. A new generation of Urban Drainage Master Plans is currently emerging in Brazil owing to the inadequacies of traditional responses. Accordingly urban stormwater management has broadened from the originally technical, sectoral discipline. As a consequence of this transition, planning approaches should now be suited for a broader scope, equality and stakeholder influence. For that matter, the decision makers should recognise that planning and design for sustainability does not merely mean copying supposedly sustainable techniques. The evaluation of the Urban Drainage Master Plan of Porto Alegre showed that a lack of awareness of or attention for the aspects involved in sustainable planning and design can finally impede the implementation of the new plans.

The evaluation further revealed the following strongpoints and, more importantly, shortcomings of the planning and design process of the Urban Drainage Master Plan of Porto Alegre.

Content
In summary this track revealed the following shortcomings:

- The concept fails to maintain the system integrity, because water quality issues are left outside the scope.
- The concept does not correspond well to the local water system. Detention ponds in public open spaces are less applicable in case of a combined system, because the parks get contaminated by the deposition of faecal material, solid waste and pathogenic organisms. Besides the detention ponds are likely to produce bad smell and attract mosquitoes.
- The concept is not sustainable in view of ethical aspects, because important stakeholders do not accept the recommended solution.
- The concept is internally inconsistent in that the positive effects of the new regulation on source control are not taken into account. As a consequence the concept may fail to inspire and secondly some detention ponds are over designed so that valuable monetary resources are wasted.
- Insufficient municipal resources (personnel, budget and knowledge) threaten successful implementation and enforcement of the concept.
- Maintenance (especially the cleaning) seems to be a critical aspect in the success or sustainability of the solution. In the past the Drainage Department was not capable to maintain the urban drainage system adequately.
- There is not yet a clear insight into effective measures to deal with the large amount of sediment and solid waste.
- There is a political reluctance to invest money or to impose taxes probably as a result of the strong opposition against the solutions.

And the following strongpoints:
- The concept is relevant in view of the goals of the Urban Drainage Master Plan.
- The 2 basic strategies are based on and provide a clear insight into the legal boundaries.
- The concept promotes equity. Because it prevents a downstream transfer of impacts. Secondly operational costs are distributed proportionally to the impermeable area of the owners.
- The concept corresponds well to the socio-economic system, because operational costs are low and the change of damage due to human errors is small.

Scope
In summary this track revealed the following shortcomings:
- Although the inhabitants and the Secretary of Environment are affected by the consequences of the solution, they had no influence on the Urban Drainage Master Plan.
- The solution is not compatible with the interests of two neighbourhood associations, of which the most important is described as quality of life.
• The Water and sewerage agency and the Department of Cleaning are not very susceptible to the urban flood problems and as such are not eager to enter the planning table. Without their co-operation it is impossible to deal with water quality issues. The exclusion of water quality issues was among other things determinative for the failing implementation.
• The future scenario does not fit the diversity in urban occupation, because it foresees densities that are sometimes more than three times as much as the actual densities.
• It is not likely that investments will be allocated to the implementation of the detention ponds in the participatory budgeting process, because the construction costs are too high.

And the following strongpoints:
• Inhabitants of the downstream neighbourhoods do support the recommended solution, because they reason to prefer inundations in parks in stead of in houses and streets.
• Co-decision making on municipal expenditures is achieved in Porto Alegre for individual inhabitants through the participatory budgeting process.
• The plan development process was relatively cheap, because students co-operated in the plan development.

Knowledge
In summary this track revealed the following shortcomings:
• The planning process was relatively closed, in the sense that only more or less completed reports were readily available and presented to outsiders.
• The Secretariat of Environment took a reserved attitude, stressing their own interests and being less susceptible to the view of others.
• The discussions were polarised by the distributive behaviour of city councillors. This compromised the position of the decision makers.
• The engineers of the Drainage Department are not educated for the discussions with the public.
It is not verified if the idea to control the water quality through extended detention times can lead to valuable results or not at all.
It is not verified if the idea to allow for multi-purpose use can lead to valuable results or not at all.
• The documentation of the progress in knowledge was sometimes insufficient. In one occasion this led to incorrect communication to outsiders, which strengthened the feeling of distrust towards the Drainage Department.
• The Drainage Department did not document the agreements of the public meetings.
• Part of the complaints of the inhabitants is due to lack of awareness and environmental education. Other complaints are pure NIMBY-interests. Better communication can prevent such complaints.
• The participatory budgeting process obstructs integrative solutions.

And the following strongpoints:
• Internal inspiration led to new knowledge that will be useful to secure future law enforcement.

Aspects
In summary this track revealed the following shortcomings:
• The importance of the initiative phase was underestimated.
• Effective implementation is hindered by the lack of support for the solution.
• Replacements of the representatives of the neighbourhoods delayed the process. Better documentation could have prevented this.
• Ecological and social values, which may not be quantifiable, like recreational values, play no role in the process.
6.3 Recommendations

On the basis of the objective, the following recommendations are aimed at improving the approaches for the development of the Plans for the hydrological basins. The recommendations relate to the planning situation in Porto Alegre. For a somewhat more general discussion into what are important conditions for policy development of Urban Drainage Master Plans is referred to paragraph 9.3.

The recommendations are divided somewhat differently than the constellation that is used in the assessment framework which is on the basis of the following four priority areas:

1. Technical
2. Economical
3. Institutional
4. Communication/Strategy

A one-to-one link between the recommendations and the in the previous paragraph indicated shortcomings is not possible, because in practise the shortcomings are to be addressed by a combination of recommendations.

Content

**Recommendations on the technical area**

- Detention facilities must be used in conjunction with other structural measures that provide sediment and solid waste control.
- Adequate maintenance access must be provided.
- Positive effects of the new regulation on source control should be considered in the future scenario.

**Recommendations on the economical area**

- Create some sort of political commitment for financial support, for example by means of an intention agreement (to impose taxes or to pay for projects).
- The national government should allocate financial resources to the implementation of stormwater control solutions, because municipal resources are often insufficient.

**Recommendations on the institutional area**

- Maintenance and inspection activities should be improved. Quality control should be developed with clear requirements (for example, concerning activities and schedule).
- Capacity building is required at administrative level: education on sustainable urban water management should be developed and extra personnel should be hired.

**Recommendations on the communication and strategy area**

- It is valuable to invite representatives of the neighbourhoods to participate in the plan development, because these people have every day experience of the local water system and other relevant systems. This is something the policy makers generally lack. For this matter workshops can be organised.

Scope

**Recommendations on the technical area**

- Design criteria and specifications for multi-objective use of the detention facilities have to be worked out, aimed at quality of life.

**Recommendations on the economical area**

- The prospect of subsidies can be an incentive to achieve integrated planning of water quality, water quantity and solid waste issues. Here lies an important role for the national government. The issue is to be laid down in the new National Stormwater Plan. For a description of the conceptual basis of the National Stormwater Plan is referred to appendix A.
- New ways to get money assigned to the projects from participatory budgeting process should be explored. Therefore the demanded expenditures should be lowered. For example, by only asking money for the re-equipment of the detention facilities.
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**Recommendations on the institutional area**
- Integrated planning requires certain equality (in dedication, contribution and involvement) between the concerned actors, in which the organisations must be capable to look further than their own responsibilities.

**Recommendations on the communication and strategy area**
- The interests of the people who are affected by the consequences of the solution should be considered. For that purpose participants can have a seat in a focus group, which periodically is asked to comment on the process results.

**Knowledge**

**Recommendations on the technical area**
- Verification of the plan is necessary to identify if extended detention or multi-purpose use can lead to valuable results or not at all. The issue is discussed in chapter 7 of this study.

**Recommendations on the economical area**
- To make budget available for the better communication and documentation.

**Recommendations on the institutional area**
- The participatory budgeting discussions should be somewhat more aimed at identifying win-win situations and at reaching integrated solutions.

**Recommendations on the communication and strategy area**
- The scope can be expanded to include recreational aspects, so to make the planning process more interesting to the Secretariat of Environment.
- The interests of the people who are affected by the consequences of the solution should be considered. For that purpose participants can have a seat in a focus group, which periodically is asked to comment on the process results.
- Debate and negotiations are necessary to arrive to a result that the participants understand and can accept. A good communication plan is certainly helpful to develop the activities in this area. It is then useful to make a distinction between communication in the project group, to the decision makers, to the own administration, and to external organisations and (organised) inhabitants.
- Communication training of public administrators and engineers should be developed.
- The documentation of the progress should be more comprehensive.
- The agreement should be documented. It is of importance to the understanding of the choices and the results to include also the planning history and the context (for example, the results of negotiations).

**Aspects**

**Recommendations on the institutional area**
- The participatory budgeting discussions should be somewhat more aimed at identifying win-win situations and at reaching integrated solutions.

**Recommendations on the communication and strategy area**
- To reduce the risk that opposition against the plan will be mobilised stakeholders should be involved. When these stakeholders and other parties have some influence over the success of the plan, then at least acceptance of the choices in the plan is necessary.
- The process should be more open to the system perception of others, so as to reach enough support for the implementation of the projects.
- The consideration of aspects of other basic approaches to sustainable development is unavoidably to reach certain agreement.
- Pilot projects can help to gain confidence in the solutions. For that reason it may be worthwhile to start the implementation in the downstream areas where is more support.
PART III: CIVIL ENGINEERING DESIGN
7 ASSESSMENT OF IMPACTS FROM DETENTION IN URBAN AREAS

7.1 Introduction
Detention is a technique to control flow rates by storing floodwater and releasing it slowly once the risk of flooding has passed. Detention ponds store water at the ground surface, either as temporary flooding of dry basins and flood plains, or permanent ponds (figure 7.1). Though the detention concept is generally well known and substantial experience about the functioning exists outside Brazil, implementation in Brazilian cities is troublesome as shows this master thesis.

![Figure 7.1 Example of typical storage facilities](image)

One of the main reasons for the failing implementation of the Areia plan is the strong opposition against the recommended solution. The opposition is fed by a widespread perception that unacceptable risks and social losses (a lower quality of life) are involved in applying the detention concept. This perception cannot be disproved due to a lack of insight in the functioning of the designed reservoir structures, that is the result of the fact that important claims and ideas of the plan were not verified (see topic K2.1 - Verification in paragraph 5.4.1).

The objective of this chapter is therefore to test the ideas that are experienced as harmful to the interests of one (or more) of the actors. The conclusions of the tests should encourage the actors to reach consensus, allowing for resolution of the flood problems.

7.2 General detention concepts
Different aspects make up the functioning of a detention pond, and should be tested for. That is hydraulic, social and environmental hygienic aspects.

7.2.1 Hydraulic functioning
The detention basins provide flood control benefits – compensating for the impacts of urbanisation – by reducing the peak rates of post-development stormwater to the desired rate by providing storage for excess flows. The storage volume required to accommodate the reduced discharge rate controlled by the basin outflow structures is depicted in a conceptual manner in figure 7.2 as the shaded area at the upper portion of a stormwater runoff hydrograph. Stormwater detention for this purpose is sometimes referred to as 'peak shaving,' since the objective is to reduce the peak rate of runoff to control flooding from relatively intense (infrequent) storms.
Storage facilities are often classified on the basis of their location and size. On-site storage is constructed on individual development sites. Regional storage facilities are constructed at the lower end of a sub watershed and are designed to manage stormwater runoff from multiple development sites.

Storage can also be categorised as on-line or off-line. On-line storage uses a structural control facility that intercepts flows directly within a conveyance system or stream. Off-line storage is a separate storage facility to which flow is diverted from the conveyance system. Figure 7.2 illustrates on-line versus off-line storage.

The 11 detention ponds in the Areia plan are all off-line facilities that store stormwater runoff from multiple development sites. Because the Areia plan is a management plan, the optimal storage volumes and by-pass flows are to be calculated at project level.

The optimum level of flood control is achieved when multiple design storms are controlled. The control of the 10-year design storm is the standard for the plan development of the Areia basin. Control of the 10-year storm is sufficient to adequately control the entire spectrum of expected flood frequencies from smaller storms.

The runoff that passes through the basin during the periods when it is inundated, pollutes the pond bottom and hinders use of the ponds for recreational opportunities. After such events the ponds should be cleaned. For both economical (maintenance costs) and environmental reasons the inundation from more frequency storms should be limited. In the Urban Drainage Master Plan the following norms and standards are chosen:
Towards sustainable planning and design of stormwater control solutions in Brazil

Quality/environmental control – The reservoirs are kept the dry during the year and are only used during events with return period above 2 years. In some cases a lower return period was used due the low capacity of the existing net.

The last part of the formulation is fairly ambiguous and may provoke negative feelings by other actors. Moreover, it is not shown in the Areia plan whether or not the recommended solution meets the (rather unclear) norm. Therefore the first research question for the assessment process is formulated as follows:

*RQ1*: Is the norm for quality/environmental control met by the recommended solution?

7.2.2 Social functioning

From the point of view of the (organised) inhabitants the solution should be compatible with their interests. Of which the most important is described as quality of life (see topic SO – Internal consistency in paragraph 5.3.1). The fact that the detention ponds are planned in public open spaces is potentially harmful to the quality of life. A local newspaper quoted the feelings of the president of the neighbourhood association: “we only have five parks ... a park is for leisure”. In order to protect the interests of the local inhabitants, multi-purpose use of the detention facilities can lead to valuable results.

Multi-purpose detention areas are site areas primarily used for one or more specific activities that are also designed to provide for the temporary storage of stormwater runoff. Multi-purpose detention areas are normally dry between rain events, and by their very nature must be useable for their primary function the majority of the time.

The second research question is then:

*RQ2*: Can a solution direction involving multi-purpose use lead to valuable results or not at all?

7.2.3 Environmental hygienic functioning

Adapting the detention ponds to achieve extended detention times is considered in the Areia Plan for quality control of the stormwater runoff. If stormwater is detained for 24 hours or more, as much as 90% removal of particulate pollutants is possible. However, extended detention only slightly reduces levels of soluble phosphorus and nitrogen found in urban runoff. Removal of these pollutants can be enhanced if the normally inundated area of the pond is managed as a shallow marsh or permanent pool. The Areia plan mentions the following intermediate values (table 7.1) for pollutant removal according to Schueler (1987).

<table>
<thead>
<tr>
<th>Project type</th>
<th>Associated pollutants</th>
<th>Total phosphorus</th>
<th>Total Nitrogen</th>
<th>DBO</th>
<th>Metals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[%]</td>
<td>[%]</td>
<td>[%]</td>
<td>[%]</td>
<td>[%]</td>
</tr>
<tr>
<td>1</td>
<td>60 a 80</td>
<td>20 a 40</td>
<td>20 a 40</td>
<td>20 a 40</td>
<td>40 a 60</td>
</tr>
<tr>
<td>2</td>
<td>80 a 100</td>
<td>40 a 60</td>
<td>20 a 40</td>
<td>40 a 60</td>
<td>40 a 80</td>
</tr>
<tr>
<td>3</td>
<td>80 a 100</td>
<td>60 a 80</td>
<td>60 a 80</td>
<td>40 a 60</td>
<td>40 a 80</td>
</tr>
</tbody>
</table>

project 1 – to store the first part of the runoff volume for 6 to 12 hours;
project 2 – surface runoff volume from a 25,4 mm storm detained for 24 hours;
project 3 – the same as project 2, but with a vegetated bottom

A key point to consider when developing, or complying with requirements for stormwater quality enhancement is sizing the control device so that it provides adequate detention time for the entire spectrum of storms. For example, if an extended detention pond is designed to store and release the one-year storm over a 24 hour period, storms smaller than the one year storm event will pass through the outlet structure much more rapidly, and in some cases, may only have a detention time of a few hours. Unfortunately, small storms deliver a majority of the annual runoff volume to the pond. As a result, the annual pollutant removal...
of the extended detention pond may be reduced if the small storms are not adequately
detained.

The last objective is to identify if extended detention can lead to valuable results or not. The
last research question to be answered in the assessment process is:

**RQ3:** Can a solution direction involving extended detention lead to valuable results or not at
all?

### 7.3 Assessment process

In order to assess the functioning of the detention ponds in the urban environment a system
analysis has to be performed. The 6 main steps of the analysis process are:

1. The specification of the objectives of the analysis and the constraints (§7.4);
2. The collection and review of existing data (§7.5);
3. The modelling of the urban water system (§7.6);
4. The testing and assessment of the functioning of the urban water system (§7.7);
5. The proposition of measures for enhanced functioning (§7.8);
6. The presentation of conclusions and recommendation (§8).

### 7.4 Objectives and constraints of the analysis

**Objectives**
The main objective of the system analysis is:

3. To allow for a resolution of the problems in Porto Alegre by testing the functioning of the
detention facilities in the study area.

The sub objectives are formulated in the form of 3 research questions:

**RQ1:** Is the norm for quality/environmental control met by the recommended solution?

**RQ2:** Can a solution direction involving multi-purpose use lead to valuable results or not at
all?

**RQ3:** Can a solution direction involving extended detention lead to valuable results or not at
all?

**Constraints**
The constraints for the assessment process are specified below:

1. The results of the system analysis are only to be used for management purposes and not
for design purposes.
2. The modelling comprises only the sub basins that are drained by gravity. For that reason
a cinematic model can be used.
3. Hypothetical storms based on Intensity-Frequency-Duration curves are used as input for
the model (in stead of times series).

### 7.5 Input data

Input data comprises the characteristics of the urban system, the stormwater system and
the rain data.

For the simulation process the urban system is divided into sub basins, that are
characterised by their area and hydrological parameters CN and Ks. These characteristic
parameters are presented in appendix C.

The stormwater system comprises reservoirs and conduits. The characteristics of the
reservoirs structures are presented in table 7.2. The dimensions of the conduits are detailed
in appendix D.
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Table 7.2 Characteristics of reservoirs

<table>
<thead>
<tr>
<th>№</th>
<th>Name</th>
<th>Volume [m$^3$]</th>
<th>Depth [m]</th>
<th>By-pass [m$^3$/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lopes Travao</td>
<td>4300</td>
<td>1.50</td>
<td>2.52</td>
</tr>
<tr>
<td>2</td>
<td>Francisco Guerra</td>
<td>2200</td>
<td>1.00</td>
<td>1.03</td>
</tr>
<tr>
<td>4</td>
<td>Quintino Bocaiuva</td>
<td>8400</td>
<td>1.50</td>
<td>4.90</td>
</tr>
<tr>
<td>5</td>
<td>La Hire Guerra</td>
<td>2800</td>
<td>1.00</td>
<td>1.05</td>
</tr>
<tr>
<td>9</td>
<td>Fortunato Pimentel</td>
<td>2600</td>
<td>1.00</td>
<td>1.10</td>
</tr>
<tr>
<td>10</td>
<td>Irani Bertelli</td>
<td>12700</td>
<td>1.50</td>
<td>4.75</td>
</tr>
<tr>
<td>12</td>
<td>Grecia</td>
<td>4200</td>
<td>1.00</td>
<td>13.55</td>
</tr>
<tr>
<td>13</td>
<td>Alim Pedro</td>
<td>7800</td>
<td>1.00</td>
<td>1.05</td>
</tr>
<tr>
<td>14</td>
<td>Parque Alemanha</td>
<td>8500</td>
<td>2.00</td>
<td>1.70</td>
</tr>
<tr>
<td>15</td>
<td>Country Club</td>
<td>26600</td>
<td>3.00</td>
<td>9.66</td>
</tr>
</tbody>
</table>

Hypothetical storms of a $\frac{1}{2}$, 1, 2, 5 and 10 year return period constitute the rain data.

7.6 Modelling

For the simulation of the hydrological processes the model IPH (version IPHS1) is applied.

IPHS1 is based on a computational model with emphasis on the determination of the project hydrographs in different sections of the water system. The evaluation of intended flood control measures is the best-known application.

7.6.1 Computation methods

The models in the area of water management in general composed of two parts:

\[
\frac{\text{input precipitation } p(t)}{} \rightarrow \frac{\text{loss model}}{} \rightarrow \frac{\text{net precipitation } p_n(t)}{} \rightarrow \frac{\text{transformation; routing}}{} \rightarrow \frac{\text{output runoff } q(t)}{}
\]

In the first part the balance between input and output is reconciled; the second takes care of the runoff retardance.

For this master thesis the following modules of the model IPHS1 are used.

7.6.2 Design storm hyetograph estimation

The alternating block method$^1$

The alternating block method is a simple way of developing a design hyetograph from an intensity-duration-frequency curve (figure 5.4). The design hyetograph produced by this method specifies the precipitation depth occurring in $n$ successive time intervals of duration $\Delta t$ over a total duration $T_d = n\Delta t$. After selecting the design return period, the intensity is read from the IDF curve/relation for each of the durations $\Delta t$, $2\Delta t$, $3\Delta t$ ... and the corresponding precipitation depth found as the product of the intensity and duration. Differences between successive precipitation depth values give the amount of precipitation to be added for each additional unit of time $\Delta t$. These increments, or blocks, are recorded into a time sequence with the maximum intensity occurring at the centre of the required duration $T_d$ and the remaining blocks arranged in descending order alternately to the right and left of the central block to form the design hyetograph (Chow et al, 1988). Figure 7.3 is an example of this temporal distribution; this shows the rainfall depths for a 2-hour storm, with a 1-minute computation interval.

$^1$ The hyetograph synthesised by this method exhibits the property that the maximum rain depth for every duration equals the depth given by the IDF curve for that duration and for a specified return period. This is equivalent to the assumption that the probability observed for various durations within a storm is constant, which is unrealistic as variations in rain severity during storms are ignored. For that reason this method overestimates the input precipitation.
7.6.3 Loss-model

The curve-number-method

The curve-number-method is a method incorporated in the model TR 55 of the American Soil Conservation Service (SCS). In this model the runoff is estimated by

\[ P_{ef} = \frac{(P - I_a)^2}{(P - I_a + S)} \]

with

- \( I_a \) = initial loss and therefore the sum of interception, infiltration, losses from pools etc.
- \( S \) = maximal amount of water retained in the soil. Then is:

\[ S = \frac{1000}{CN} - 10 \]

The curve number depends on the ground use and on the type of soil. There are 4 types distinguished. For the choice is referred to the handbooks.

In this study it is assumed that \( I_a = 0.2 \, S \), although doubt about this exists. In that case the runoff and with that the precipitation loss can be read from figure 7.4.
7.6.4 Transformation model

Clark's Unit Hydrograph method
Clark's model derives a watershed UH by explicitly representing two critical processes in the transformation of excess precipitation to runoff:
1. Translation or movement of the excess from its origin throughout the drainage to the watershed outlet; and
2. Attenuation or reduction of the magnitude of the discharge as the excess is stored throughout the watershed.

The Clark Unit Hydrograph procedure is a two-step procedure for the development of a unit hydrograph. The first step of the procedure is the development of a time area (TA) curve based on watershed characteristics. This curve is then routed through a linear reservoir to produce the final unit hydrograph. The difference between the time-area translation hydrograph and the basin outflow hydrograph (figure 7.5) is caused by basin storage and the resulting attenuation of the hydrograph.

Figure 7.4 Graphic solution of SCS runoff equation (Kibler, 1982)
The TA curve relates time to the fraction of the total watershed area, which contributes to runoff. A TA curve can be developed by determining this contribution for time intervals between 0 and the total time of concentration of the watershed. These time intervals are drawn onto a plan drawing of the watershed, and the total contributing area of each watershed is shown in Figure 7.6. The total time of concentration of the watershed is broken into a number of intervals and for each of these intervals the ration of this time to the total time of concentration is calculated.

\[ T_i = \frac{t_i}{t_c} \]

with

- \( T_i \) = ratio of time to total time of concentration
- \( t_c \) = total watershed time of concentration
- \( t_i \) = time step in question

The cumulative TA curve (figure 7.7) may be developed from

\[ TA_i = 1.414T_i^{1.5} \quad \text{for} \quad 0 < T_i < 0.5 \]
\[ TA_i = 1 - 1.414(1 - T_i)^{1.5} \quad \text{for} \quad 0.5 < T_i < 1.0 \]

with
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$TA_i =$ cumulative value of time area curve
$T_i =$ ratio of time to total time of concentration

Figure 7.7 Cumulative TA curve and accompanying shape of the basin

Once the TA curve is developed, the Clark unit hydrograph is generated by routing this TA curve through a linear reservoir with a routing parameter $R$. The routing parameter $R$ is used to calculate a routing coefficient $c$ using

$$c = \frac{2\Delta t}{2R + \Delta t}$$

with

- $c =$ linear routing coefficient
- $R =$ Clark storage coefficient
- $\Delta t =$ time step of analysis

The basin storage coefficient, $K$ (now termed $R$ in most references to the Clark method), is an index of the temporary storage of precipitation excess in the watershed as it drains to the outlet point. Germano (1995) observed that for urban basins in Brazil it is possible to establish the following relation between the basin storage coefficient and the time of concentration:

$$K \approx 0.5 \cdot t_c$$

The routing coefficient and the TA curve are used to find the instantaneous unit hydrograph (IUH) using the linear routing equation

$$IUH_i = c\overline{TA}_i + (1 - c)IUH_{i-1}$$

with

- $IUH_i =$ increment of the instantaneous unit hydrograph
- $c =$ linear routing coefficient
- $\overline{TA}_i =$ average time area ordinate at step $i$. $\overline{TA}_i = 0.5(TA_i + TA_{i-1})$

The final unit hydrograph can then be generated by averaging two instantaneous unit hydrographs which are the time step $\Delta t$ apart.

$$UH_i = 0.5(IUH_i + IUH_{i-1})$$
7.6.5 Flow model
The flow model serves to rout the runoff through (i) the reservoirs, described by the modified Puis routing method, and (ii) the canals and conduits, described by the Muskingun-Cunge method.

**The modified Puis method (for reservoirs)**
The Modified Puis routing method is based upon a finite difference approximation of the continuity equation, coupled with an empirical representation of the momentum equation. For the Modified Puis model, the continuity equation is transformed as follows:

\[(I_1 + I_2) + \left(\frac{2S_1}{\Delta t} - O_1\right) = \frac{2S_2}{\Delta t} + O_2\]

with
\[I\] = inflow
\[O\] = outflow
\[S\] = storage

This simplification assumes that the lateral inflow is insignificant, and it allows the width to change with respect to location. \(\Delta t\) must be chosen so that the hydrographs are approximately linear over the time increment.

A relationship between storage and outflow is required to solve the Pulse model. From that function the relationship of outflow \(O\) versus \((2S/\Delta t) + O\) is computed for various stages. The number of points used to represent the relationship should be sufficient that the use of linear interpolation between adjacent points will not lead to significant errors. Given the inflow hydrograph, the initial values of outflow \(O_1\) and storage \(S_1\) and \(\Delta t\) a tabular computation sheet can be developed to iteratively solve the Pulse model.

**Muskingun-Cunge Method (for canals and conduits)**
The Muskingum routing model, like the modified Puis model, uses a simple finite difference approximation of the continuity equation:

\[\frac{I_1 - I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{\Delta t}\]

Storage in the reach is modelled as the sum of prism storage and wedge storage. As shown in Figure 7.8, prism storage is the volume defined by a steady-flow water surface profile, while wedge storage is the additional volume under the profile of the flood wave. During rising stages of the flood, wedge storage is positive and is added to the prism storage. During the falling stages of a flood, the wedge storage is negative and is subtracted from the prism storage.
Figure 7.8 Wedge storage (from Linsley et al, 1982)

The volume of prism storage is the outflow rate, $O$, multiplied by the travel time through the reach, $K$. The volume of wedge storage is a weighted difference between inflow and outflow, multiplied by the travel time $K$. Thus, the Muskingum model defines the storage as

$$S = KO + KX(1 - O) = K[XI + (1 - X)O]$$

with

- $K$ = travel time of the flood wave through routing reach
- $X$ = dimensionless weight ($0 < X < 0.5$).

Combining the two equations to eliminate the storage variables and solving for the unknown $O$, given $I_2$, $I_1$ and $O_1$ the following equation results

$$O = c_0I_2 + c_1I_1 + c_2O_1$$

with

- $c_0 = \frac{-KX + 0.5\Delta t}{K - KX + 0.5\Delta t}$
- $c_1 = \frac{KX + 0.5\Delta t}{K - KX + 0.5\Delta t}$
- $c_2 = \frac{K - KX - 0.5\Delta t}{K - KX + 0.5\Delta t}$

and $c_0 + c_1 + c_2 = 1$

As noted, the feasible range for the parameter $X$ is $(0, 0.5)$. However, these other constraints apply to selection of $X$ and the parameter $K$:

1. As with other routing models, an accurate solution requires selection of appropriate time steps, distance steps, and parameters to ensure accuracy and stability of the solution. With Muskingum routing, as with modified Puls routing, the distance step, $\Delta x$, is defined indirectly by the number of steps into which a reach is divided for routing. And as with other models, $\Delta x/\Delta t$ is selected to approximate $c$, where $c = \text{average wave speed over a distance increment } \Delta x$. With the Muskingum model, the wave speed is $K/L$, so the number of steps should be approximately $K/\Delta t$.

2. The parameters $K$ and $X$ and the computational time step $\Delta t$ also must be selected to ensure that the Muskingum model is rational. That means that the parenthetical terms must be non-negative; the values of $K$ and $X$ must be chosen so that the combination falls within the shaded region shown in Figure 7.9.
Figure 7.9 Feasible region for Muskingum model parameters

K and X can be estimated from channel characteristics. K can be estimated as

\[ K = \frac{\Delta x}{c_0} \]

and \( c_0 = \frac{dQ}{dA} \)

The derivation of the discharge may be estimated for each depth \( h \) with Manning's equation

\[ c_0 = \frac{1}{b} \left( \frac{Q(h + \Delta h) - Q(h)}{\Delta h} \right) \]

and

\[ Q = \frac{AR^{2/3}S^{5/2}}{n} \]

Jones (1981) analysed the precision characteristics of the numerical schematisation of the Muskingum model in order to solve the diffusion equation and to suggest an estimation for the relations between and X for different errors of damping and velocity. In the interval \( 0.4 \leq X \leq 0.5 \) the following equation may be applied

\[ \frac{K}{\Delta t} = 0.32X^{1.25} \]

For the interval \( 0.4 \leq X \leq 0.5 \) \( K/\Delta t \) can be estimated as \( K/\Delta t \approx 1 \).

Cunge (1969) estimated X as

\[ X = \frac{1}{2} \left( 1 - \frac{Q_0}{BS_0c\Delta x} \right) \]

with
- \( Q_0 \) = a reference flow from the inflow hydrograph
- B = top width of flow area
- \( S_0 \) = friction slope or bed slope
- c = flood wave speed (celerity)
- \( \Delta x \) = the length of reach
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The reference flow is an average value for the hydrograph, midway between the base flow and the peak flow (Ponce, 1983).

7.6.6 Simulation process

Based on simulation models and associated computational methods, IPHS1 is a tool for hydraulic assessment of interventions in a water system. Using a graphical user interface (figure 7.10), the functioning of the water system can be simulated. Therefore a 1-D schematisation of the water courses and storage basins is needed.

![Graphical User Interface of IPHS1](image)

Figure 7.10 Graphical User Interface of IPHS1

Some of the studied hydrographs at the lower end of the sub basins are shown in appendix E, representing a storm event with a return period of 10 years and the future scenario.

7.7 The testing and assessment of functioning of detention ponds

By means of the simulation model the ideas and claims in the Areia plan are tested in this chapter. The outcome of the tests is interpreted on the basis of knowledge from the case study and expert judgement. Because the assessment has in part a subjective character, the choices are clearly motivated.

7.7.1 Hydraulic functioning

Tests

The norm for quality/environmental control is formulated in the concept of the Urban Drainage Master Plan.
Quality/environmental control – The reservoirs are kept the dry during the year and are only used during events with return period above 2 years. In some cases a lower return period was used due the low capacity of the existing net.

For the tests the computed maximum water levels in the reservoirs as the result of a storm event with a return period of 2 years, are compared to the norm. A distinction is made between the protection under the current scenario conditions and the future scenario conditions. The results of the tests are presented as inundation levels in figures 7.11 and 7.12.

Under current scenario conditions three reservoirs meet the norm, namely reservoirs nº 2, nº 5 and nº 12. Reservoirs that do clearly not meet the norm are reservoirs nº 4, nº 9, nº 10, nº 13 and nº 15. Under future scenario conditions none of the reservoirs meet the norm.
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The reservoirs that do not meet the norm are qualified as potential bottlenecks, because the reservoirs cause nuisance if the areas are polluted too often. How to deal with the potential bottlenecks will be discussed in the assessment.

**Assessment**

The test results need to be considered as an overview of potential bottlenecks (reservoirs that do not meet the norm). In fact, the evaluation of the planning and design of the Areia plan showed that not all potential bottlenecks are really experienced as threatening. For that reason a assessment is necessary, that leads to a list of real bottlenecks that need to be taken care of.

Obvious bottlenecks are reservoirs n° 1, n° 2 and n° 4 (respectively "Lopes Travao", "Francisco Guerra" and "Quintino Bocaiuva"). These reservoirs are located in the neighbourhoods "Três Figueiras" and "Chácara das Pedras". The organised inhabitants of the two neighbourhoods experience the development of detention ponds in the local parks as a serious threat to the quality of live in the neighbourhoods. They find that the parks need to be reserved for recreation. Because the test results show that the reservoirs are to be used more than twice annually in the future scenario recreational functions cannot be performed properly. Therefore the design of the three reservoirs requires renewed attention. The discussion on reservoir n° 5 "La Hire Guerra" is already resolved, because another location has been appointed to its use.

The idea to develop reservoirs n° 9, n° 10 and n° 12 (respectively "Fortunato Pimentel", "Irani Bertelli" and "Grecia") is fairly well received by the inhabitants of the concerned areas. The inhabitants feel that it is better if the parks get flooded occasionally than that the streets and houses get inundated. The three detention ponds are not considered as real bottlenecks.

A second criteria not to qualify a reservoir as a real bottleneck is if it is located in a undeveloped area. The motivation is that no functions are to be lost. This applies to reservoirs n° 14 and n° 15 (respectively "Parque Alemanha" and "Country Club").

The only reservoir that needs to be taken care off too is n° 13 ("Alim Pedro"). The reason is that its primary purpose is to be used as a soccer field.

### 7.7.2 Social functioning

**Tests**

All multi-purpose detention facilities must be designed to minimize potential safety risks, potential property damage, and inconvenience to the facility's primary purposes. Design criteria for multi-purpose detention areas in high-density public areas such as parks are available in literature from the USA:

*These areas can be designed to flood no more than once or twice annually, and provide important open recreation space during the rest of the year*.¹

For the tests the computed maximum water levels in the reservoirs as the result of two storm events, one with a return period of 1 year and the other of half a year, are compared to the norm. A distinction is made between the protection under the current scenario conditions and the future scenario conditions. The results of the tests are presented as inundation levels in figures 7.13 and 7.14.

---

¹ 'Georgia Stormwater Management Manual'

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Under current scenario conditions only two reservoirs do not meet the norm, namely reservoirs n° 10 and n° 13. All other reservoirs meet the norm and thus allow for recreational uses in the current situation. However, due to increased stormwater runoff as the result of extra urbanisation, the reservoirs flood too often in the future scenario to be useable for their primary function the majority of the time.

The reservoirs that do not meet the norm are qualified as potential bottlenecks, because the reservoirs do not allow for multiple uses of the site areas. How to deal with the potential bottlenecks will be discussed in the assessment.
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**Assessment**

The actual functions of the areas are relevant to assess if multi-purpose use of the detention facilities can lead to valuable results. At present two areas are still undeveloped, namely reservoirs n° 12 and n° 14. The area of reservoir n° 13 is used for athletic facilities. All other areas are used as a public park.

In the interest of the inhabitants it is valuable to maintain the actual functions of the areas. But since none of the reservoirs meets the norm for multi-purpose use under future scenario conditions, every reservoir with the exception of those two located in undeveloped areas, needs to be taken care off. Only if the norm is met can multi-purpose use of the detention areas lead to valuable results.

**7.7.3 Environmental hygiene functioning**

**Tests**

Stormwater detention for water quality control employs an entirely different storage strategy than for the quantity control (depicted in figure 7.2). An important distinction is that while peak runoff rate is the key parameter for flood control, the runoff volume is significant for water quality control. Basins constructed for water quality control must capture and detain almost all runoff for the design storm; however, the design storm is a much smaller event.

The detention basins have been designed in the Areia plan to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. But it is possible to modify these facilities to incorporate features that provide water quality treatment. Literature from the USA provides basic guidelines for sizing dry extended detention ponds.

Two project types are tested for volume-based design to achieve pollutant capture through extended detention times:

- To detain the runoff of a one-inch storm for 24 hours (about 25.4 mm), according to Schueler (Controlling urban runoff, 1987);
- To detain the runoff of a one-month-to-month storm for 24 hours (about 44.2 mm), according to Roesner (Sustaining urban water resources in the 21st century, 1997).

The testing is only done for the future scenario, as the enhancement of water quality through extended detention times is only an option in long run, namely after a separated system is implemented. For the tests it is assumed that no runoff water drains away from the facility in the first 24 hours. The results of the tests are presented in table 7.3 as storage volumes to accommodate the runoff produced by the events corresponding to the two project types.

<table>
<thead>
<tr>
<th>Nº</th>
<th>Name</th>
<th>Quantity control</th>
<th>Quality control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Volume [m³]</td>
<td>1-inch storm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Volume [m³]</td>
</tr>
<tr>
<td>1</td>
<td>Lopes Travao</td>
<td>4300</td>
<td>3900</td>
</tr>
<tr>
<td>2</td>
<td>Fransisco Guerra</td>
<td>2200</td>
<td>1800</td>
</tr>
<tr>
<td>4</td>
<td>Quintino Bocaiuva</td>
<td>8400</td>
<td>5700</td>
</tr>
<tr>
<td>5</td>
<td>La Hire Guerra</td>
<td>2800</td>
<td>2000</td>
</tr>
<tr>
<td>9</td>
<td>Fortunato Pimentel</td>
<td>2600</td>
<td>2500</td>
</tr>
<tr>
<td>10</td>
<td>Irani Bertelli</td>
<td>12700</td>
<td>11000</td>
</tr>
<tr>
<td>12</td>
<td>Grecia</td>
<td>4200</td>
<td>10300</td>
</tr>
<tr>
<td>13</td>
<td>Alim Pedro</td>
<td>7800</td>
<td>2500</td>
</tr>
<tr>
<td>14</td>
<td>Parque Alemanha</td>
<td>8500</td>
<td>4700</td>
</tr>
<tr>
<td>15</td>
<td>Country Club</td>
<td>26600</td>
<td>13300</td>
</tr>
</tbody>
</table>

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Assessment
Caution should be exercised when adapting the flood control detention facilities for water quality detention. In particular the flood control performance of the basin must be evaluated for larger storms with the modified outlet. If a combined strategy is to be considered the basins need to be modified to increase the storage volume available, compensating for the decreased outflow rate at lower basin stages during larger storms.

In addition to being much larger, the reservoirs are to be used much more frequently too if a combined strategy is to be implemented, because the facilities must capture almost all runoff. Especially the latter issue is threatening to the interests of the population: it impedes that the sites are used for recreational opportunities. For that reason pollutant removal through extended detention is not considered feasible at the sites in question.

7.8 Measures
Appropriate measures are to be generated to solve the identified bottlenecks and to meet the standards for system behaviour resulting from the functional demands. In the targeted situation the detention areas must be useable for recreational opportunities the majority of the time. Correspondingly, the objective of the measures is that the reservoirs are kept the dry during the year and are only used during events with return period above 6 months.

An effective and cheap measure to achieve this is to build the detention ponds with two sub basins or stages, according to figure 7.15.

![Figure 7.15 Example of reservoir with two sub basins](image)

The first compartment is used for the control of more frequent storms, with a capacity to detain runoff from storm events with a return period until 6 months, while the second compartment is designed for more extreme storm events with a return period up to 10 years.

The main advantage of this type of structure is that it can simplify maintenance activities. To achieve this, the first sub basin that normally receives the highest pollution load should be executed in concrete for easiness of cleaning after inundation events.

The second basin can be unlined and it should be integrated in the landscape, for example, in the form of sport fields. Because it receives water no more than twice annually it allows perfectly for multiple uses of the area.

The distribution of areas between the two basins is indicated in table 7.4 on the basis of a design return period for the first sub basin until 6 months.
Table 7.4 Dimensions of partitioned reservoirs

<table>
<thead>
<tr>
<th>Nº</th>
<th>Name</th>
<th>Entire basin Volume [m³]</th>
<th>Distributor H [m]</th>
<th>Sub-basin 1 Area [m²]</th>
<th>Sub-basin 2 Area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lopes Travao</td>
<td>4300</td>
<td>1.4</td>
<td>530</td>
<td>2340</td>
</tr>
<tr>
<td>2</td>
<td>Fransisco Guerra</td>
<td>2200</td>
<td>0.9</td>
<td>510</td>
<td>1690</td>
</tr>
<tr>
<td>4</td>
<td>Quintino Bocaiuva</td>
<td>8400</td>
<td>1.4</td>
<td>1640</td>
<td>3960</td>
</tr>
<tr>
<td>5</td>
<td>La Hire Guerra</td>
<td>2800</td>
<td>0.9</td>
<td>680</td>
<td>2120</td>
</tr>
<tr>
<td>9</td>
<td>Fortunato Pimentel</td>
<td>2600</td>
<td>0.9</td>
<td>870</td>
<td>1730</td>
</tr>
<tr>
<td>10</td>
<td>Irani Bertelli</td>
<td>12700</td>
<td>1.4</td>
<td>2900</td>
<td>5570</td>
</tr>
<tr>
<td>12</td>
<td>Grecia</td>
<td>4200</td>
<td>None</td>
<td>4200</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Alim Pedro</td>
<td>7800</td>
<td>0.9</td>
<td>2430</td>
<td>5370</td>
</tr>
<tr>
<td>14</td>
<td>Parque Alemanha</td>
<td>8500</td>
<td>None</td>
<td>4250</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Country Club</td>
<td>26600</td>
<td>2.9</td>
<td>2660</td>
<td>6210</td>
</tr>
</tbody>
</table>

Primary functions that should be considered in the Areia basin are athletic facilities, such as soccer fields, tennis courts and tracks, and public common areas such as plazas and parks.
8 CONCLUSIONS PART III

8.1 Conclusions

This chapter comments on the objective and the related observations and conclusions based on the assessment of the impacts from the detention facilities in the study area. The objective for this part is:

3. To allow for a resolution of the problems in Porto Alegre by testing the functioning of the detention facilities in the study area.

For that purpose important assumptions in the Areia plan are verified by means of a simulation model. The analysis showed that the quality of life is threatened in the future situation, because the developed solution does not meet the standards for multiple use of the sites intended for recreational opportunities.

To resolve the problem partitioning of the reservoir structures is proposed. In a partitioned reservoir structure the first compartment is used for the control of more frequent storms, while the second compartment is useable for recreational functions.

By their very nature multi-purpose detention areas must be useable for their primary function the majority of the time and must be normally dry between rain events. As such, multi-purpose detention areas should not be used for extended detention. For that reason extended detention is not considered feasible in the Areia basin.

8.2 Recommendations

A number of bottlenecks is identified in the verification of the solution. The following issues are recommended to deal with the bottlenecks:

- To apply a lower norm for quality/environmental control. According to the Urban Drainage Master Plan the reservoirs should be used only during events with return period above 2 years. From literature it is known that reservoirs may as well be designed to flood no more than twice annually, if multiple use is the objective. In such a way an effective resolution for the bottlenecks (one that meets the norm) is more easily realisable.
- To research other measures for water quality control: end-off-pipe solutions seems to be more appropriate in view of institutional and environmental issues. Extended detention can not lead to valuable results.
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9 CONCLUSIONS AND RECOMMENDATIONS, OR RATHER, LESSONS RECEIVED

9.1 Applicability of the method 3D-bril as an assessment framework for UDMP’s

The main objective of this study is:

To improve the approaches for the planning and design of stormwater control solutions in Brazil, through the evaluation of a case study, focussing on both content and process.

For that purpose the planning process of the Urban Drainage Master Plan of Porto Alegre is evaluated with a particular focus on which aspects are determinative for the success (or failure) of a plan. Rijsberman (2004) has developed a method (3D-bril) that is used as an assessment framework, focusing on relevant criteria concerning content and process. The criteria indicate the normative principles that determine a positive or negative judgement.

On the basis of the method 3D-bril a lot of shortcomings are uncovered (paragraph 6.2). The question is how to use this information to propose more sustainable planning and design approaches. For that matter, the criteria do not give a structure to the process nor direction to the concept of the plan. Nonetheless, the applicability of the method 3D-bril seems legitimate because the criteria reveal relevant aspects concerning content and process.

The first step to answer the question is to identify critical factors for the success of the Urban Drainage Master Plan. Therefore, table 9.1 pays attention to the most important information and insights that came to light on the basis of the criteria. The corresponding topics are appended.

Table 9.1 Critical aspects in the plan development as a result of the case study

<table>
<thead>
<tr>
<th>Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$ - Correspondence and $C_5$ - Sustainability</td>
</tr>
<tr>
<td>The concept has to correspond to the local water system and other relevant systems. Besides the concept has to maintain the system quantity, quality and integrity.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_0$ - Internal consistency and $S_2$ - Power, Resources and Moral right</td>
</tr>
<tr>
<td>Actors that have a power over or a interest in the relevant issues (at least quantity, quality and amenity) have to participate in the planning process.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{1,2}$ - Openness and $K_{2,1}$ - Verification</td>
</tr>
<tr>
<td>Important problems came up in the communication and verification of knowledge.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process phases and Continuity</td>
</tr>
<tr>
<td>A robust concept can accommodate the continuity of the process. Also, the importance of the initiative phase is underestimated in practise.</td>
</tr>
</tbody>
</table>

A brief explanation belongs to each aspect.

Concept
The evaluation of the concept of the Urban Drainage Master Plan of Porto Alegre provides a clear insight in its role in the process. In the case study the concept is leading for the development of the structural alternatives. A success factor in the process is that the strategy supports the continuity of the process, for example, because it provides insight into the legal and institutional boundaries as early as possible.
The concept should correspond to the local water system and other relevant systems and it should maintain the system quantity, quality and integrity. The concept in Porto Alegre involves detention in public open spaces. However, because the stormwater is transported through a combined system in the project area, such a concept is less applicable as the facilities get contaminated by the deposition of faecal material, solid waste and pathogenic organisms.

Scope
The evaluation of the scope brings to light important causes for the exclusion of water quality and amenities issues. It is observed that water quality issue is not dealt with, because the actor that has the administrative power over the issue was not eager to enter in the planning table. And with regard to the amenity issue, the actors that have an interest in the issue were only informed after the fact and had no actual influence on the solution.

Knowledge
The development, communication and verification of knowledge seems to be crucial in the acceptance (or at least understanding) of the solution. In that respect the consideration of different aspects and interests is essential. Communication is therefore more than one-way traffic of information from the plan developers to the interested stakeholders. In addition to communication of ideas, verification is just as important. The case study shows that a perception of unacceptable risks involved in the operation developed around the concept. The perception could not be disproved, because important assumptions were not verified.

Aspects
The most important observation on the basis of the evaluation of the aspects is that the importance of the initiative phase is underestimated. For that matter, a thorough exploration of the scope and the creation of sense of urgency for the actors to join the planning table is indispensable for the success of the plan. However, in practise the negotiation process that is necessary to make the actors participate seems to be difficult. As a result it is tempting to start solving these problems, one by one, in stead of striving for a more integrated and sustainable solution.

9.2 Conditions for policy development of Urban Drainage Master Plans
The analysis of critical factors in the planning and design process is the first step towards the recommendation of guidelines about how to improve the planning and design approaches for the development of an Urban Drainage Master Plan.

In spite of the fact that the information is mainly based on a single case study, i.e. Porto Alegre, a number of aspects can be mentioned that apply to all Urban Drainage Master Plans. Besides, the author takes into consideration and refers to knowledge obtained from the experiences with urban water plans in the Netherlands (Nelen, Van de Ven and Rijsberman) to shape the guidelines.

The following 5 guidelines are aimed at more sustainable for the planning and design of stormwater control solutions in Brazil:

1. Joint initiative
Any urban (storm) water policy starts with defining the scope, with its actors, areas and issues, as indicated in Figure 5.6. The change of a successful Urban Drainage Master Plan is considerably greater if the planning makers take sufficient time to agree on the issues to be covered, their approach, the actors to be involved and their way of involvement. An important question to be answered is if the sense of urgency to solve the problems is high enough among the various actors. In order to achieve the co-operation of actors it is important to make the individual interests of the various actors explicit and to look for win-win situations. On the other hand, the national government has an important role to fulfil, in the first place, by creating the right conditions for co-operation between municipal organisations and public participation, by facilitating regional initiatives and furthermore as (financial) partner in the initiatives. This aspect can be targeted in the
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National Stormwater Plan (appendix A). Because municipal governments usually have insufficient monetary and personal resources, the program should also allocate the necessary resources to the cause (i.e. co-operation between municipal organisations and public participation).

2. Sustainable development
The involvement of a much larger group of actors to the planning process leads to increased demands to the performance of the urban water system, e.g. with respect to water quality, recreation, and its role in urban landscapes. A broader scope calls for sustainable urban water management. Sustainable development is an elusive concept: however, Rijsberman (2004) distinguished five key elements that constitute the core of the concept:

- Needs of the present – e.g. safety against floods, reliable sanitation, and a pleasant living environment
- Needs of future generations – presumably similar to those of the present, but hidden in the future
- Recovery or maintenance of system parts – like rivers and lakes, ground water, biodiversity, recreational opportunities, financial position (all in quantity and quality)
- Recovery or maintenance of system integrity – processes like infiltration and drainage, social coherence
- Equity – development should be equitable, both within generations as between present and future generations i.e. problems should not be solved at the expense of others; present inequity should be combated

The concept of the Urban Drainage Master Plan should be in correspondence with those key elements to have a legitimate claim to sustainable development.

3. Verification
An important characteristic of the Brazilian situation that makes it more difficult to realise sustainable development is that the population uses to dispute innovative solutions. In view of this practise, the verification of knowledge is essential to defend the solution and to avoid endless discussions on the results. Verification is required in any process phase, from initiative to use (think of monitoring). Knowledge that needs to be verified are claims, assumptions, ideas and data. Obviously it is most important to test the ideas that are experienced as harmful to the interests of one (or more) of the actors.

4. Public and administrative support
A Urban Drainage Master Plan requires enough support among the population and the involved administration. To obtain enough support by all participants it is important that the own administration, involved organisations and the population are properly informed and that ideas that live in the society are used. In view of this, elements of a process oriented approach (see paragraph 4.2.2) are valuable and useful. Rijsberman mentions four central elements that are a prerequisite for participatory planning processes.

- Openness; in content in the process, in entrance of participants to the process and in behaviour of those participants
- Equality; the contribution of participants is assigned equal value (or at least as much as practically possible)
- Debate and negotiations; the presence of processes of debate and negotiations are necessary to arrive to a result that the participants understand and can accept
- Influence; participants have actual influence on decision making, their input is not just window-dressing

Depending on the issues to be targeted, sometimes a open, interactive process (for example by means of a workshop) is required, other times public consultation or participation (for example by means of a focus group) is enough. To develop the necessary activities in this area it is helpful to have a good communications plan.

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5. Continuity
In conclusion continuity is considered to be a critical condition in the policy development of Urban Drainage Master Plans. In the case study both the concept and the project coordinator supported the progress of the process. The concept should therefore accommodate continued learning and modification of the plan or design. On the other hand it should be reasonably robust in the sense that new information does not mean a rigorous break from the past (Rijsberman, 2004). The project leader, as the dragger of the process, has the important task to inspire the project members, to sufficiently involve stakeholders and to organise the communication and verification of knowledge.

9.3 Ways of dealing with the complex problem in Porto Alegre
The method 3D-bril has demonstrated its value for the evaluation of the Urban Drainage Master Plan of Porto Alegre. The evaluation led to relevant guidelines for the planning and design of stormwater control solutions. To close, the author emphasises the suited way of dealing with the differences of opinion in Porto Alegre. After all, the problems in Porto Alegre are the cause that prompted the initiative for this study.

As the contents of the Urban Drainage Master Plan have no legal basis, the issues to be covered is not a fixed agenda. It is up to the main actors to decide which issues are to be included and which not. In practise, amenity and water quality issues are not addressed in the Plan for Areia basin since important actors did not co-operate in the policy development. From the point of view of the inhabitants the recommended solutions is conflicting with their own stakes. By describing the problem as a choice between solutions the problem is in fact formulated as a conflict of interests between the stakeholders involved or as a political problem. So, the complexity of the problem automatically leads to a negotiation process rather than an optimisation process. The table 9.2, relating agreement on objectives to the availability of means to reach those objectives, illustrates the characteristics.

<table>
<thead>
<tr>
<th>Objectives</th>
<th>agreed</th>
<th>not agreed</th>
</tr>
</thead>
<tbody>
<tr>
<td>known</td>
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<td>Negotiation</td>
</tr>
<tr>
<td></td>
<td>'structured problems'</td>
<td>'political problems'</td>
</tr>
<tr>
<td>not known</td>
<td>Innovation</td>
<td>Chaos</td>
</tr>
<tr>
<td></td>
<td>'scientific problems'</td>
<td>'unstructured problems'</td>
</tr>
</tbody>
</table>

In order to reach consensus on the objectives (i.e. to move from 'not agreed' to 'agreed') process approaches are the best suited. The results of the verification should be the basis for the discussions, as partitioning of the reservoir structures can allow for a resolution the problem.
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REFERENCES

Allasia, D.G. (2002) 'Impacto das incertezas no custo de uma rede de macrodrenagem urbana'

Buis, J; van Dorst, M; van Keeken, E. 'Leren van Lerner; Duurzame ontwikkeling in Curitiba en Paraná'

Canali, G.V; Correia, F.N; Lobato, F; Machado, E.S. (2000) 'Water Resources Management; Brazilian and European Trends and Approaches'

Delft Cluster (2004) 'Water in de stad: duurzaam stedelijk waterbeheer (DusWat)'

IPH (2002) 'Plano da Bacia do Arroio Areia; Plano Diretor de Drenagem Urbana de Porto Alegre'

IPH (2000) 'Fundamentos do plano; Plano Diretor de Drenagem Urbana de Porto Alegre'

McCuen, RH. (1989) 'Hydrologic analysis and design'

Menegat, R. (2002) 'Participatory democracy and sustainable development: integrated urban environmental management in Porto Alegre, Brazil'

Nelen & Schuurmans Consultants BV. (April 2004) 'Leidraad toetsing regionale watersystemen m.b.t. wateroverlast'


Rijsberman, M.A. (2004) 'Sustainable Urban Water Systems; Planning and design'

Rowney, A.C; Stahre, P; Roesner, A. (1997) 'Sustaining Urban Water Resources in the 21st Century'


Stichting POA Gezondheidstechniek en Milieukunde (2002) 'Beheerst de stad het water?'

Stowa (2000) 'Leve(n)de stadswateren'

Tucci, C.E.M. (2002) 'Flood control and urban drainage management'

Tucci, C.E.M. (2005) 'Plano Nacional de Águas Pluviais; Proposal of'


Tucci, C.E.M. 'Urban flooding'


van de Ven, F.H.M. (2004) 'Water management in urban areas'

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Wanielista, M; Kersten, R; Eaglin, R. (1997) 'Hydrology, water quantity and quality control'

A. CONCEPTUAL BASIS OF THE NATIONAL STORMWATER PLAN

The National Stormwater Plan (Plano Nacional de Águas Pluviais, 2004) aims to reduce the vulnerability of the population to urban floods and to minimise environmental impacts through a policy that involves institutional, economic, environmental and technical elements and a plan of actions for the management of stormwaters in conjunction with other aspects of urban development of Brazilian cities. In general the Program presents a strategic approach in search of sustainability, using the following components: institutional, technical, economic, public participation and a plan of actions.

An essential cause of the problems (negative impacts of urban development) falls to the municipal jurisdiction. However the greater majority of Brazilian cities does not have the technical capacity to deal with this type of problems. For that reason, the program's legal component determines certain rules that the cities have to obey. On the other hand, the financial-economic component gives the opportunity of financial support for compliance of the rules on sustainability based on cost recovery and long-term financing. In support of this process components concerning management, capacity building and science and technology are defined.

Within the managerial and legal scope two distinct levels exists: the municipal level and the federal/state level. The management of the city and the development of a Environmental Sanitation Plan that should give a solution to the set of impacts on water infrastructure inside the city, have to be tackled at municipal level. At the federal and state level the directives on the required contents of the plans, the subsidies for the obedience of the legal elements and the financing for the necessary investments will be given shape.

The legal component is based on the water resources legislation that foresees a licence on effluents that modify the water quantity and quality, or produce whichever impact on the downstream fluvial system. The licence is supplied by the federal authority for federal rivers and the state authority for state rivers. The regulation of the grant is carried out by the resolution of National Water Resources Council that can establish the requirements for the cities through the obligatorily development of the Municipal Environmental Sanitation Plan. The directives for the Municipal Environmental Sanitation Plan are aimed at structural and non-structural measures of the economic, legal and environmental scope for the program.

Considering that it is not possible for all cities to implement the process at the same time, several stages are planned in accordance with the dimensions of the cities, given that bigger cities experience greater loads and impacts and, moreover, have a larger investment capacity or doubts. The distribution of the Brazilian municipalities, in accordance with the population size, and the periods for development of the action plans and the works are represented in table A.1. In the same way the required total investments by the virtue of the Stormwater Plan are presented. The figures show that in annual terms, the investments represent at most 0,12% of the Brazilian Gross National Product.

1 "Plano Nacional de Águas Pluviais; Proposal of" (C.E M. Tucci, 2005)
Table A.1 Schedule of the Program

<table>
<thead>
<tr>
<th>Classification of the cities</th>
<th>Number of cities</th>
<th>Population [mln]</th>
<th>% of the population</th>
<th>Term for conclusion of the Plans [years]</th>
<th>Term for conclusion of the works [years]</th>
<th>Necessary total investments [mln R$]</th>
</tr>
</thead>
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<td>P = population</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td><strong>166,112</strong></td>
<td><strong>100</strong></td>
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<td></td>
<td><strong>21.380,3</strong></td>
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</table>

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B. BACKGROUND INFORMATION ON BRAZILIAN HISTORY

Brazil was claimed for Portugal in 1500 by Pedro Cabral. Sugar was introduced in 1532. The plantations depended on slavery, that at first used native Indians, but they were gradually replaced by Africans. In the 17th and 18th century the Portuguese clashed as a result of their expansion drive to the South and the West, in search of gold and diamonds, with Spain regarding the borders. In 1808, when Portugal was itself threatened by a French invasion, the royal family fled to Brazil. The regent Dom João introduced reforms, making Brazil an equal partner of Portugal. Leaving his son Dom Pedro as the new regent, he returned in 1821 as king to Portugal. When Portugal tried to make Brazil a colony once more, Pedro declared Brazilian independence and named himself emperor (1822). After loosing the war with Argentina Pedro resigned in 1831 in favour of his son Pedro II, whose long reign brought stability and economic growth. Opposition of the landlords (indignant on the abolition of slavery in 1888) and the military (excluded from political power) led to a coup d’état in 1889 and to the end of the monarchy. After followed a period of civil war.

In 1930 Getulio Vargas seized power. He ruled authoritarian, but accomplished to support the economy leaning on a big middle class. He was overthrown by general Dutra in 1945 and a democratic constitution formulated. Vargas became president again in 1950 (this time elected) but committed suicide in 1954. From 1956 onwards up to 1961 J. Kubitschek was president, he promoted the founding of Brasília as the new capital. After that Brazil was governed by J. da Silva Quadros, F.B.M. Goulart, M.H. Castelo Branco and M.A. da Costa e Silva in succession. The latter was chased away by a coup d’état (1964).

From 1964 onwards up to 1985 Brasil was governed by the military. In that time the economy grew fast, but political and social rights were restricted. The last military president-general, J.B. Figueiredo, entered power in 1978. Step by step he had to tolerate the revival of democracy. In 1985 and 1990 civil governments were installed once again. The civilian T. Neves was elected president in 1985. In 1992 the Brazilian civil democracy proved capable to peacefully depose president Color de Mello, who was accused of fraud. At this moment, Lula da Silva is president of Brasil.

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1 'Duurzame ontwikkeling in Curitiba en Parana' (J. Buis; M. van dorst; E. van Keeken)
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C. CHARACTERISTICS OF URBAN SYSTEM

Table C.1 Characteristics of sub basins – Current scenario

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<thead>
<tr>
<th>Sub basin</th>
<th>Density [inhab/ha]</th>
<th>Imp. area [%]</th>
<th>CN</th>
<th>T&lt;sub&gt;c corr&lt;/sub&gt; [min]</th>
<th>Area [km&lt;sup&gt;2&lt;/sup&gt;]</th>
<th>K&lt;sub&gt;s&lt;/sub&gt; [hours]</th>
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<table>
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<tr>
<th>Sub basin</th>
<th>Density [inhab/ha]</th>
<th>Imp. area [%]</th>
<th>CN</th>
<th>(T_{c,corr}) [min]</th>
<th>Area [km²]</th>
<th>(K_s) [hours]</th>
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# D. CHARACTERISTICS OF WATER SYSTEM

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Towards sustainable planning and design of stormwater control solutions in Brazil
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E. PREDICTED HYDROGRAPHS FOR THE SUB BASINS

Figure E.1 Hydrograph for sub basin A

Figure E.2 Hydrograph for sub basin B
Figure E.3 Hydrograph for sub basin C

Figure E.4 Hydrograph for sub basin D

Figure E.5 Hydrograph for sub basin F
F. INTERVIEWED PERSONS

Carlos E.M. Tucci – Project coordinator (IPH)
Daniela Bemfica – Technical support group (Stormwater Department)
Marcus A.S. Cruz – Technical support group (Stormwater Department)
Adaila de Castro Rechden – President of neighbourhood association (AMATRES)