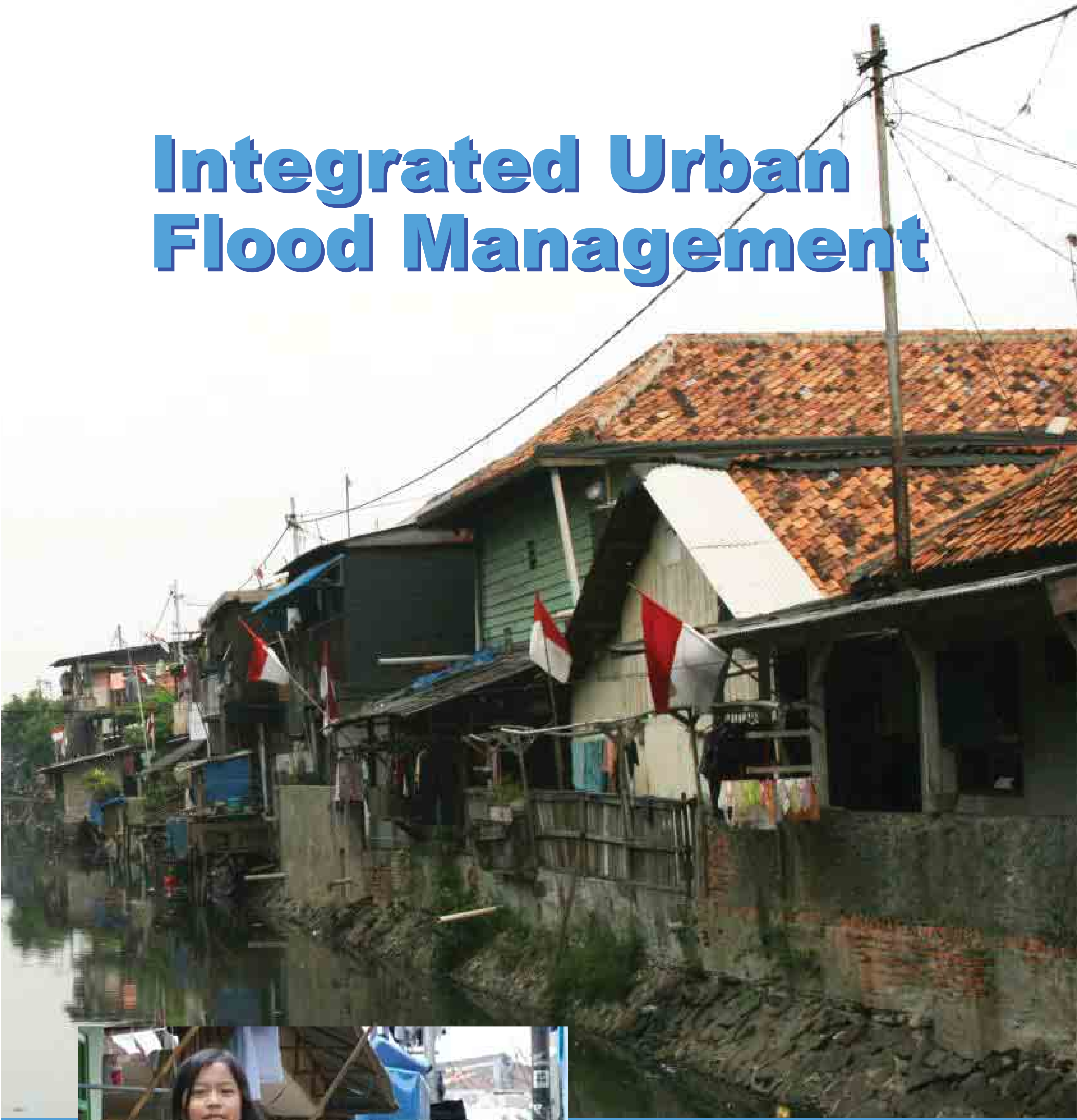
Integrated Urban Flood Management



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FOREWORD

Global climate change is increasing the variability and intensity of extreme flood events. Floods are the most common and widespread of all natural disasters. Current measures to mitigate flood impacts specifically for urban environments no longer provide optimal solutions for previously planned flood risk intervals.

Most of the water and sanitation management in the cities are fragmented and do not take into account all components of urban water fabric, resulting in the interconnection of storm water and sewer networks, the lack of or insufficient domestic sewage treatment, an increase in floods on the urban drainage, losses in the water distribution systems, solids in the drainage, erosion and occupation of risky areas of floodplain and hillsides, limited garbage collection and education, among others. In low-income countries many communities often live in poorly drained areas, where urban runoff mixes with sewage from overflowing latrines and sewers, causing pollution and a wide range of health problems.

In terms of victims, floods are responsible for more than half the deaths caused by natural catastrophes. As flood events appear to be rapidly increasing world-wide, an advanced and universal approach to urban flooding and how to manage becomes imperative to reduce flood impact.

Urban drainage and flooding, including urban drainage and solid waste interactions, sustainable urban drainage, and flood-resilient planning and building, flood insurance, flood proofing techniques, risk perception and preparedness and flood forecasting in an integrated manner is therefore extremely important.

This training manual addresses a broad spectrum of relevant issues in this emerging field of integrated urban flood management. It is expected to provide course participants and practitioners with best practice concepts and application with the intention to further inform and engage stakeholders in promoting integrated and cooperative approaches in water management in general. The manual integrates expertise from disciplines such as hydrology, sociology, economics, architecture, urban design, construction and water resources engineering and management. The subject is approached from an international perspective and case studies, exercises, expert advice and literature recommendations are included to support the theory and illustrations.

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ACKNOWLEDGEMENTS

This training manual has been prepared for Cap-Net/UNDP and partner organisation WMO by **Dr Carlos E.M. Tucci**, professor at the Institute of Hydraulic Research of the Federal University of Rio Grande do Sul, Brazil. The manual is largely based on previous work undertaken by Dr Tucci for the Cap-Net – WMO collaborative programme on capacity building in integrated flood management. We are grateful to Mr Gabriel Arduino, Dr Wolfgang Grabs and Mr Giacomo Terruggi of the technical support unit of the Associated Programme on Flood Management of WMO for their diligent review of earlier drafts of the manual. The final version of the manual was managed for publication by Kees Leendertse of the Cap-Net secretariat. Participants in several training courses held in Latin America and Southeast Asia, in which the training package has been tested, provided valuable feedback contributing to improvements to the manual, of which the final result is presented here.

CONTENTS

1. URBAN FLOOD MANAGEMENT

1.1 Urban environment and natural disasters

The increasing trend of natural disasters is related mainly to population growth and occupation of risk areas (floodplain and coastal); economic development leading to pressure on the environment and urbanisation; and the effects of climate variability and change on the hydrologic cycle. In recent years, 90% of natural disasters have been related to climate conditions (Box 1.1). These factors are interrelated and this trend of natural and water-related risk is one of the main challenges for poverty reduction and environment sustainability.

Box 1.1. Natural disaster statistics

From 1992 to 2001, developing countries accounted for 20% of the total number of disasters and over 50% of all disaster fatalities (WWAP, 2005).
From 1991 to 2005 close to 1 million people were killed and another 3,5 billion affected by disasters (ISDR, 2010). The economic losses amounted to about 88-billion dollars annually. Of the top 25 countries affected (inhabitants killed or affected) most are developing or least developed countries in Africa, Asia and Latin America. Developing and least developed countries have a higher risk of disasters in terms of the loss of lives, injured inhabitants and economic losses. Between 1985 and 1999 the Least Developed Countries lost 13.4% of their GDP to disasters, while developed countries lost over 4%.

1.2 Water-related impacts

Water-related impacts are mainly due to the effects on the population and environment of the natural and anthropogenic process developed in the water systems. In terms of environment and human development, they could be classified based on the system or source, such as urban development; supply and sanitation, urban drainage and solids; Energy: demand and production (hydropower); Transport: navigation; Rural development: supply and agriculture environment; Water-related natural disasters: floods, droughts, health, landslide, avalanche and famine; Environment: system sustainability such as wetlands; and water quality and forest burn.

This is a very broad classification of affected areas of water resource management. It is a combination of socioeconomic areas and natural environment systems. These groups overlap to a large extent, for example: During an urban flood, energy, transport, agriculture and the environment could be affected in the same way as during other natural disasters. Urban development could also increase the chances of disasters such as landslides, urban drainage floods and environment impacts on water and deforestation.

ISDR (2010) organised the data of **natural disasters** into three specific groups:

- **Hydro-meteorological disasters**: including floods and wave surges, storms, droughts and related disasters (extreme temperatures and forest/scrub fires), and landslides and avalanches;
- **Geophysical disasters**: divided into earthquakes, tsunamis and volcanic eruptions; and
- **Biological disasters**: covering epidemics and insect infestations.

Figure 1.1 shows the high increase of hydro-meteorological disasters in the last part of the twentieth century. About 50% of the events between 1990 and 2001 were floods, and 49% of 2,200 water-related disasters in the period occurred in the Americas and Africa.

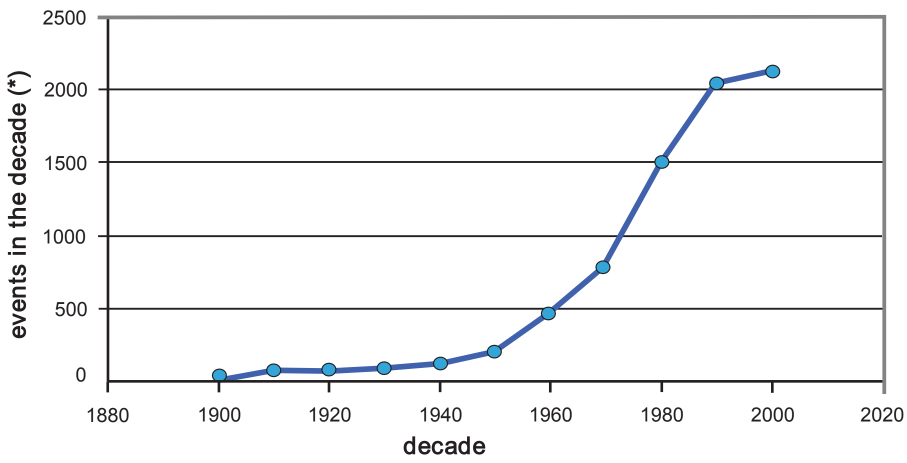

Figure 1.1 Increase of the number of hydro-meteorological events during the 20th century, by decade (ISDR, 2010). **(*) In 2000, the events are for 2000-2005.**

Box 1.2 Floods statistics

- Floods account for 15% of all deaths related to natural disasters.
- Approximately 66-million people suffered flood damage between 1973 and 1997.
- Between 1987 and 1997, 44% of all flood disasters affected Asia, claiming 228,000 lives (roughly 93% of all flood-related deaths worldwide);
  Economic losses for the region totalled US$ 136 billion.

1.3 Sources of the Impacts

The sources of risk are related mainly to the pressure society exerts on the environment, impacts of the climate variation on the society and social and economic vulnerabilities.

1.3.1 The pressure that society exerts on the environment

This is a scenario where the water and environment are in danger and the impact is on the resource. In some way, the impact will reflect on humans, since damaging the natural system through pollution, its physical conditions such as river channels and basin characteristics will in the end affect the human's quality of life and the potential use of the resources.

Development tends to exert pressure on natural resources, particularly when the control of human activities is ineffective and when there are complex impacts. The former of these occurs most often in poor and developing countries where the need for growth and improvement in the quality of life takes precedence over environmental considerations. In the long term, the quality of live is also affected, but the decision is made based on the short-term issues. The second is much more a problem of advanced societies, where a great range of products (especially chemical) continues to emerge without sufficient understanding of their complex interactions with the environment and with their potential to threaten the improved quality of life resulting from the development.

1.3.2 The impacts of climate variation on society

As the demands for water resources of a sophisticated society increase, together with its requirement that such resources be sustainable, climatic fluctuations can bring about conditions which prejudice this sustainability in the medium term.

The uncertainties related to this unknown impact of long-term trends are from climate variability and climate change due to the greenhouse effect. Climate variability has been a major factor on long-term human sustainability on the earth. Population movement due to the lack of water or agricultural sustainability is well documented in history.

Box 1.3 Examples

- In Brazil, 93% of energy is from hydropower. In the last 30 years the average flow of the Parana River (in which 60% of Brazilian electric energy is produced) increased about 30%, creating a new level of available energy. Since this increase could be mainly due to climate variability and could decrease in the future, the system vulnerability is high. The key question without answer is: Is this increase permanent or will flow return to its previous level?
- A sequence of bad water years for agriculture without irrigation could be enough to create an important economic stress in a country, which has been the scenario in many countries in Africa after the 70s.

According to the IPCC (2007), it is likely that extreme weather events will increase the frequency and severity during the 21st century as a result of the climate change. Population vulnerability varies with climate conditions. For instance, humid tropics and tropics have more intense rainfall for the same risk and duration than non-tropics. The urban drainage design will require more investment for the same risk in the tropics. Since the developed countries are in temperate or cold climates and some of the developing countries are in tropical climates, the lack of funds and prevention in developing and least developed countries increases the inhabitants' vulnerability.

1.3.3 Social and Economic Vulnerabilities: Urban Development

Social and economic vulnerabilities are based on the economic, political and institutional development of societies. Developed countries usually have more funds and sound institutions to deal with hazard events and to develop prevention, and populations are therefore less vulnerable to disasters. The vulnerability increases with poverty and the lack of funds, policies and institutions that could minimise the population vulnerabilities.

The main vulnerabilities related to social and economic aspects are:

- **Poverty**, which is related to the lack of economic sustainability on a daily basis, aggravated by the occupation of risk areas such as hill slopes and floodplains; and the lack of access to clean water and adequate disposal of human waste;
- **Weak Institutional arrangements**: Most of the developing and least developed countries have weak institutions and decisions, resulting in corruption, bad investments and the lack of prevention and mitigation of disaster events;
- **Lack of integrated risk management**, which takes into account all the components and uncertainties together with the public perceptions of the risk. Lack of integration can be seen (Rees, 2002) in: cost shifting, which is the

transference of impact in space and time; and inequities in risk allocation investments. Very often the poor receive less protection than others; and fragmented management usually leads to a specific solution which may be in conflict with others;

- **Political decision**: Usually the cost of prevention is small compared to disaster scenarios, but many decisions are taken on short-term bases, assuming that low frequency events would not occur;
- **Public x professional perception of the risk** (Margolis, 1996): Very often it can be seen that the perception of risk between professional and public are in conflict, which creates a difficult process of decision on water risk management;
- **Social, Economical and financial evaluation and decision**: Reduction of natural disaster risk usually involves high costs, which individuals in the population cannot afford.

1.4 Risk Management in Water Resources

Management of water uses, such as hydropower generation, water supply irrigation, navigation, flood control and environment preservation, is dependent on the amount of water in the river systems, population demand and conservation. Since the future climate is uncertain, all these water uses are planned based on the stationary historical flow statistics. However, there are many uncertainties related to climate, human demand and environment, together with complex interactions among these aspects.

Some of the main uncertainties related to these aspects are:

- Climate trends have been detected in a number of flow series around the world, and the possible effects of climate change of hydrologic regimes have also been identified (IPCC, 2007);
- Soil use has been one of the main concerns regarding the environment change with consequences on the water systems, such as deforestation, urbanisation (flow increase and occupation of floodplain) and change in agriculture practices;
- Water demand and pollution: increasing population, irrigation and degradation of water quality due to diffuse and point pollution sources and decreasing the available clean water for human, animal and industrial use, together with the supply for agriculture, conditions for energy production and navigation; and
- Urban developments are increasing the impervious surfaces and occupation on floodplain and coast areas, which increases and amplifies disaster risks.

Although risks have changed over time (e.g. due to the above average change in the rainfall and soil use), the majority of water infrastructure is designed based on the recorded stationary series[1]. This increases uncertainties and the probability of hazardous events. The increasing social, economic and environment impacts from disasters require the development of knowledge and actions for prevention and mitigation in order to recover the design risk and decrease the impact of low-frequency events, improving the population's quality of live and environment conservation.

Risk management of water-related natural disasters entails the development of actions through prevention and mitigation in order to reduce the risk of disasters. Some of the main definitions used in the disaster management are presented in box 1.4.

[1] Stationary hydrologic series such as annual rainfall and flow do not change its statistics in time (mean and standard deviation).

Box 1.4 – Definitions in disaster management

Disaster is the "situation or event, which overwhelms local capacity, requiring a support from national or international level of external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering" (ISDR, 2005).
Hazard is "a threatening event, or the probability of occurrence of a potential damaging phenomenon within a given time period and area" (DHA, 1992).
Water-Related Natural Disaster is the event in which water is the cause or consequence of the disaster.
Vulnerability is "the degree of loss (in % of total) resulting from a potential damaging phenomenon" (DHA, 1992).
Resilience is the ability to return to a previous state of the event.
Capacity is "a combination of all strengths and resources available within a community or organisation that can reduce the level of risk or the effect of a disaster" (ISDR, 2005).

ISDR (2010) mentioned that disaster risk management comprises "the systematic process, administrative, decisions, organisation, operational skills and abilities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters".

Risk reduction can be planned through structural or non-structural measures. Structural measures are planned to protect the population from the event by avoiding impacts. Non-structural measures do not change the event level of occurrence for the population but reduce the vulnerability through some of the following measures: early warning, insurance, disaster relief and institutional measures.

1.5 Water resource risk management framework

The technological developments of recent decades have resulted in a significant increase in the quality of life for one part of the world's population. Most of the remainder has yet to benefit from these developments and the thrust of international assistance is to bring this about. Some of the main challenges to society arising from the evolution of technology are discussed in the following sections.

The Framework of water risk management, as described in figure 1.2, is based on the **source or cause of risk, actions to reduce vulnerability** and **main overall goals**.

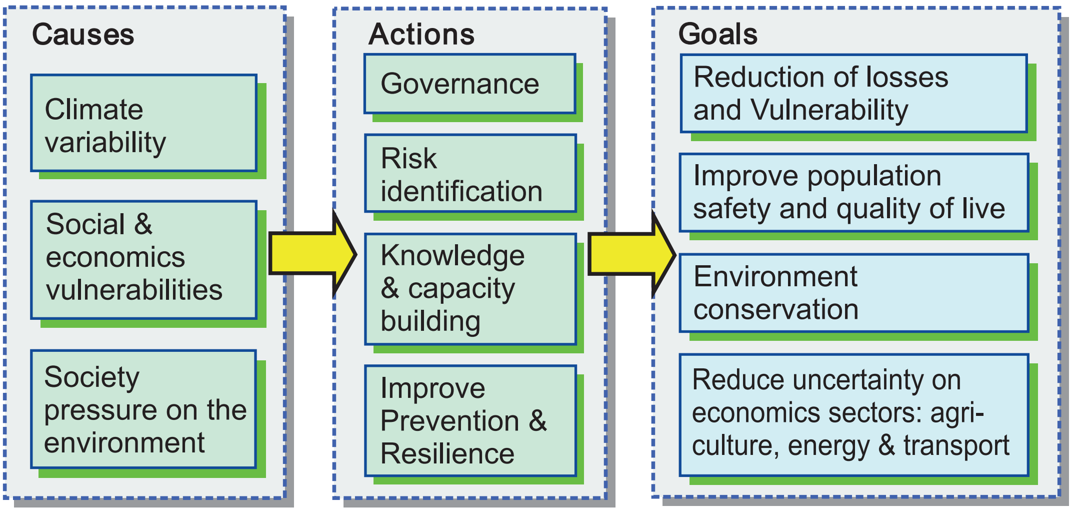

Figure 1.2 Water risk management Framework

Management of action developed in the prevention has three main steps: preparedness, intervention and recovery. Preparedness is the phase where the planning, insurance and forecasting are developed as prevention actions. The intervention is the phase just after an event where mitigation of rescue and mitigation of damage are developed, together with data collection. Recovery is the phase of reconstruction, resilience or repairs. All the steps can be planned in advance to minimise the vulnerability and improve the resilience to extreme events.

SUGGESTED READING AND INTERNET SITES

ISDR, 2010 – Introduction – International Strategy of Disaster Reduction
http://www.unisdr.org/disaster-statistics/introduction.htm
WWAP (2005) – Managing Risks – World Water Assessment Programme
www.unesco.org/water/wwap/facts_figures/managing_risks.shtml.
Access: September 21, 2005.

For more information, visit the following site:
http://www.unisdr.org/

2. SUSTAINABLE URBAN DEVELOPMENT

2.1 Urban development

Urban systems[2] are mainly areas of consumption and living. These areas may have many dimensions, from small towns to metropolitan areas. The main indicators of urban development are the following:

- Population: growth, migration and urban densification;
- Economic: income, gross product and production profile; and
- Soil use: area coverage distribution of use, such as residential, commercial and industrial.

Usually, urbanisation increases economic growth, since it increases services in the economy and decreases the population growth due to social factors.

In 1900, 13% of the world population was urban, whereas nowadays it is about 50%. This fast urban development in a single century has concentrated too many people in small areas, competing for the same resources (soil and water) and modifying the natural biodiversity. This is a live dynamic system with too many internal and external pressures interconnected. The main goal of a society in an urban environment is to improve its quality of life represented by a healthy environment, comfort and safety.
The main components of urban management are:

Urban Planning and management of the soil use: The land use is defined by city zoning, together with construction standards. These contents are developed in the City Master Plan;
Urban Infrastructure: Energy, water, communication and transport are the main elements. These systems should be developed together with the city Master Plan; and
Social and Environmental: Management of the environment takes into account the different levels of legislation in order to build a sustainable urban environment.

2.2 Population

The population in developed countries is stabilised and decreasing[3], but in developing countries it is forecast to increase until the middle of this century. Most of this population increase is moving to cities (see box 2.1 and table 1). The continent with the largest population still has an urban population of below 50%, but they are moving fast to having an urban population of between 70% and 80%, as has happened in Europe, North America and South America. Large cities have been developed since last century, such as the Metropolitan area of São Paulo in Brazil, which had about 50 thousand inhabitants at the beginning of the 20th century and 17 million at the end of the same century, which represented a 34-fold increase with an average annual rate of 8.5%.

Box 2.1 Population and cities

- There are 388 cities in the world that have more than 1-million inhabitants (McGranahan and Marcotulio, 2005) and 16 that have above 10 million.
- In the rank of the 20 most populated cities in the world, 17 are in developing countries.
- It was forecast that in 2010 there would be 60 cities with a population of more than 5-million inhabitants.

2 Urban systems are bounded areas of high population density sustained by biophysical systems of larger coverage than the urban area. (Rees, 2003)
3 When the average number of children per couple is below 2.1, the population tendency is to decrease in a generation.

Table 2.1 **Urban Population** (UNESCO-WWAP, 2006, % of total population)

Year	World	Asia	Africa	Europe	Latin America & Caribbean	North America	Oceania
1950	29,1	16,6	14,9	51,2	41,7	63,9	60,6
1970	36	22,7	23,2	62,9	57,4	73,8	70,6
1990	43,2	31,9	31,9	71,5	71,1	75,5	70,1
2000	47,1	37,1	37,1	72,7	75,5	79,1	72,7
2010*	51,3	42,7	42,4	74,2	79,4	82,3	73,7

.*projection

2.3 Impacts of urban development

Urban development in developing countries has high population density in small areas, poor public transportation a lack of water facilities, as well as polluted air and water. This poor environmental conditions result in diseases and a low quality of life. The main causes relate to one or more of the following conditions:

- A lack of jobs, income and housing, as a result of the high frequency of economical turbulence, which has a greater impact on poor populations;
- Poor people from rural areas move to the cities, which do not support this population increase, resulting in a high rate of inhabitants in unregulated areas in the city border limits, often in the water supply basin. This urbanisation is developed without sewage treatment or waste collection, resulting in water sources pollution;
- Limited institutional capacity of the communities with a lack of legislation, law enforcement, maintenance of facilities, technical support and funds. Usually the cities manage the areas of high economic income where legislation is enforced and property rights are regulated, here called **regulated city**. In the **illegal city** there are usually not enough services and facilities to support the population level. Cities are often not prepared to plan and manage this complex development;
- Lack of Integrated Urban Water Management: Most of the Water and Sanitation Management in the cities do not take into account all components of Urban Water Facilities, resulting in the interconnection of stormwater and sewer networks, the lack of or insufficient domestic sewage treatment[4], an increase in floods on the urban drainage[5], losses in the water distribution systems, solids in the drainage, erosion and occupation of risky areas of floodplain and hillsides (which has been the main causes of deaths during storm events), limited garbage collection and education, among others.

2.4 Sustainable urban development

Urbanisation changes the natural ecosystem at local, regional and global level. Some of the main impacts are:

- deforestation and change of the urban surfaces with roofs, streets, sidewalks, etc; temperature increase due to changes in the urban surfaces with asphalt and concrete; impervious areas which do not allow water infiltration;
- an increase in air pollution;
- pollution from urban effluents such as stormwater and sewers (with and without treatment);
- erosion of unprotected areas and sedimentation in the rivers;

4 In the region the proportion of waste treated is about 10% with an unknown degree of efficiency.
5 Theses floods are created by the urbanisation due to poor and outdated engineering, corruptions related to high-cost design and the lack of institutional measures.

- production of solid waste, of which part is left in the natural environment;
- transforming natural creeks and rivers in canals and conduits; and
- fragmentation of ecosystems.

The impact on the ecosystem (air and water pollution, and modification of fauna and flora) and on the quality of life (safety, temperature, social degradation, small public space, etc.) is larger with a high level of occupation, but if the occupation is sparse the cost of infrastructure (transport, water facilities, distance to work, etc.) is relatively higher.
Table 2.2 shows the relationship of impacts, causes, coverage and measures.

Urban sustainability is the equilibrium of human and environment needs in the dynamic of economic development. The human needs a minimum space for habitation, energy, water, communication, streets and others ways of transportation, commerce, and industrial production. The basic standard for densification and conservation is related to economic efficiency and social and environment conditions.

The objectives of public policies for sustainable development are (Tucci, 2007):

- Social justice and equity based on environmental sustainability;
- Maintenance of environmental capital;
- The rate of use of natural resources not exceeding the rate of reposition of these resources; and
- Rate of pollution emission not being greater than the capacity of absorption of natural systems, i.e. water, air and soil.

These objectives lead to the following principles:

- The conservation of the biodiversity and natural habitats;
- Increasing the use of public transportation and developing an efficient public transportation with low gas emission from fossil fuels;
- The rational use of energy in public areas and programmes of energy reduction;
- Using material ecologically certificated for construction together with recycled material;
- The rational use of water, domestic and industrial treatment of the effluent waste and priority for reuse;
- The reduction of garbage by recycling;
- Planning the new development, taking into account the environment conservation such as infiltration, water ways, soil conservation, reduction of diffusive pollution and preservation of flow of natural conditions;
- Developing risk prevention in urban zoning, taking into account the occurrence of natural disasters such as floods and landslides;
- Using economic incentives such as environment certification in order to implement the urban sustainability;
- The promotion of capacity building for decision makers, technical professionals and population as a whole; and
- The promotion of knowledge development on sustainability of urban systems.

Table 2.2: Relation of impacts, causes, coverage and measures in urban environments

System	Impacts	Causes	Coverage	Measures
Air	• air contamination; • temperature increase; • rain contamination; • climate change; • diseases	• gas emission by car, buses, industries, etc. • change in the surfaces and reduction of albedo	***Local:*** increase in temperature, diseases and environment; ***Regional:*** acid rain; ***Global:*** greenhouse effect and climate change	• reduction of emissions by cars and industries; • increase in green areas and trees
Soil	• eroded areas and soil contamination; • landslide; • floodplain; • reduction of flora and fauna and ecosystem impact	• deforestation and increase in flow velocity and paved areas; • occupation of steep areas; • occupation of floodplain; • increase flow velocity	***Local:*** hazard areas by erosion, contamination and floods; ***Regional:*** downstream floods, sedimentation and pollution; ecosystem fragmentation	• soil conservation; • preservation of steep areas; • risk area zoning; • control the flow
Aquatic	• lack of water • water contamination • floods • river erosion • garbage contamination • diseases; • solid waste	• lack of sewage treatment; • lack of diffusive pollution control; • change surfaces with impervious material and canalisation of the flow; • lack of solid waste services	***Local:*** the impacts on the population inside the city; ***Regional:*** exporting pollution and floods downstream of the city	• improve the water and sanitation; • sustainable occupation of urban spaces; • damping the flow; • improve urban water services

SUGGESTED READING AND INTERNET SITES

McGRANAHAN, G.; MARCOTULIO, P. 2005. Urban Systems. *Ecosystem and Human Well-Being Current State and Trends*. Volume 1. Island Press.

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www.unu.edu/env/urban/urban.html

3. URBAN WATERS

3.1 Urban Waters

Urban Waters systems generally include both water supply and sanitation facilities (WSS). Sanitation refers to domestic and industrial sewage collecting and treatment. It usually does not include urban stormwater or solid waste management systems. Urban waters are the services, namely water supply, sanitation, stormwater and solid waste, together with environment conservation. Integrated urban water resources management (IUWRM) is the modern concept of planning to address these issues.

3.2 Water Supply and Sanitation

Water supply: The proportion of people worldwide with access to improved water supply has risen from 77% in 1990 to 83% in 2002 (95% for urban population). The population served with improved water supply in developing countries has increased by 8% between 1990 and 2002, which amounts to 1,044-million more people (586-million in urban areas and 459-million in rural settings) served in 12 years, representing 79% (JMP, 2002). Table 3.1 presents a summary of the coverage on some regions.

Table 3.1 Proportion of urban population with improved[1] water supply and waste disposal in 2002 (%) (adapted from JMP, 2002)

Region	Water supply[2]	Waste disposal[3]
Northern Africa	96	89
Sub-Saharan Africa	82	55
Latin America and Caribbean	95	84
Eastern Asia	93	69
South Asia	94	66
Western Asia	95	95

1–improved water is a generic term of water delivered without population contamination. It is not the same as "safe", which is based on some specific indicators; 2 – water supply is understood as water for population; 3 – Waste disposal is understood as the disposal of waste in a network or in the soil. It does not mean treatment of waste.

Lack of management and economic capacity of countries are the main causes of limited investments and services. There are many regions where about 460 million (8% of the total population) are vulnerable or very often lack water supply. Table 3.1 shows the proportion of population that has improved water in some regions. The main indicators of water supply demand are: the population covered (as mentioned above), per-capita consumption rate and losses in the water supply network. Some developed countries have high consumption rates, and in developing countries, demand is to a large extent related to inefficiency of water distribution.

Sanitation: When the urban communities are small, the solution for waste disposal is local, such as septic tanks. When the population increases the construction of sewer network and treatment plants are needed. The main obstacles relate to the following:

- **The lack of political will**: Investment in facilities is usually not a priority in the political agenda, if there is no public pressure or environmental concerns in the population. This scenario usually occurs with the increase income (Tietenberg, 2003);

- **Economic conditions**: Since facilities have a high cost, only median and large cities have feasible conditions, but they require financing, which in many countries is not available or the communities are not economically sound;
- **The lack of integrated design and institutional arrangement**: Sanitation has been developed as "supply-driven" principles (Wright, 1997). Networks and treatment plants are designed and constructed without connections to the houses because the investment was not planned and the population does not want the connections because they have to pay for the service. Since institutional arrangements to enforce it are not planned, the investment has no "cost recovery", the sewage flows without treatment through drainage pipes to the rivers and the investment in the sewage network and treatment plants are lost. When the construction of the sewer network is not followed by the construction of treatment plants, the sewage concentrated in a section or reach of the main river increases the impact on the local river.
- **Bad maintenance**: Low waste treatment efficiency and interconnections with stormwater network results in impacts on the environment.

3

Most of these difficulties are related to the lack of goals and efficiency in management by the institutions responsible for management of the system.

There are two main types of risks in supply:

(a) Quantitative: when the amount of water is not enough to meet the demand, water supply systems are inefficient or there are not enough funds for investments;
(b) Qualitative: When there is enough water volume but the source of water is polluted and there is a lack of safe water. This last scenario has been frequent in developing countries due to the lack of waste treatment in cities and decreasing dilution capacity of the rivers because of high urbanisation rates.

3.3 Floodplain and Urban Drainage

Flood impacts on population have been caused by two types of development conditions:

Floodplain and hill slopes: The occupation of risk areas such as floodplains and hill slopes during dry years results in flood impacts during wet years; and

Urban drainage: Urban development increased the impervious areas and channels for the urban creeks and minor drainage, which increases the peak and volume of floods, inundations and frequency of impacts on people. The main impacts of the urban development on the drainage and on the environment are: an increase in flood peaks, volume and frequency; degradation of urban areas due to erosion and sedimentation; and water quality impacts from wash-load of urban surface and solid waste.

3.3.1 Floodplain Impacts

Floodplains are natural environments in medium-size and large rivers, and when the population occupies these areas, they could be affected by floods. The main impacts on the population occur due to a lack of: knowledge regarding the occurrence of flood levels, and planning for space occupancy according to the risks of flood events.

A common scenario is the uncontrolled urbanisation in the floodplain during a sequence of years with low flood levels. When high flood levels return, damage increases and public administration has to invest in relief efforts. Structural solutions such as dams, dikes and river channel changes have higher costs, and it is feasible only when damage costs are greater than their development or when social or political aspects are considered. Non-structural measures have lower costs, but there are some difficulties in their political implementation (see chapter 4).

The main issues on flood management are related to: the occupation of risk areas on the floodplains and in the hills; and the management of the flood frequency increase in the urban drainage.

The risk areas are usually occupied by low-income groups and during sequences of low annual peak flow by the population with better incomes. Poor populations usually occupy these areas illegally and during flood seasons receive support from the public sector. When government transfers populations out of risk areas, others usually take their place. This scenario usually does not occur when government develops the area with public facilities.

The main issue is the lack of urban planning, which takes into account the flood risk areas, and the lack of management of the urban development for the city scenarios. For the city that develops flood zoning, the main issue has been the invasion of public areas and the law enforcement of private-area regulation. Regarding the public areas, there is the risk of invasion by the poor-income population, while in the private area the issue is related to illegal developments.

3.3.2 Floods in the Urban Drainage

Floods are related to the increase of the impermeable areas and man-made drainage such as conduits and channels. These floods are not natural events; they occur as a consequence of population development.

Usually the land use surface in small urban basins consists of roofs, streets and others impervious surfaces. Runoff flows through these surfaces to the stormwater at high velocity, increasing the peak flow and overland flow volume, while decreasing groundwater flow and evapo-transpiration. The main impacts are:

- An increase in overland flow and peak discharge together with the flood frequency (Tucci, 2001 and Leopold, 1968);
- An increase in solid waste and sedimentation by erosion and garbage in the drainage and rivers; and
- The water quality deteriorating because the surface is washed during rainy days, increasing the pollution load in urban environment and to downstream rivers.

Cities have been developed according to Urban Master Plans, which usually do not consider the impact of urbanisation on drainage flows. Therefore, impervious areas and urban drainage flow are not regulated. City engineering departments commonly do not have the hydrologic support to address this problem through regulation, and engineering works – such as channels and pipe installations – are designed without taking potential downstream impacts into account. It increases the flood frequency on the drainage with important economic losses and in some scenarios the loss of lives (figure 3.1).

The actual **urban drainage design is often misconceived, since it is based on the concept of draining water from urban surfaces as quickly as possible through pipe and channel networks**; **but this increases the peak flow and the cost of the drainage system**. There is no control of peak increase at a minor drainage level and most of these impacts will appear in larger drainage levels. To cope with this problem, city and public administrations develop many works, such as canals in the major drainage and pipes, in the secondary drainage network. This type of solution has only transferred the flood problem from one section of the basin to another downstream, involving high costs. In addition, the water quality decreases, since the overflow is of water with a larger amount of solids and load of metals and other toxic components.

Since the 1970s in developed countries the source control of urban drainage has been developed by detention and retention ponds, permeable surfaces, infiltration trenches and others source control measures. It was implemented through national regulation and the cost of implementation is paid by the developer. In developing countries this type of control usually does not exist and the impacts are transferred to downstream in the major drainage. The cost to control this impact is transferred from the individual to the public, since the government has to invest in hydraulics works structures to reduce the downstream flood impacts.

3

3.4 Water Quality

In the urban environment the main causes of deterioration of water quality are: Contamination of the aquifers by different sources of contamination: sewage, gasoline and oil storage, etc; non-treated and treated sewage sent to pipes and rivers from houses and commercial and industrial facilities; and contamination by sediments and garbage. Most nutrients come to water aggregated onto sediments; carried by overland flow washing over urban surfaces.

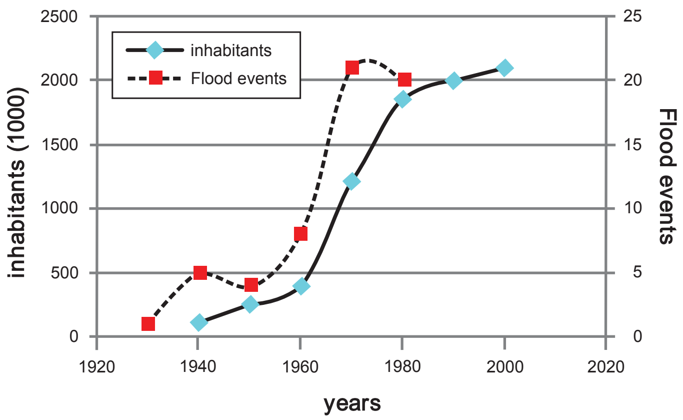

Figure 3.1 – Population increase and flood events in Belo Horizonte, Brazil
(based on data of Ramos, 1998)

Water quality is the result of urban occupation, sewage, urban drainage and solids management. The main risks for the environment and population are: contamination of water supply sources (rivers and aquifers); spreading diseases; and modification of the fauna and flora of the water systems (box 3.1).

In cities with low efficient urban water services (sewage collection and treatment), only sewage flows in the stormwater drainage during dry weather periods. The natural flow is minimal since during the rainy days the impervious areas do not allow soil infiltration, which recharges the aquifers and could maintain the flow in the rivers. This scenario decreases the population's quality of life, since it is potentially an environment for disease proliferation and damage to the natural environment.

Box 3.1 – Water supply contamination by toxicity

When urbanisation develops from downstream to upstream in the water supply basin without control of its sewage and stormwater, the nutrients from the development flows into the reservoir, changing its trophic conditions. It results in a eutrophic reservoir allowing algae grow, which may produce toxicity in the water. Usually, water treatment for domestic supply does not eliminate toxicity, which has accumulated consequences for human health in time and may develop serious diseases.

3.5 Water-related diseases

In the humid tropics, some of the main diseases are related to water supply, sanitation and drainage, such as diarrhoea, cholera, malaria, dengue and leptospirosis. More than 50 communicable diseases are associated with poor sanitation, which results in millions of deaths, of which are mainly children. For instance, Bangladesh has twice the number of infant deaths in urban slums compared to urban areas as a whole (Wright, 1997).

Diarrhoea is a disease that is closely related to water supply quality and sanitation. It is the main cause of child deaths in developing countries. Adequate water supply and adequate sanitation decrease the mortality rate in children by 55% (World Resources Institute, 1992). Malaria is endemic in some countries and 40% of the world population has this disease, most of them in the humid tropics. Environmental conditions related to drainage that help to spread malaria are stagnant waters, deforestation, soil erosion and flooding. The vector is a mosquito, genus Anopheles, whose proliferation is directly related to watercourses, and its ideal conditions are clean water, shade and small flow velocity.

Dengue fever is prevalent in warm climates and its distribution depends on the mosquito, which lives in clean and stagnant water detained in homes (e.g. tires and vases) during rainy seasons. On-site detention should be carefully designed in this type of climate in order to not create a favourable environment for this kind of disease.

Schistosomiasis has as intermediate host a genus *Biomphalaria*, which is the host of the larvae (miracidia), developed in the aquatic environment. Creeks, streams, lakes, wetlands or artificial water systems such as irrigation canals and small impoundments with some plants favour the development of the snail (Santos, 2005).

Building small dams, impoundments, mining and irrigation all support the proliferation of the intermediate host, the snail, which is the vector that transmits the disease in the tropics. The main action has been the development of the drainage as fast as possible, which conflicts with some strategies of temperate climate, with storage as a main strategy.

3.6 Urban Water Main Issues

In most developed countries, water supply and sewage treatment and quantitative aspects of urban drainage are no longer an issue, since its coverage is high. The main issues are the control of the stormwater quality and managing flood hazards (table 3.3). However, for developing countries access to sanitation is still an important issue. Urban waste disposal without treatment affects the amount of clean water available for supply, and new investments have to be made to maintain and improve supply.

The cost and the development of sanitation still are a major challenge. The total coverage may look good, but most of the sanitation is for the wealthy areas of the cities and the poor lack all the basic facilities for proper living. Sanitation coverage is one of the key indicators of urban poverty since overcrowded and unhealthy living conditions of the urban poor in developing countries are made even more degrading by the lack of adequate systems to dispose of human waste (Wright, 1997). Table 3.3 shows the comparison of developed and developing countries for each aspect of water in urban areas.

Table 3.3 – Urban water management of developed and developing countries

Facility	Developed country	Developing country
Water Supply	Total coverage with some risk from non-point sources	A lack of supply, and Contamination of water sources due to a lack of sanitation
Basic Sanitation	High coverage of secondary treatment	Low coverage and low efficiency of existing treatment and network systems
Stormwater	*Quantitative control*: Floods are regulated non-structural measures and developed structural measures form existing impacts; and *water quality* has been an important issue under development	• A lack of measures for water quantity of quality with a high level of impacts; • The cost of the impacts are transferred to the public or to environment; and • The interventions are developed with a high cost.
Flood Hazard	mainly non-structural measures with insurance, zoning and flood alert	• occupation of floodplain without control; bad or low investments in structural • solutions; and occupation by the poor during drought • season and high impact during flood season.

Most of the developing countries adopted the convenient "lay-out" of planning its water supply intake upstream of the city in order to use clean water and dump the waste downstream without treatment and leave to the river the task to dilute its pollution. With the population increase together with urbanisation, the cities are spreading in large areas and there is always a city upstream that can dump untreated sewage in the river and another downstream that collects water for supply, reflecting what is called the contamination cycle. This is the condition found along the river basin (figure 3.2). This scenario has resulted from the so-called hygienist period (table 3.4) when the impacts were transferred to downstream of the cities, far away from the population but without care for the environment.

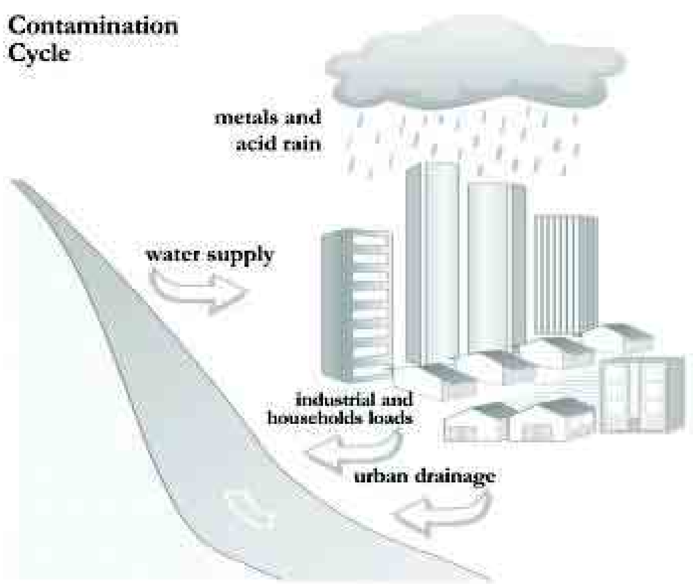

Figure 3.2 – Contamination cycle

Table 3.4 Stages of Urban Water developments in developed countries

Stages	Period	Characteristics
Pre-hygienist	Until the early 20th century	Urban systems without sewer and stormwater networks and treatment; sometimes septic tanks and stormwater in the streets with high proliferation of water-borne diseases.
Hygienist	Until the 70s	Safe water supply, sewer network without treatment plants and river contamination; and channels and conduits in the stormwater or street flows, transferring the impact of impervious surface to downstream.
Correction	After the 70s	Sewage treatment, detention and retention ponds in the stormwater systems, regulation for increased flow from urbanisation
Sustainable	After the 90s	Regulation and measures for stormwater pollution; natural practices of infiltration and recovery and maintenance of natural functions of the basin; and planning the urban space taking into account its natural flow conditions.

Developed countries moved during the early 70s to a correction stage (table 3.4) with high investment in sewer networks and treatment plants, improving the downstream rivers together with regulation and urban drainage management by using detention and retention ponds called (**flow storage**) to reduce the stormwater impact transference. Since the 90s, the sustainable development concepts such as Green design and LID, **low impact developments** (NAHB,2004) have been introduced to address the source pollution from stormwater and the use of infiltrations practices to recover the natural functions of the basins (table 3.4). However, developing countries are often still in the first stage, far from sustainable development, trying to move to the second stage.

SUGGESTED READING AND INTERNET SITES

TUCCI, C. E. M; PORTO, R. L, 2001. *Storm hydrology and urban drainage*. In: Tucci,C. Humid Tropics Urban Drainage, chapter 4. UNESCO.

WRIGHT, A M. (1997) *Toward a Strategic Sanitation Approach: Improving the sustainability of urban Sanitation in Developing Countries*. UNDP – World Bank 38p.

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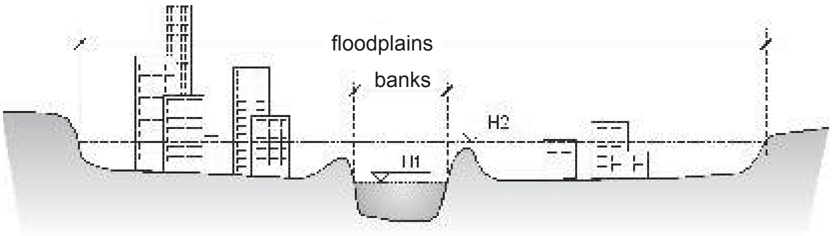
http://www.gdrc.org/uem/water/urban-water.html
http://www.unep.or.jp/ietc/Brochures/IUWM.pdf
http://www.epa.gov/nrmrl/pubs/600r99029/600R99029chap2.pdf

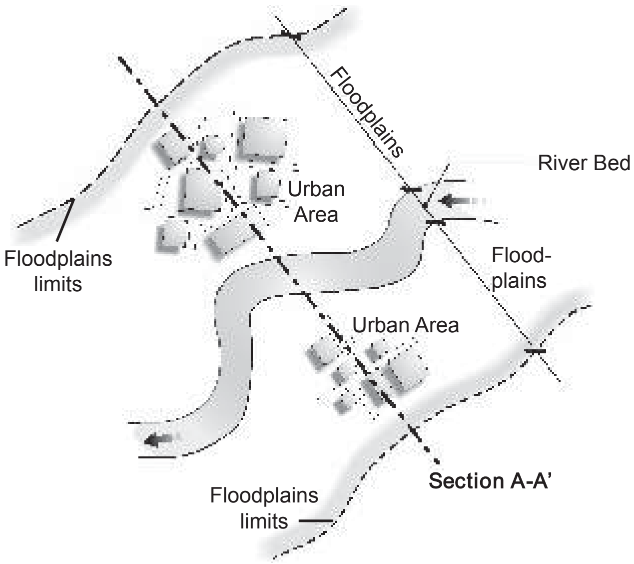
4. FLOODPLAIN MANAGEMENT

4.1 Main causes and impacts

Inundation in the floodplains occurs when the river overflows its banks. It is usually a natural process related to rainfall intensity and physical conditions of the basin. It has a return period[6] of 1.5 to 2 years. Figure 4.1 presents the main feature of the river section and the floodplains.



a – River and floodplains cross-section



b – Plain view of river and floodplains

Figure 4.1 Characteristics of Floodplains

The main natural causes of floods are related to rainfall intensity and space distribution, basin soil and coverage, and geomorphologic conditions such as basin area, slope and river length. Changes in river and basin could modify the flood risk. Some of these artificial changes are deforestation, changes in agriculture practice, urbanisation, reservoirs and channel changes. The combinations of all these factors are the main causes of floods at a specific river section.

The impact is related to human and environment conditions. The impact on human conditions could be:

- Loss of lives: usually due to levels and velocity of the flow near rivers or hill slides, which destroy houses and kill people;
- Direct economic impact: losses in agriculture produce, houses and commercial and industrial buildings due to water depth and velocity; or

6 *Return period*: is the mean flood frequency (usually years) of a flow or level. It is the inverse of the probability of the flood in any year.

- Indirect economic losses: working hours, trade, industrial production and agriculture yields.

Planning the occupation of floodplains is not a novel activity. Box 4.1 shows that over 3,000 years ago planning was done for floodplains areas in Egypt. The pressures of occupation of these areas have increased with population, economic growth and low flood frequency in some periods, when the population disregarded the flood risk.

Box 4.1 Floodplain in Ancient Egypt

Akhenaten in 1340 BC selected a new capital, Amarna, which was planned taking floods into account. There were two dry floodplain areas where nothing was constructed because of the flood fears, while the city was sub-divided in three parts: downtown and residential neighbourhoods in the North and South. (Brier, 1998).

Box 4.2 presents a sample of floodplain occupations and impacts, together with related costs. The sustainability of occupations could change depending on social and economic vulnerability. Climate change has been an additional issue, as it could change risk conditions. The increase of rainfall intensity could represent a higher flood risk for the same return period.

4.2 Flood Assessment

Water level and flow of the rivers are functions of local conditions. There are two major types of estimation: **Flow forecasting** and **flow prediction**.

Flow forecasting is related to the flow evaluation in a lead time. The river flow forecast can be estimated in *short-term*: a few hours or some days of lead time; and *long-term* (***also** called seasonal forecast*), up to nine months.

Short-term forecasting (also called real time) can be done continuously or only after some warning condition. The former is usually done when it is required for operational purposes, such as hydropower and navigation. In hydropower systems the planning is usually done based on flow statistics and adjusted on monthly, weekly and daily bases. When the system has multiple uses, such as flood control and power production, a waiting volume is used in the management of the reservoir.

Usually, flood forecasting is done during the flood season after a warning condition is reached in the basin, which could be a specific river level, rainfall or climate condition. It can be classified based on the required lead time or the basin's time of response to rainfall. Some of these floods are: flash floods and medium and large basin floods. Flash floods are mainly a combination of a meteorological event, usually convective storm-related with a particular hydrological situation such as small basin, a steep slope and low infiltration capacity. The forecasting is strongly dependent on the quantitative precipitation forecast (QPF) since the time between the rainfall and the peak flow is very small for the warning and relief measures during the flood (Krystofowicz, 1995). Georgakakos and Hudlow (1984) mentioned that 25% of communities across US have a lag time of less than four hours between rainfall and flow from the basin. Usually, flash floods are related to rural basins, but in large cities with the increase of impervious areas the basin time of concentration decreases and the peak flow increases. Managing the urban drainage system of conduits and controlling the traffic during heavy rainy days during the wet season require a warning system based on a quick evaluation and forecast. The main characteristics of this type of flood forecasting is the requirement of the rainfall evaluation for actual and future type steps, which requires QPF (figure 4.4 a).

Box 4.2 Case studies of floodplain occupation and impacts

Iguaçu River: Figure 4.1 shows the flood levels of the Iguaçu River at União da Vitória (Brazil). For a long time, floods remained below the five-year return period (1958–1981) almost every year. From 1982 to 1993, the flood damages were over 180-million dollars for a community of about 90,000 inhabitants.

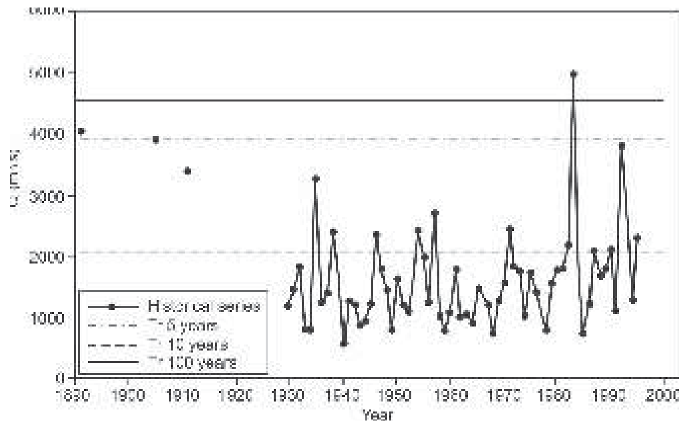


Figure 4.2 Maximum flood levels in Iguaçu River at União da Vitória (a basin of approximately 25,000 km²), Tucci and Villanueva, 1997

Paraguay River: Pantanal is one of the largest wetlands of the world. It is in the Upper Paraguay River. Water levels have been recorded at Ladario since the beginning of the century. In the period 1900–1960, the average flood area was 35,000 km²; from 1960 to 1973, it decreased to 15,000 km²; and in the recent period of 1973 to 2000, the average flood area was about 50,000 km². During the second period, the flood areas were smaller and with shorter duration. After 1973 the population was transferred due to climate variability.

US Damage impact: Figure 4.3 indicates the annual flood damage in the United States in percentage of GDP. It shows it varies from 0.02 to 0.48% of GDP with an average of 0.081%, representing about US$ 9.6 billion nowadays.

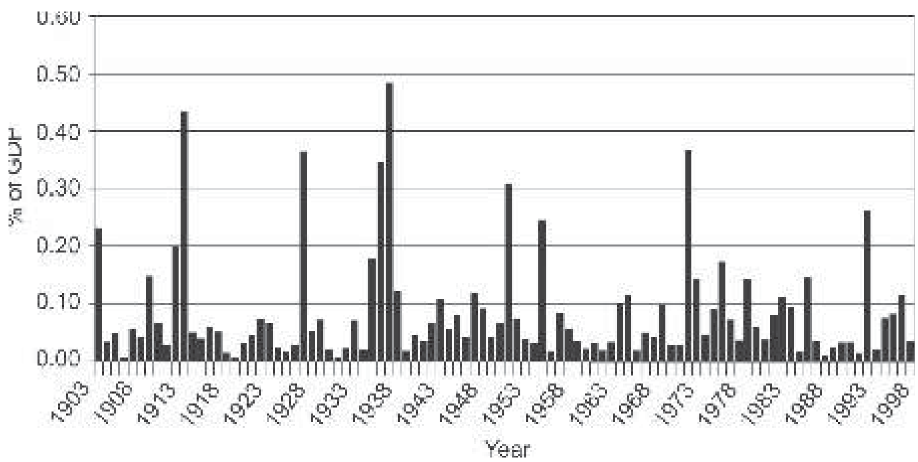
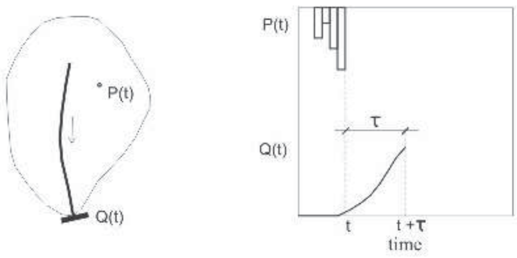
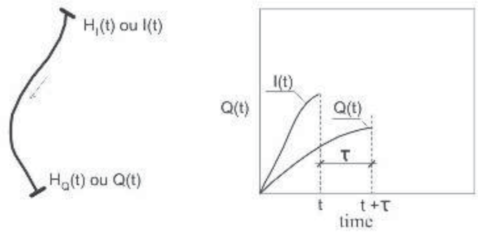


Figure 4.3: Historic series of annual flood damage in % of GDP (Priscoli, 2001)

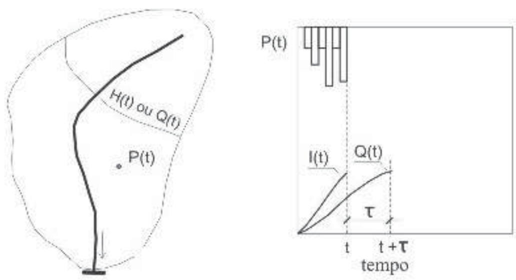
Medium-basin flood forecasts can be done through a combination of upstream level observation and rainfall evaluation in the intermediate basin, together with the upstream level or discharge.



(a) Forecast based on precipitation



(b) Forecast based on level or flow



(c) Forecast based on precipitation or flow

Figure 4.4: Scenarios of hydrologic forecast

Long-term flow forecasting (also called seasonal forecasting) has been used to describe the methods used to forecast flow in seasonal systems (Villanueva et al, 1987; Druce, 2001). After the use of climate models (Tucci et al 2002) or empirical and probabilistic relationship among climate variables and flow (Anderson et al, 2001), this forecast has been improved. Long-term forecasting can decrease the uncertainty in economic evaluation of some commodities related to water resources such as: planning energy price in the system where hydropower has an important share of the production; agriculture production for non-irrigated areas; and management of water conflicts.

Prediction is the probability of flood occurrence based on historical flow records. It does not specify when the flood is going to occur, but specifies the chances in a year for it to happen. It is used for evaluation of flood risk scenarios. In statistical terms the flood probability is estimated by taking into account historical levels or flood occurrences in a location. This series has to be: stationary – the statistics of a series do not change over time; representative: the historic period should represent the future scenarios of risk; and independent: the historic series values should not have time correlation among them.

The chance (probability, p) of values equal to or greater than Qp occurring in any year is estimated by fitting a statistical distribution to the historic series. The return period is (Tr) = 1/p (see footnote on Page 6 for definition). The chances of a flood greater than a specific value (Q > Qp) occurring in a sequence of n years is obtained by P(Tr,n) = 1 – (1-1/Tr)n. (See Box 4.3 for more examples). For instance, the chances of a flood occurrence (time of return of 50 years) during the dam construction of four years is calculated by the former equation and is 7.8%. The 50-year flood has a chance of 0,02 (2%) to occur in any year (1/50).

4.3 Flood Control Measures

Flood control measures are classified as either structural or non-structural. Structural measures are related to the change of the basin and/or the river, such as dams, dikes, channel conveyance and basin forestation. Non-structural measures are based on measures related to flood mitigation, such as: insurance, flood zoning and flood forecasting. Structural solutions are costly and are feasible only when flood damage costs would be greater than the development of structural measures or when they provide intangible social benefits.

4.3.1 Structural Measures

Structural measures are classified as either extensive or intensive. The extensive measures are developed at basin level, such a reforestation and soil conservation, among others. These measures can usually be developed only in small basins because of the costs of the intervention. The intensive measures are developed in the river, for example reservoirs, dikes, river section changes and slopes, and river deviation. Table 4.1 presents a summary of possible intensive measures.

Table 4.1 Intensive structural measures for flood control

Measure	Descriptions	Application	Limitations
Reservoirs for flood control	A reservoir can have a single purpose or multiple purposes. A reservoir constructed for flood control is more effective. A flood control reservoir uses its volume to dampen the peak flow downstream.	Small and medium-size basins	• For small frequency floods, the effect of a reservoir decreases; • Use of land for reservoir volume
Dike	Local or specific control of the flood. Requires the use of pumping the flow from the drainage of protected areas. Increases the level for upstream and the velocity for downstream.	Large basins	• Usually limited to six metres high; • The risk of breaking, which creates more damage if it does not exist; • Requires flood forecasting
Change River section	Decreases the flood level in the area of interest, increasing the flow capacity. Increases river section, decreases roughness or increases river slope (cutting meanders or change channel bed)	Small and medium-size rivers	• Environment impacts in the reach and downstream; • High cost with an extended reach intervention
River deviation	Changes the direction of the flow to another river basin. It decreases downstream flow for the existing basin.	Small and medium-size rivers	• An environment impact in the receiving river; • High cost of intervention

4

Reservoir

The main use of a reservoir in flood control is to store water and decrease the peak flow downstream (figure 4.5). In a single-purpose reservoir, when the objective is flood control, its operation and design features have to take into account flood conditions downstream. In that way the reservoir should store upstream volume only after a critical level for downstream floods, since many floods occur after a sequence of rainy days filling the reservoir, and when the peak flood arrives, the reservoir is already full. Figure 4.6 illustrates this type of scenario.

A reservoir constructed for water supply, irrigation or hydropower is usually in conflict with flood control, since the objective is to keep the reservoir full, while for flood control the objective is to keep the reservoir as empty as possible to receive flood water. In order to have a multi-purpose reservoir strategy, during the wet months (high risk of a flood), the level is decreased for flood control. This is called **waiting volume**.
The designed dam should also take into account the impacts they may produce downstream and upstream from developments described below.

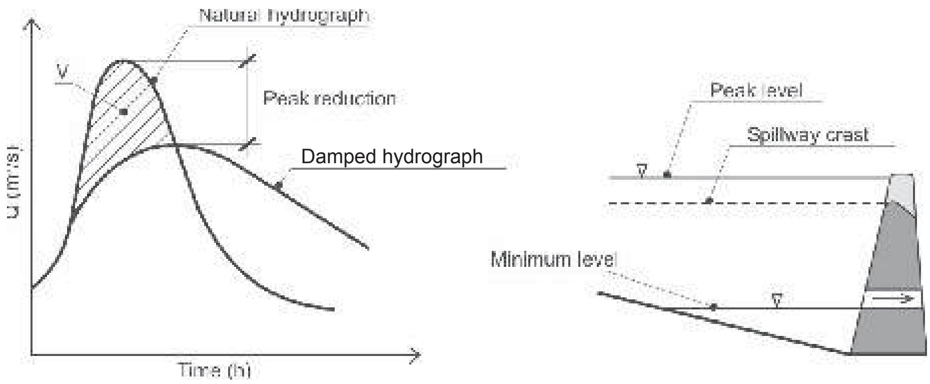


Figure 4.5 Flood control through a reservoir

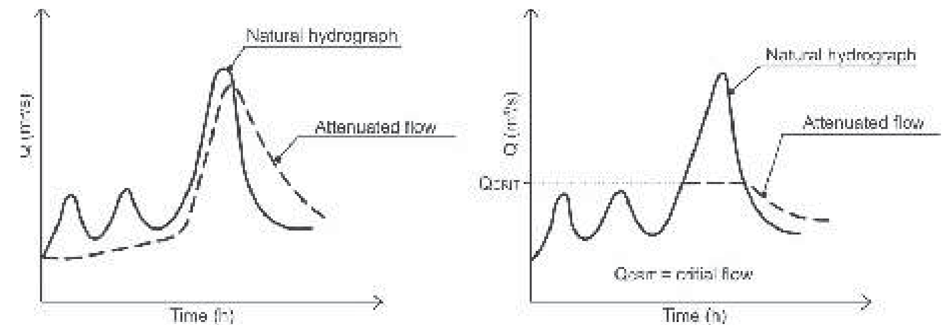


Figure 4.6: Reservoir without managing flood (left) and with managing flood (right)

Downstream: Areas downstream of a dam are usually subject to flooding. When the dam is built, the tendency is for the reservoir to dampen small floods in riparian areas. A population may move in during dam construction and afterwards because of the proximity of the development. It could well increase the operational restrictions of the dam and in years of low flood frequency (high return period) when the dam cannot dampen the floods (large volumes) the impact will be important. If the dam does not dampen the frequent floods, mitigation may be pushed for by social pressure. Thus, the downstream constraint becomes the maximum stream flow from which the population could be affected. During flooding periods there will be events in which the dam will not be able to dampen the flow and floods will occur.

The public perception of this situation is usually to blame the dam for what has happened. Therefore, it is necessary to have an effective operational system, as well as reliable monitoring and forecast of the hydrological data in order to demonstrate operational conditions and justify dams' actions. An alternative is to develop together with the dam, zoning of the flood risk area.

Upstream: The construction of a reservoir could result in the following impacts upstream:

- During flood conditions the backwater curve could increase levels to upstream areas; and
- These conditions could change over time due to sedimentation in the reservoir, which initially occurs in the area lying furthest upstream. For this reason, the previously identified flood levels may rise, reaching areas outside the boundaries of expropriated properties.

Dikes

Dikes are lateral walls of earth or concrete, with some slope or vertical, constructed at some distance from the river banks. A dike restricts the flow inside the walls and the riverbed, increasing the flow level and the velocity in the main channel. Dikes can increase the bed erosion and reduce the time transport of the flood to downstream areas (figure 4.7). There is a seasonal dike for small flood elevations which is used only during flood seasons.

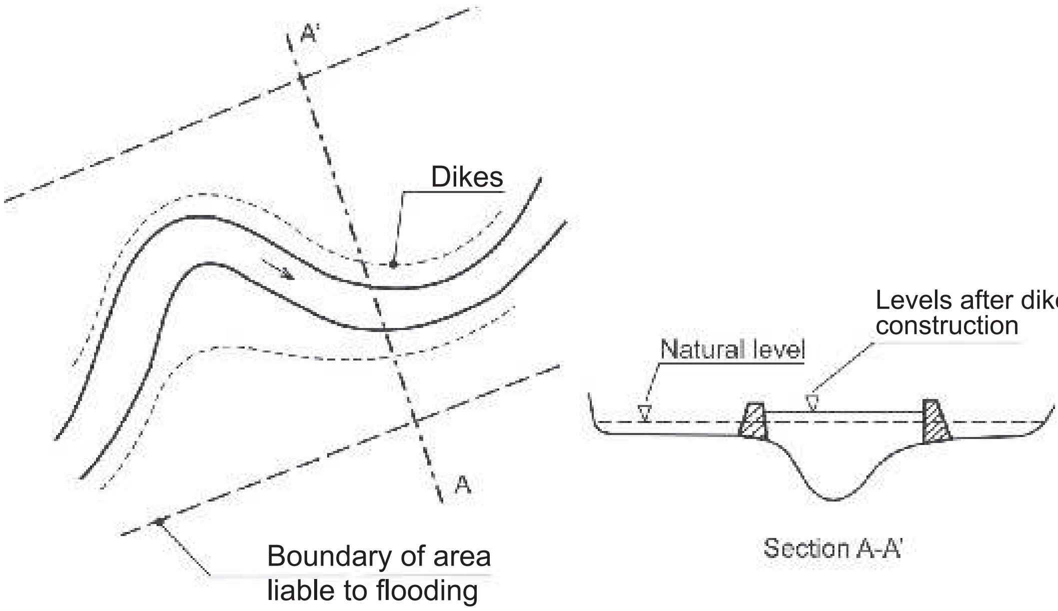


Figure 4.7 Dike protection (on the left) and river section (on the right)

The flow of sub-basins that contribute to the main river, where the dikes will be constructed, has to be taken into account in the design. For a larger inflow river the dikes could follow the topography entering the tributary. In small rivers the hydrographs should be controlled. When the tributary river has a flow level smaller than the main river with the dike, it can flow by gravity; but when the tributary river has a level greater, a gate type such as a "stop-log" is used to not allow backwater to flow in the lateral area. During that period the inflow from the lateral basin is pumped to the river. Depending of the volume, a lateral small reservoir is designed to decrease the pump flow capacity (figure 4.8).

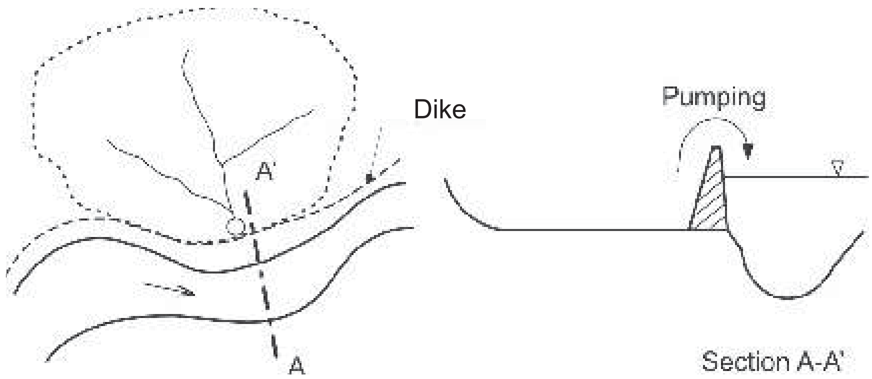


Figure 4.8: Tributary river basin and its contributions to the main river system

Changes in the river canal

Interventions on the river canal could include:

- **Cross-section change** such as increasing area, depth and roughness. The effects are the following: increasing the section area and depth increases the flow capacity and reduces the flood level in the section, in the same proportion. The decrease of roughness (obstruction removal and concrete surfaces, among others) increases the flow capacity and decreases the level for the same flow.
- **Changing the slope** by cutting meanders or increasing the depth for some reaches: The slope increase increases the flow and decreases the flood level.

These effects can be seen by using Manning's equation for discharge calculation, which is (if you do not like equations, skip this):

$$Q = \frac{A.R^{2/3} S^{1/2}}{n} \qquad (4.1)$$

A is the river cross-section area; R is the hydraulic radio obtained by = A/P; P is the cross-section perimeter; S is the river bottom slope, and n is the roughness. It can be seen from this equation that: (i) when A, R and S increase, the flow increases; and (ii) when roughness increases, the flow decreases.

Some specific change results are:

(a) In a river section when the surface of the section is changed from soil or vegetation to concrete, the roughness decreases, and for the same flow there is a smaller flow depth; and
(b) When the cross-section is increased by changing its width, it is possible that the depth for the same flow is also decreased.

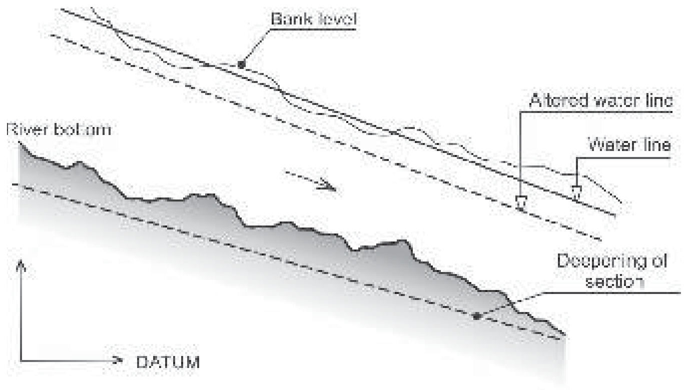
The equation 4.1 could be changed to the following:

$$Q = K.\, S^{1/2} \qquad (4.2)$$

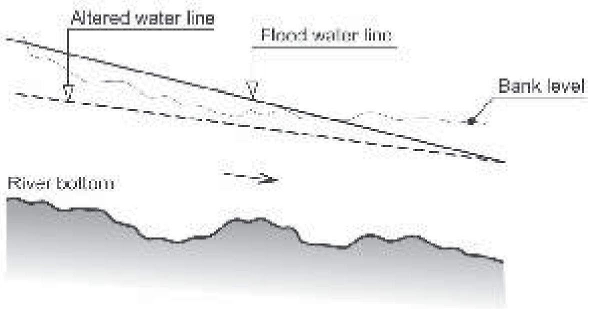
Where the term K = $\frac{A.R^{1/2}}{n}$ is called the conveyance of the river section. This is the local capacity of flow. The slope term in the equation can control the downstream effect, because it is the river channel slope. When there are downstream effects (constriction, lake or sea level, etc.) the slope decreases, decreasing also the flow and increasing the level. In some scenarios the water level could be negative and the flow is going upstream.

In the scenario of increasing the river slope, the flow capacity increases in the proportion of square root of the slope. Figure 4.9 shows the procedure used for reducing water depth by increasing the depth and changing the slope of a river. Figure 4.10 presents the changing in the riverbed by cutting meanders. In some alluvial channels, the river can naturally change the riverbed in the same way during a very large flood event.

There are important environmental impacts in these measures and usually they are not feasible in medium and large rivers. In the scenario of figure 4.10 the changing in the slope could increase the velocity in the downstream, leading to erosion of the bed. In small rivers it could be used but with a careful environmental assessment and mitigation of the potential impacts.



a - Deepening the section



b - Widening the section or reducing the roughness

Figure 4.9: Increase of the depth for river flow control

4.3.2 Non-structural Measures

Structural measures are not designed for full flood protection. It would require protection against the largest flood, which we do not know and the cost would not be feasible. The danger of structural measures is to create among the population the feeling of complete safety, which does not exist. Consequences could include the increase of population in risk areas, which could increase the future potential impact of floods.

Non-structural measures could be applied as a solution or in combination with structural measures in order to deal with floods in a specific area. Non-structural measures are less expensive, but there are some difficulties in their implementation because most people do not want to live with floods but rather want full structural protection, which in most communities is a hard, if not impossible, task for decision makers. Some of the usual conflicts are:

- Property owners will fight against regulation of their areas and usually have influence in municipal politics;

- When floods occur, the local government receives a non-refundable loan or other assistance from central government, thus discouraging incentives for a prevention programme; and
- Structural measures are usually not financially feasible but have much more political visibility. Non-structural measures require much effort from both the population and politicians. This is a difficult political task and politicians usually do not practise it.

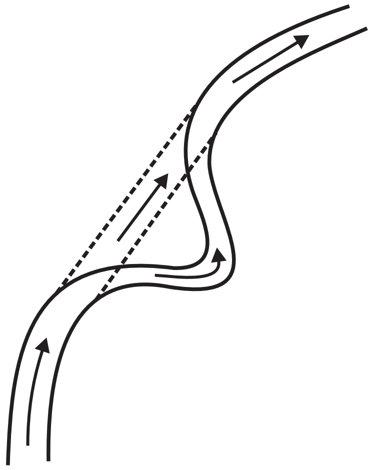


Figure 4.10: Changing a riverbed by cutting meanders

4

The main non-structural measures usually are flood zoning, flood alert or forecasting, insurance and individual protections, among others.

- Flood zoning is the planning of the soil occupation and regulation in order to decrease future flood impact, since part of the population will still be living in risk areas;
- Flood forecasting is developed in order to alert the population and decrease damages by floods;
- Insurance is a preventive procedure used to recover the cost damage of floods. Insurance coverage for natural disasters is not available in all countries;
- Flood proofing is an individual measure by a property owner to protect his/her physical assets.
- Increase of flood resilience is the combination of individual and public actions in order to cope with the flood in an area by using individual and planned measures. Some examples are floating houses and seasonal local dikes.

Flood zoning

Flood zoning is the definition used for the land use spatial planning in order to regulate the occupation of flood risks areas with the main goal of minimising the flood impacts. Flood zoning allows for rational occupation of floodplain risk areas. The regulation of the space is based on flood mapping, where the risks are estimated based on historical data series and specific conditions of the land use.

In order to develop the flood zoning, two steps should be developed: flood maps and flood land use zoning.

Flood Maps: To develop flood zoning, it is important to develop a flood risk map that shows the risk area of the city and an alert map that helps the population live with the flood when it occurs.

To develop these maps, the following information is required:

- **Topography of the risk area**: The resolution depends on the changing river levels and topography, but a 1m (1:2.000) spacing is usually enough. When that type of information is not available, a preliminary map can be developed with a resolution of 5 m (1:10.000 scale);

- **Slope of river level**: It can be estimated by bathymetric sections[7] along the rivers or by flood marks in the buildings of some historic floods.

- **Flood levels and discharge** of gage in the river when it crosses the city: Usually the gages are in the river crossing the city. At least 15 years of records would be needed to have a representative sample. When the series is short (and even for a long series), it is important to validate the records with a regionalisation analysis to determine how representative the flow record of the floods is. In this case, historical marks of floods will help to improve the evaluation of the flood risk. Box 4.3 shows the example of Blumenau (Brazil) and its flood series sample.

Box 4.3 Floods in Blumenau (Brazil)

For the Itajaí River at the city of Blumenau, flood levels have been registered since 1852 (only flood events). Between 1852 and 1991 there were a few important floods with values above 13.0 m. Floods with higher values are firstly 17.10 m in 1880, secondly 16.90 in 1911 and thirdly 16.30 in 1852. From 1912 to 1982 there were also small floods (values below 13.0 m). It was a period biased in terms of risk. The economic grow and development of the city was higher after 1970 and the continuous record of levels started only in 1935 (figure 4.11). In 1983 there was a larger flood of 15.34 m with major damage to the community. Calculating the flood risk for 1983, taking only the continuous series, the risk would be more than a 100 years, but with the flood marks it would be near 30 years.

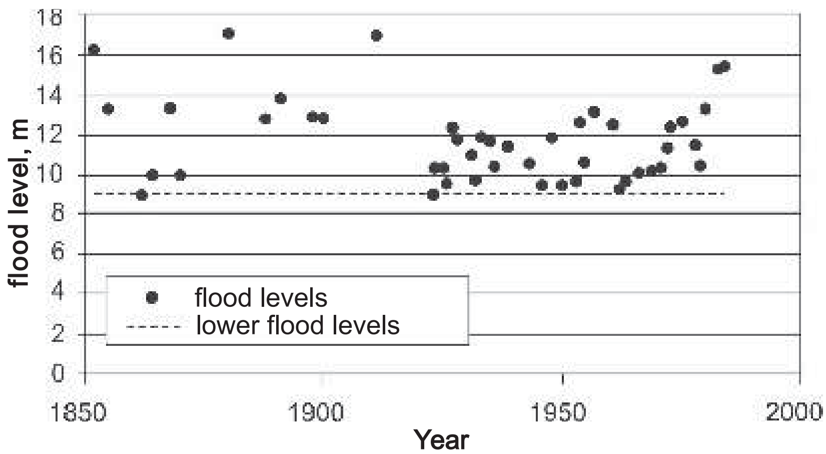


Figure 4.11: Flood levels in Blumenau

[7] Bathymetric sections are the levels of the riverbed along a river cross-section.

The steps for the flood risk map preparation are described below
(*you can skip this part of the text if you do not plan to do this*):

(a) Prepare the flood flow frequency based on the yearly peak discharges existing in the gage section (figure 4.12).

(b) Select a risk (return period) and determine the flow in the flood flow frequency for the gage section. Use the rating curve of the gage (which is the flow x level relationship for the gage section), figure 4.12;

(c) Determine the river level with this return period. This level has to be converted at the same reference level of the city topography;

(d) Using this level, it is possible to find in this section the width (both sides of the river) of the flood flow.

(e) The same width can be found in the upstream and downstream section of the gage using the river slope (figure 4.13). It also can be calculated by the mathematical model when that type of information from similar floods is not available;

(f) The procedures from b to d can be repeated for each flood risk selected.

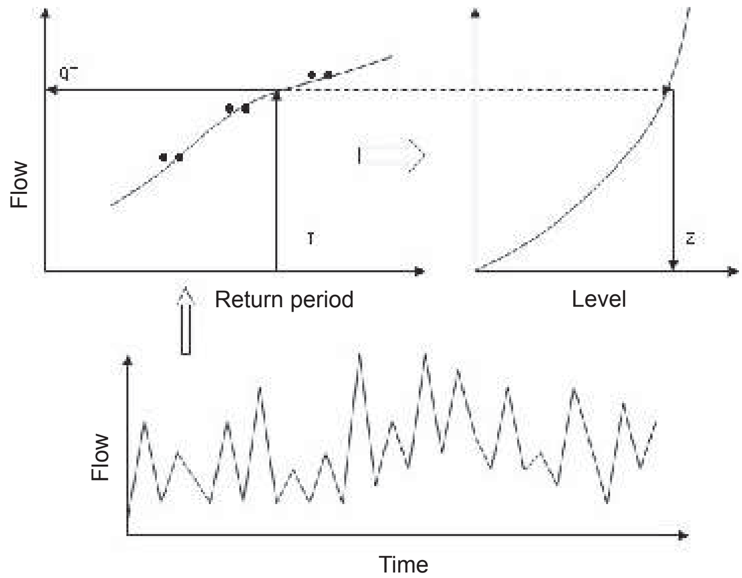


Figure 4.12: Flow series, flood frequency and rating curve

Figure 4.14 presents the type of map that could be obtained using this procedure. The map allows the planner to understand the risk areas and develop specific uses for them. The following step is zoning of the space, based on known risks. The main practice is to select risk lanes related to some risks and river functions.

The **alert map** is used during the flood occurrence. It gives the city topography related to the level in the gage. For instance, if a city location on the map shows 17.0 m, it means that the water will reach the terrain level when the gage of the city is at 17.0 m. This map is constructed in that way because the information is always related to the gage. The level forecast is advertised and it is related to a specific place, which is usually the level at the gage.

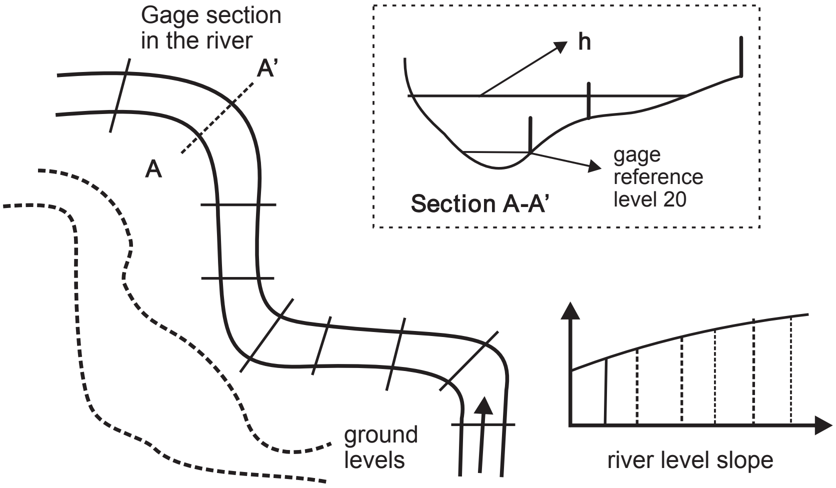


Figure 4.13: River section, terrain and river levels and gage

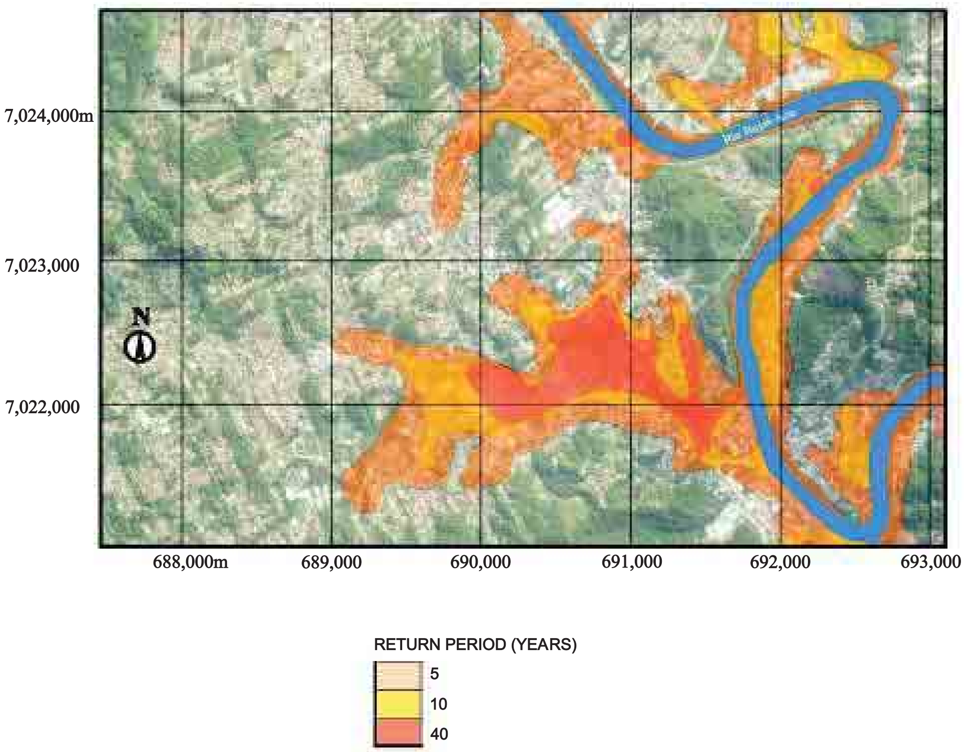


Figure 4.14: Risk map of Blumenau, Brazil

This map can be used together with the forecast. Using flood level forecasts and population information, it is possible to assess the areas that will be flooded and plan for an evacuation.

Flood Land use zoning is based on selecting the space and defining the occupation conditions. The number of zones or lanes depends on each case, but usually there are three major types (figure 4.15):

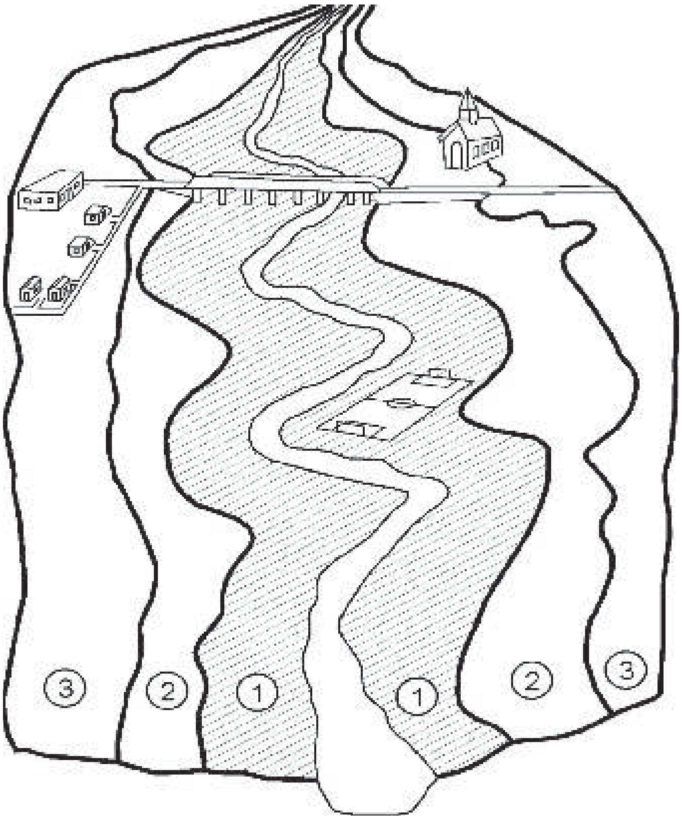


Figure 4.15: Flood zone regulation (Water Resources Council, 1971)

- Floodway – the area the river uses to develop flow: Occupation of this area could increase the level upstream.
- Area with restrictions: Occupation is allowed under some conditions.
- Low-risk areas – where there are still some restrictions but it is more a warning to property owners.

The technical criteria for development of flood zones are the following:

Flood limits: The flood limit is usually determined by the 100-year flood risk, or based on an important well-known flood that occurred in the risk area in the last 100 years. It states that there is a 1% chance each year of a flood occurring in a given area.

Floodway - In the flow through the city the river slope can change due to obstruction to the flow by landfills, bridges, other constructions and hydraulic works. Figure 4.16 presents the flood flow of natural river conditions and the level increase due to a decreasing river section area caused by obstructions from urban development. The floodway should be left unoccupied, because the development could create a backward effect in flood levels. In regulating, there is a limited assumed value of level increase in the floodway to minimise its effects. The technical definition of the floodway is described in the box 4.4.

The main aspects of the flood zone are:

- In this zone there should not be constructions that could decrease the river flow capacity;
- For existing works and constructions, there is a need to evaluate their effects and plan to change conditions. The plan should allow for transference of the population

to a safe area, together with the demolition of constructions. It requires an assessment, since the cost of transference should not be greater than the mean flood impact cost;

- In works such as bridges, roads, landfills and other infrastructures, the simulation of hydraulic river levels for the scenarios with and without the obstruction will allow for the correct assessment of investments; and
- The use of the area can be for recreation such as parks, for agriculture (mainly for vegetables), infrastructure that does not obstruct, or parking lots, among others.

Area with Restrictions – In this area, population occupation of the flood area is allowed but with some restrictions in order to mitigate potential risks. In this area, the flow velocity should be small and the impact is much more related to inundation. The main uses of the area could be:

- Parks and sports areas for recreational activities;
- Agriculture area for vegetables;
- Residential areas for two-floor buildings where the upper floors are at a safe level, allowing their use during flood events;
- Industrial and commercial areas of loading, parking lots and storage of equipment that can easily be removed or is not subject to flood damage; and
- Basic services like transmission lines, roads and bridges (without increasing the upstream floods).

Low-risk areas – This area has low probability to be flooded; however, it can happen, and the population needs to be informed of the risk. In this scenario, it is likely that the flow velocity and flood levels are small. Usually this area is not regulated, but if the risk is small and the velocity is high, it is important that the regulation would focus on prevention of construction.

Regulation of the flood areas – Regulation of these areas starts with a technical proposal based on hydrologic and hydraulic aspects. After that it requires a discussion within the community, as there are many stakeholders. It needs to be included in the framework of a construction code or an urban master plan.

Some of the regulation measures are the following:

- The use of at least one floor above the flood level (level above the low risk area);
- The use of materials that are resistant to submersion or water contact;
- Prohibition to store, process or manipulate contents that could be unsafe to human, animal and/or environment when coming into contact with water;
- Landfill protection against erosion;
- Protection of electrical systems;
- Taking into account the flood levels in the design of stormwater and sewage systems;
- Taking into account the design of the construction, the protection against hydraulic pressure and velocity, such as leakage, being under pressure and buoyancy;
- Plan openings such as doors, windows and ventilation; and
- Protecting walls and buildings structurally.

In developing countries, a city's poor population usually occupies the floodplain areas with higher risk because of the low value of the buildings. In this situation it is more feasible to transfer the population to safe areas with better buildings than protecting them in the risk area.

Box 4.4: Estimate of the floodway

The steps of calculation are:

1. Determine the 100 years flood level for the sections along the city. It can be done by section spacing of about 300–500m, always taking into account the section of decreasing conveyance.
2. The design criterion is to assume a level increase in the floodway section due to obstruction in the part of the section that stays out of the floodway. In the USA an increase of 30.45cm (=1 feet) is allowed.
3. Calculate the floodway section as presented in figure 4.16. In this scenario, all the flood discharge flows through the floodway section and in the other sections the flow is zero. It allows the calculation of the position of the points C and D.

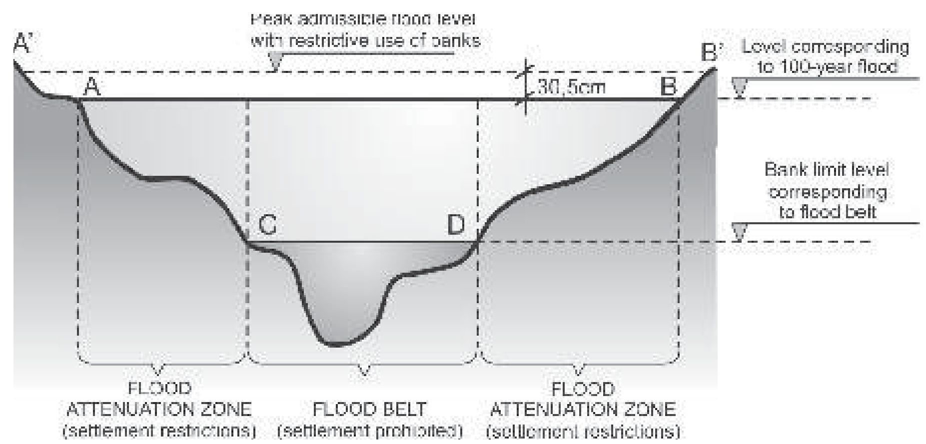


Figure 4.16: Floodway definitions

The flood strategy has to be developed together with the zoning. Some of the strategic actions are:

- Identification of the population in the flood risk, construction conditions and value of goods;
- Development of a long-term plan for transference of population, together with use of the area after the population, is removed. There is a significant risk that when the population has been removed another group would move to the risk area. In that way, the future use should be implemented together with the transference. When there is delimited use (parks, sports, other recreational uses, avenues, etc.), there is no invasion in the area;
- Implementation of the actions is more feasible just after the floods because the land value is lower and the risk perception is high. After some time it may change and the value may increase;
- Raising the public's awareness of floods by means of publication and advertising of the flood maps, the use of flood marks in public facilities such as posts and walls, etc;
- Development of a specific plan for transferring of people from hospitals, schools and other public buildings to safe areas;
- Developing a long-term plan to transfer the main urban functions to safe areas;
- Recommendation for funding agencies, banks and others to avoid financing construction in risk areas; and
- Development of a financial mechanism to give value to flood land and its protection, such as (a) tax exemptions, (b) creating a flood market for risk areas (see box 4.6) and (c) develop financial incentives for agricultural use.

Box 4.5 Flood zoning and management case

Floodplain zoning: Studies of flood zoning have been developed in five cities along the Uruguay River and eight cities on the Itajaí River. For both rivers, the studies were implemented by State and Federal organisations without local participation. The results of the studies were not implemented since the cities did not participate and the municipal administration did not have any interest in that type of solution.

In Estrela (Rezende and Tucci, 1979) the study was prepared for the city together with the Urban Master Plan and implemented in the municipal regulation. After the legislation was implemented the risk areas were preserved and the remaining population was gradually removed to safe areas through using taxes incentives. The tax incentives were to offer building construction permits in another area downtown. Flood damage losses and population involved have decreased over the years since 1979.

União Vitória and Porto União (Tucci and Villanueva, 1997) are on the border of the State of Parana and Santa Catarina and make up a community of about 90,000 inhabitants. This urban area is subjected to frequent floods, but in 1980 a large hydropower reservoir was constructed downstream. In 1983, a major flood had a severe economical impact (sixty days of flooding) on the area. The population began to blame the Electric Power Company COPEL, which claimed that it was a natural flood and that the dam did not create any additional impact. However, in 1992 another major flood took place. Even though it was smaller than the 1983 flood, it also had a high-damage impact. It created a major conflict between the city and the Company. An NGO (non-governmental organisation) was created by the population, and the study was developed for this organisation whose goals were: diagnosis of the flood conditions, negotiations with the company for operation rules and flood zone planning for the city. The study brought some results and the negotiations improved the city's capability of dealing with floods (see chapter 8 for further details).

Flood proofing and flood resilience

Flood proofing is a measure developed to protect the individual (personal, commercial or industrial) from floods. It is usually more feasible when the flood protection is smaller than the cost of transference. These measures include the following:

- Temporary closing of openings in buildings;
- An increase in the level of construction;
- Dikes for the protection of the construction;
- Use of special material for protection, reinforcing the structures and hydraulics protection with valves, among others.

Flood resilience is the increase of the local or individual capacity to cope with floods in order to decrease its vulnerability during events. Nowadays, resilience starts in urban planning and construction projections in flood plain areas through using innovative solutions such as floating houses.

Insurance

Flood insurance is a preventive measure that is feasible if the owners are able to pay for it. In some countries there is no insurance coverage for disasters, independent of the purchasing power, because it needs overall management of risk distribution in the country, which is often not developed by the government. In some countries the insurance is developed institutionally, such as in the USA, where there is a public flood insurance programme. For instance, the insurance cost for a house valued at 100,000 USD in an average risk area is from 300 USD per year. In other countries, such as England, the cost of flood insurance is distributed among the entire population, even if they are not at risk, since the country is small and it is not possible to have a risk distribution. This kind of measure is not feasible for a low-income population, and based on the economical value, it is not worth being insured. In addition, it is not feasible to insure illegal settlements.

(a) gate in a building (b) house in the floodplain

Figure 4.17 Individual flood protections

4

4.4 Economic assessment of flood measures

The economic assessment of a flood control design project can use different methods. The most used has been based on the **benefit and cost relationship**. A project is economically feasible when the benefits of avoiding the floods are greater than the measure cost of protection (structural and non-structural).

In this analysis, there is a need to estimate the damage, since it is potential damage. There are tangible and intangible damages. The tangible damages are those where it is possible to direct measure such as physical damages, emergency and economic losses. The physical damages are the cost for cleaning the building, losses of goods, furniture, equipment and other storage products. The emergency losses are related to cleaning, damages, evacuation costs, alerts, communications, temporary housing, etc. The economic impacts are related to losses of commerce, a reduction of normal services and a lack of industrial production. The intangible damages are those that cannot be valorised in economic terms, such as the loss of lives and historic building.

The steps for developing this analysis are:

- Estimating the flood damage curve for the actual scenario and future scenario with the measures planned to control the flood; and

- Obtaining the average annual difference by the flood damage assessments of the scenarios, taking into account the discount rate of the measures implementations. The average annual benefit of the measures is the reduction of damages.

The usual methodologies for assessing the damages are the following (Simons et al, 1977): (a) damage-level curve; (a.1) survey of potential damages; (a.2) historic curve method; and (b) aggregate damage method.

4.4.1 Flood damage-level curve

The flood damage curve relates flood risk to damages. The methodology to develop this curve is presented below:

1. There is a curve that relates flow to risk (probability or return period), called flood frequency curve. See figure 4.18a. This relationship can be obtained by using history flow levels in the area, as has been discussed in this chapter [Q = F (P), where P is the probability of floods above the Q, and F [.] is the flood frequency curve.
2. In a river section there is the level–flow relationship (rating curve) (figure 4.19c).
3. The curve that relates level to damage can be construction based in a survey of the area, assuming the river level and calculating the potential damage (see below). It is called the level–damage curve, where D is the damage in country currency units, and L[.] is the level–damage function. (figure 4.18c).

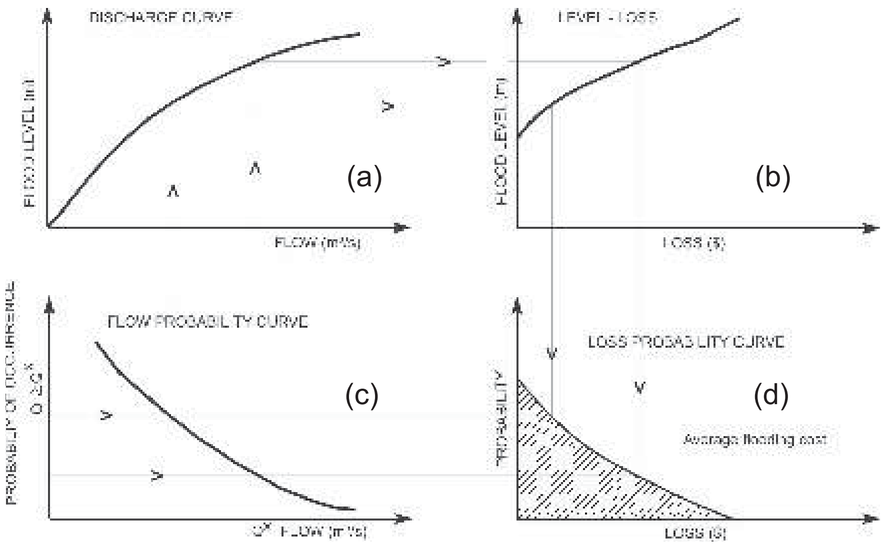


Figure 4.18: The curves and relationship that allow the construction of the flood damage curve

From the above three curves, it is possible to construct the probability – damage losses curve. It can be done graphically as presented in Figure 4.18. Select a value for Q in Figure 4.18c. It has a probability P. The same discharge Q represents a level in Figure 4.18a and a Loss (L) in Figure 4.18b. With P and L Figure 4.18d is obtained.

The shadow area of the curve in Figure 4.18d is the average flood damage due to the floods in the area.

Level–damage curve based on actual survey

The first two curves (flood frequency and rating curves) are well-known procedures in hydrology and the required information is usually available. The level–damage curve is more difficult to develop because it requires an extensive survey of information about the potential damage.

It can be developed based on a historic event assessment (see below) or by a survey of potential damage. This survey can be done using a standard type of housing and building. In the USA there is a standard damage–level curve (relates the level from the bottom of the construction and proportion of damage related to its value) for houses and other buildings developed by institutions such as the Soil Conservation Service, the Corps of Engineers and Federal Insurance Administration (see Figure 4.19).

After the standard curves have been developed, together with topography and the survey of the constructions, it is possible to estimate the damage level. It can be developed by GIS programs, together with a data bank of information of the area.

Level of damage – flood based on historic events

Eckstein (1958) used this procedure using information from historic floods. Since the flood levels were known, together with discharge and risk, using the damage data of the events it is possible to construct the curve (Box 4.6).

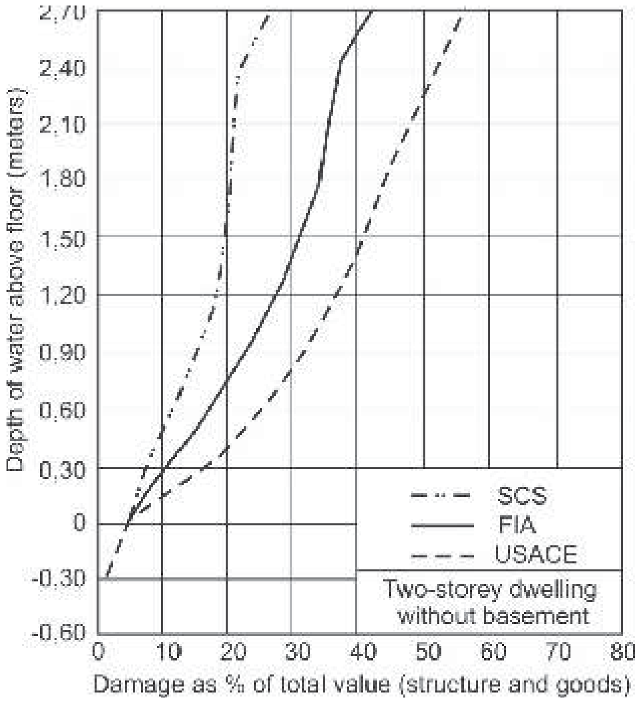


Figure 4.19: Standard Level – damage curves for a double-storey house (without basement) (Simons et al,1977)

Box 4.6: Case study in União da Vitória – Brazil

The total losses caused by the floods that occurred in the cities of União Vitória and Porto União (twin cities divided by a railroad) are presented in Table 4.2. The probability damage curve as presented in Figure 4.20 has been constructed from this data. The average annual flood damage was estimated by the curve area to be US$ 8-millions.

Table 4.2: União da Vitória and Porto União flood damage

Year	Level (m)	Damage US$ 1,000	Probability (%)
1982	746.06	10.365	19
1983	750.03	78.121	0.8
1992	748.51	54.582	2
1993	746.86	25.993	10

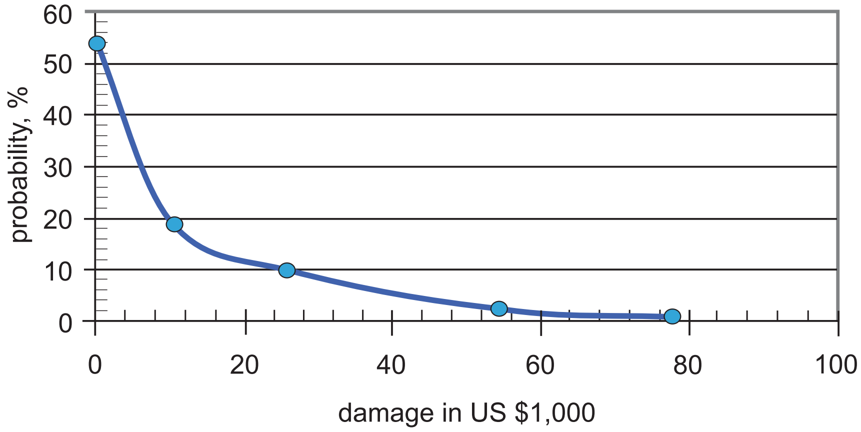


Figure 4.20: Probability–damage in União da Vitória and Porto União

This procedure assumes the following:

(a) The city did not change much during these flood events in the components of damage risk;
(b) Damages were repaired in between floods;
(c) Costs resulting from flood events have changed; and
(d) The procedure used in the flood damage assessment should be the same.

4.4.2 Aggregate damage equation

James (1972) presented an equation for aggregate damage based on the linear growing relationship between damage and level in the floodplain. The equation is the following:

$$C_D = K_D \, h \, M \, U \, A \qquad (4.4)$$

Where CD is the total damage of the event; KD is the damage index in currency units per level units (metre, for instance); h is the depth of the flood; M is the market index of development of the area in currency units per unit of development; U is the proportion of the occupation in units of the flood area; A is the inundation area.

The index KD is obtained by:

$$K_D = \frac{\partial D}{\partial y} \qquad (4.5)$$

Where D is the damage; y is the depth. It is obtained by the damage depth curve. Homan and Waybur (1960) estimated this value as 0,052 for floods of 5 feet of depth (~ 1.5 m). James (1964) presented an average value of 0,044. When the velocity is high and the amount of sediment is high, the damage potential increases and the index also increases. The other factors are obtained for each location.

SUGGESTED READING AND INTERNET SITES

ANDJELKOVIC, I., 2001. Fudelines on Non-structural measures in urban Flood Management. IHP-5 Technical Documents in Hydrology n. 50 Unesco.

IHE, 2010. Flood Management Educational Platform: Tutorial – UNESCO – IHE http:/www.ihe.nl/flood-management-education-platform/tutorial.

Internet sites:

www.apfm.info
http://ec.europa.eu/environment/water/flood_risk/index.htm
http://www.fema.gov
www.dfm.water.ca.gov
http://www.floodsite.net/

4

5. URBAN DRAINAGE

Goals
Urban development produces impacts on the stormwater, infrastructure, population and environment. The main goal of this chapter is to understand how it happens and how it can be managed.

Objective
To identify the main impacts of urban development on urban drainage and to suggest control measures that could be used to mitigate these impacts

5.1 Impacts of urban development on drainage

5.1.1 Source of the impacts

Urbanisation changes the natural space with impervious surfaces such as roofs, walkways and streets. Water that used to infiltrate the soil, now flows from impervious surfaces to gutters, pipes and canals with a speed higher than the usual flow in the natural terrain (figure 5.1). These two main changes of increase of impervious areas and flow velocity have as main effects in the urban drainage:

- Change in volumes of hydrologic cycles;
- Increased overland flow;
- Peak discharges;
- Decreased evapo-transpiration and groundwater flow;
- Increased erosion and sediment production and deposition;
- An increased amount of solid wastes; and
- Water quality degradation.

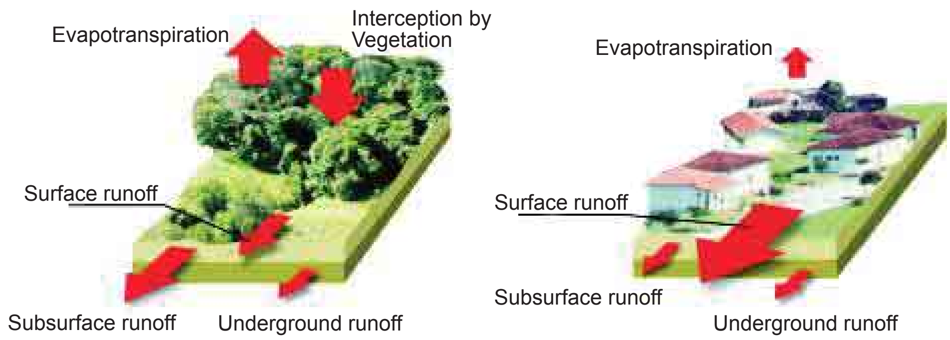


Figure 5.1: Change of soil use due to urban development

5.1.2 Change in the hydrological cycle

In urban areas the overland flow volume increases from about 5% to 15% of the rainfall to more than 60%. Together with the volume increase the peak flow also increases to between 3 and 7 times the discharge from natural conditions (Figure 5.2). The flow coefficient[8] changes with impervious areas, as it can be seen in Figure 5.3 with data from Brazil and the US.

[8] Flow coefficient is the total flow divided by total rainfall.

The two main hydrological indicators of urbanisation that affect urban drainage are impervious areas and time of concentration. Impervious area increases with urban population density, depending on the type of development, as can be seen in Figure 5.4. The watershed time of concentration[9] decreases, since the flow velocity increases with the urbanisation and man-made changes to the flow systems (impervious areas and conduits). Changes in the characteristics of the urban occupation can lead to changes in spatial planning of e.g. streets, green areas and buildings. This is included in the density and impervious area relationship of Figure 5.4. See the examples of boxes 5.1 and 5.2.

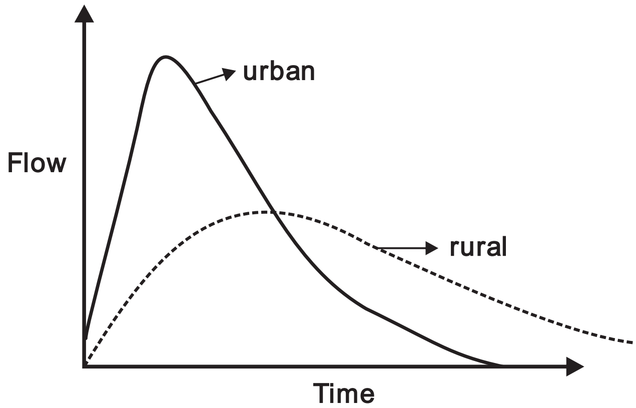


Figure 5.2: Hydrograph of a natural basin and an urbanised basin

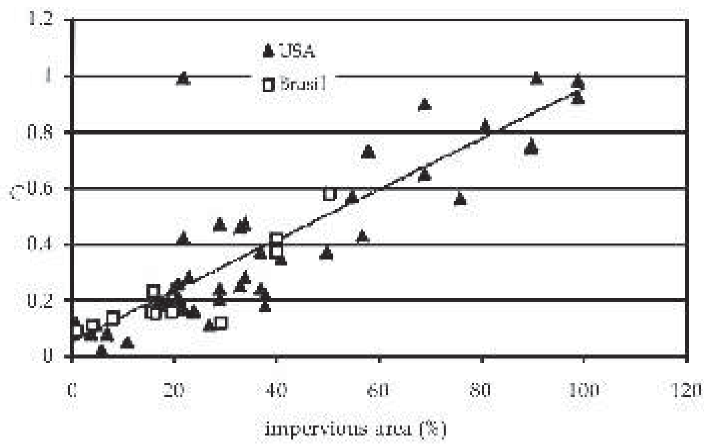


Figure 5.3: Flow coefficient and impervious areas

Box 5.1: Example of Managing urban density and impervious areas

The density and impervious areas depend on the urban area, the number of persons per residential unit, the number of units per plot and the planned impervious areas of public and residential areas. Some of these parameters could be regulated in order to enforce a limited impervious area. Assuming one unit per plot with 300m^2 each, four inhabitants per unit, 35% of public spaces with 80% of impervious area, and 65% of private area with 60% of impervious area, results in a total of 67% of impervious area and a density of 86 inhabitant per ha. Using the relationship C = 0.05 + 0.9, AI (from Figure 5.3) shows that the flow coefficient for the urban area is C = 0.824 (AI is the proportion of impervious area). A natural flow coefficient is where C is about 0,05. The flow increase can be estimated by I = 0.824/0.05 = 16.48 (1648%).

[9] Time of concentration is the maximum time of contribution of the upstream basin to the main section.

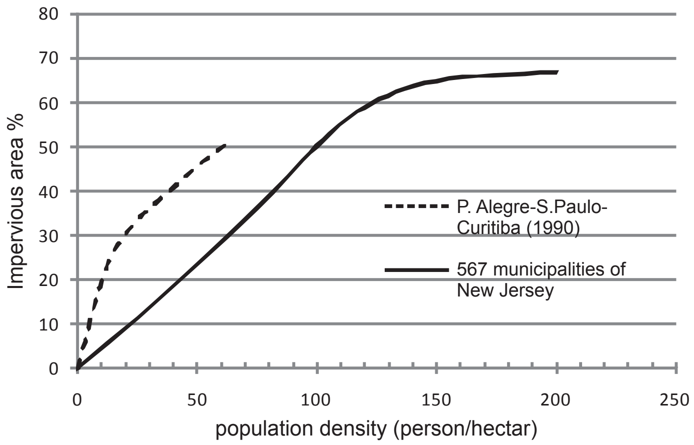


Figure 5.4: Impervious areas as a function of inhabitant density

Box 5.2: Case study of the Dilúvio Basin in Porto Alegre, Brazil.

The Dilúvio basin in Porto Alegre with 30 km² had a development from 15% of impervious area between 1978 and 1982 to 40% of impervious area between 1995 and 1997. Figure 5.5 shows the increase in the flow volume over the time period and Figure 5.6 shows the change in the flow coefficient.

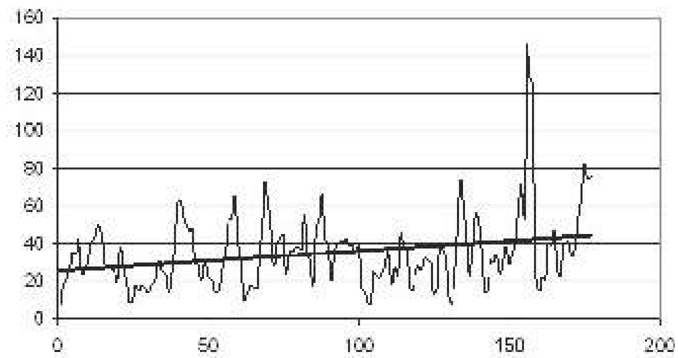


Figure 5.5: Overland flows in the Dilúvio Basin from 1982 to 1995

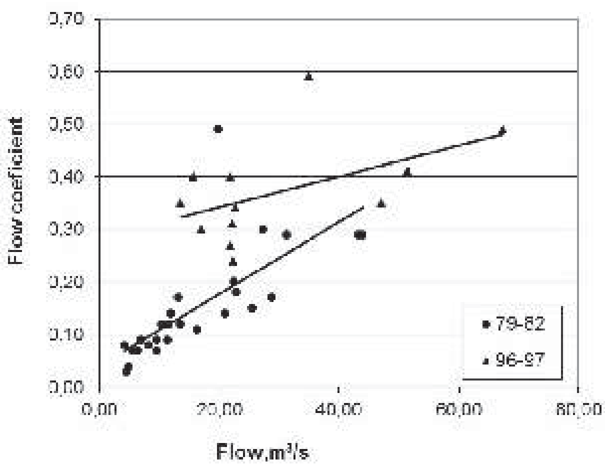


Figure 5.6: Flow coefficient function of peak flow for two scenarios of the Dilúvio Basin.

5.1.3 Total solids increase

The following main types of solids are produced in the urban environment: (a) sediments and vegetation produced by rainfall and flow velocity action along the basin; (b) solid waste: residuals generated by people, such as plastic, paper and others. On the urban surface, street cleaning, vegetation and sediments are collected together with the solid waste. Solids are an important source of loads to the river systems, since organic and chemicals arrive in the aquatic system aggregate to the solids. In addition, there are many types of waste, such as plastic, that take very long to dissolve in the environment.

In the urban development there are two main stages of total solid waste production:

(a) At the start of a development, there is a larger amount of sediment as compared to natural conditions, because of the urban implementation resulting in unprotected surfaces. Energy from rainfall intensity and high water velocity stemming from the overland flow from impervious areas increases soil erosion and transports more sediment and vegetation to urban creeks, creating degraded areas by erosion. Sedimentation of the creeks reduces the conveyance capacity, which increases the flood frequency and magnitude;

(b) After the urbanisation is settled, sediments are still the main volumes, but the solid waste increases mainly due to human activities and the lack of efficiency of street cleaning services and waste collection, together with the often low public awareness regarding wastes.

Urban sediments

Soil erosion in urban environments could be important in the following cases: (a) high slopes and the lack of drainage could destroy houses and jeopardise lives; (b) unprotected surfaces increase sheet flow erosion[10], which increases the amount of sediment flow; (c) increased flow velocity from impervious surfaces, pipes and canals without hydraulic dissipation leads to an increase in degraded area. Velocity and flow increase because of impervious areas and the constructed storm drainage. If this discharge flows into a downstream natural canal, erosion will occur, creating a degraded area; and (d) high erosion rates in canals can affect the sewer or stormwater networks.

Table 5.1 shows the amount of sediment dredge from some urban rivers in Brazil. Dredging and solid waste disposal represent an important maintenance cost to municipalities for maintaining the conveyance of the natural and constructed drainage networks. Taking into account the volumes of Table 5.1, the cost may vary between US\$2,000 and US\$12,000 per km^2 per year $^{-1}$.

Table 5.1: Volume of sediment yield in some urban basins

River and city	Characteristics of the source	Volume $m^3 . km^{-2} . year^{-1}$	Reference
Tietê River in São Paulo	Dredge sediment	393	Nakae and Brighetti (1993)
Tietê River tributaries in São Paulo	Bed sediment	1400	Lloret Ramos et al. (1993)
Pampulha Lake in B. Horizonte	Sediments from 1957 to 1994	2436	Oliveira e Baptista (1997)
Dilúvio Creek in Porto Alegre	Dredge sediment	750	DEP (1993)

[10] Sheet flow erosion is the soil erosion distributed based on high velocity and small flow depth.

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The suspended sediment yields of some urban basins in Curitiba at different stages of urbanisation are presented in Figure 5.7. Atuba Basin was in urbanisation, showing higher values of concentration for the same specific discharge. Palmital was a basin where the urban development was lower than that of Atuba, and Pequeno was a rural basin in most of its area. The main difference between the curves could be seen as the specific discharges increase together with the concentration of urbanised areas.

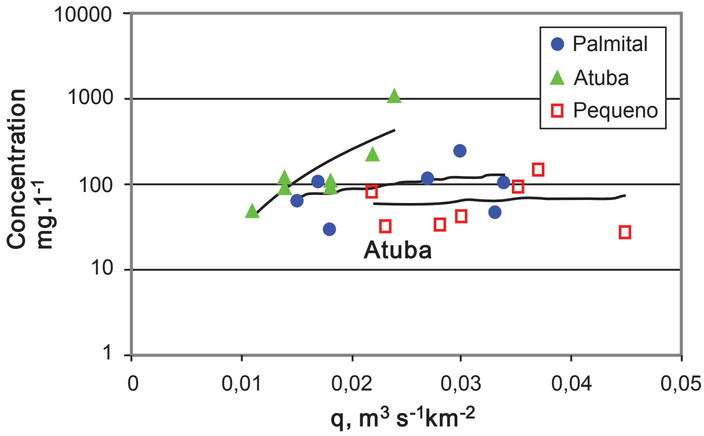

Figure 5.7: Suspended sediment concentration as a function of the specific discharge[11] for some Curitiba basins, Atuba (15% of impervious area); Palmital (7% of impervious area) and Pequeno (almost rural) (Tucci and Porto, 2001)

Solid waste

Solid waste in an urban environment is the sum of the amount collected in buildings, the amount obtained from street cleaning and the amount that has arrived in the drainage. Solid waste increases with the population, which requires more efficiency in managing the first two components in order to have a minimum amount of drainage, which has higher cost of cleaning and an impact on the environment and on the flood frequency.

The management efficiency is based on: (a) population education; and (b) coverage of the waste collection and frequency (In some developing countries, these services do not cover the whole city due to the difficulty of truck mobility on narrow streets [Box 4.1] or some neighbourhoods being very dangerous due to drug dealers' controls); (c) low efficiency of street cleaning; and (d) lack of management at construction sites.

The collected solid waste requires a disposal site with a controlled environment impact. However, it could be reduced by recycling. Recycling is a function that requires the population to be educated regarding the separation of waste before it is collected. In developing countries, the main incentive is economical since it brings a partial income to poor populations that make a living by recycling aluminium cans and other profitable metals, paper and plastic.

When these services are not efficient, the solid waste in the drainage increases, leaving consequences to the environment. The effect of the solids in the drainage is the decrease of the conveyance of the stormwater networks and the environment degradation. When the services are not reliable, the consequences are: (a) an increase in the cost of maintaining the urban drainage; (b) environment degradation by erosion and transport of polluted water; (c) obstruction of urban drainage; (d) losses of hydraulic efficiency of the drainage; and (e) an increase in flood frequency.

[11] Specific discharge is the discharge per unit of area of a basin. This variable is used as comparable indicator among basins.

Box 5.3: Exchange solids

In Curitiba, Brazil, a programme has been developed in lower-income neighbourhoods to exchange solids collected by the population for bus tickets, since it costs the municipality less to provide the bus tickets than it does to provide solid waste services. The bus tickets do not increase the cost since the city pays for the number of buses in the streets and not for each ticket. It is not the best solution, but it created an economic value for the solids collected by the population and its selection.

Solids production and collecting: The statistics of solids production are usually mainly related to solids collected in buildings. The unit often used is kg per person per day and varies with income, seasonality, regional and characteristics, among others. In the US the average value is 2.02 kg per person per day (EPA, 2000); while in Brazil it is between 0.5 and 0.8 and an average of 0.74 kg per person per day (IBAM, 2001).

Solids recycling have been improved by awareness, economic incentives and enforcement. In developing countries, solids recycling increases when it has economic value (reducing the waste in the drainage). In developing countries, aluminium cans have a high rate of recycling (> 80%), but some types of plastic do not have economical value for recycling. In Brazil, the plastic content has increased over the last few years, but organic matter still represents 30 to 70%, paper 25 to 50%, and metal and glass about 10%. Plastic has been the solids that are found most in the environment. It represented 59% of the collected waste in the cleaning coast programme (EPA, 2004). Marais and Armitage (2004) reported that plastic is the main solid waste found in the drainage in cities of South Africa, Australia and New Zealand.

Street cleaning and drainage: Street cleaning is strongly dependent on the cleaning frequency in public areas, awareness and rainy days. Armitage et al (1998) mentioned that in an area of 299 ha, with 85% of commercial and industrial area, 82.5% is cleaned by the solid waste service and 17.5% reaches the drainage. After streets have been cleaned, 0.8 kg of solid waste per person per year still moves to the storm network of San Jose, Ca, USA on rainy days (Larger et al, 1977).

Neves (2005) presented a summary of the solids in drainage estimated in some countries (Table 5.2). There is a large variability of this data because of other interconnected factors, such as the type of urbanisation, efficiency of the services of collecting, street cleaning and site and urbanisation regulation in order to control erosion and population education.

Table 5.2: Total solids in the drainage

Area description	Weight Kg. $ha^{-1}.year^{-1}$	Volume 10^{-3} $m^3.ha^{-1}.year^{-1}$
Springs, South Africa: Of 299 ha, 85% is commercial and industrial and 15% is residential[1].	67	0.71
Johannesburg (downtown): 8 km^2, commercial, industrial and residential[1]	48	0.50
Sydney, Australia: 322,5 ha, commercial, industrial and residential	22	0.23
Auckland – New Zealand Residential: 5,2 ha Commercial: 7,2ha Industrial: 5,3ha	2.8 61.7% 26.1% 12.2%	0.029
Cape Town (downtown): 95% residential, 5% industrial[3]	18	0.08

1 - ARMITAGE et al. (1998) - 2 - ALLISON et al. (1998b) – 3 - ARNOLD and RYAN (1999)

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Table 5.3: Composition of solid waste in some cities

Local	Composition
Springs[1]	62% plastic, 11% polystyrene, 10% paper, 10% cans, 2% glass and 5% other material
Johannesburg[1]	Sediments, suspended solids (80% plastic packs), floating matters and other material
Melbourne[2]	80% vegetation and waste related to pedestrians and car drivers
Auckland	53% rigid plastic, 1,9% soft plastic, 10,5% plastic fibre, 0,3% glass, 3,3% aluminium, 0,5% tin cans, 26,8% paper and 3,5% other material
Cape Town[3]	More than 50% of plastic in the industrial and commercial areas. Metal, wood and rubber have contributed greatly.

1,2 and 3: The same as Table 4.3

Types of Drainage Solids: The composition of the garbage that arrives in the drainage varies in function of the urbanisation, recycling and services efficiency. Table 5.3 presents solids classification found in the drainage, related to the data of Table 5.2. It can be seen that plastic is the main type of solids, mainly because of low recycling value of some types of plastic and its increased use with improving income.

5.1.4 Water quality degradation

The pollution of stormwater can occur through one or more of the following processes:

- The absorption of air pollutants by rain. About 90% of air substances that drop in impermeable areas are transported to rivers (Oberts, 1985);
- The washing of urban surfaces (pervious and impervious). In the urban areas the surfaces are contaminated by the population through chemistry compounds, organics, etc. It can be aggravated by the water acidity;
- Pollution has accumulated in rivers and lakes over many years. These deposits could come to suspension in water during large floods; and
- The washing of contaminated deposits.

On rainy days the surface wash-load is mainly from sediments, litter and other streets detritus (garbage). This water is polluted by organic matter and metals from the washing of urban surfaces and aggregated to solids. Most of the loads come during the first part of the rain (in the first 20 to 35 mm of rain), when the days before the event were dry (EPA, 1993). The water quality concentration (polutogram) and flow hydrograph are presented in Figure 5.8a. For rainy days previous to the event, the concentration peak is lower and moves to the right of the peak flow (Figure 5.8b).

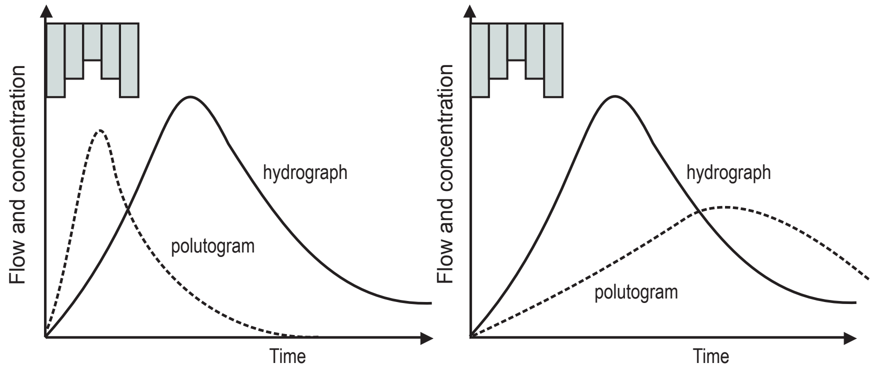
In urban rivers, there are two critical water quality scenarios:

- The dry season when the flow is small and its dilution capacity is also small, resulting in highly concentrated pollution; and
- Rainy days when the stormwater loads are higher, combined with untreated sewage loads.

The main difference on the load characteristics between sewage and stormwater is that sewage waste is mainly organic with high BOD[12] and Coliforms[13], while stormwater has more metals, such as copper, zinc and lead. Table 5.4 shows some concentration parameters of stormwater of US cities and Porto Alegre, Brazil.

[12] BOD: Biochemical Oxygen Demand is a indicator of water quality and organic load;
[13] Coliforms are a biological indicator of animal load to the river.

Table 5.5 shows median values of concentration and its variance coefficient obtained for each water quality parameter in a programme developed in many USA cities. The importance of metal concentration can be seen. These values are only for stormwater. When the drainage flow receives also sewage from non-treated domestic sources or the connections to the sewer system are not efficient, the water quality flow is a combination of sewage and stormwater pollution.



a – previous days without rain   a – previous days with rain

Figure 5.8: Hydrograph and polutogram (water quality concentration in time)

Table 5.4 Comparison of average values of water quality parameters of stormwater in several cities (mg/l)

Parameter	Durham (1)	Cincinnati (2)	Tulsa (3)	P. Alegre (4)	APWA (5) Interval Lower	Upper
DBO		19	11,8	31.8	1	700
Total solids	1440		545	1523	450	14,600
Ph		7.5	7,4	7.2		
Coliform (NMP/100 ml)	23,000		18,000	$1.5x10^7$	55 $11.2x10^7$	
Iron	12			30.3		
Lead	0.46			0.19		
Ammonia		0.4		1.0		

1. Colson (1974); 2 – Weibel et al. (1964); 3 – AVCO (1970), 4 – Ide (1984); 5 – APWA (1969)

Table 5.5: Mean Concentration of rainy events (EPA, 1983)

Type (mg/l)	Residential Median	CV	Commercial Median	CV	Industrial Median	CV	Non-urban Median	CV
BOO	10.0	0.41	7.80	0.52	9.3	0.31	-	-
COD	73.0	0.55	65.0	0.58	57.0	0.39	40.0	0.78
TSS	101	0.96	67.0	1.10	69.0	0.85	70.0	2.90
P_b	0.144	0.75	0.114	1.40	0.104	0.68	0.03	1.50
Cu	0.033	0.99	0.027	1.30	0.029	0.81	-	-
Zn	0.135	0.84	0.154	0.78	0.226	1.10	0.195	0.66
TKN	1.900	0.73	1.290	0.50	1.180	0.43	0.965	1.00
NO_{2+3}	0.736	0.83	0.558	0.67	0.572	0.48	0.543	0.91
TP	0.383	0.69	0.263	0.75	0.201	0.67	0.121	1.70
SP	0.143	0.46	0.056	0.75	0.080	0.71	0.026	2.10

BOD – Biochemical Oxygen Demand; COD – Chemistry Oxygen Demand; TSS – Total Suspend Solids; P_b – Plumb; Cu –Copper; Zn – Zinc ; TKN: Total Kjeldahl nitrogen; NO_{2+3} Nitrite and Nitrate; TP: total phosphor; SP: soluble phosphor.

5.2 Flood Control policies

5.2.1 Main issues

The main institutional causes for the flood management problems in the urban environment are:

- Urban development in the developing countries' cities occurs too fast and unpredictably. Usually the tendency of this development is from downstream to upstream, which increases the damage impacts (Dunne, 1986);
- Urbanisation in peri-urban areas is usually developed without taking into account the city regulations. This urbanisation is as follows: **Unregulated developments**: In peri-urban areas of big cities the real estate is priced low. Regulation of this area requires investments that are almost the value of the land. As a consequence, private land owners develop urbanisation without the infrastructure and sell it to the low-income population; **Invasion of public areas** (such as public green areas): usually the invasion of public areas that were planned in an Urban Master Plan for future parks, public construction, and even streets. Due to low-income conditions (the homeless) and slow decision-making by public administration, these developments are regularised and receive water and electricity;
- Peri-urban and risk areas (floodplain and hillside slope areas) are occupied by low-income populations without any infrastructure. Spontaneous housing developments in risk areas in Humid Tropic cities are on land that is prone to flooding e.g. Bangkok, Bombay, Guayaquil, Lagos, Monrovia, Port Moresby and Recife; and hill sides prone to landslides: Caracas, Guatemala City, La Paz, Rio de Janeiro and Salvador (WHO, 1988);
- In developing countries, the municipality and the population usually do not have sufficient funds for the supply of basic water, sanitation and drainage needs; The lack of appropriate garbage collection and disposal decreases the water quality and the capacity of the urban drainage network due to filling. Desbordes and Servat (1988) mentioned that in some African countries there is no urban drainage and when system drainage exists it is filled with garbage and sediments. Tokun (1983) also mentioned this type of problem in Nigeria, where the drainage systems are used as a garbage collector;
- The lack of institutional organisation in urban drainage at a municipal level, such as regulation, capacity building and administration. There is a lack of: comprehensive project organisation and a clear allocation of responsibilities; adequate urban land-use planning and enforcement; and the capability to cover all phases and aspects of technical and non-structural planning (Ruiter, 1990).

5.2.2 Unreliable flood management practices

Flood control policies in most of the developing countries are not adequate to minimise the related impact. The main aspects of these policies are presented below:

Urbanisation from upstream to downstream: Urban drainage is designed based on the concept of draining water from urban surfaces as quickly as possible through pipe and channel networks; however, this increases the peak flow and the cost of the drainage system. There is no control of peak increase at a minor drainage level and most of these impacts will appear in the main drainage (Figure 5.9).

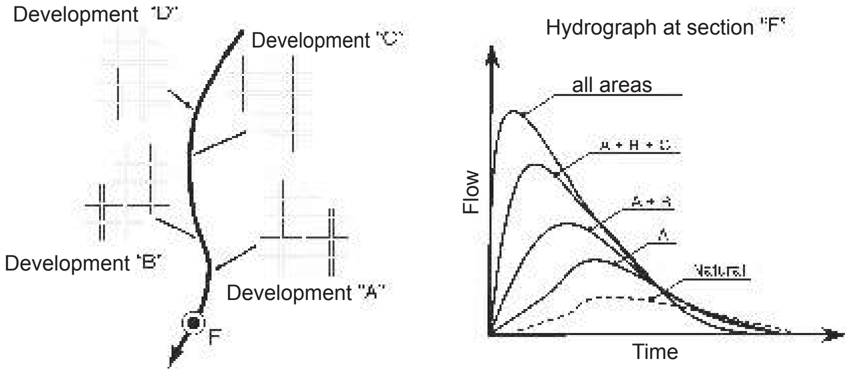


Figure 5.9: The development is implemented and the flood peak increases

Another common scenario is the increase of the development from downstream to upstream. In this scenario, the new development increases the hydrograph[14] to downstream river reaches, affecting the existing population.

When flood frequency starts: In the above scenarios the floods starts to occur. To cope with this problem, a public institution has usually developed many works such as canals in the main drainage and pipes in the secondary drainage network. This type of solution has only transferred the flood problem from one section of the basin to another, with high costs. In addition, the water quality impact is great, because the overflow is of water with a larger amount of solids, a higher metal load and more other toxic components.

This process is illustrated in Figure 5.10. The hydrographs of Figure 5.10a shows the stage when there are floods at section A and not in B. The fragmented solution usually used in cities is to construct a canal to increase capacity in A. When it is done, the flood is transferred to section B (scenario 5.10b). This is done because the manager most of the time does not have the concept of managing the basin and develops its project only to reaches, transferring the problem from one part of the population to another. This management could potentially cause the responsibility for the damage to be assumed by the local government, since the main causes of the floods were created by the municipal canal.
Even if the municipality did not construct the canal, it is responsible for the damage caused, since it approved the individual project without controlling the flow increase.

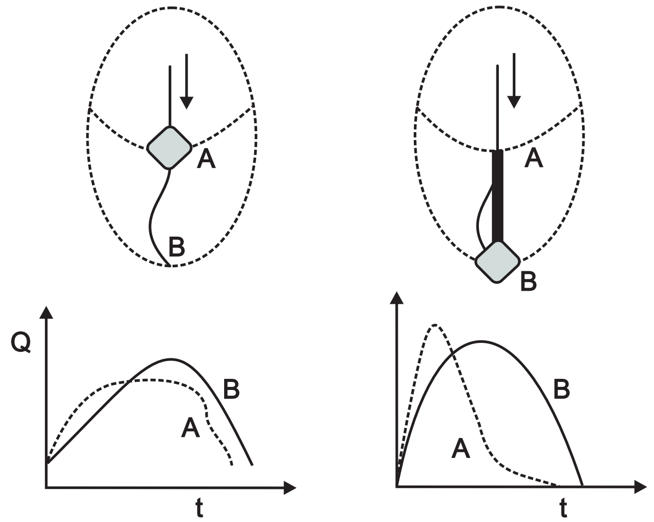
Many cities in developing countries are short of money to invest, and when they invest in urban drainage, this sequence showed that it is done in the wrong way, creating more problems than they had before, with loss of public money.

Scenario of Floodplain and urban drainage: Figures 5.11a and b present a common scenario of cities that have both types of floods (floodplain and due to urbanisation). In the first stage, the flood frequency does not allow the population to occupy the floodplain. With the increased value of the real estate in the neighbourhood of the flood areas, the pressure for its occupation also increases, which occurs during a sequence of low-flood-level years.

During wet years the population suffers due to the floods and due to pressure from the public and construction companies. The solution for flood protection is to increase the river flow capacity or a levee system, taking into account the urbanisation scenario of that stage. In this situation, the population feels safe and occupies the whole area. Over the following

[14] Hydrograph is the variation of the discharge in the time as presented in Figure 5.9

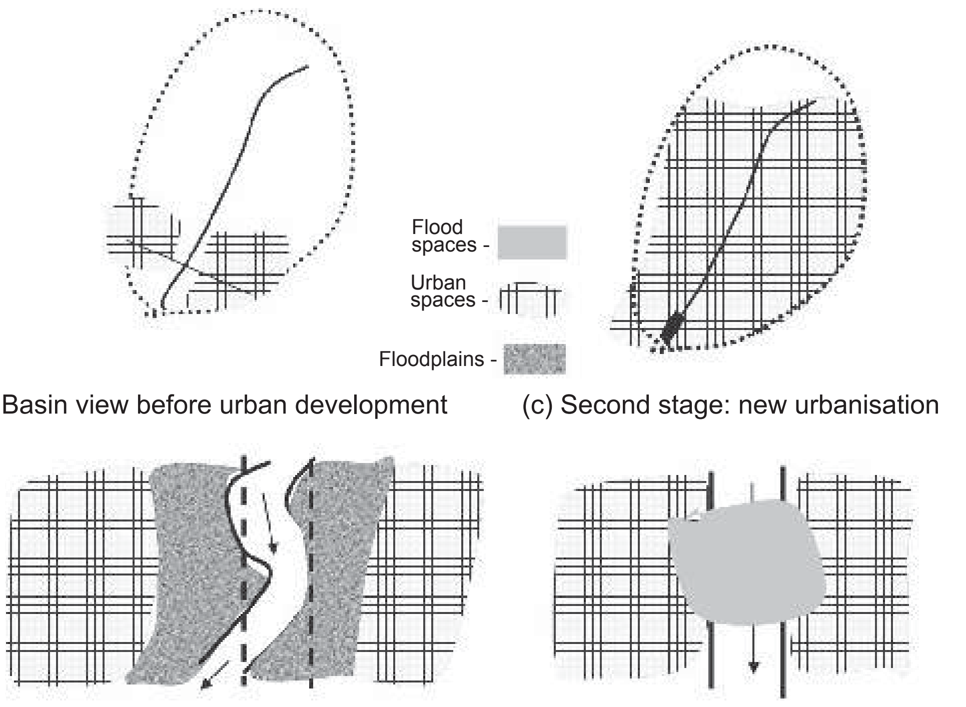
years the upstream basin is also urbanised and the flood levels downstream increase again. As a consequence, the channel does not have the capacity to cope with these peak flows, which brings back flood damages to the same city area. (Figure 5.12c and d).



a – First stage: The flood occurs in A.

b – A canal has been constructed to cope with the flood in A and the flood is transferred to B.

Figure 5.10: Transference of Floods by bad management



(a) Basin view before urban development

(c) Second stage: new urbanisation

(b) local view of flood areas and nearby

(d) second stage: occupation of flood

Figure 5.11: Stages of basin occupation and impacts

During this last stage of flood control, flood control costs are sky high, compared to prevention measures, since structural controls such as river deepening (there is no more lateral space), building upstream reservoirs and other high-cost measures are the only options left.

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5.3 Main Principles for sustainable urban drainage

The experience in flood control in many countries has led to the following main principles in urban drainage management:

- Flood control evaluation should be done in the whole basin and not only in specific flow sections;
- Urban drainage control scenarios should take into account future city developments;
- Flood control measures should not transfer the flood impact to downstream reaches, giving priority to source control measures;
- For new developments the priorities of sustainable solutions, which keep the natural functions of land and aquatic systems such as infiltration, should be taken into account;
- The impact caused by urban surface wash-off and others related to urban drainage water quality should be reduced;
- More emphasis should be given to non-structural measures such as regulation, capacity building and other preventive programmes;
- Management of control starts with the implementation of an Urban Drainage Master Plan at municipal level;
- Public participation in urban drainage management should be increased; and
- The development of urban drainage should be based on the cost recovery on investments.

5.4 Measures for urban drainage planning and design

The measures for urban drainage can be selected by the stage of the urban development. When a city is already established, the main objective is to correct the existing impacts or to re-naturalise the river systems. To correct existing problems the practice is to use measures at minor and major drainage. The re-naturalisation[15] or re-urbanisation requires more funds and willingness than conventional solutions, since all aspects of urban waters have to be developed. When the city is in a planning stage, the sustainable development of urban spaces is the best choice, as the implementation moves in the direction of preserving the natural functions of the land and aquatic systems. In this scenario, source control measures are recommended.

The measures that can be classified by scale of interventions are:

Source control measures: These are measures inside a development, such as a plot, a shopping centre, a parking lot and parks.

Minor or major drainage: The drainage measures taken in an urban basin or sub-basin that can be small for example only with pipes or a major drainage of urban creeks.

The measures can also be classified by the way they affect the hydrograph of a basin (variation of the flow with the time). The main measures are:

Infiltration and percolation: Increase of the infiltration or percolation area of the basin. In that way there is less flow in the drainage and more to recharge the aquifers. This type of solution decreases the overland flow and the stormwater, recovering the land infiltration, delaying the flow and decreasing the peak flow. Since urban developments require impervious areas, the infiltration can be recovered by using a combination of storage and infiltration of the left pervious surfaces.

[15] Re-naturalisation is the recovery of the natural functions of a river system, and re-urbanisation is the integration of river restoration with re-urbanisation.

Storage: Temporary storage of the water can be developed to decrease the peak flow. Figure 5.12 shows the hydrograph of a natural basin, the potential hydrograph (flow in the storm drainage in time) after urbanisation and the hydrograph where there is a reservoir.

Increase flow conveyance: This measure increases the flow capacity of a section by a pipe, canal or increasing the natural flow conditions of a river by changing its sections or by decreasing the flow slope. Sometimes this measure is required to transfer the hydrograph to a reservoir or to a section that supports the volume and peak increase.

Dike or pump station: This is a solution for a very specific area and flood conditions of urban areas.

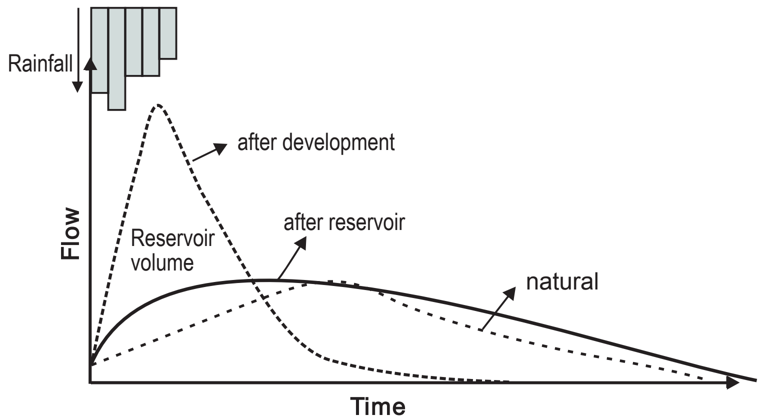

Figure 5.12: Hydrographs of natural conditions, after the development with impervious areas and after the reservoir has been constructed.

5.4.1 Source control measures

The main measures for local control in housing developments, car parking, parks and public thoroughfares are normal termed "source control". The main measures are the following: increasing areas for infiltration and percolation; and temporary storage in residential or covered reservoirs.

The main characteristics of local control of runoffs are (Urbonas and Stahre, 1993):

- A more efficient drainage system downstream of the controlled places;
- Systems having a greater capacity to control flooding;
- The difficulty of controlling, designing and maintaining a large number of systems; and
- The possibility of operating and maintenance costs being high.

This type of system has been adopted in many countries with the help of appropriate legislation, or through a flood control programme, as described by Yoshimoto and Suetsugi (1990). For the watershed of the river Tsunumi, where some 500 detention basins of 1.3 m^3 were built.

One of the main strategies adopted by many cities is to limit the peak flow to natural flow before it enters the public drainage system from housing developments, and commercial and industrial installations. This limit generally corresponds to the natural flow from the housing development for a given return time (for instance ten years). This flow is restrictive and obliges the entrepreneur to use the systems mentioned within the area under development in order to maintain the downstream flow.

Infiltration and percolation

Infiltration is the process of transfer of the flow from the surface to underground. The infiltration capacity is the amount of water the soil can absorb in a period of time. It depends on the soil properties and the humidity of the top stratum of soil, also known as unsaturated zone. Percolation also depends on the humidity and type of the top stratum soil. Certain soil types are less prone to percolation and can store low volumes, making them unstable for use, since they may: (a) keep water on the surface for much longer; and (b) do little to reduce the final volume of the hydrograph. Infiltration depends on the soil characteristics.

The advantages and disadvantages of infiltration and percolation devices are: (Urbonas and Stahre, 1993):

- They increase the recharge, recover the water table, preserve the natural vegetation and reduce pollution discharged into rivers, flow velocity, peak and conduits' size;
- Soil in some areas may become impervious over time, due to a rise in the water table;
- When the overland flow is polluted it can pollute the aquifer and the soil.

Some type of infiltration scheme used for source control is presented below:

Infiltration surfaces: These are of various types, depending on the local circumstances. In general, the infiltration area is an area of grass that receives precipitation water flowing from an impervious area. It is used as side space in parking lots, residential or building areas (Figure 5.13). During heavy rainfall, these may be submerged if the precipitation exceeds their capacity. Where the drainage carries a lot of fine material, the infiltration capacity may be reduced, requiring the surface to be cleaned to keep it working.

Box 5.4: Example

On a plot, there is a lawn that makes up 1/3 of the total area. What should the level increase of the drain be for it to store five years' flood water in the lawn?

The five-year's flood water for one hour is 30 mm, assuming that the natural flow is 15% of the rainfall, which results in 25.5 mm from the impervious areas. The proportion of impervious areas is three times greater than the pervious areas. Multiplying the net rainfall by 3 then gives 7.7 cm. This is the water level in the lawn, which would be stored for a five-year flood to keep the flow below 15% of the rainfall. **Using it as a lower level of the lawn drain, this water is stored and infiltrates over time** (Figure 5.14c).

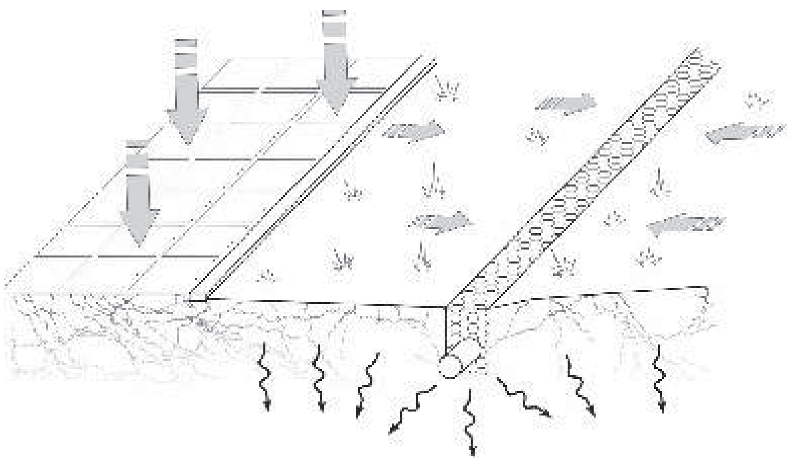

Figure 5.13: Infiltration Plan and a swale

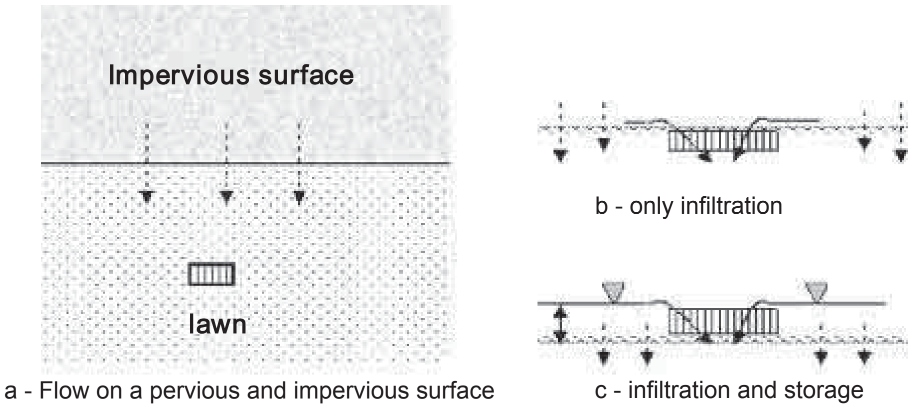

Figure 5.14: Flow from an impervious surface to a lawn

With surfaces of internal areas, the drainage is often placed on the impervious surfaces. Instead of that, allowing water to flow onto the lawn, the water can infiltrate and be stored until it is drained (Figure 5.14).

The infiltration surfaces need to have a small slope (<5%) for water to spread on the surface without creating a preferential flux, which reduces infiltration. It is also used to reduce pollution in overland flow. For a slope of 1%, about 3 to 15m of lawn surface is needed to decrease the concentration in 75%.

Infiltration trenches: This is used to store water in the soil, delaying its flow to downstream through percolation and groundwater flow, reducing the overland flow. The storage takes place in the top layer of the soil and its efficiency depends on porosity and percolation. The water table must therefore be low to allow space for storage. They are made by digging out the soil and backfilling with gravel to create the storage space (Figure 5.16). Certain soil types require the creation of better drainage conditions. In clay soils that have low percolation, the outlet needs to be drained. The main difficulty with using this type of system is that the spaces between the stones get clogged by the fine material entering it. It is therefore recommended to use a filter of geotextile material. It needs to be cleaned after some time (Urbonas and Stahre, 1993).

5

Pervious hydraulic structures: There are various types of systems that drain runoff and can be constructed to allow infiltration. Examples are:

- **Pervious inlets** to the drainage system: Figure 5.17a shows a filter in the top of the chamber to prevent obstruction;
- **Pervious trench**: It consists of a chamber with gravel and a filter, with a porous or perforated pipe passing through (Figure 5.17b); and
- **Pervious curvet**: It is used outside housing, commercial or industrial spaces (Figure 5.17c).

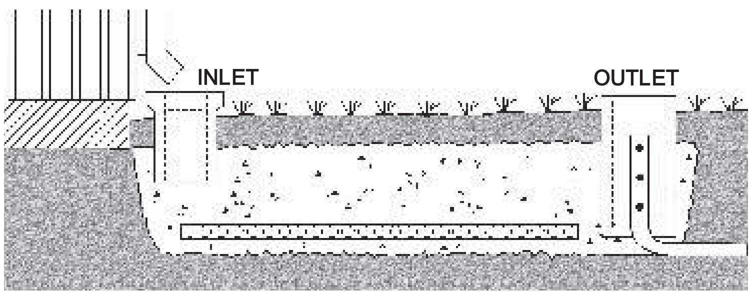

Figure 5.16: Infiltration trench (Holmstrand, 1984)

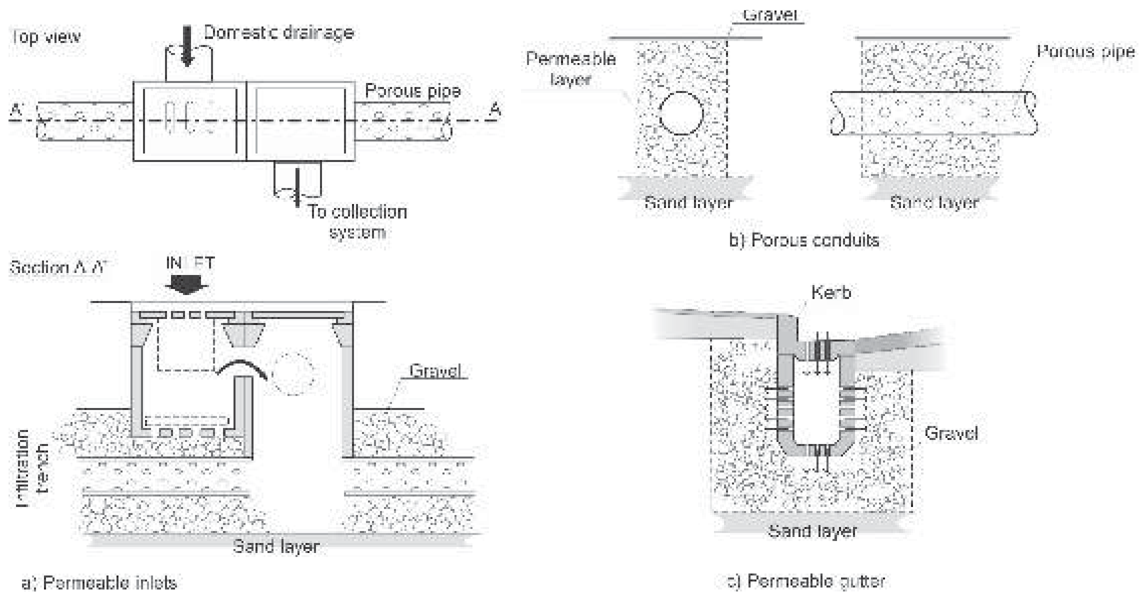

Figure 5.17: Pervious hydraulics structures (Fujita, 1984)

Pervious paving: Pervious paving can be used for public thoroughfares, car parks, sport fields and streets with light traffic. In streets with heavy traffic, this paving can be deformed or blocked, thereby becoming impervious.

This type of paving can be made of porous concrete or asphalt (Figure 5.18). The concrete and asphalt are made in a way as conventional paving, except that the fine material is left out of the mixture.

When this paving is designed to hold part of the drainage, its base must be at least 1.2 m above the water table in the wet season. The drainage system has to be designed to absorb the volume held in the soil layer for a period of 6 to 12 hours (Urbonas and Stahre, 1993). This system is feasible when the soil has an infiltration capacity of more than 7 mm/h. It is recommended for use in soils with more than 30% of clay or 40% of silica and clay combined. This type of control can have the following advantages: reduction in planned surface runoff in relation to an impervious surface; reduction of storm drain diameters; reduction of storm drain costs and of standing waters on car parks and public thoroughfares. The disadvantages are: maintenance of the system to prevent clogging over time; pervious paving may cost 20 to 30% more than conventional paving, as it has to be laid on a base (without taking into account the benefits of the reduction in cost of the downstream drainage); and potential aquifer contamination.

Araujo et al (2001) carried out experiments in some surfaces (Table 5.6): (a) **compacted earth**: having a gradient of 1 to 3%; (b) **impervious**: an area of ordinary concrete, made of cement, sand and gravel, having a gradient of 4%; (c) **semi-impervious surface**: an area of regular parallelepiped granite slabs, with sand joints, having a gradient of 4%; and another area laid with machine-made concrete blocks, also with sand joints known as blockets, having a gradient of 2%; and (d) **pervious paving**: an area of concrete blocks with vertical orifices filled with granular material (sand) having a gradient of 2% and an area of porous concrete having a gradient of 2%. The experiments were conducted with rainfall of 110 mm/h, equivalent to a 5–year return period for a duration of 10 minutes (Table 5.16). The parallelepipeds absorbed part of the rainfall and the pervious paving produced a very small amount of flow. It was a rain simulation on a surface of only 1m^2 in a short period.

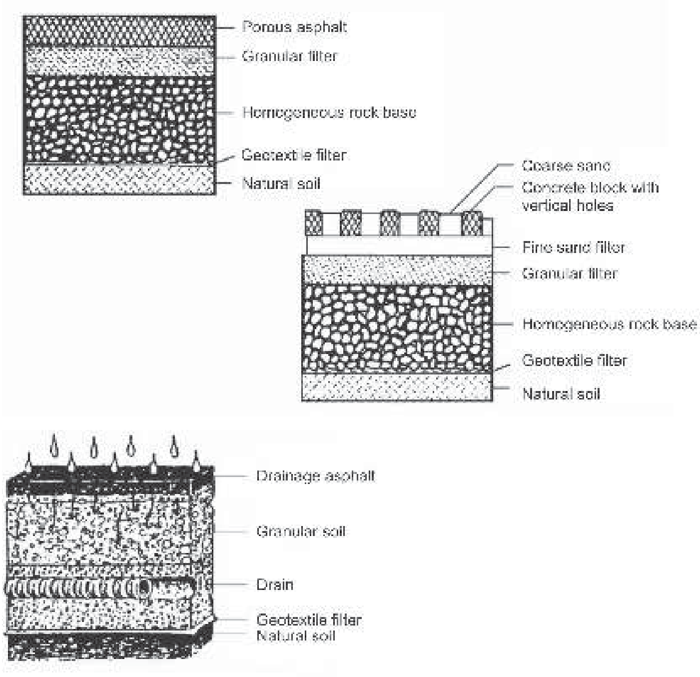

Figure 5.18: Pervious paving

Table 5.6: Experiments in unit module surface of 1m^2 with rainfall of 110 mm/h and a duration of 10 minutes (adapted from Araujo et al, 2001)

Type of surface	Flow coefficient
Compacted soil	0.66
Impervious	0.95
Semi-impervious – Parallelepipeds	0.60
Blockets	0.78
Pervious	0.03

Figures 5.19 to 5.20 depict various systems that favour infiltration of runoff, in addition to having a structural function in building. The summary of infiltration systems used for source control is set out in Table 5.7.

Figure 5.19: Photo (left) paths with grass alongside to increase infiltration;
Photo (right) pervious paving perforated blocks for car parking.

Storage

Storage can take place on roofs, in small residential reservoirs, car parks, sports fields, etc. Below, we present the main characteristics of some storage systems.

Figure 5.20: The photo (left) shows a street that allows part of the runoff to infiltrate into grass alongside (Mimicking, 2004).
The photo (right) depicts an infiltration area in a flower bed (Weinstein, 2003).

Table 5.7: Summary of Infiltration devices

System	Characteristics	Advantages	Disadvantages
Infiltration surfaces and trenches with drainage	Grass, lawn and any other material that allows infiltration	Allow water infiltration and decrease overland flow	Solid material carried to infiltration area can reduce infiltration capacity
Infiltration surfaces and trenches without drainage	Grass, lawn and any other material that allows infiltration	Allow water infiltration and decrease overland flow	Accumulation of surface water may impede traffic
Pervious paving	Concrete, asphalt and perforated blocks	Reduces water surface and increases infiltration	Not to be used for streets with heavy traffic

Roofs: Rooftop storage involves some difficulties, namely maintenance and reinforcement of structures. Given the characteristics of some climates and the type of roofing materials usually used, it would be difficult to apply this kind of control.

Urban housing developments: Storage in a housing development can be used to attenuate runoff in combination with other uses, such as water supply, lawn irrigation and washing of surfaces or vehicles. Figure 5.21 shows a reservoir of this type. In areas with a low water distribution capacity, precipitation on roofs runs directly into an underground well and is then chlorinated for domestic use. Water collected on rooftops of sports centres can be collected directly for use in cleaning. An area of $120m^2$, with annual precipitation of 1500mm, can produce $360m^3$, or nearly $15m^3$ a month, which is more than enough to supply a household. Obviously, the more water is kept in the reservoir, the lower its attenuation capacity.

There are various possible configurations for reservoir lay-out into urban housing developments and projects, as shown in Figure 5.21 and 5.22. The volume is generally estimated on the basis of the limits set by the public authorities for input to the storm drains. In Porto Alegre the limit is 20.8 l/(s.ha), which gives a reservoir size based on the following equation:

$$V = 4.15.AI.A$$

Where AI is the impervious area as a percentage; A is the area of the housing development or project in hectares and V is the required volume in m^3. For a building project of 1,000m^2, with a total impervious area of 80%, the required volume is 33m^3. Using a depth of 1.5m, an area of 22 m^2 would be required.

5.4.2 Control measures in minor and major drainage

In minor drainage, the conventional means of controlling runoff is to drain the urbanised area through storm drains to main storm drainage or to an urban river. This type of solution has the effect of transferring the increase in surface runoff downstream at a higher velocity, as the runoff takes less time to move than in pre-existing conditions. This causes floods in the major drainage. Impervious surfaces and canalisation increase the peak flow and overland flow. To prevent this increase in flow from being transferred to downstream, the hydrograph peak is attenuated using retention systems such as: tanks, lakes, open and covered reservoirs. The purpose of retention is to reduce the flow peak to previous conditions.

This type of control has the following advantages and disadvantages: lower cost as compared to conduits; lower operating and maintenance costs; easy administration of construction; difficulty in finding suitable sites; the cost of purchasing areas; and the population is opposed to large reservoirs if they are not integrated with the urban environment.

This control has been used where municipal authorities impose restrictions on the increase of peak flow due to urban development, and it has accordingly been used in many cities in various countries. The usual criterion is that the peak flow of the area with urban development must not exceed the peak flow in the pre-existing conditions for a given return period.

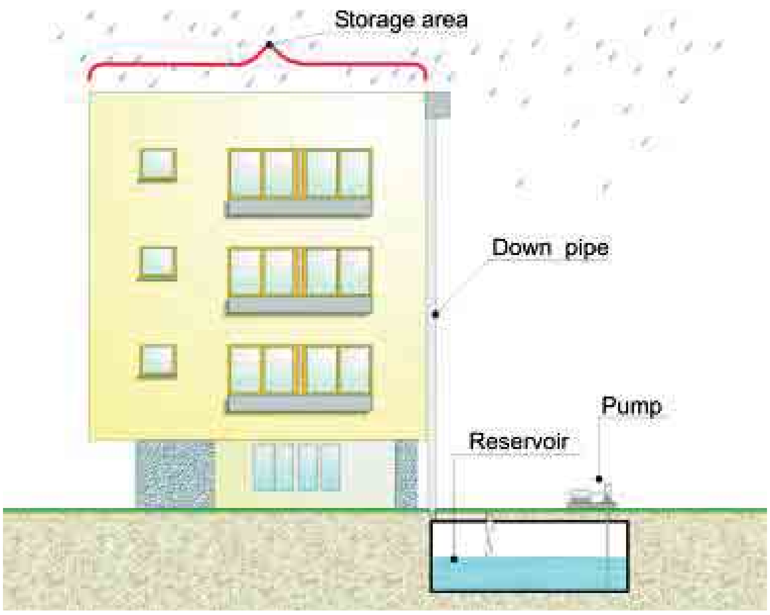

Figure 5.21: Reservoir in a building (Campana, 2004)

Figure 5.22 Storage in a parking lot of a shopping centre (left) and in a condominium (right)

Characteristics and functions of reservoirs

Urban reservoirs can be used for:

Controlling peak flow: This is the typical application for controlling the effects of flooding in urban areas. The reservoir is used to attenuate the upstream peak, reducing the hydraulic section of the conduits and maintaining the flow inside the conveyance capacity.

Control of volume: This type of control is usually used when sewage and stormwater runoff are carried in combined conduits or when the water comes from an area liable to contamination. As a treatment plant has a limited capacity, the volume for treatment must be stored. The reservoir is also used for the deposition of sediments and the treatment of water quality, keeping its volume in the reservoir for longer. The detention time, which is the difference between the centre of gravity of the inlet and outlet hydrographs, is one of the indicators of the reservoir's treatment capacity.

Control of solid material: When a significant quantity of sediment is produced, a detention basin can retain part of the sediment so that it can be removed from the drainage system.

Reservoir types

The reservoirs can be designed to be of such a size that they always hold a certain amount of water, known as a **retention pond**, or so that they dry out after use, during heavy rainfall, and then be used for other purposes. This type is known as a **detention** pond (Figure 5.23).

Retention ponds that keep a certain quantity of water in them are designed to stop undesirable vegetation from growing at the bottom, dampening the peak flow and reducing downstream pollution. Their use as an integral part of parks can create a pleasant leisure area. The advantage of this type of dry system is that it can be used for other purposes. One common practice is to specify a wet area to be large enough to absorb frequent flooding, for example two years' flood water and to design the overflow area with landscaping and sports fields to handle flooding above the correspondent to the selected risk. When this occurs, it will only be necessary to clean up the area that flooded, without further damage upstream or downstream. The main disadvantages of a retention pond are the need for a larger reservoir volume and to control water quality. Figure 5.23 is a schematic representation of dry and wet ponds. Dry reservoirs are most commonly used in many countries. When designed for flood control, they empty rapidly in up to six hours and are not very effective at removing pollutants. Increasing water detention closer to 24 hours can improve pollutant removal. This type of system retains a substantial proportion of solid material. Since most of the pollution comes at the start of the rain, a common practice is to retain the first part of the rainfall in detention for 24 hours in order to decrease the downstream contamination. Some regulation suggests that if the overland flow of two years' flood water remains in detention for 24 hours, 80% of solids is removed.

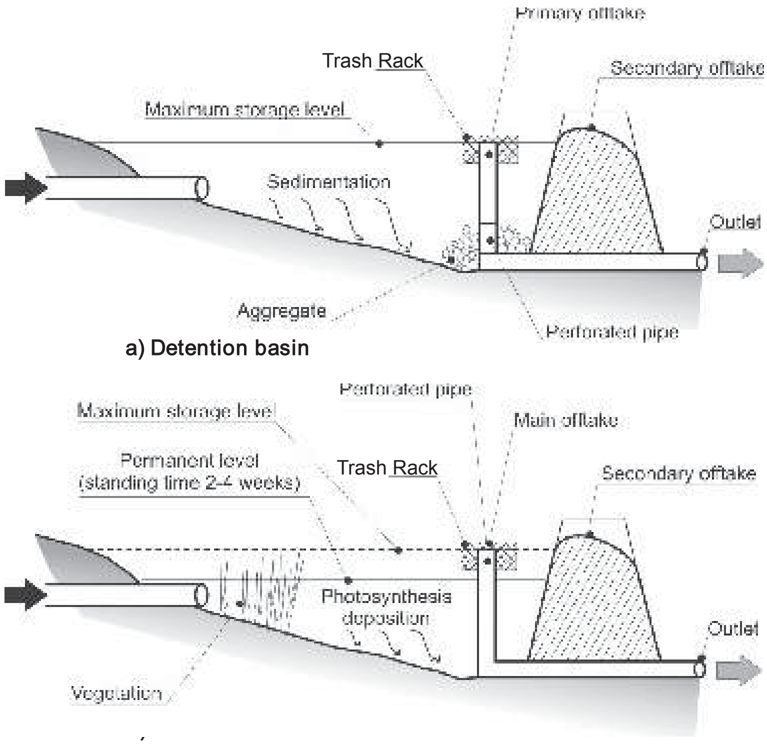

Figure 5.23: Detention and Retention ponds (Maidment,1993)

When drainage uses the system's extra capacity for attenuation, and is connected directly to the drainage system, this is known as an **in-line system** (Figure 5.24). When runoff above a certain flow level is transferred to the attenuation area and receives only the excess from the drainage, it is called **off-line** (Figure 5.25). When in the stormwater network, where there are a large number of clandestine connections or sewers with a great amount of pollution, the use of in-line detention is not recommended.

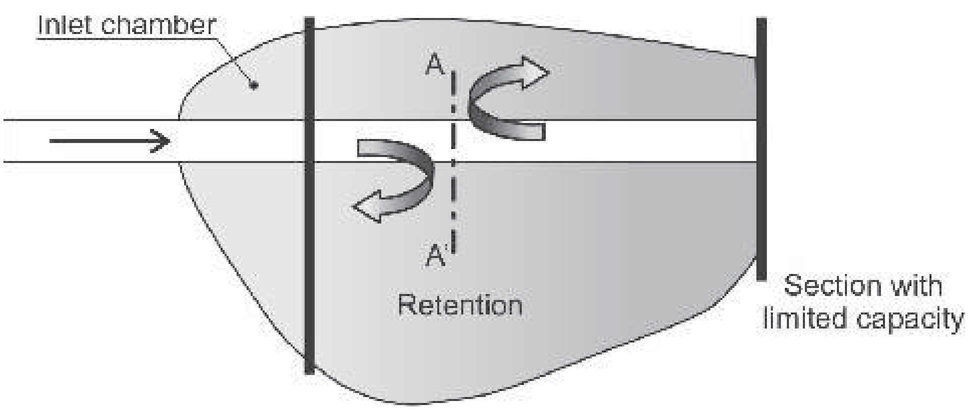

Figure 5.24: Detention pond off-line

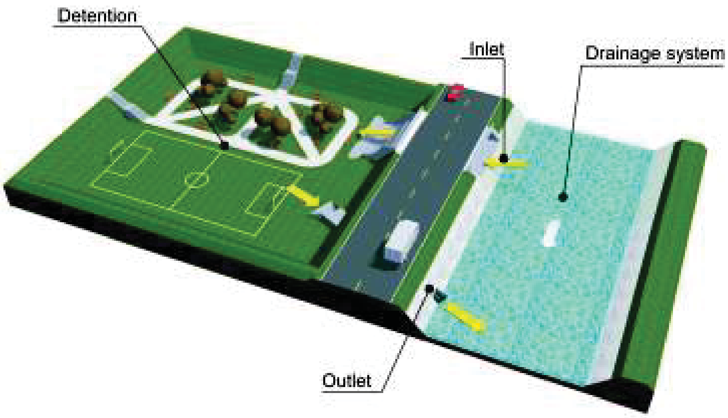

Figure 5.25: Detention pond off-line

The detention can be natural, excavated or concrete bottom. Concrete reservoirs are more expensive, but they can have vertical walls and hence have a higher volume, which is useful for high cost space. Detention ponds may be open or closed. The former usually costs less and they are easier to maintain. The second type is more expensive (about 4 to 7 times more) and they are more difficult to maintain. It is used when the space above it is needed for other uses or because there is pressure from the community nearby regarding open detention. Communities used to fear that the maintenance would not be efficient and that their real state would depreciate.

Off-line detention ponds can operate automatically by gravity (Figure 5.25) or by pumping, when more volume is required for a given space (Figure 5.26). The difference is that, in the first case the flow floods the detention pond and flows back by gravity. In the second scenario the increased volume is below the stormwater network and this volume needs to be pumped back after the flood.

Figure 5.26: Detention pond with pumping

ASCE (1985) mentions that the most successful detention installations were of the type that also had other uses such as leisure, as they are used by the community for recreation on a daily basis. The detention pond should therefore be integrated into the planning of the use of the area.

Location

Usually, about 1 to 2% of the basin area is required for dampening the peak flow of about ten years' flood water to the existing flow capacity of the drainage. The identification of the best area for a detention pond is based on the following factors:

- In highly urbanised areas it depends on the available space and the ability to attenuate the flow. If the available space is upstream, the effect will be reduced by draining small basins. The cost is smaller for areas near the main drainage and increases when the available spaces are far from the main drainage, which requires new pipes to transfer the flow during floods;

- In areas to be developed, the reservoir should be situated on an area of land near the stormwater and where it usually floods during wet seasons, taking advantage of natural depressions or existing parks. A good indicator for location is the natural areas where small lakes or ponds form before development.

5.4.3 Compatibility of systems – sewage effluent

In urban water systems there are: (i) combined sewer systems: when sewage and stormwater flow in the same pipe network, or when the amount of sewage in the drainage is very high; and (ii) separate systems: when there is a network for sewage (a sewer network) and another for stormwater.

Combined: This is the scenario where the city did not construct a sewer network and the sewage flows through the same pipe system of the stormwater. It is found in old cities and in developing countries' cities that did not invest in the sewer network, or there are two networks but the connection of sewer pipes in the stormwater is still high. The use of off-line detention until the connection problem or another sewer network is developed is recommended in this situation. The flow and sewage flow through the pipes to downstream and when the flow exceeds the design capacity during flooding, the excess is discharged to a detention pond. The disadvantage is the unpleasant odours and the risk of proliferation diseases. In the environment compliance of combined systems the flow and waste of the dry season are collected and sent to the sewage treatment plant.

Separate: This system has independent sewage and drainage networks of pipes. In-line detention systems are used that control the solid residue and manage the pollutant load. The advantages are the proper management of urban detention and retention basins with a longer holding time, which allows water quality to be controlled, prevents contaminated water in flooding exceeding the design level, prevents odours in the dry season and prevents the collapse of drainage systems through corrosion. The disadvantage is the high initial cost for investing in two sewer networks (Figure 5.27).

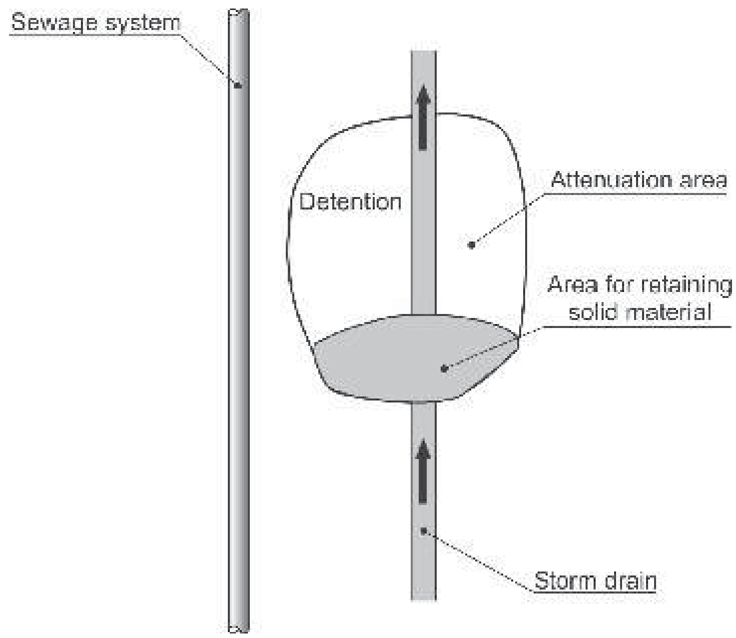

Figure 5.27: Separate system

Transition: When the city has an extensive storm drainage system but a small sewage system, it may be costly to upgrade from a combined system to a separator. To spread the costs over time, it is possible to adopt a strategy of a combined major-drainage system (Figure 5.28). Later, the project may implement a sewage system using secondary systems, eventually covering the whole city. When the separator system covers the city, the connections may be removed.

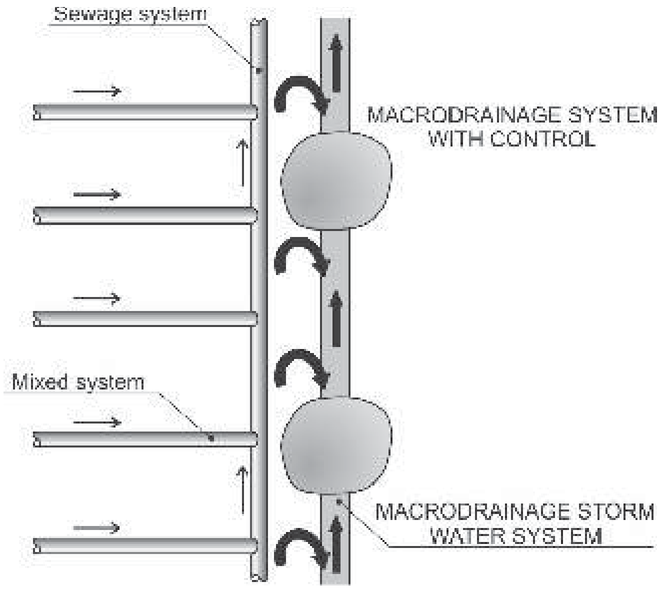

Figure 5.28: Transition system

5.4.4 Planning the Basin and major drainage

As has been presented before in this chapter, most of the management of the basins has been through increasing the flow capacity of every reach that is under flow capacity (flooding). But it has demonstrated that it transfers the flow increase to downstream and the problem is getting greater, since the canal needs more and more capacity, which is economically unsustainable.

The solution for control in an urban basin is a combination of distributed measures, but especially the combination of an increase in flow capacity or dampening peak flow by storage (detention or retention pond). The cost of flood management in a basin varies from about US$300,000/km^2 to US$7-million/km^2. The lowest cost is for the use of only a detention pond without land costs (public areas) near the drainages. The high cost is for the use of conduits underground with high urbanisation.

Some important principles in planning the storage in flood management are: (i) the storage has to be integrated to the urban landscape in order to be accepted as an asset by the community; (ii) maintenance is important to keep the storage as an asset. Population could be against this type of solution after bad services; (iii) reserving the areas near to the natural drainage and former flood areas for storage; and (iv) the reservation of area is based on 1 to 2% of the basin area (Table 5.8).

In reality there are two major scenarios: **developed urban basin area and basin to be developed**. For the developed basin, there is a need to determine the critical points and look for suitable areas for attenuation runoff, rather than transferring it downstream. The ideal combination would be to have the lowest cost reservoirs and to increase runoff in a way that is best suited to the urban area, i.e. low cost and environmentally appropriate.

Table 5.8: Indicators for urban reservoirs*

Indicator	Interval
Volume for detention pond for a ten-year return period (m³/ha)	100 to 450
Mean cost for open detention without lad cost (US$/m³)	25 to 60
Mean cost for closed detention without land cost (US$/m³)	100 to 350
Basin area used from the basin (%)	0,5 to 2
Cost of Works for flood control (millions of US$/km²)	0.3 to 8

* These indicators can change because of rainfall intensity for the same risk and are based on the cost of projects in Brazil.

In a basin to be developed, that is not completely urbanised and flooding occurs in the urbanised reaches, some areas are not settled because of the frequent flooding. When the basin reaches an advanced stage of development, expensive structural measures tend to predominate. However, these costs can be minimised by increasing the storage capacity in the natural basin, endeavouring to recover as far as possible the natural storage capacity by exploiting all the possible areas. Figure 5.29 shows that if you reserve areas, taking into account they constitute about 1-2% of the upstream basin, they can be integrated in parks and there is no transfer of impacts downstream.

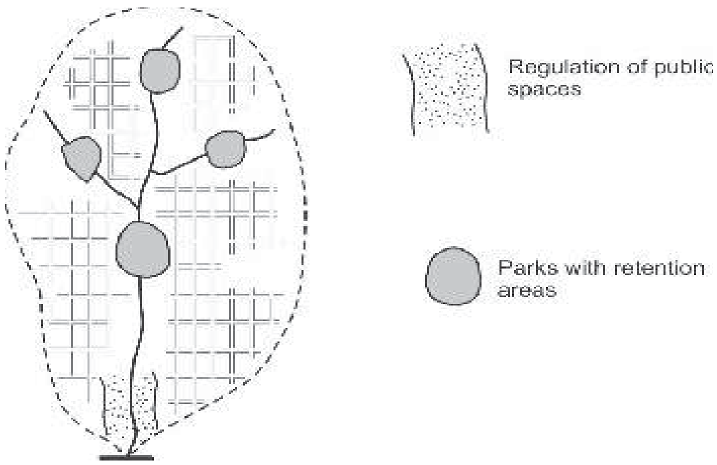

Figure 5.29: Distribution of storage for a planned urban basin

QUESTIONS FOR DISCUSSIONS

1. Why does peak flow increase with urbanisation? Discuss this effect in your city.
2. The management tends to increase the problem. Why? How has this problem been managed in your city?
3. Analyse the types of measures for controlling runoff at source for urban drainage, and describe their uses, advantages and disadvantages.
4. What is porous paving used for in a drainage project? What are its advantages and disadvantages?
5. What is the difference between detention and retention in controlling flooding that results from the urbanisation process? What impacts do these systems have on flooding?
6. What types of flooding are there and what are their respective impacts?
7. With reference to the previous question, when are impacts transferred?
8. What are the main strategies for managing urban drainage for existing cities and for future development?

5

ADDITIONAL READING

www.stormh2o.com
http://images.google.com.br/images?q=stormwater+photos&hl=pt-BR&rlz=1B3GGGL_pt-BRBR279JP295&um=1&ie=UTF-8&sa=X&oi=images&ct=title
http://www.fishkillridge.org/scrapbook/2004PipeDiversion.htm
http://www.georgiastormwater.com/
http://www.michigan.gov/stormwatermgt

5

6. INTEGRATED URBAN WATER MANAGEMENT

Goal and objective

At the end of this module the participant will be able to analyse the interconnection between urban water components and management alternatives at city and basin levels; present the interface of the urban water components and the impact of their management; and to describe potential institutional arrangements of the basin IWRM and the Urban Water Management.

6.1 Background

Integrated water management, in the sense of interdisciplinary and inter-sectorial integration of the components of urban water, is a necessary approach for achieving results in line with sustainable urban development.

In recent decades, urban development has changed most of the concepts used in **water infrastructure in cities**. The approach for developing these topics within management has been based on imparting knowledge in each discipline without an integrating solution.

The urban planning and other areas of infrastructure are developed without integration. Following this approach, water is drawn from the upstream source (hopefully not contaminated) and discharged untreated downstream; drainage is designed to remove water as quickly as possible from any place, transferring the surplus downstream. The solid waste is deposited in a remote place so as to not disturb the city dwellers. This set of local solutions may be justified within a local project with all the equations devised over the years by hydraulic, hydrology and sanitation engineers to solve a “given problem”.

What is the consequence of these projects to society? Unfortunately this approach has been quite disastrous. To use medicine as an analogy, it is as if a number of specialists were prescribing medication for different symptoms in one person without taking into account the combined side effects suffered by the human body.

Today’s problems are reflected in public health, frequent flooding and the loss of a rich and diversified environment in many regions. With the transformation of rural environments into urban environments, this problem is getting worse, and the longer the situation lasts, the greater the legacy of incompetence and liability of actual managers will be for future generations. What is wrong and what can be done to remedy the situation?

- **Urban development** must not take place without considering the sustainability of the place where people are settling. To achieve this, rules for land use and settlement must be defined that preserve the natural conditions and enable the system to handle transport water supplies, sanitation systems, effluent treatment, urban drainage, and garbage collection, cleaning and disposal;
- **The water supply** must be provided from reliable uncontaminated sources;
- Excess sewage must be treated so that the water used is not contaminated and the water system can recover;
- Management of urban drainage must mitigate the effect of impervious areas increasing infiltration and storage to avoid flow, volume and contaminant load increase from stormwater runoff, which could result in floods and impacts on the environment;

- **Solid waste** must be recycled to encourage sustainable financial exploitation of this resource, and the disposal of the remaining material must be minimised.

These goals require integral planning, willingness from decision makers and financial return for long-term development.

6.2 Integrated aspects

The main goals of Integrated Urban Water Management are human and environment sustainability. Urban water management usually has two main levels:

- **Municipal level**, which is the area of the urban development in many small urban basins; and
- **Basin Level**, in which the city takes water and sends back its waste, usually a major-size basin where the city development is an additional user.

Within the city, the management is at municipal jurisdiction, but at basin level, a State/Province or National Management (depending of the country) or another entity through a Basin Authority is required. The connection of these levels of institutional management is one of the key elements in the IWRM and IUWM developments in a city. Table 6.1 presents the common scenario of integration of Basin and Municipal Water Planning in a federal country.

Table 6.1: Integration of Basin and Urban Waters Management

Space	Administration level	Management	Instrument	Characteristics
Basin[1]	Nation or State	Basin Committee and Agency	Basin Water Plan	Sustainable Management of quantity and quality of the rivers in the basin, avoiding impact transferences
County/ municipality[2]	County/ municipality or Metropolitan Area	County/ municipality	Integrated Urban Water Plan	Sustainable development of urban water facilities within the city and avoiding transference of downstream impacts in the river system base on the basin regulations

1 – Usually large basins (>1000 km^2);
2 – Area covered by the county/municipality and its small major drainage basins (<50 km^2).

6

6.3 IWRM at the basin

At the basin level the planning is developed by taking into account all water uses and environment impacts related to social and economic development. The effect of each city in the basin is assessed and an agreement on managing the effects in the basin management is developed.

The main effects that the cities could export to the basin level are: (a) water consumption and reduction of water volume; (b) a water quality impact due to urban development; and (c) an increase in flood conditions due to urbanisation.

Planning at basin level should develop boundary conditions to mitigate these impacts with other uses and effects among cities and water uses in the basin.

The main difficulties usually found are:

- The lack of institutional capacity and integration of national and local levels (municipalities), such as a national basin committee and Water Supply and Sanitation (WSS) at municipal level. Water Plans and Basin Committees have to be developed in connection with the Urban Water Management. It has been a main problem in many countries due to the difference in the level of government (municipal, state and federal) management and also the difference of background of the professionals involved at basin level and on WSS management; and
- The lack of long-term permanent investments and commitment on strategic planning in order to meet the goals: The process of developing basin committees and many of the instruments of IWRM are important, but it requires measurable output.

6.4 IUWM at municipal level

Overlapping interaction of urban facilities: There is a strong lack of knowledge and development of Integrated Urban Waters Management. The urban facilities are developed by fragmented planning where urban planning (urbanisation) and urban waters are not connected: the water supply basin is polluted by the lack of waste treatment, decreasing the existing safe water; and a network of sewers without house connections, impervious areas and canals increases the floods and pollution in urban drainage, among others.

Urban planning must consider aspects relating to water, land use and the definition of the trends of the city's expansion vectors. The water-related aspects are closely interrelated. Water supply is obtained from sources that may be contaminated by sewage, rainwater or garbage. The solution for controlling stormwater runoff depends on the existence of sewage collection; a treatment system; and the removal of any connections between the systems.

Integrated Urban Water Management requires the development, the planning and management of components of the urban water services: water and sanitation (U & S), urban drainage (UD) and total solids (TS) together with Urban Planning, Environment and other facilities. These services have many overlapping interactions together with urban development. In most of the countries, it has been developed by different institutions, which results in difficulties for managing the common issues. The main overlapping issues among the systems are (Figure 6.1):

- **Water supply:** (a) Waste and stormwater sewers pollute the water supply basin and groundwater; (b) Garbage landfill may pollute the groundwater and down-stream rivers; (c) Erosion caused by floods may affect water supply and sanitation facilities;

- **Waste and urban drainage:** (a) Combined network systems for waste and rain stormwater require a common design; (b) In separate systems, there are many management difficulties linking systems; and

- **Urban, Drainage, total solids and waste:** (a) Urban drainage network efficiency is independent of the street cleaning and solids collecting services as presented above; and (b) Drainage and soil erosion control require common strategies.

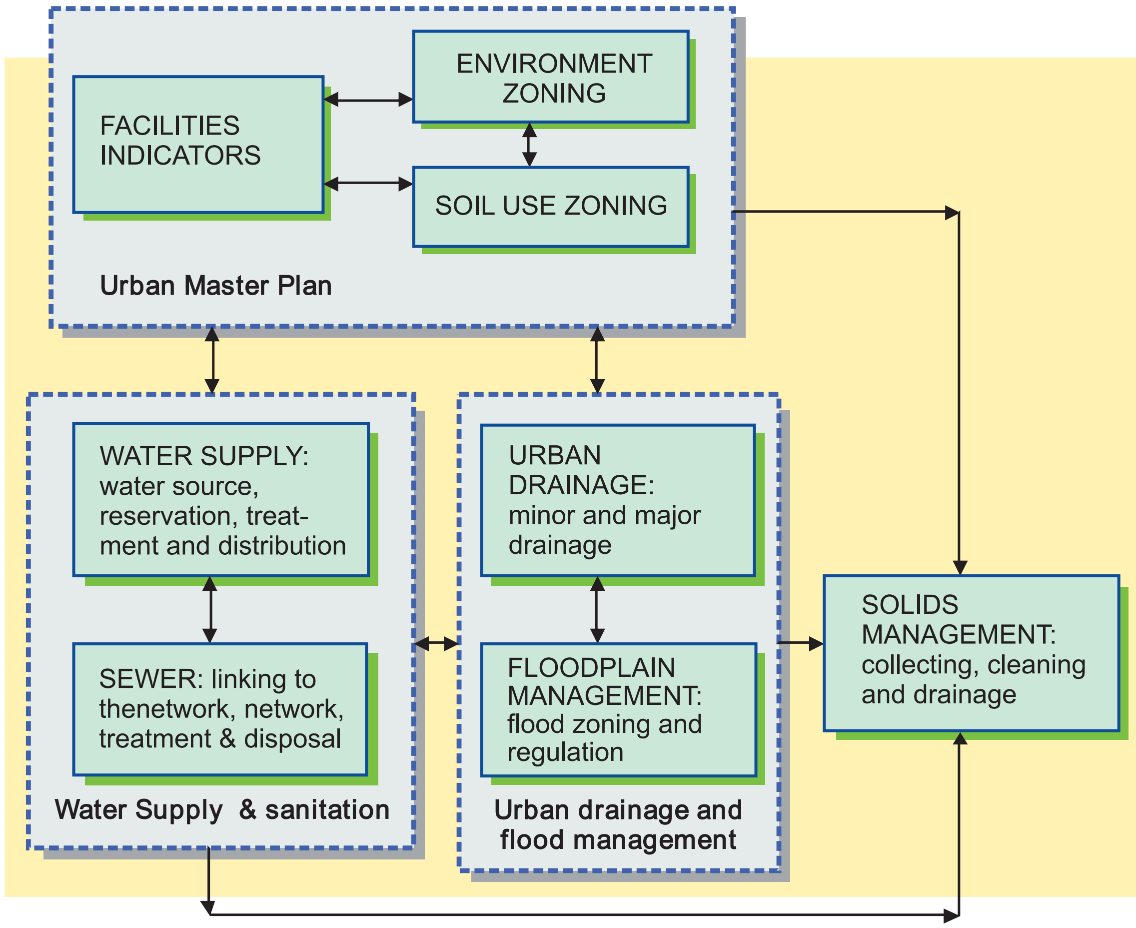

Figure 6.1: Interconnection of Urban Water Facilities

The institutional management of these facilities is usually the main difficulty, since: (a) there are many institutions that cover these services without integrated management; (b) some of the services are not measurable and the public perception is weak with low feasibility for cost recovery of services[16], such as for urban drainage and solids management; (c) there is a lack of law enforcement and a regulatory agency. In this scenario there are not indicators for the services, and the price is usually high with low efficiency.

Successful management has been obtained when only one institution manages all these services and the population has a better perception of the overall services together with a regulatory agency that enforces the public rights and interests.

Implementation of Integrated Urban Water Management is developed in each scenario through the Integrated Urban Water Plan (IUWP). This Plan could be developed by each municipal water service by using overlapping in the reference terms in order to have the integrated aspects or by an Integrated Urban Water Plan. The former is based on keeping a fragment strategy for management, which is the usual scenario. The last is based on the modern concept of integrated management of urban water facilities, but it requires transformation in the municipal management. Figure 6.2 presents the Overall Framework at city level, showing the integration of the Plans and the Management framework; while Figure 6.3 presents the framework of the IUWP.

[16] Cost recovery is usually done by municipal taxes or tariffs.

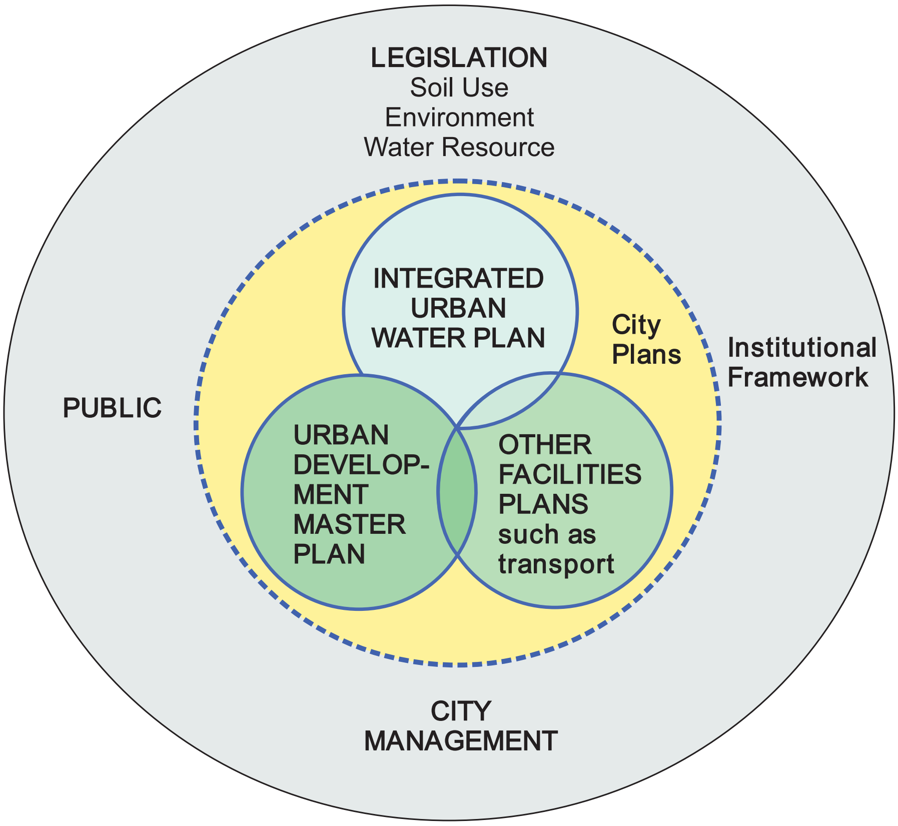

Figure 6.2: Municipal Management Framework

The main targets in developing a sound strategy for Integrated Urban Water Management are (Figure 6.3):

- Sustainable urban development: developing new urban development standards, taking into account the sustainability on water issues: (i) limits for densification and impervious areas; (ii) reserving areas for parks and flood management; (iii) restrictions and economic incentives for conservation of urban source basins;
- Protecting the water supply sources: regulating the occupation of the water supply basin; controlling the load of water supply basin; and improving its water quality.
- Improving water supply distribution: developing a programme of investment to increase the water supply network and improve the water supply quality;
- Developing a system of waste treatment: investment in the collection and treatment system for all urban areas;
- Flood Control Management: developing regulations for new development, controlling the future increase of floods; developing a flood management plan for each basin;
- Total Solids Management: developing sound services for total solids to decrease the amount of solids in the drainage; and
- Water and environment conservation: controlling stormwater pollution, and recovery of a selected environment.

These targets have to be developed by integrated and interrelated aspects within an area, which may cover more than one basin. Every component of the plan requires specific goals and strategies.

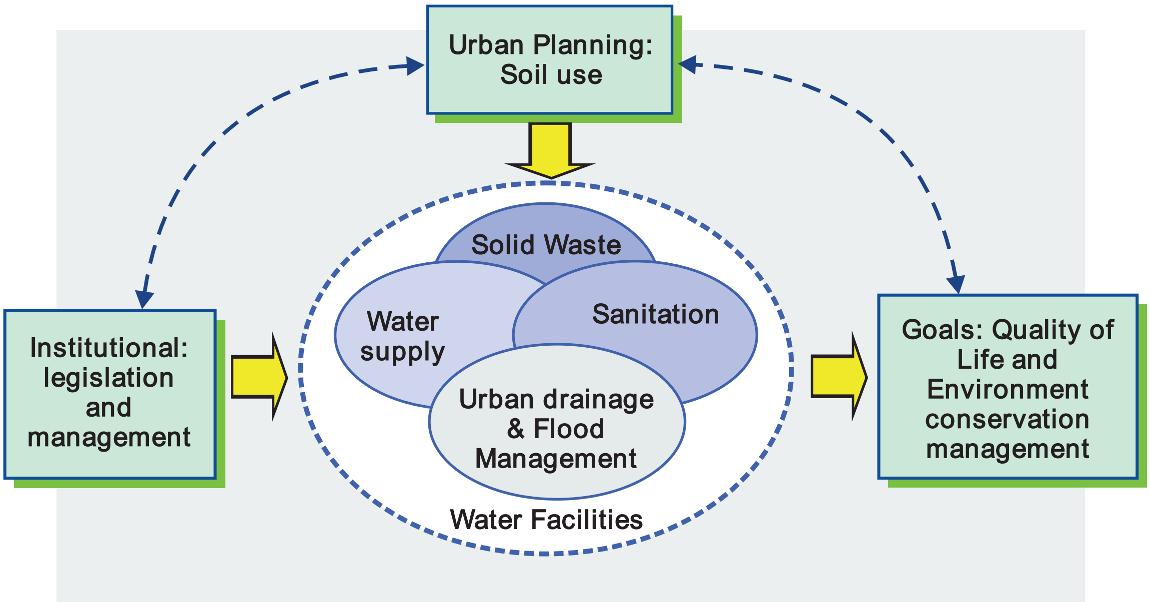

Figure 6.3: Integrated Urban Water Management

QUESTIONS FOR DISCUSSIONS

1. Explain how flood management is institutionally organised in your country.
2. How can water resources management in a country control a city that is transferring flood and water quality impacts downstream?
3. Describe the main aspects that are the interface of the urban water services in a city.
4. What should be the main goals of Integrated Urban Water Management?

ADDITIONAL READING AND SOME SITES

http://www.owue.water.ca.gov/urbanplan/index.cfm
http://www.clearwater.asn.au/
http://water.usgs.gov/nrp/IHP/URBAN%20WATER%20MGT%20BROC.pdfwater.usgs.gov /nrp/ IHP/URBAN%20WATER%20MGT%20BROC.pdf

7. INTEGRATED URBAN FLOOD MANAGEMENT PLAN

Goals and objective

The objective is to teach the student the main components of the urban flood management plan, in order that he would be able to manage this type of a plan for a city. This Plan allows the implementation of the measures presented in Chapters 4 and 5.

7.1 Components of the integrated urban Flood Management Plan

A proper Integrated Urban Flood Management Plan (IUFMP) has four major sections: **(i) policies**: definitions of objectives, principles, goals and scenarios for the studies in the plan; **(ii) assessment** of existing conditions related to floods. It evaluates which are the floods along the cities for the scenarios and presents the follow-up recommendations; **(iii) development of the measures** (non-structural and structural) to reduce the impacts and reach the goals; and (iv) delivering the outputs and outcomes for the city (Figure 7.1).

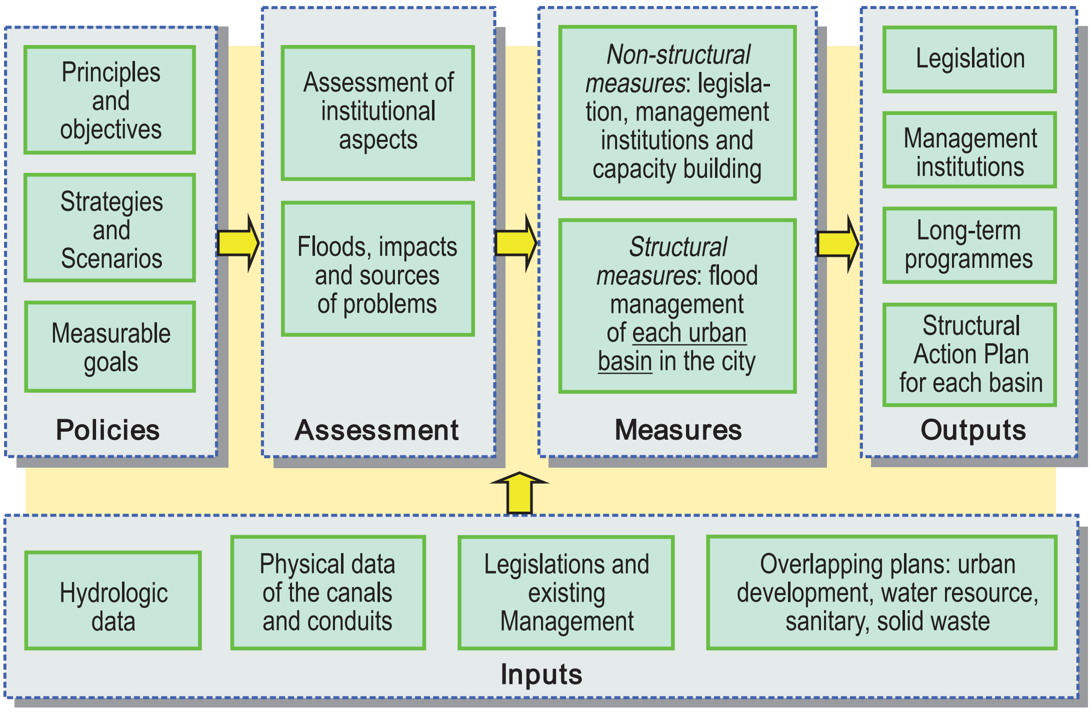

Figure 7.1: Components of an Integrated Urban Flood Management Plan
(adapted from Tucci, 2001)

7.2 Policies

The main policies of flood management are principles, objectives, goals, strategies and scenarios of urban and risk design.

Principles: The **main flood management principles are**: (a) flood management has to take into account the basin; (b) floods or water quality impacts should not be transferred downstream; (c) the natural behaviour of the hydrologic cycle should be preserved by recovering the infiltration, erosion protection and water conservation; (d) any new development has to maintain the flow below its natural value; (e) non-structural measures should receive priority; (f) flood management structural measures and its operation should have their cost recovery from the upstream basin population.

Objective and goals: The **objective of flood management** is to minimise the impacts of rainwater distribution in time and space on the population and on the environment. The main goals are: (a) to eliminate urban drainage floods for an urban development scenario and risk selected, such as the 2030 urban scenario, together with ten year flood; (b) to minimise the flood impacts for lower risk; (c) to decrease the solid waste to a specific level; and (d) to improve the overland flow water quality.

Strategies: The strategies can be established in line with the preparation of the plan and environmental control. The strategies related to the plan preparation are: (i) **for unsettled areas**: devising non-structural measures relating to regulations on urban drainage and settlement of risk area, endeavouring to contain the impacts of future developments. These measures are designed to transfer the cost of controlling hydrological changes due to urbanisation to whoever makes those changes; (ii) **for settled areas**: devising specific studies for urban macro-basins with the aim of planning the measures necessary to control the impacts within those basins, without them transferring the existing impacts downstream. This planning gives priority to using temporary storage in detention basins.

As regards environmental management, covering the quality of stormwater runoff, solid material in transit and contamination of groundwater, the strategies are as follows: (i) For areas having no sewage systems or a large number of sewage connections to the storm drains, control measures give priority to quantitative control. This type of measure uses detention only for the volume exceeding the current drainage capacity, so preventing runoff in dry seasons, and the volume of the first part of the hydrograph contaminating the detention basins. These storage areas are kept dry during the year and are used only for events with a return time exceeding two years. In some cases they have to be used for lower risks owing to the low capacity of the existing system; (ii) When the sewage system is implemented, the plan can move into a second stage in which the runoff system is modified together with the detention basins so that they can also help to control stormwater quality; (iii) to control contamination of aquifers and control solid material, medium-term programmes will have to be set up with the goal of reducing such contamination by means of measures distributed throughout the city.

Scenarios: The scenarios for devising the plan must take into account the following aspects: (a) urban development scenarios; and (b) risk of the flood for structural measures. The urban development scenarios are: (i) **Present** – present urbanisation conditions, obtained by means of population estimates and satellite images; (ii) **Present scenario + Urban Plan**: This scenario involves the present settlement for the parts of the basin where the plan's forecasts were exceeded, together with the plan's guidelines for the areas in which the plan was not exceeded; and (iii) **maximum settlement**: This scenario represents the situation that occurs without disciplined land use.The second scenario represents the most realistic situation, since it accepts development carried out outside the master urban plan and the guidelines of the plan for the parts being developed.

Regarding the control measures adopted in each scenario of the plan, the following should be taken into account: (a) The planning for the present scenario with non-structural measures presupposes that they come into effect on the date of the survey in the basin. This is not realistic, since some time will pass between the end of the studies and the approval of the ordinances; and (b) It is possible to adopt the future scenario as a higher level of action, as it presupposes that the regulation measures can be applied with some delay. When the regulation is approved the scope of the alternative will have to be reviewed at project level.

The return period can be calculated by economic assessment such as benefit – cost analysis as described in Chapter 4. The risk in major drainage usually ranges between 10 and 25 years, and in major urban rivers it can be 50 years. Often, the ten years' return time is chosen since a longer return period is not economically feasible. In urban drainage the cost of high-frequency floods is usually greater and the cost to control low frequency (high return period) is very high and has less economic benefit.

7.3 Assessment

An assessment strategy is developed to find the conditions of the following: (a) data for the plan: hydrologic, physical, institutional, etc. The key information is related to the conduits and canal sections and topography levels and its real flow conditions; (b) identification of the place and frequency of floods in the basin or the area of planning; (c) assessment of institutional aspects, such as legislation and management in the city; (d) description of the main tendency related to urban development and impacts and priorities in development of the plan; and (e) selection of the alternatives for structural measures and identify the main non-structural issues. The city is sub-divided into sub-basins, and for each basin a Flood Management Plan is developed. The first phase of the basin plan is presented in item 7.4.2 and Figure 7.2.

7.4 Measures

7.4.1 Non-structural

Non-structural measures are developed to prevent future impacts, and possible actions are: (a) regulation: legislation in order to cope with the flow and solids increase and water quality loads that flow downstream; zoning of flood areas; and alert system, among others; (b) management: to improve management and maintenance; and (c) programmes: long-term activities along with and after the plan.

The **non-structural measures** are less capital-intensive but more difficult to implement due to political and institutional constraints. These are measures that could mitigate future impacts mainly by: (i) introducing a regulation that any new development should keep the natural flow conditions; (ii) reserving at least 5% of the basin area for detention or retention reservoir. The storage need for flood management is usually 1% of the basin area. This reservoir will receive solids, which will require maintenance; however, the advantage is that it will be concentrated in some places and will therefore be less costly, and keeping the conveyance[17] conditions to downstream reaches; (iii) introducing tax based on the impervious area of developments. It gives an incentive to the population to develop source control corrective measures to avoid this tax system; (iv) developing capacity building in the region by spreading awareness on the new flood management framework and technical capacity building to develop these strategies; and (v) developing conditionality through financing mechanisms through government authorities. The central government (state or federal) can develop a funding loan programme to fund the implementation of these measures. Usually, financial mechanisms are instrumental in achieving goals. For instance in a National Programme, the local governments are entitled to receive funds for an Action Plan for structural measures after they start to implement them. The central government can develop manuals and standard procedures to support these activities.

Legislation is used to prevent the negative impacts of developments. The main goals are: (i) water quality: reduction of the load from urban areas; (ii) river sections' protection against erosion; (iii) minimising the urban drainage flood by controlling the peak flow increase; and (iv) minimising the floodplain impacts by regulation of urban occupation in these areas (Table 7.1).

[17] Conveyance is the flow capacity of the rivers and canals.

Water quality: The regulation of water quality has the objective of treating stormwater and avoiding the pollution of aquatic systems. EPA (1993) identified that reducing suspended solids by 80%, lowers the general pollutant load. Regulation is based on retaining the first part of stormwater (two years' flood volume or the rain of 90%) in the detention or retention for 24 hours. Depending on local conditions, it could represent about 25 to 35 mm of the rainfall.

Table 7.1 Impacts and regulation of rain water

Effect	Impacts	Objective	Action
Water quality	Increase of the loads from urban surfaces	To reduce 80% of the load	Retaining the volume of water and suspended solids[1] in detention and retention ponds for 24 hours
Erosion	Erosion of river channel after flow and velocity increase	To reduce the flow energy	Dissipating the energy by storage and Works in the flow system
Urban drainage	Flood in the urban drainage due to flow increase and bad design	To keep the peak flow equal to or lower than that of pre-development	Using source control measures
Floodplain	Impacts due to extreme events in the floodplain	To minimise the flood impacts	Regulating the soil use occupation in floodplain areas

1 – The reduction of solids implies the reduction of other pollutants.

Erosion: It is controlled by: (a) the reduction of the velocity by infiltration; (b) the dissipation of energy, which increases the roughness of the channel; and (c) by storage reducing the velocity.

Urban drainage flood: The control is done by peak flow. Regulation keeps the peak flow of pre-development area for a selected risk. The developer should introduce source control measures in the developed area.

7.4.2 Structural Measure

An urban flood management plan is developed to find the best alternative economic and social alternative to mitigate floods in each basin of the city for a certain risk and scenario (Figure 7.2). The first phase is to prepare basic information for the plan, followed by a selection of the model and definitions of the basins in the city.

Assessment of floods in the city

For each basin the capacity of urban drainage, simulation and identification of floods are assessed for the selected scenarios together with water quality. The steps are:

- **Existing runoff capacity**: analysis of the conditions of runoff into the system, determining the runoff capacity in each defined discrete section of the drainage system in the watershed. In this phase, it is possible to identify the critical places due to the variability of the runoff capacity that generally occurs in urban areas. Sections with a lower runoff capacity downstream than upstream of the section are common.

- **Simulation of the present state of urbanisation and the future state** of the storm water runoff system for the present and future scenarios. In this simulation it is possible to identify the critical sections or reaches where the existing capacity is insufficient to handle the simulated flow.

Study of alternatives

The study of alternatives is the procedure developed to find the combination of works that eliminate the floods assessed with the minimum social and economic cost.
Every basin has as restriction the actual flow capacity to downstream. If for any engineering justification the flow should increase, the plan has to increase its study up to the section in which the flood capacity is not changed for the design risk and urban scenario. The main conditionality is to avoid the transference of impacts and problems through different basins and cities. Each watershed is a planning unit with its owns responsibilities and constraints in flood management (social, economic and environmental). The cost of development of the measures and operation and maintenance is distributed to the population of the basin, taking into account the impervious areas of each urban site. The strategy for a quantity action plan has to be followed by the water quality and total solids plans.

The steps of the study alternatives usually are (Figure 7.2):

- **Alternatives:** formulation of possible control measures by means of the following: (a) identification in the field of possible sites for detention basins; (b) evaluation of available volumes on the basis of water levels; and (c) sections that can be widened and associated constraints.

- **Assessment of feasible locals:** local analysis of cost and feasibility in terms of area use and interference with other utilities and real estate value.

- **Simulation of alternatives:** simulation of the selected alternatives, checking their effectiveness for the various scenarios. Various layouts are defined with the physical alterations that control existing flooding. The best economic solution is the one that costs the least to install, taking into account social aspects. This can be achieved by trial and error, varying certain combinations, or using an optimisation model in combination with a hydrological model.

- **Verification of design** with a hydrodynamic model that takes account of runoff under pressure. Check for conditions of higher risk than those adopted for the project. Assuming, for example, that a return time of ten years has been selected for the project, the plan must assess the impacts on the drainage for risks of more than ten years, proposing preventive measures for the various most critical places.

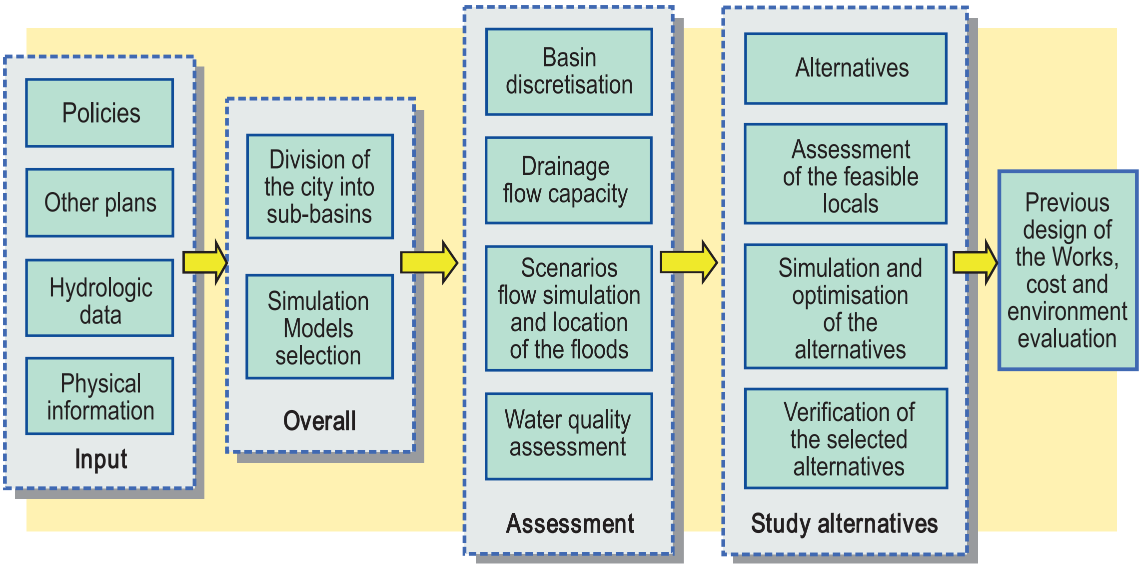

Figure 7.2: Framework of Flood urban plan for the basins in the city
(adapted from Tucci, 2007)

Characteristics of models

The models used in urban watersheds generally have two modules: (a) watershed module, which calculates from precipitation the resulting flow entering tunnels and canals; and (b) modules for rivers, canals, tunnels and reservoirs; transporting runoff in canals, tunnels and detention basins.
Generally, the algorithms used vary with the chosen level of detail for representing the watershed and its characteristics, and with the effects of runoff to be taken into account. Two types of models can be used:

(a) **The Hydrological model:** In this case, only the watershed module only is available and possibly the canal module. The watershed module comprises hydrological functions for determining runoff into the macro-drainage conduits by means of algorithms such as initial losses, infiltration and propagation of surface runoff. Examples of models that handle this module only are IPH-II (Tucci *et al.*, 1981) and SCS. The IPHS1 model (Tucci *et al*. 1989) includes watershed and canal algorithms.
In the canal module the flow is transported by storage equations such as Muskingum, or modified versions of it, such as Muskingum-Cunge. In detention basins, the Puls method is used. This type of model identifies the places where flooding occurs owing to flows exceeding the runoff capacity, or to high water, with the help of height-flow curves for the sections.

(b) **Hydrological-hydraulic model:** This type of model is generally used only in conditions of backwater and runoff under pressure, leading to flooding in various places that need specific solutions, or when there is a major interaction in the system. In this case, the tunnel module is represented by the dynamic equations (by Saint Venant) for open surfaces or runoff under pressure, adapted to the "Preissman slot" scheme. This model is also used for design checking and assessing the impact for risks exceeding the design values.

The simulation of alternatives is one of the main stages in devising an urban drainage master plan. The simulations to be carried out cover situations such as:

- Various phenomena, such as rainfall-flow transformations and runoff into canals;
- Runoff into canals may happen according to various regimes: free, under pressure, sub-critical, supercritical; and combinations of and transitions between them;
- Simulation of special structures such as detention basins or pump houses; and
- Various scenarios for the settlement of the watershed, relating to present and future urbanisation; or various watershed settlement patterns.

In addition to this variety of conditions there are other constraints:

- The need to represent interactions in the conduit system (e.g. backwater effects);
- It must be possible to estimate the parameters of the methods on the basis of physical characteristics of the watershed or drainage system, whether in the absence of adjustment data or for simulating future situations;
- Since the urban drainage master plans generally analyse the major-drainage only, detailed designs and major-drainage designs are carried out separately. The parameters and criteria adopted in these projects must therefore be consistent with those used in the plan. This implies using accessible methods and criteria that are readily spread, to the extent that may even be included in products such as drainage manuals;

- To be able to spread the criteria, parameters and methods used, it is best to avoid the use of specific software methodologies on which it is not easy to find references, examples or other types of support for the application (the methods should not be “software dependent”);
- There is a very high volume of simulations to be carried out. Assuming that the major-drainage piping is 1m in diameter upwards or equivalent, the average size of “basic watersheds” is generally 0.5 to 1km^2. The methods adopted must not involve excessive work, especially for determining the parameters.

When selecting the methodologies for simulating and estimating the parameters, it is essential to observe the applicability conditions for each of them, as much in general terms as for the specific conditions of use. Most common rainfall-flow simulation techniques, and most parameters for this transformation, have been developed for rural areas. The use of these techniques should be avoided, or they should be used when corrections can be introduced that take account of conditions in urban watersheds. For instance, the Kirpich formula for concentration time must be applied with the corrections applying to urbanisation (Tucci, 1993).

The use of parameters from the literature is not a validation, although it is often inevitable owing to a lack of data on rainfall and especially flow. An alternative would be to calibrate the models for a similar watershed and transpose the parameters. In this case and where some data is missing, qualitative calibration (Cunge, 1980) has to be used. This technique consists of comparing the results of the simulations with the location and apparent magnitude of the flooding occurring in the watershed, and other phenomena such as: runoff conditions into open canals, water overflowing out of inspection pits or storm drains, etc. This procedure is easier to use with low-recurrence storms – one to two years, since they are more readily remembered by the population. Another alternative is to use historic high-impact floods, which are better identified by the population, as long as rainfall records are available.

The information that the municipality has on problems caused by flooding is very valuable in connection with this; it can enable storm drainage professionals to make at least a reasonable mapping of the places and the frequency of flooding. Another interesting source of information is the transport authorities, as road traffic is affected by flooding.

7.5 Outputs

The outputs are the following:

(a) Flood management regulation, as described in the non-structural measures;
(b) The management proposal for the county/municipality administration structure, which includes, project evaluation, maintenance, law enforcement, and implementation of the plan;
(c) An Action Plan for each main basin which will define the sequence of works and implementation over time;
(d) **Programmes** – long-term activities identified in IUWP planned to complement the needs of the water facilities in the city over time, such as: monitoring hydrologic and water quality variables, urban occupation and soil use, impacts records and evaluations of the effects;

The programmes are additional medium-term and long-term studies recommended by the plan to help offset the deficiencies encountered while implementing the plan. They could cover the following aspects: Monitoring programme; Additional studies needed to improve the plan; Maintenance; Inspection; Education; and Development of manuals.

The programmes under the urban drainage development plan were designed to be medium-term and long-term activities required to improve the planning of urban drainage in every city.

7.6 Action Plan

Management

The Action Plan is the step of the implementation of the measures. It mainly depends on the municipality administration. In the development of Flood Management and Urban Drainage there is usually not an institution responsible for the activities. It is usually inside an organisation with many other objectives. In this scenario the services are not provided and flood prevention and mitigation are limited. In this scenario the first step is to implement the institution and identify its main objectives and goals. In the USA this type of organisation has been called the storm water utility (mainly for storm water). When it is related to flood plains it involves more municipalities and the State or National organisation develops actions for mitigation, and at municipal level it is included in the city zoning.

The organisation will need funds to develop its activities. It could be from:

- overall tax income of the municipality (It is usually a difficult task because the municipalities usually lack funds); or
- specific taxes for services (These scenarios are usually based on the population's willingness to pay for the service, which requires some political will. It has been based on a property's impervious area.)

Implementation of the Plan

The Implementation of the Plan starts with non-structural measures, since its costs are low but it requires more social, legal and political arrangement to prevent the impacts in dealing with floods. The Plan needs to be discussed with the community through a public participation process, since it has to address public concerns related to the issues. In the implementation process, there will be a new regulation for soil use and a restriction on new constructions related to stormwater and flood plains. Measures of this type have to be approved in the municipal legislation after a public discussion.

In addition, the organisation requires (a) management structure; (b) capacity building for the professional, which will enforce the legislation, maintenance and implementation of all measures; and (c) a financial mechanism for the structural measures in the city.

Structural Measures are implemented by basin, based on the following: (a) priority areas; (b) the flow conditions taken into account; and (c) financial conditions and funds in support of the works.

During the development of the Plan, issues that require long-term investments and solutions will be identified in the assessment. To deal with these issues, the Plan should present some programmes. Some of the usual programmes are: (a) implementing or updating the monitoring network to improve information on water quantity and quality; (b) recovery of degraded area by erosion or another environment impact; and (c) recovery of water quality of the urban aquifers.

QUESTIONS FOR DISCUSSIONS

1. How do you determine the feasibility of your city's Urban Flood Management Plan?
2. What do you think are the main difficulties to implement the non-structural measures?
3. After the Water Plan, one of the outcomes is the Urban Drainage Manual. What should be the contents of this type of manual? To whom should it be directed?
4. If the structural measures are developed per basin, what should be the main boundary limits of the plan of each basin?

7

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