From threat to opportunity

Spatial strategies integrating urban and water dynamics towards a sustainable redevelopment model for informal settlements in Mexico City’s periphery

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Cover image:

View of Valle de Chalco Municipality from the Xico Crater.
Source: Photo by author, 2010
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Final Project Report
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This thesis tells a story of today, of my city, and a plan for a desirable future for the Municipality of Valle de Chalco, an informal settlement affected by the metropolitan mismanagement of water resources.

Today uneven developments dominate in Mexico City Metropolitan Area, a result of a Neoliberal urbanization process. The current urban reality is the result of the unbalanced power relations between the city makers that prioritize the city core and the city dwellers that are pushed into urban poverty towards peripheral areas. Those areas are not perceived as part of the city and therefore experience water-related problems: flooding and lack of basic services such as safe water supply and sanitation. The Neoliberal policies in the urban process had emphasized the class polarization of the citizens. Valle de Chalco Solidaridad at the south-east periphery of the city is a fine example of a marginalized society in struggle.

Moreover, the rapid population growth has led human interventions to affect natural processes and contribute to the growing destruction of natural ecosystems. The story of the natural ecosystems coevolves with the story of the development of Mexico City’s settlement. The human story intersects with that of nature. Until today humans had gain at the expense of nature, which moves ineluctably towards ecological disequilibrium. Current risks of flooding and fresh water scarcity that Mexico City Metropolitan Area is facing will increase if the denial for interaction between the city and water continues. A city that once was an island in complete synergism with water needs to learn how to live with it again and create opportunities from the interaction with it. The desirable is a win-win situation in which harmony between humans and their natural environment is re-established.
... Looking Back to See Forward

MEXICO CITY 1500
Source: http://www.mexicomexico.org
Introduction

Mexico City Metropolitan Area [MCMA] is one of the world’s most populated cities, located in a large valley in south central Mexico. As the country’s capital it works as the economic, industrial, political and cultural centre. With a population exceeding twenty one million people nowadays, the metropolitan area is facing a critical situation in terms of spatial, social and environmental aspects.

The reduction, negation and elimination of nature’s presence throughout the development of the city have caused a complete ecological disequilibrium. The city’s uncontrolled urban growth and inappropriate planning framework has put at risk both its natural ecosystems and its inhabitants. While urban development threatens to destroy natural ecosystems, natural forces such as floods and landslides are threatening the inhabitants. Informal settlements located on peripheral areas of the city are the most vulnerable to water related risks.

Moreover, the expanding population as well as growing industrial and commercial activities have generated an increasing demand of services including water and sanitation. However, policies and responsible institutions for these services have been unable to cope with those needs in an equallitarian way leaving peripheral areas partially unattended.

The present urban and environmental challenges that Mexico City Metropolitan Area is facing call for urgent spatial strategies feasible from social, technical, economic and political perspectives for improving the water supply and wastewater management practices to balance the current unsustainable situation. My thesis project combines both challenges: the urban and the environmental, the informality and the water problematic which I consider are the most imperative ones for my city. It is my main interest to merge both challenges to deliver strategies and solutions that follow innovative concepts of water management in accordance with the needs and the social and economic context of my city.

The project starts by analysing the water and urban problematic at the metropolitan scale and then focus on a strategically chosen location that combines both issues. A deeper understanding of the implications that metropolitan mismanagement of water resources has had and the spatial and socioeconomic conditions of informality is done at local scale. By looking the problem at a local level the project seeks to deliver strategies that can be implemented not only at the chosen location but also in other areas of the city with similar conditions. In this way my project seeks to be evaluated and probably transferred to generate change at a metropolitan scale.

Through the [first] chapter I present first of all what motivates me to conduct this research. After that I present the problem my project tackles and the questions it explores. Finally I present the objectives of the project, its relevance and the methodology I followed during the process.

With the [second] chapter I present the concepts guiding my research and my proposals in order to make clear the eyes through which I looked into the problems and the approach I took for the planning strategies and design proposals. In the last part of this chapter my hypothesis is stated.

On the [third] chapter I introduce my city and the chosen location of my project. Looking back to what the city was and how it developed to what it is now through two analyses: a historical one in which the evolution of the city and the water story are combined and another one of the current situation in which water and urban issues become clear. During both analyses key references are done to the area of the chosen location to give an idea of the reasons to choose it as an exemplary case. The problem statement of my project comes from the conclusions from both analyses presented at the last part of this chapter.

On the [fourth] chapter I present the chosen location of my project: the Municipality of Valle de Chalco. This chapter will focus on the analysis of the chosen project location to make clear the problematic of the area related to water and informality. Furthermore the aim of the analysis phase is to reveal the problems and opportunities within the project area, which result into guidelines for the strategy and design phase. From the last part of this chapter, the diagnosis of the area is made, the latter gives the premises for the strategic plan, developed and presented in the [fifth] chapter. The Design Phase is also presented within this chapter, illustrating desirable physical interventions [strategic parts of the redevelopment plan].

At the last part of this thesis, chapter [six] my complete review paper ‘Living with Water and its Risks’ is attached. This paper complemented my research with literature review on integrating human and natural processes within urban ecosystems. Finally interviews conducted with inhabitants of Valle de Chalco municipality and government authorities are included. Those interviews gave me insight on the social and economic aspects of the people living in the area and also helped me figure out their most important spatial needs. A summary of those interviews can be found at the Appendix 7.2.
1.1. Motivation

The theme of water in Mexico City is becoming a priority in the agenda of politicians, professionals and academics in the country as it is being realized the water crisis the city is going into. Nevertheless spatial strategies and water management related policies have been inadequate or insufficient causing deterioration of the environment, health and socioeconomic conditions of the population.

My motivation for this graduation project is the crisis that my city is facing in terms of water availability and the sustainable management of this vital natural resource. The mismanagement and miss use of water in Mexico request for new spatial alternatives and design solutions that combine water management and urban planning. I believe there is a great potential to integrate water in spatial urban solutions in order to improve quality of life and attain sustainable development of informal settlements. As one can expect, the vast majority of the population in Mexico City’s periphery is poor and vulnerable to water problems. Therefore it is this most vulnerable population what motivates me to start from the local; to seek for a community where interventions according to their specific needs can be the key to change their living conditions. Moreover, I believe that local projects can trigger change in a bigger scale and can be used as example for other areas to follow.

1.2. Problem statement

This project takes as the problem field two major issues that have arisen throughout the development of Mexico City Metropolitan Area. On the one hand the lack of integration of environmental factors in the planning and decision making processes throughout the growth of the city has led to a serious hydrological imbalance at metropolitan scale. On the other, the failure of planning to manage urban growth has caused spatial fragmentation and social segregation of peripheral areas where the urban poor have been pushed towards. My graduation projects aims to give an alternative solution to the combination of those two problems, departing from the following statement:

‘In addition to their negative spatial characteristics and disadvantageous socioeconomic condition, peripheral informal settlements in MCMA are becoming more vulnerable to water related risks [flooding and scarcity] caused by the metropolitan water resources mismanagement.’

Valle de Chalco Municipality is chosen as an exemplary case because it represents a marginalized informal settlement where all the problems related to water [flooding risk from surface water, risk from open air sewage canals and water scarcity] become visible.
The key research questions the project addresses are:

**How can local strategic urban interventions based on sustainable water management improve spatial and living qualities of informal settlements in Mexico City’s periphery?**

To what extent those interventions can contribute towards the hydrological metropolitan regeneration?

Given the spatial and environmental problematic that informal settlements in the south-east periphery of the metropolitan area are facing, the objective of my graduation project is to develop a strategic plan for the Municipality of Valle de Chalco as an exemplary case of what can be done in terms of urban planning and water resources management for the redevelopment of these areas.

The main objective of the project can be summarized as follows:

To define an alternative spatial organization system for the redevelopment of informal settlements having water management as the structural element, towards building an integrative developing model potentially transferable into other informal settlements.

The proposed spatial strategies will aim to counteract the negative spatial characteristics of informal settlements, minimize water related risks, create new economic opportunities [locally] and contribute towards the hydrological metropolitan regeneration.
1.5. Relevance

a. Societal Relevance

The rational exploitation and preservation of water at national, regional and local levels have become imperative tasks for the future growth of MCMA. It is certain that water either promotes or restricts the economic growth and the social development of a region. Moreover, it can also affect the living and cultural patterns of a community (Paredes, 1997). The sustainable management of water resources integrated with spatial strategies can bring multiple opportunities for the redevelopment of marginalized communities. It is essential to put forward spatial alternatives that help restore the relation between ecological processes and urban development in order to create a sustainable urban environment. By integrating water dynamically in living spaces, threats to inhabitants can be diminished and opportunities for social and economic development may be created.

b. Scientific Relevance

There is considerable international scientific research on integrated approaches towards sustainable urban water planning and management for the cities of the future. Current problems related to urban growth and climate change are increasingly challenging cities all over the world but to a greater extent fast growing developing cities. Guiding models and planning policies to make water and green structures the basis for sustainable urban development have derived over the past years from learning-by-doing processes in developed cities.

New experiences in other contexts may further contribute to this learning process. My project explores the feasibility of implementing sustainable strategies combining water management with urban design into a new and more complex context ‘the informal’. My goal is to accelerate the sharing and adoption of sustainable urban water management strategies to improve the spatial and living conditions of marginalized informal areas. The challenges related to water and informality are also common to most developing cities, hence the importance of developing alternatives that tackle both issues.
For the purposes of my research I proceeded by a phases on process. In the first phase a historical analysis at the metropolitan level was carried out to identify the different periods of the development of the city in relation with its water systems. This analysis of the development of the spatial agglomeration shows the evolution of the city and explains how the city has been built, planned and managed. On the basis of its urban structure, urban morphology and water resources management, this analysis makes clear the moment in which the rupture between urban and natural processes began. Once the historical background of the city is understood, the identification of the current problematic in terms of water and fragmentation of homogenous poor peripheral areas is done in a second phase. This analysis of the present situation, reveals the relation between the two most critical problems that the Metropolitan area is facing: unsustainable management of water resources and spatial fragmentation and social segregation of peripheral informal settlements.

This research takes as the main problem the combination of both issues. A hypothesis derives from literature review on possible strategies to tackle the combined problematic [informal settlements facing socio-spatial fragmentation and increasingly vulnerable to water related risks] two main research questions are formulated to prove the hypothesis. The hypothesis states that integrative spatial interventions at the local level based on the sustainable management of water may improve spatial and living qualities in informal settlements and possibly contribute for a metropolitan hydrological regeneration. In order to prove the proposed hypothesis, in a third face a representative municipality was selected, Valle de Chalco Municipality [VDC] a large mono-residential and socially excluded peripheral settlement affected by metropolitan unsustainable water resources mismanagement. This approach was taken in order to analyse in depth a vulnerable community; to assess and evaluate analytical categories at the local level: its morphology, its territorial elements and the socioeconomic characteristics of its inhabitants. The outputs of this approach should serve two purposes.

On the one hand through a research by design process a strategy is developed for VDC municipality based on its specific characteristics [environmental, spatial and socioeconomic], some of them being common to other informal settlements and some being completely specific. A diagnosis of the area using the three analytical categories reveals potentials and constraints providing the basis for the interventions. From there a vision for VDC Municipality is proposed as the desired effect from the local interventions. Strategies are developed considering four main groups of stakeholders who are involved in different phases in varying degrees. The latter generates different scenarios for some of the interventions, giving flexibility to the plan. The development strategy therefore is conceived as a framework; the combination of different possibilities would bring different outcomes but will follow the same goal.

The strategic plan for the area is also conceived following a well-phased implementation scheme for the interventions. Finally, a new landuse plan for the area is developed after a reflexion on the government plan for the area. Two specific areas of the Municipality are selected as design locations because of their crucial role for the strategic plan. Both designs are evaluated against the proposed landuse plan to show the coherence between strategies. The strategic plan is also evaluated against the hypothesis to validate it as a positive answer for the research questions.

On the other hand, as a final phase of this research project, the municipal development strategy for VDC is evaluated in order to realize its potential to be modelled and transferred into other informal settlements facing similar problems. This evaluation will aim to make clear the flexibility of the strategy.
Reference projects

Territorial analysis

DIAGNOSIS Potentials & Constraints

STRATEGIES

VISION

DESIGN

Evaluation

EVALUATION

Hypothesis

Theoretical Framework

City scale

Historical morphological analysis

City profile: current situation

Local Scale

Morphological analysis

Territorial analysis

Socioeconomic analysis

DIAGNOSIS Potentials & Constraints

VISION

STRATEGIES

EVALUATION

POTENTIAL TRANSFERABLE MODEL

Reference projects

Evaluation
2.1 Sustainable Development: Integration of environmental, social and economic issues

What if natural ecosystems protection and their sustainable use could contribute to mitigating the impacts of climate change and driving sustainable development?

(UNEP, 2010)

In 1987 the Brundland report introduced the term of sustainable development for good reasons. During the 20th century cities tended to put economic drivers on their agenda at the cost of social well being and environmental equilibrium. Social and environmental effects from that were for instance placelessness, criminality, loss of cultural identity and low-density urban sprawl. After the global adoption of sustainability an environmental planning discourse evolved in developed cities in the context of the trinity of sustainability principles: environmental sensitivity, economic opportunity and social equity (Novotny et al., 2010).

There are hundreds of definitions of ‘sustainable development’, the 1992 Earth Summit in Rio de Janeiro defined it as a ‘development that meets present needs without compromising the ability of future generations to achieve their needs and aspirations’ (Jenks 1996, p. 233). Urban sustainability is a particular case of sustainability concerning continuous transformation processes of economies and cultures where their impacts on the built and natural environment can be understood as a product. Hence, it has been understood that the drive of an unsustainable development is human behaviour. Humans are the course of environmental problems, the victims of environmental problems and hopefully the solution to these problems (Van Dorst, 2011).

This complex relation was for the first time recognised also in 1992 Earth Summit (UN 1992) where the first principle of the conclusion was that ‘Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature’ (UN 1992). It has then been realised that economic, social development and quality of life and the environment are intertwined as an interacting trinity. Sustainability is only achieved when these three components are in balance; a change in one component affects the other two. From a global perspective, social sustainability emphasis the basic needs of humans as its primary goal since today 1.4 billion people live in extreme poverty (World Bank, 2011). Liveability represents a set of relevant topics within social sustainability that are related to the physical environment. Liveability is defined as ‘fit to live in’; standing for this human perception but in relation to the environment. This system oriented definition fits best the ecological approach (Van Dorst, 2011). The city as an urban ecosystem with ecological processes driven by human activities is the theory behind new initiatives on sustainability and resilience in the planning and design disciplines.

The UN ecosystems approach is an integrated strategy for managing land, water and living resources that recognizes the strong linkage between ecosystem services and human well-being. It ensures that these essential services, and the systems that support them, are correctly valued, protected and managed.
Human well-being depends on the health of ecosystems. An ecosystem is a dynamic complex of plants, animals, microorganisms and their nonliving environment, of which people are an integral part (UNEP, 2010). The benefits that we derive from nature and rely on every day, from timber and food to water and climate regulation, are all ecosystem services. The ecosystem services concept in the context of sustainability may be a key concept for water planning and design in today cities. The concept states that the protection of landscapes that provide ecosystem services can be justified on economic terms and conversely their absence or degradation can have negative economic and ecological effects. Ecosystem services in relation to water are classified as provisioning [eg. drinking water], regulatory [eg. flood protection] and cultural services [eg. recreational and aesthetic benefits] (United Nations’ Millenium Esosystem Assessment, 2005).

In the context of the ecosystem approach sustainability can be the appropriate relationship between humanity and the environment. Liveability in an ecosystem definition is the appropriate relationship between people and their environment. In this way, the similarity between sustainability and liveability becomes evident (Van Dorst, 2011). Liveability is an ecological interpretation of the ‘people’ aspect in the sustainability trinity. In relation to the built environment the basic needs that makes up social sustainability in relation to the built environment are:

1) Health and safety  
2) Material prosperity, income inequality, inequality in happiness  
3) Social relations  
4) Control  
5) Contact with the natural environment

These needs give insight in programmatic demands for a social sustainable living environment: a collection of environmental qualities contributing to a health, safety, social relations, control and contact with the natural environment (Van Dorst, 2011).

This research project places an emphasis on wellbeing of humans together with environmental concerns as the goal of sustainable development; since it targets the inhabitant’s of informal settlements in Mexico City Metropolitan Area.
In Mexico the concept of sustainable development is one of the primary topics still under discussion on the working national agenda, although it is becoming the model of development to follow. Mexico City’s commitment to a more sustainable future is also represented by its active involvement in the C40 – Cities Leadership Group, a group of major world cities promoting action and cooperation on reducing greenhouse gas emissions.

Today, there are numerous social, economic, and environmental drivers for a change and a switch towards sustainability such as population growth, water scarcity, increased frequency and magnitude of extreme meteorological events and the need for the city to become more resilient to water related problems.

The soundness of my research and design project is based on the correspondence that its underpinning framework, objectives, findings and proposals have with the current city government’s ideas. Nearly twenty city agencies are working together to make the $1 billion-per-year investment in green living a reality in the urban environment. The Green Plan is a key priority of the Mexico City government and represents about seven percent of Mexico City’s total yearly budget.

The Green Plan is Mexico City’s Government’s medium-term (fifteen-year) course of action and guideline comprising strategies and actions to lead the city towards its sustainable development. Presented in 2007 by Mayor Marcelo Ebrard, the Green Plan is a living instrument that will constantly be evaluated and enhanced. The topics the Green Plan comprises are: Land and Conservation, Habitability and Public Space, Water, Transportation, Air, Waste, Climate Change and Energy. Each area has its own set of objectives and strategies proposed to achieve them.

The Green Plan regarding Water, the most important topic for this research has as a main objective to achieve water self-sufficiency and the improvement of water management. The strategies mentioned within the Plan are:
- To attain balance of aquifer resources
- To reduce residential water consumption
- To reduce losses in the water mains
- To increase re-use and treatment of water
- To create lakeside water (lacustrine) parks in Tláhuac and Xochimilco

With regard to the last strategy concerning the chosen location of this research, three main goals are stated:
- To recover lacustrine landscape in 250 hectares of Tláhuac and Xochimilco, starting in 2008.
- To build ecological corridors in lakeside water parks.
- To strengthen the zone’s lacustrine vocation and hydric regulation.

Among the different strategies outlined in the plan from other topics also relevant for my project are:
- 5000 of Mexico’s micro-buses will be replaced with less polluting alternatives.
- Extending the “day without a car” program to Saturdays. Currently the program limits car use by one day during weekdays.
- Evaluating the creation of a green tax to pay for the services offered by the ecosystem.

- Requiring a ‘Clean Building Label’ for all new construction.
- Launching a new social housing model that incorporates green areas, public spaces and environmental design.
- Building 300 kilometers of bicycle highways by the year 2012 that will help reach the mark targeted by the government of at least five percent of person-trips to be done by bike.
- Developing green corridors that will expand the amount of green space in the city to nine square meters per inhabitant.
- Enforcing the use of school buses for all private school students by the year 2012.

The government is aware that if the plan is to succeed, it will need not just public acceptance, but also require complementary strategies across different competencies and areas of government to guarantee the resources needed for its execution. Transversality, a notion that describes how spaces can intersect; is described as the Green Plan’s core principle for the achievement of its goals. To go beyond the technical and operational reach of government’s responsibility and tasks.

Six of those transversality strategies are the most relevant for this research project considered as key instruments for its execution:

- Financing via varied mechanisms, so that the plan’s actions have the resources needed for their execution.
- Legal, regulative and institutional framework: some of the proposed strategies outlined in the plan will require updating and modifications of the city’s laws and regulations.
- Environmental education that will motivate citizens to participate.
- City participation: being a living instrument, the plan requires active participation during its execution and follow-up.
- Regionalization: Mexico City is part of a larger megalopolis that includes neighboring states (State of Mexico and State of Hidalgo). The city will need reach cooperation agreements with these states: so that the actions proposed by the Green Plan find correspondence. State of Mexico for the case of this research project where the Municipality of Valle de Chalco is located (See Map on the previous page).
- Transparency & accountability: citizens have to be certain that the economic and human resources used for designing and executing the plan are being put into good use.

Source: www.sma.df.gob.mx
2.2. Integrated water resources management

In terms of water resources the switch towards achieving an integrated water resources management [the fifth paradigm shown in the figure at the bottom of this page] requires a new holistic approach and a high level of political cooperation. It requires the interests of civil society, hierarchy (government), social movements (NGO’s) and the private sector to be included in the policy making discourse (Novotny et al., 2010). A transdisciplinary approach involves not only the professional and academic specialists, but also engages the stakeholders and decision makers meaningfully, throughout a continuous, interactive and iterative process of urban planning and design. Transdisciplinarity provides a new level of involvement in policy development, including public, private and not-for profit interests in developing and implementing strategies to attain the fifth paradigm of water management for cities of the future.

A holistic approach towards integrated water management as part of an upgrading process within the context of informal settlements, would also mean finding an alternative to the, sector-based approach in dealing with the multiplicity of community needs and demands that exist within the settlement (Abbot, 2002). Moser (1995) provides a starting point declaring a demand-driven approach and inter-sectoral policy linkages as critical, arguing that individual sectoral interventions have no guarantee of impacting on urban poverty reduction. She states that on the contrary of households who plan cross-sectorally; in a supply-driven approach, planning agencies plan at the sectoral level disabling households to make contextually and culturally specific cross-sectoral trade-offs.
As population grows and climate changes with regard to managing water, modern notions as risk and resilience and related terms as hazard, vulnerability, adaptation and mitigation can be particularly useful to better understand and address future hazards. Risk is the key concept with regard to managing water hazards however it is a subjective and complex issue in itself. Therefore there is a need to be aware of the constraints of the concept and how it can assist in decision making so that planning systems may be effective agents of risk management. According to White (2010) the risk of flooding or drought can be viewed as a function of both the existence of a hazard (the potentially damaging event) and vulnerability (the susceptibility to its impacts); the intersection of both, an area at risk and a population variably subject to its impacts. Vulnerability in this instance does not only focus on land use or physical environment but also incorporates social, economic and cultural factors such as wealth, access to resources, social networks and ethnicity (White, 2010).

According to Abbot (2002), the starting point for the development of the planning framework for an upgrading process of informal settlements is the recognition that there are two underlying developmental needs that are linked to their vulnerability. The first of these is to deal with the issues of social exclusion and sustainability. And the second developmental need is to integrate all the elements of vulnerability into the upgrading process. According to Moser (1995) there are two dimensions of vulnerability; its sensitivity (the magnitude of a system’s response to an external event), and its resilience (the ease and rapidity of a system’s recovery from stress).

2.2.1. Risk, Vulnerability and Resilience

‘The urban study defines vulnerability as insecurity and sensitivity in the well-being of individuals, households and communities in the face of a changing environment, and, implicit, in this, their responsiveness and resilience, to risks that they face during such negative changes’ (Moser, 1998:23). Environmental changes that threaten welfare can be ecological, economic, social and political. Analyzing vulnerability involves identifying not only the threat, but also the ‘resilience’ in exploiting opportunities, and in resisting, or recovering from, the negative effects of a changing environment.

Resilience is a new way of thinking about sustainability, more strategic than normative, that must be based on environmental, ecological, social, and economic drivers and dynamics of the specific context and integrated across scales. Understanding resilience is central to understanding sustainability. It has been viewed as a key idea to tackle risk, the concept has been recently advocated to describe the way in which cities can attempt to recover from disasters and to the effective implementation of contingency features into planning, governance and response systems (White, 2010). This term has been widely appropriated within urban risk management and the built environment professions as it offer promise in moving towards cities less exposed to flooding and water stress.

According to White (2010) resilience also has a strong human element most relevant to this research, which focuses on the ability of a society to meet future challenges incorporating social and cultural aspects. Therefore a key feature of modern understanding of the concept is its ability to connect not only physical and social

RESILIENCE

HAZARD
Flooding
Land subsidence
Earthquakes
Landslides
Land with high groundwater
Diseases

RISK

VULNERABILITY
CAUSES OF VULNERABILITY
ROOT CAUSES
Limited access to power, structures and resources
DYNAMIC PRESSURES
A. Lack of: local institutions, training, appropriate skills, local investment and local markets
B. Macroforces: rapid population growth, rapid urbanisation, unsustainable resources management [deforestation, wastewater floodings, decline in soil productivity]
UNSAFE CONDITIONS
A. Fragile physical environment: dangerous locations, unprotected infrastructures
B. Fragile local economy: livelihoods at risk, low income levels
C. Vulnerable society: social exclusion, lack of local institutions
D. Public Actions: lack of disaster preparedness

Source: Based on http://log.logcluster.org/
preparedness/intervention-types/index.html
systems with each other but also connecting those to natural systems; through this, vulnerability of ecosystems to human or natural threats can be acknowledged and strategies may be adopted to preserve resources. Recently resilience has been understood as process orientated, as a wider and encompassing process through which the resilience capacity of communities can be enhanced and augmented; this contemporary perception provides a key link to the escalating reality of risks in our cities.

Based on the idea that resilience is not an unconnected aim but is rather embedded in the concept of risk, it can be seen as a mechanism to manage the consequences of risk on people and places via spatial planning. The addition of the exposure constituent provides a stronger spatial element than vulnerability in itself cannot provide. Considering consequences for people, natural and built environments provide a useful slant for spatial planning.

‘Identify what the poor have, rather than what they do not have...’
Moser (1998:21)

Natural resources are the basis of subsistence in many poor communities and the livelihoods of developing country populations are directly dependent on healthy ecosystems. There is a recognized link between poverty alleviation and the benefits that people derive from ecosystem services. Protection and sustainable management of ecosystems is therefore a critical element of poverty reduction strategies, as it helps maintain or enhance the delivery of the water, food and other ecosystem services poor people rely on (UNEP, 2010).

What if healthy ecosystems could be used to help reduce poverty and hunger in vulnerable populations?
(UNEP, 2010)

Moser (1995) suggests that the means of resistance of vulnerable populations are the assets and entitlements that individuals, households, or communities can mobilize and manage in the face of hardship. Vulnerability is therefore closely linked to asset ownership. The more assets people have, the less vulnerable they are. According to these, strategies need to look for the activation of economic opportunities in order to diminish the vulnerability of the people and look for ways in which their assets may be a way to make them less vulnerable. Hence the objective of upgrading informal settlements should be to reduce the vulnerability of those living in the settlement.

From an intervention perspective, an asset vulnerability framework can help to reduce household poverty and vulnerability as it facilitates interventions promoting opportunities and removing obstacles to ensure that poor residents use their assets productively. The asset vulnerability framework is presented below and applied into Valle de Chalco Municipality as part of the analysis at local level. It is presented at the end of the fourth chapter as part of the concluding diagnosis of the area.

### ASSETS AS MEANS OF RESISTANCE

**‘RESILIENCE STRATEGY’**
[Moser, 1998]

**LABOUR** considered as the poor’s greatest asset; generating income either directly, in terms of its monetary exchange value through wage employment, or indirectly, through the production of goods and services, which are sold mainly through informal sector self-employment activities.

**HUMAN CAPITAL** connection between, on the one hand, social and economic infrastructure (the former being health and education, the latter being municipal services such as water, transport, electricity) and, on the other hand, a household’s immediate and long-term income-earning capacity.

**PRODUCTIVE ASSETS** the most important one being housing as it has direct implications for a household’s capacity to earn an income through, for instance, renting rooms and the use of its space for home based production activities.

**HOUSEHOLD RELATIONS** a mechanism for pooling income and sharing consumption being a household’s composition and structure and the cohesion of family members.

**SOCIAL CAPITAL** being trust, reciprocal arrangements, and social networks within the community.

### Notes:
1 *PSU refer to primary sampling units defined in the context of the 2000 census.
2 In addition to those living in low-income neighborhoods, Mexico City also has a significant homeless population which is particularly vulnerable to extreme events. Importantly, this segment of the population is not accounted for in the city’s calculations of urban poverty, as such information relates to those who possess a dwelling.

Vulnerability matrix in terms of population and housing in Mexico City.
Source: World Bank, 2011
2.3 Participatory Governance and Strategic Urban Planning

‘Collaboration between local governments and communities empowers both’
(Isla Urbana, 2010)

...Even the improvement of the physical environment can produce a very positive impact, the engine of change is the community, which must be mobilized to continue the development process. Without a strategy for long-term participation, no project can be truly sustainable.
(Imparato and Ruster, 2003)

One of the main problems of the municipality is segregation and fragmentation and therefore solutions may be formulated by integrating the concepts of ‘participatory governance’ and ‘strategic urban planning’. The formulation of a strategic planning framework allows for the transformation of the area, for new land uses and strategies that lead to the improvement of the current spatial structures.

Sustainable development represents new and complex planning situations, where a wide variety of information and knowledge and the integration of more stakeholders are needed. New methods of planning are recognized as being fundamental to tackle the challenges of increasingly fragmented cities such as Mexico City Metropolitan Area. Planning approaches have been developed based on a switch to participatory approaches that respond to user needs and environmental factors. The failure of top-down approaches has led to alternative theories such as strategic and communicative planning methods. These methods attempt to simplify planning by breaking it into steps and widening its scope by giving a say in the process to diverse interest groups and stakeholders.

Strategic urban planning is a way in which the planning process can be organized built under the principles of participatory governance. This concept is understood as a way of empowering the citizens to participate in the core actions of the state. Based on its principles it has been recognized that involving the community in the process of urban planning can be a way in which the problems of socio-spatial segregation and fragmentation can be countered. Instead of a supply oriented approach strategic urban planning is a need oriented approach implying a phased process. The steps within the planning process act as a logical structure for developing dialogue, creating participation and guiding actions.

Firstly, a diagnosis of the current situation made by the community and others is needed to identify the problems. Secondly, objectives and possible alternative solutions must be developed aiming to solve the problems. The selection process of the most suitable alternatives is made and finally the selected alternative is divided into operational parts to be further developed. Strategic urban planning offers various potentials, as it is need oriented and promotes an institutional awareness of local problems.

Participatory observation has been recognized as essential for an upgrading process of informal settlements. The participatory process may improve project design and effectiveness through organized expression of demand, which allows a project to access local knowledge taking all relevant factors into account in the solutions proposed by a project. It enhances the impact and sustainability of projects through demand expectations and responsiveness, which are key in enhancing local ownership of a project.

Participation contributes to reach goals such as good governance, democratization, and poverty reduction by building local capacity to interact with authorities and other stakeholders to further common goals. It establishes clear channels for community participation in decision-making, giving people the opportunity to influence the actions that shape their lives (Imparato and Ruster, 2003). Participatory tools are commonly recommended in strategic planning frameworks and many success stories

Furthermore, to operate simultaneously at different levels of decision-making requires a knowledge of what decisions lie at what level and a clear understanding of roles and relationships recognizing that these might be different at the different levels of decision-making (Abbot 2002). The distinction between consensus decision making on the one hand and inclusive (i.e. community-based) decision-making on the other is that in the former, a number of diverse parties have input into the decision-making process. The community, through its representatives, is one of these groups, and therefore it has an equal, but not an exclusive, right. In the latter case the situation is different. There the government may be responsible for setting the enabling framework, but it is the community that takes decisions and the government supports those decisions. According to Abbot (2002), in the context of informal settlement upgrading, what this means is a need to have a variable relationship between the community and the government, as well as different sets of organisational relationships operating within the community itself. The issue becomes identifying the decisions that need to be made and linking these to the appropriate form of decision-making.
Achieving sustainability of water resources has been acknowledged as the central challenge for sustainable urbanism, because water is essential to all life, and because future water quality and management for urban uses are threatened by urbanization itself in most cities of the world. Urban environments properly configured and managed, are key to providing sustainable water resources and uses to meet the needs of expanding urban populations (Novotny et al., 2010).

Innovative and sustainable alternative approaches for water resources management have been introduced in several countries around the world. Water Sensitive Urban Design is the interdisciplinary cooperation of water management, urban design, and landscape planning. It considers all parts of the urban water cycle and combines the functionality of water management with principles of urban design. WSUD develops integrative strategies for ecological, economical, social, and cultural sustainability. WSUD considers the management of entire water systems (drinking water, storm water run-off, waterway health, sewerage treatment and re-cycling), but is concerned mostly with issues of rainwater management. The concept and several solutions for a sustainable stormwater management have been introduced worldwide:


For the success of decentralised stormwater management in combination with urban design (Water Sensitive Urban Design), it is important that the solutions follow 5 basic principles:

1) Solutions should use decentralised methods to bring urban water management closer to the natural water cycle.
2) Aesthetic benefit: solutions should be used to provide an aesthetic benefit where possible.
3) Integration in surrounding area: solutions should be adapted to the design of the surrounding area.
4) Appropriate design: solutions should be used in an appropriate way, adapted to the local basic conditions and the intended use.
5) Appropriate maintenance: solutions should consider the corresponding maintenance requirements.
6) Adaptability: solutions should consider possibilities for adaptation to uncertain and changing basic conditions [e.g. demographic change]
7) Appropriate usability: solutions should be used to create places that are usable for recreation and/or nature conservation purposes.
8) Public involvement: solutions should consider the demands of all stakeholders and involve them in the planning process.
9) Acceptable costs: costs should be comparable to the costs of conventional solutions.

It is necessary to involve residents in the planning process so acceptance and appropriate use and care of urban spaces can be sustained. Additionally, through community participation, the needs and wishes of local residents and other stakeholders can be known. This is crucial for ongoing WSUD development. Direct discussion with stakeholders offers the opportunity to discuss the advantages and disadvantages of decentralised stormwater management to eliminate prejudices (Hoyer, 2010).

Reclaiming Wastewater for Agriculture

Reclaiming wastewater for agricultural reuse is increasingly recognised as an essential strategy in areas of the world where water is in short supply. Wastewater reuse has two major objectives: it improves the environment because it reduces the amount of waste (treated or untreated) discharged into water courses, and it conserves water resources by lowering the demand for freshwater abstraction. In the process, reuse has the potential to reduce the cost of both wastewater disposal and the provision of irrigation water.

In terms of wastewater management it has been acknowledged globally that poor sanitation leads to degradation of living conditions, health and economic opportunities this is the reason why sanitation is included as one of the United Nations Millennium Development Goals (Luthi et al., 2011). The objective of a sustainable waste management is to turn waste into a resource. In a sustainable community waste production must be minimized and resources used as efficiently as possible. In response to the deficiencies of centralized approaches to service delivery, in recent years there has been increasing emphasis on the potential benefits of adopting decentralised approaches to sanitation and wastewater management, which are considered to be particularly appropriate for peri-urban areas.

In planning and implementing sanitation systems an analysis of the physical and environmental factors, combined with an assessment of the social groups and institutional structures within these domains, as well as the respective incentives for being involved in sanitation improvements, forms the basis for identifying opportunities for intervention. A well-developed awareness of the context and priorities of the community and other stakeholders and the social-cultural elements are key elements for sanitation planning. The choice for a specific sanitation system has to be context specific.
and should be made based on the local environment (temperature, rainfall, etc.), culture and resources (human and material) (Luthi et al., 2011).

Within the framework of a participatory approach it is important to share the knowledge and to involve stakeholders to make well informed decisions during the planning process for sanitation. The latter will allow choosing appropriate and sustainable systems and technologies that keep project costs affordable and acceptable.
Local strategic urban planning

Strategic urban planning approach offers various developing potentials, as it is need oriented model and promotes an institutional awareness of local problems. As such in a more local level strategic urban planning can be an appropriate approach to cope with the problematic of social and spatial fragmentation to which the Municipality of Valle de Chalco is dealing with.

Integration of environmental factors and community empowerment

The integration of environmental factors into the planning framework may help to improve spatial and living conditions of marginalised communities. Spatial strategies based on the sustainable and local management of water [e.g. decentralised rainwater collection and management, local wastewater treatment and reuse] can be used as an upgrading approach for informal settlements to create a mutual beneficial relation between the water cycle and inhabitants to fulfil their needs and turn present risks into development opportunities.

Through the empowerment of the people in low income communities for the self management of their water resources, disconnecting from the unsustainable metropolitan systems may be the key towards their sustainable development and social inclusion.

Water, integrated spatially and functionally in the urban structure of informal settlements may improve urban quality, diminish flooding risk, satisfy water demand and provide new economic opportunities [e.g. urban agriculture, aquaculture.]

Furthermore I believe that the sum of local interventions following a sustainable system of water management in informal settlements may contribute to the restoration of the metropolitan hydrological imbalance.

2.5. Hypothesis

Integration across physical scales
[Metropolitan scale and Municipal scale]
-Spatial needs | functional potentials-

Integration between stakeholders
[Public sector, Private sector, Organizations and Community]
- Entrepreneurial processes (Friedmann) -

Integration between different sectors
[Urban Planning + Water Resource Management]
- Water as an asset for marginalised communities -

Sustainable redevelopment strategy for informal settlements in Mexico City’s towards the hydrological metropolitan regeneration
During the development of Mexico City water has had a symbolic and functional importance. The historical, cultural and social evolution of this territory has always developed based on water. The exact location of Mexico City’s historical centre corresponds to the ancient capital empire of the Aztec civilization Tenochtitlan, founded in 1325 on an island in Lake Texcoco. A system of interconnected lakes occupied a large area of the valley, of which Lake Texcoco was the largest (the other main lakes being Zumpango, Xaltocan, Xochimilco and Chalco lakes).

Over the time the five lakes had gradually been drained as the valley of Mexico became urbanized, starting from the times of the Spanish conquest of this territory. While the ancient civilizations took advantage of living with water, with a complex system of canals, dikes, and levees to keep floods at bay, the Spaniards sought to turn the capital into a city on dry land. The result over five centuries has been considered as one of the most radical transformations in the history of urbanization. By the beginning of the 18th century, Lake Texcoco was no more than a seasonal swamp, and Mexico City was no longer an island (Stanton, 2010).

Since the beginning of the modern urbanization process of Mexico City and its Metropolitan Area, water has not been considered as a structural element for the growth of the city. Rivers and natural water bodies have not been used as spatial guiding elements to design the urban space; instead its water structure had become invisible over time, losing an invaluable natural and cultural heritage from the past.

The normal practice in the past has been to enclose rivers and canals to prevent floods and ensure healthy environments. Some of the rivers are currently used as open-air sewage canals, posing serious risks to inhabitants. Those practices need to change, as it has been realized that enclosing water takes away great opportunities for urban areas to cope with environmental challenges and improve urban quality (González, 2010).

In order to understand better the relationship between water and the city, a historical morphological analysis is presented in the following pages.

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“ And when we saw all those towns and villages built in the water, and other great towns on dry land, and that straight and level causeway leading to Mexico, we were astounded. These great towns . . . and buildings rising from the water, all made of stone, seemed like an enchanted vision. . . . Indeed some of our soldiers asked whether it was not all a dream . . . It was all so wonderful that I do not know how to describe this first glimpse of things never heard of, seen, or dreamed of before.”

— Bernal Díaz del Castillo, The Conquest of New Spain

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Tenochtitlan, looking east. From the mural painting at the National Museum of Anthropology, Mexico City. Painted in 1930 by Dr Atl. Source: (Stanton, 2010)
Mexico Tenochtitlan was founded in 1325 on an island in the middle of Texcoco lake. The small island, enlarged via a system of land refill and reclamation through small, floating, plots of land known as chinampas, gave rise to numerous small canals which connected a great number of houses, palaces, temples, plazas, markets and aqueducts. All this infrastructure supported a social and political organization centred around the Calpulli (productive communities) located at the main cardinal points: Azacoalco (northeast), Zoquiapan (southeast), Moyotla (southwest) and Cuepopan (northwest).

The city sustained an intense relationship with the rest of the dominated towns in the valley via the enormous causeways with their network of bridges and dams and by four main roads. The trade in produce that arrived in the city by canoe or on the backs of human porters filled the tianguis (markets) which, as in the case of the Tlatelolco market, offered every possible good and product for sale or trade. The lacustrine towns in this territory lived in complete equilibrium with their natural environment. The management of the resource was well balanced, dikes were constructed to control flooding and to avoid the mixture of brackish water with fresh water. The Mexica undertook the construction of an aqueduct to bring drinking water from the natural springs at Chapultepec.

The city of Mexico-Tenochtitlan and the poly-nuclear system of shore towns which structured the whole territory in the valley supported a symbiotic relationship between the natural and the urban worlds. Water was considered the main element for the spatial structure, as well as for production, social relations, recreation and transportation. It was the structural component of the whole region, it worked as social space, communication structure and as the base of production. It is owed to the Xochimilcas ancient people the invention of the chinampas (artificial islands), as one of the most productive methods of cultivation until now, same that were conceived for both, agricultural and residential use.

Martinez, a German cosmographer, was the responsible for proposing a project for drying the lakes by a great ditch to the north: 'El Tajo de Nochistongo' and by 1789 the unwise process of drainage started. At the same time, construction of aqueducts was made to bring water from other closer springs being the main drinking water source for the citizens.

(*) Main source:
González de León, Teodoro & Kalach, Alberto, 2010.

Under the Spanish dominion the construction of the great ditch caused the premeditated death of the lacustrian city. The application of the Imperial bylaws was made by the imposition of Spanish cultural symbols in the native's social, cultural and religious temples and ceremonial structures, although respecting and emphasizing the former urban structure.

Life in the city was much like a game of chess, aligning Spanish against Indian, in which each side occupied a well-defined position. The Indian world was relegated to the outskirts of the city. Certain Indian nobles are absorbed into the Spanish way of life, and the Mexica past is recorded in vibrant symbols.

The poor vision of Spaniards and null skills of water management were the cause of several and severe flooding, being the most serious, the one of 1629 occasioning more than 30,000 deceases, maintaining the city inundated for almost five years. Enrico
In 1821 Mexico becomes independent from the Spanish as a new Mexican empire. With the Federal Constitutive Agreement in 1824 and the Federal Constitution, Mexico City is declared the seat of the Federal Powers, that is to say, the seat of the Federal District. During the first half of the XIX century, the city started to grow following the previous grid and gradually attaching the closer ancient towns and villages, like Tacuba, Tacubaya and Iztacalco.

Since then, Mexico City has maintained its hegemony as central space, complemented by a peripheral growing. The construction of El Paseo de la Reforma Avenue in 1864, inspired by the Parisian Champs-Élysées, detonated the city development to the west and with this, the displacement of the commercial activities to this area. The city experienced important structural changes. The period known as el Porfiriato, (Porfirio Diaz, 1876-1910), was deeply influenced by the European trends, and left strong traces in the structure, as well. More European inspirations were being manifested at the beginning of the XX century, with the development of housing developments to the south mainly for upper and middle classes, driven by the recently introduced electric tram network. Therefore, the working class was pushed to the northern and eastern peripheral part of the city.

The Nochistongo dyke was no more able to decrease the risks of flooding and an alternative plan appeared: The Grand Canal and the Tequisquiac Tunnel were inaugurated in 1900. At that moment, Chapultepec and Santa Fe springs were exhausted, raising the necessity to bring fresh water from further springs. The construction of a new underground aqueduct to bring water from Xochimilco springs started in 1900, and with this, the first pumping station was made to satisfy the demand for water of the city and in 1903 the first sewerage system was inaugurated.

(*) Main sources:
González de León, Teodoro & Kalach, Alberto, 2010.
People were escaping from the revolutionary battles, moving from smaller and closer towns to Mexico City. After the Revolution, the country enter a process of reconstruction, with the vision of transforming the country into a more prosperous one. Mexico City was taken as the main scenery to make real all this urban blooming dreams, with the most important concentration of population and being the most dynamic city in the country.

The restitution of the financial system and the application of a set of legislative regulations for the consolidation of the New Mexican State, promoted a nationalist and popular project of development in which urbanism and planning were focused to a wider vision about social and spatial organization of the territory. The city was, then, object of several interventions translated mainly in infrastructure, urban equipment, public buildings and housing projects. The intention of the government was to bring the benefits of modernity to the society.

In 1929 a new regimen was applied; the Federal District was created and with this, the municipal formula of the Federal District was no longer valid. Municipalities with more-or-less autonomy lost their relative independence and were added to the administrative and political limits of Mexico City. After 1930, the industrialization contributes to the urbanization process; commercial activities in the centre of the city were displaced to the borders.

As the process of expansion of the city, the lakes continued to be drained. Meanwhile, water demand was increasing and by 1930 the city had 350 wells about ten meters depth that pumped water out. In 1936 wells from more than 200 meters depth were drilled, initiating the formal intensive exploitation of the aquifers. From 1943 to 1960 Mexico City’s main rivers were covered over.

(*) Main source:
González de León, Teodoro & Kalach, Alberto, 2010.
In the past decades transformations from the global economy produced important changes in the metropolitan dynamics. Those changes not only redefined the economic base of the city but also its territorial patterns. A declining trend of urban growth of the city started since 1970. In the period between 1970 to 1990 the growth dropped to 1.64% when at the early 1980s the generation on manufacturing employment was reduced.

Decentralization policies started in the 1970s due to high levels of air pollution, increasing crime rates and declining quality of life. From the mid to late 1980s the export-oriented model (intensive trade relations with US) strength the decentralization from the manufacturing activities (Aguilar and Ward, 2003). Consequently, the industrial sector suffered a backward step, the informal economy started to grow and the tertiary sector increased enormously representing today the main economic activity employing 70% of the active population of MCMA.

From 1950 to 1980s a dynamic process of occupation of the peripheries started. In the late 1960s the city grew exponentially, expanding along the periphery where cheap communal land was transformed into irregular low density housing for the working class. This is the period of the called ‘paracaidistas’ first irregular settlements –slums– forced to occupy peripheral land because of the lack of legal available one, according to their economic capacity. The periphery experienced from this moment on an endless dynamic of occupation and posterior consolidation, occupying risk areas, thus being exposed to natural hazards such as floods and landslides (Carrasco A., Roque J. & Andrés C., Hena, 2011).

In 1951, the Lerma Water Supply System is opened to bring water from other hydrologic basins 60 km away. Almost three decades later, another structure was constructed to bring more water to the city: the Cutzamala System 150 km away. In parallel, the works for a complex network of sewage started. The sewage system has 1353 km of underground tunnels that reach a depth of up to 240 meters (Tortajada, 2006).
During the second half of the twentieth century Mexico City experienced very intense demographic dynamics. Like other large cities in Latin America the period known as Import Substitution Industrialization (ISI) promoted concentrated urban, industrial and political activities in the main metropolis. High rates of economic growth (increment of the GDP of the country up to 35%) created a great attraction of migrant labour causing the city to spread outwards. The uncontrolled expansion and emergence of informal settlements generated important problems in the peripheries such as poor infrastructure systems and loss of fertile land.

The highest growth rates of the city where in the period between 1950 and 1960 but after 1970 its growth started to decline due to economic crisis and instability (Aguilar and Ward, 2003). Even so, between 1960 and 1980 the city doubled its population; growth was fuelled by an immigration process caused by the industrial apogee and high rates of internal increase of population. During this period, the government of Mexico City decided not to authorize more housing construction within its limits. Consequently, while the suburbs of the city grew through middle income residential development, its periphery did with irregular development of self-build settlements taking over a great part of the areas designated as conservation areas.

The turn to Neoliberal politics and free market ideologies started in the early 1980s and culminated in the North American Free Trade Agreement NAFTA of 1994, opening up Mexican markets to foreign investment. With the modification of a Constitutional law in the early nineties, allowing the legal trade of communal land for dwelling, land speculation became the best business in Mexico City. Real State Development since then is the ‘institutional way to make city’. Massive land incorporation for housing development carried out by private and group’s economic interests to stop the production of irregular settlements was conceived as the strategy for ‘urban development’. This led to the development of middle class gated communities in the peripheries, being pockets of formal urbanization within a sea of informality. This urban phenomena

1985 -2010 | The Neoliberal City - Periphery and land speculation
Exceeding 21 million inhabitants
Hydro-ecological deterioration and emerging risks
The New Chalco Lake

Lake Nabor Carrillo
had severe social, economic and ecological effects on the whole territory.

In 1985 Mexico City experienced the most catastrophic natural event in its history. An earthquake of 8.1 degrees in Richter scale collapsed an important part of the central city. This caused the displacement of many homeless families to the periphery, increasing its process of urbanization as people moved outside the high-risk areas of the central city. In recent years, minor catastrophes have been caused by flooding and landslides due to the severe rainfall that the city experience every year.

Two trends can be identified in the last decades on population redistribution in MCMA: a depopulation of the historical city centre and a demographic concentration in the metropolitan areas of the State of Mexico. During the period between 1990 to 2000 the annual population growth of Federal District was 0.4%, compared to the growth of MCMA which was 2.9% due to immigration from the rural areas and from medium and small-size cities around (Tortajada, 2006). In 2001, in order to alleviate the still increasing housing shortage while at the same time controlling metropolitan expansion, a set of policy guidelines known as ‘Bando Dos’ directed at the re-densification of the inner city and control of peripheral sprawl were implemented. Moreover, the renovation and beautification of the historical centre in the past years lead to gentrification and emphasizes the priorities of the government of servicing the city’s core, while neglecting the peripheries.

As an effect of the urbanization and the subsequent loss of vegetation and land erosion, the city was often covered by heavy and toxic dust storms coming from the dried bed of the lakes. In 1971, an hydro-ecological regeneration project started -Texcoco Lake Project- creating a 1000 hectares lake ‘Lago Nabor Carrillo’ as an important proof that ecological and hydrological regeneration is still feasible. Interrupted by periodical economic crisis, of the 80’s, and 90’s, finally the project returned recently to the discussion board.

Today, new hydraulic works and huge investments are in progress, meanwhile the drilling of wells and overexploitation of aquifers continues. Land subsidence in the central area and in the south-east area of the city is dangerously increasing. For this reason from the mid 1980’s a New Chalco Lake emerged where the former Xochimilco lake disappeared in the beginning of the 20th century.

(*) Main sources:
González de León, Teodoro & Kalach, Alberto, 2010.

(**) All maps from the historical morphological analysis are made by author based on González de León, Teodoro & Kalach, Alberto, 2010.
PROCESS OF URBAN SPRAWL IN MEXICO’S BASIN.
Source: Map by author based on González de León, Teodoro & Kalach, Alberto, 2010
PROCESS OF DRAINAGE OF THE FIVE LAKES IN MEXICO’S BASIN.

Source: Map by author based on González de León, Teodoro & Kalach, Alberto, 2010
Location of Mexico City Metropolitan Area.
Source: Maps by author.
Location & Context

Mexico City Metropolitan Area is located in a natural closed basin at 2240 meters a.s.l. in south central Mexico. It covers an area of 4925 km² representing about 0.25% of the national area and its population density varies from 13500 to 131 persons/sq.km. (Tortajada, 2006). Since the accelerated urbanization period started, MCMA has continued to incorporate more and more distant municipalities into the definition of metropolitan area. Therefore the expansion of the city’s metropolitan influence and transformation of its immediate rural peripheries has been consistent throughout the past decades. The area designated nowadays as MCMA incorporates 16 boroughs of the Federal District, 37 municipalities of the State of Mexico and one municipality of the state of Hidalgo (Tortajada, 2006).

The area of study is the Municipality of Valle de Chalco Solidaridad one of the municipalities of the State of Mexico. It borders to the north with the municipalities of Ixtapaluca, and Los Reyes La Paz, to the east and south with Chalco in the State of Mexico and to the west with the Federal District borough of Tláhuac.
**Topography**

The basin of Mexico City is surrounded by mountains and volcanoes rising up to 4000 m. above the sea level. This geographical barrier limits any further expansion of the city in some areas and traps city smog and pollution within the valley, thus intensifying the air quality problem. The basin of Mexico has north-south and west-east inclination.
Soil

The urban sprawl mainly extends over lacustrine and alluvial soil. Because of its physical properties, and the overexploitation of aquifers, the lacustrine soil has experienced increasing subsidence due to its capacity of compression. Alluvial soil in the skirts of the mountain, allows the natural rainwater recharge to the aquifers, nevertheless this land qualified for infiltration is partly being covered by informal settlements, thus helping to intensify the hydrological imbalance.
Precipitation

The south of the basin receives between 700 and 1200 mm of rainfall per year, while the north receives between 400 and 600 mm per year. Rainwater surplus is transferred to the north 23 km across the metropolitan area with high energetic costs, keeping it from the local inhabitants that are the most needed.

During summer the high quantity of rainwater keeps the city in constant risks of flooding and landslides. Rainwater is a vast unused resource. If sanitation of open-air channels could be achieved, and rainwater could be captured it could be used in place of groundwater, and thus increase the recharge of aquifers. This would decrease the risks and costs associated with mass transfer of water from the peaks of rainfall, because of the pumping counterslope from the south -where there is more precipitation- up to the outputs at the north part of the Basin.

Average annual precipitation from 1960-2003

Source: Map by author based on data from Instituto Mexicano de Tecnología del Agua, México [IMTA], 2010

Source: CONAGUA, 2010
Fresh water supply and water use

Water infrastructure was never conceived for making use of rainfall. When the river springs became exhausted, it was necessary to find others ways to satisfy the fresh water supply. Aquifers overexploitation and importation from distant regions are now the main drinking water supplies. Excessive water extraction from aquifers, added to insufficient recharge because of urban sprawl is generating the subsidence of the central and the south east part of the city. Soil subsidence, combined with the less or no maintenance, provokes serious leaks in the water supply system.

Nowadays, the water supply system in not sufficient to fulfil the demands of the city. The city’s water management policies and practices grossly under serve a significant portion of the population, with informal and low income communities on the eastern edge of the city particularly vulnerable to the city’s looming water shortage.

As a subsidized commodity, drinking water is relatively cheap for the inhabitants, this causes the misuse and waste of the resource.

82% of the population receives indoor running water. This percentage drops to 50% in informal settlements.

Primary Network: 1.048 km
Secondary Network: 12.278 km
Water treatment plants: 34 with a capacity of 2.117 litres per second operation
Chlorinators Plants: 12
Wells in operation: 614

Fresh water supply

Total 81.9 m3/s
aquifers 59.5 m3/s
river springs 2.7 m3/s
importation 19.7 m3/s
Chalco-Amecameca aquifer 1.78 m3/s

Water use

46%
domestic use 37.7 m3/s
17%
agricultural and industrial use 13.2 m3/s
37%
system leaks and illegal connections 30.3 m3/s
about 40% - 130 lt/person/day - enough for 4 million people per day
Sewage system and water reuse

Throughout the city, a network of surface canals currently conducts storm runoff, along with domestic and industrial liquid waste, to the main drainage canal in the north of the city. A set of deep drainage tunnels has subsequently been added to the northern drainage system to handle the increasing flow rates. The primary reason for the increasing flow volumes in the drainage system has been the progressive increase in local groundwater extraction rates, and the introduction of additional water being brought into the Basin through pipelines from distant reservoirs to handle the increasing water demand.

Primary Network: 2.107 km
Secondary Network: 10.237 km
Deep drainage system: 166 km
Pumping stations: 87
Pumping plants overpasses: 91
Electricity consumption: 100,000 KW capacity produced by power plants
Storage dams: 21
Dams, lakes and lagoons of regulation: 133 linear km of open-air channels and 49 linear km of enclosed rivers

Open sewage canals crossing the city.
Source: (Burdett, 2007)
Land subsidence and flooding risks

Flooding risks from surface water in the city persist despite the advanced system to drain the basin, during summer the risks of flooding increase. The flood prone areas are related to the land subsidence caused by the overexploitation of aquifers. Therefore the central and the south-east areas are today the most vulnerable to floods.

Groundwater extraction at the southeast of Mexico City, is causing one of the more important environmental changes of the landscape within the Basin of Mexico in the last two decades. In the middle of the plain of the Chalco-Amecameca sub-basin, land subsidence of 40 cm/year has occurred as a result of the transient aquitard response to pumping in the underlying main aquifer. A new lake is developing in this topographic depression due to the accumulation of surface water. The New Chalco Lake surface is located 12 m below the original position of ground surface, covering a total extension of 1,000 ha. (Ortega and Ortiz, 2007).

As shown on the map, it seems that the lakes are regenerating themselves, recovering the land that once belonged to them. The water is looking for more space in this city, collapsing the city during the rainy season (June to August) and threatening today urban areas.
Settlements [Types of occupation]

The physical extension of the city is the result of the concentric growth of the core. The metropolitan configuration has evolved from a polycentric organization towards a mono-centric structure. The centre reached and overtook satellite ancient villages and towns.

The way of differentiating living spaces in the city has been made by recognizing the relationship between the processes of production of the built areas, their spatial characteristics and the social characteristics of residents. The origin of the urbanization of each area has been determined by two basic criteria: urbanization date and form of production of the residential space. For each occupation type there is an approximated correspondence with the density, level of services, socioeconomic strata of the inhabitants, heterogeneity level between inhabitants and the mixture of land uses.

The way of producing the urban space determines, to a great extent, the spatial qualities and posterior evolution. It is estimated that 30% of the total urban surface corresponds to the ‘popular neighbourhoods’ type of occupation. This kind of settlements are produced by popular modes of settlement, through direct intervention of private, social and public developers, regardless of regular or irregular status of land tenure. The degree of consolidation of this type of settlement varies; as time passes, these neighbourhoods experience a double process of improvement of infrastructure and housing, while increasing density. This kind of settlement can be found in all sectors of the city, but certainly in higher concentrations to the east, where historically the poorest groups have settled.

Across the metropolitan area, the ‘popular neighbourhoods’ contain little more than half of the population (51.5%) and 50.5% of the total number of dwellings; this percentage slightly lower reflects the higher housing density in these neighbourhoods. Almost a quarter of the metropolitan population lives in ‘popular neighbourhoods’ built between 1953 and 1970, rather than the neighbourhoods built during the next twenty years, home to 20% of the population (Connolly, 2005).

Vulnerable groups ‘popular neighbourhoods’ were identified and mapped in terms of population and housing characteristics by doing a cluster analysis with data from the 2000 official census. [See map below]. The Census data are coded, for all variables, in Primary Sampling Units (PSUs) or territorial units called by Mexican official census institution basic geo-statistic areas (AGEB’s which stands for Areas Geoestadísticas Básicas) (World Bank, 2011).
Urban structure

At the metropolitan level in the analysis of the urban structure the existence of historical and structural factors that have moulded the city need to be understood in order to achieve social and environmental objectives. As explained before within the historical morphological analysis of the city, demographic and socioeconomic conditions have had a major influence on the overall urban growth and land use of the territory in Mexico City Metropolitan Area. The structure of the city is clearly a centralized structure. There is a privileged supply of goods and services located in its central part. Work supply is also concentrated in the centre, specially the service sector, causing long commuting times, worsening traffic problems and saturating public transport systems.

Peripheral zones where several homogenous areas (informal settlements) in terms of their morphological attributes can be identified are the less privileged, added to the bad accessibility to the centre in which most of the services and equipment are located. The industrial sector is located mainly in the north part of the city, an important fact that detonated significant urban expansion to this area. To the west part, Santa Fe, the main corporative and business centre is being developed since the nineties, generating a new area of development for high purchasing power groups.

The ecological network

Mexico City Metropolitan Area over the past fifty years has taken over almost every available surface. The city developed without adequate green open areas. Nowadays the city counts with only 1.94 m2 of green areas per inhabitant, which is well below the 9m2 per capita recommended by the World Health Organization. Large rural areas around the city still remain as agricultural land with high and medium productivity. Sixty nine percent of the eastern region is occupied by forestall and agricultural land use.
Infrastructure

a. Basic services

The areas inside the Federal District limit, the wealthier areas, have better overall living conditions compared with the adjacent municipalities of the State of Mexico. The evolution of the management of water and wastewater systems must be seen parallel to the rapidly expanding metropolitan area during the last decades. The provision of all services, including water supply and sewerage has been a challenging task for authorities from different levels of the government. The latter have not been able to cope with the increasing demand because of lack of planning and political interference. As the city grew these infrastructure was left behind, until today new infrastructure projects are on their way to serve the peripheral areas.

b. Road infrastructure

The road network has been essential for the evolution of the city, it represents an important part of its urban structure. The road network is determined by the superposition of two layouts: an orthogonal trace maintained from ancient times and the one overlapped in the middle of the last century, with a radial configuration. The accelerated growth of the city has caused deficiency of the network, translated into big traffic problems. The average daily commuting time either by car or public transport is on average around 2 and 3 hours. The city has a long way to go towards sustainability. It is currently car-dependent with a vehicle fleet of 2.9 million cars (Burdett, 2007). The excessive use of cars results in extremely high pollution levels and massive road infrastructure result in the spatial fragmentation of the city and eventually, social segregation.
c. Public transport

Mexico City’s infrastructure systems have failed to address the implications of rapid growth and change. The modes of public transport are distorted and disintegrated because high capacity network public transport –subway (metro), buses and trolleybuses– have not been able to form the public transport backbone. Instead concession services such as minibuses and collective taxis had proliferated and compete with themselves causing sometimes an over supply of the service and big traffic and polluting problems.

The metro system was state of the art when it was built, but has failed to adapt to what has been going on around it and the city has outgrown it. Containing 180 km of tracks with the 12th line currently under construction, the metro system serves 29.1 million passengers daily (Burdett, 2007).

The more recent ‘Metrobus’ BRT project (Bus Rapid Transit System), has been realized during the past 5 years and new lines are scheduled for the near future, today it serves 315,000 passengers (Burdett, 2007). Another recent project is the suburban train, two lines are already in service to the north part of the city however, the line three that was meant to serve the south-east area is on hold since 2009.
a. Hydrological metropolitan imbalance

The lack of integration of environmental factors in the planning and decision making processes during the growth of the city caused the current hydrological metropolitan imbalance. Increasing urbanization and high population density in the MCMA has produced important water challenges such as water scarcity, groundwater overexploitation, land subsidence, the risk of major flooding, poor water quality, inefficient water use and a low share of wastewater treatment.

Nowadays, 77% of the water used in the Basin of Mexico comes from underground sources, and two out of every three cubic meters extracted come from overexploitation. Land subsidence, cracks and cavities are signs of the need to reduce the volumes extracted (Barragán, 2009). The other percentage of used water comes from long distances causing enormous costs and loses. It is estimated that the lost water due to leakages in the network would be enough to provide the service to 4 million people more, as 40% of water is lost for this reason (Tortajada, 2006).

Determining aspects of the current water management model in the Basin of Mexico City include the massive export of waste water, aquifers overexploitation and importing water from other basins. To this is added the increasing urbanization of recharge sites. The current model is based on the extraction, use and disposal of water, a linear system that is reaching its limits (Barragán, 2009).

Furthermore there is an enormous imbalance between water availability and its use among the different regions within the MCMA. The uneven distribution and use of water between rich and poor areas makes more obvious the economic and social inequities between regions. Population wastes enormous amounts of water, people living in wealthy areas use up to 600 litres per capita per day, while the corresponding rate in poor areas is about 20 litres (Tortajada, 2006).

There are important social and energetic costs of the current water resources management in the Basin of Mexico. One of the key contradictions is the transportation of rainwater surplus from the south to the north keeping it from the local inhabitants that are the most needed. There are also crop loses in these areas from the lack of water. The transportation of water also mean going through the metropolitan area over 23 km by pumping wastewater combined with rainwater on counter slope through open-air sewage canals with high and growing risks and enormous energetic costs (Barragán, 2009).
### MCMA water cycle

- Rainfall: 215 m$^3$/s
- Evaporation: 159 m$^3$/s
- Free drainage from rain: 23 m$^3$/s
- Re-use: 5.7 m$^3$/s

Additional flows:
- Domestic and non domestic residual drainage: 51.1 m$^3$/s
- Total residual drainage: 74.1 m$^3$/s

### MCMA water imbalance

- Aquifer exploitation: 40 m$^3$/s
- Aquifer natural recharge: 19 m$^3$/s

### Chalco-Amecameca sub-basin water balance

- Aquifer exploitation: 8 m$^3$/s
- Aquifer natural recharge: 6.5 m$^3$/s

Source: Map By Author based on diagram of Barragán, P. M., 2009.
b. Spatial fragmentation & social segregation of peripheral informal settlements

The contemporary fragmented urban reality of the Mexican capital city is the result of the implementation of planning and management policies following a Neoliberal framework. The dissolution of social housing and the prevalence of low density and periurban sprawl, have had spatial consequences upon the urban, creating uneven geographical development. Those policies are the cause for its spatial, social and jurisdictional fragmented state. Kozak (2008) refers to the contemporary Latin-American city as a 'city of fragments'. He states that identifying the urban transformations that Latin-American cities have experienced in the past decades requires a clear understanding of the concept of urban fragmentation as a spatial phenomenon.

The urban reality of the city is a consequence of the coexistence of two extreme opposite models of development. At the one end the top-down planning model taken over by powerful private development companies envisioning profit maximization. This model implied minimum involvement of conflicting interests, as well as reduction of city’s complexities to rational models and forms planned as absolute, without the possibility for inhabitants to contribute anything in their own reality. The developments under this model have been profit driven and spatial, environmental and social issues have been neglected. On the other hand the informal had organized the city out of the bare necessity to create their living environment limited by economical possibilities as well as restricted knowledge and expertise. With the retreat of the welfare state the informal has taken unimaginable dimensions in Mexico City, today its urban south east periphery hosts the largest ‘megaslum’ in the country with 4 million people (Davis, 2007).

The characteristics of the housing market are the main cause of growth of the peripheral areas and the continual pushing of the population with fewer resources on the outskirts of the city. It is there where the urban poor have found cheaper housing within illegal subdivisions on communal land property. Although illegal, this method of urban development has become institutionalized to the point that for the poor, illegality is the most ‘rational’ appropriation of urban space. Legalization processes undertaken by public authorities in Mexico represent a public recognition for this low-income group.

Mexico City retains a strong mono centric form but its uncontrolled growth over the decades has led to many new centralities and polycentric forms at its peripheries. From past research it has been concluded that there cannot be an equitable integration of polycentric centralities in a megacity without an efficient mass transport system; if the transport system is not accessible to a large proportion of the population it may increase inequalities and fragmentation, this is the case of Mexico City where its polycentric form largely represents a process of fragmentation from a greatly ineffective integration of a transport scheme.

Historically, urban segregation in Mexico City was caused by topography and colonial land use, with the flood-prone areas to the east of the city being occupied by the lower classes. The most critical housing conditions are in the newer or unconsolidated irregular settlements, or colonias populares, resulting from
Unauthorized land development and construction, with deficits in urban services, often in high-risk areas and with dubious property titles. Most settlements have been improved to varying degrees as property is regularized, infrastructure and services put in and houses solidly built. Irregular settlements constitute roughly half of the urbanized area and house more than 60 per cent of the population (UN-Habitat, 2003).

Spatial fragmentation and social segregation can be materially perceived in the peripheries of Mexico City. Valle de Chalco Solidaridad is a municipality that clearly represents an eviction zone spatially and socially segregated from the rest of the city.

Introduction

The municipality lies on the old bed of Lake Chalco, which was substantially drained in the nineteenth century. The municipal seat is Xico, after a high point of land that once formed an island, and now remains as a small hill within an otherwise monotonous urban expanse. ‘Chalco’ refers to the Chalca tribe, whose territory covered the area around the lake, prior to the Spanish Conquest of Mexico.

Valle de Chalco is a municipality of the State of Mexico, considered part of the Mexico City Metropolitan Area, created during recent years and officially founded in 1994, following massive settlement in the agricultural neighbouring municipality of Chalco. In this territory, agricultural land was originally appropriated after the construction of el Gran canal during the 19th century. After the Mexican Revolution, the haciendas and other large agricultural properties were expropriated and distributed as ‘ejidos’ or agrarian communal properties to the local communities. By the late 1970’s Mexico City’s growth began to affect the Chalco area. On one hand, the demographic growth of the local communities meant that agriculture was increasingly unfeasible as a mean of subsistence, on parcels of ejidal land averaging 1.7 hectares per household. On the other hand demand for housing meant that the illegal sale of this land was an attractive proposition.

In the case of Valle de Chalco, before 1984 many of the transactions were not handled by the land owners themselves but by professional intermediaries or developers who bought the land from the individual owners, parcelled it out into lots of mostly between 120 and 250 square meters and sold them on credit. By this means the settlement process began between 1970 and 1980, when the population of the area almost doubled from 44,000 to 82,000 inhabitants, living in eighteen neighbourhoods. During the following decade the population increased about 220,000 reaching over 323,000 inhabitants in 2000.

The state embarked on an extensive regularization process; in 1998 90% of the plots in Valle de Chalco were already regularized. Once this was underway, material improvements to the area were financed by the new federal poverty programme Solidaridad, which invested 407.9 million pesos (about US$160 million) between 1989 and 1993. Basic services such as street lighting, water infrastructure, schools, electrification, hospitals, pavement and main drainage were provided to the area. However, this regularization of tenure, public works and social investment programmes, as well as influx of national and international NGO’s and religious groups was not reflected in the 2000 housing indicators where: 78% of the dwellings had no inside tap; 40% had corrugated cardboard roofing and 20% had only one room. Today, Valle de Chalco still has some of the worst housing conditions in Mexico City.

During the last three decades the provision of basic services like drainage and water supply for households in most of the peripheral sub-centres had a general improvement. However, Valle de Chalco was one of the exceptions where the situation in 1990 was much worse than in 1970, the speed of population growth was way ahead the provision of services. The growth of Valle de Chalco was due in part to the chaotic expansion of the metropolitan area. Thus, it is not surprising that only the youngest
members of the families were born in the municipality. Most of the current residents come from another town in the Metropolitan Area. They come particularly from Iztapalapa borough of the Federal District and from the municipality of Nezahualcóyotl of the State of Mexico, residents also come from other states of the country: Oaxaca, Puebla, Veracruz and Hidalgo. A basic reason to feel involved in a place is to be born in it, this may help explain the widespread disaffection and no sense of belonging in the territory.

It has been recognized that the main reasons to establish residence in this municipality is basically due to the fact that previous home was rented or borrowed, the interest of home ownership and the desire to establish a family or wanting to live alone were reasons to come to live here. In Valle de Chalco, there is a type of social subject with a history of life characterized by high territorial mobility that, despite its current place of residence they do not feel any attachment to it. In this sense, all suggests that poverty is an element that stops the social participation and building a sense of belonging.

The inhabitants of Valle de Chalco, despite not feeling comfortable in their place residence, they share some emotional ties to it, in particular with their homes. Building their own houses however, did not bring together the sense of belonging or place identity. In general social relations of the population are limited to their closest relatives. The long hours they spend commuting to their place of work and unrest in the neighbourhood do not help the link to a supposed community. The complications between the desired reality and sense of identity can be associated with the difficulty of the need to feel comfortable in an actually complicated reality, as the periphery of the city.

![](Valle de Chalco Municipality.jpg)
Source: Photo by author

![](Xico crater.jpg)
Xico crater

The crater in the centre of the municipality, landmark from the south region, serves as a boundary between water, urban sprawl and an enormous void of unproductive land in the limit with the neighbouring municipality of Chalco. The name of this crater is 'Xico' that in Nahuatl means navel of the earth. Its presence suggests the intervention of its surroundings to prevent that urban sprawl takes over its natural character and current use as agricultural land.

Source: www.imagenesaereasdemexico.com
Municipality Valle de Chalco
<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>Population growth</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>219,773</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>287,073</td>
<td>67,300</td>
<td>5.34</td>
</tr>
<tr>
<td>2000</td>
<td>323,461</td>
<td>36,388</td>
<td>2.39</td>
</tr>
<tr>
<td>2005</td>
<td>332,279</td>
<td>8,818</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Source: INEGI 2005

The forecasted population for 2010 was 406,521 inhabitants and for 2020 it is expected almost to double to 745,622 inhabitants.

Surface = 4636 ha
Average density = 150 inhab/ha

According to INEGI in 2005 there were 77,323 dwellings from which: 4.48% had no access to water, 5.46% had no sanitation and 4.10% had no electricity.

Today there is an approximate of 87,612 dwellings in the territory with an average of 4.64 inhabitants per dwelling.
Why Valle de Chalco Municipality?

The contradictions of the metropolitan water resources mismanagement become visible at the local level. South-eastern peripheral settlements are very poor and therefore the most vulnerable areas to water threats. Permanent ecological deterioration, increasing ground subsidence, poor sanitation and inadequate policy responses are realities of this area. Moreover Valle de Chalco is a municipality that clearly represents an eviction zone spatially and socially segregated from the rest of the city.

Continual flooding in Valle de Chalco is the result of the complex interaction between urbanization in an ex-lacustrine area. Paradoxically the location hosts different urban problems related to water:

[1] On one hand inhabitants, mainly low-income families, live in constant risk as the area has been inundated with waste water two times in recent years (2000 and 2010). Floods were caused by the rupture and discharge of La Compañía Canal, an open-air sewage canal that collects domestic wastewater from two municipalities in the state of Mexico: Valle de Chalco and Chalco (Aragón-Durand, 2007). The people in this area were severely affected and unable to cope with the disaster caused by the mismanagement of the

[2] On the other hand part of the population living in this area does not have access to basic services such as water supply and drainage, since the provision of services has lagged behind the speed of population growth.

[3] Furthermore part of the urban area from this municipality is in high risk of flooding from the new lake emerging from the accumulation of rainwater on the lowest part of the sub-basin. On the following pages the evolution of groundwater extraction leading to ground subsidence causing the emergence of the new Chalco Lake is further explained.

Valle de Chalco Flooding in 2010.
Source: González de León, Teodoro & Kalach, Alberto, 2010
Evolution of groundwater extraction from Chalco-Amecameca sub-basin

The Chalco-Amecameca sub-basin is a territory lying in between political borders of Mexico City and the State of Mexico at the south-east part of the Basin of Mexico. This was the place where one of the last remnants of the former Xochimilco Lake was until the early XX century when it was completely drained.

In the beginning of 1940’s the pumping out of groundwater started for local agricultural and urban use. The south part of the lacustrian aquitard was an area for the groundwater discharge of the water coming from the Sierra de Chichinautzin at the south of the sub-basin before the intensive groundwater extraction in the 1950’s.

The first wells constructed to provide fresh water for Mexico City were drilled in the basaltic aquifer in the foothills of the Sierra de Santa Catarina Chichinautzin in the early sixties. The springs located at the foot of the Sierra de Chichinautzin disappeared accordingly. In 1975 the total extraction in the Chalco sub-basin was about 5 m3/s. In the early eighties fourteen deep wells, called Mixquic-Santa Catarina System were drilled in the plains of the ancient Chalco lake at depths of 400 m, to meet the growing demand of fresh water of the Mexico City Metropolitan Area.

From 1984 these wells have contributed between 1.4 and 1.75 m3/s to the MCMA. The total amount of groundwater extracted in the Chalco sub-basin was estimated at 7.75 m3/s in 1988 and in 1991 was estimated at almost 8 m3/s against an estimated recharge of 6.5 m3/s. Today from the total aquifer extraction 59.5 m3/s for the city, 3% is extracted from the Chalco-Amecameca aquifer.
Land subsidence in Valle de Chalco territory

The New Chalco Lake

As a result of the continual groundwater extraction at the Chalco-Amecameca sub-basin the aquitard has been consolidated. The subsidence recorded in the land surface, are due to the contribution of groundwater from the aquitard to the underlying aquifer, which results in a volumetric change of highly compressible sediments (Ortega & Ortiz, 2007).

The elevation from the Chalco sub-basin in the beginning of the 1970's where the lacustrian plain was practically flat and did not had significant influence of subsidence influenced by pumping. The elevation at the centre of the plain was 2240.3 meters above sea level. In the late 1970's reported elevations were between 2 237 and 2 238 masl. within the area, indicating an average land subsidence between 0.10 and 0.15 m per year induced by groundwater local pumping prior to the construction of the fourteen wells of the Mixquic-Santa Catarina System.

After the start of the system in 1984, the vertical deformation field was clearly differential, being higher in the middle of the plain and progressively lower towards its lateral limits. This rapid differential subsidence led to the formation of a topographic depression located approximately in the centre of the plateau, which is forming a new lake from the accumulation of rainwater that does not flow by gravity through the channel system in the area.

The magnitude of the vertical deformation of the territory in the Chalco sub-basin has already exceeded the resulting subsidence after one century of overexploitation of the aquifer in the downtown area. On this basis, the centre of the Chalco plateau is today one of the lowest topographic levels in the Basin of Mexico.

Based on the controls and magnitude of the regional land subsidence, it is expected that the lake surface will grow about 1500 ha by the year 2015, increasing the risk of flooding to the urban areas of Valle de Chalco Municipality. Urban areas within a radius of 2.5 to 3 km with centre in the well P9 of the MSCS Mixquic-Santa Catarina System are considered high risk areas (Ortega & Ortiz, 2007). The neighbourhoods in Valle de Chalco at highest risk are: Américas I, Américas II, María Isabel, Niños Héroes, Alfredo Baranda, San Miguel Xico (sections 1 to 4) an approximate of 15,000 families.
Land subsidence values range from 0 m to -13 m. Non-subsidence occurred toward Sierra Santa Catarina, but from there progressively increasing subsidence occurs toward the middle of the Chalco Plain. The New Chalco Lake follows the -12 m contour. Maximum total subsidence of 13 m occurs at the south and may extend toward the bottom of the lake (Ortega & Ortiz, 2010).

The New Chalco Lake has worked in certain extent as a limit for urban expansion and environmental control. It was declared a water sanctuary and ecological reserve in 2004.

The New Chalco Lake in Chalco sub-basin. Source: Map and graph by author based on (Ortega & Ortiz, 2007).
**Hydrology**

The municipality is located in a runoff area from the surrounding hills. In the past important channels came to the territory, these channels have been disappearing due to upstream towns which have drained them. Currently there are three major rivers in the area which have been transformed into open-sewage channels.

1. La Compañía canal responsible for conducting the wastewater from the municipality and the other 3 neighbouring ones.
2. Acapol canal which drains the western part.
3. The Amecameca River which drains the southern part of the municipality, reusing the water in the agricultural zone, resulting in a serious risk of infection for consumers of these food.

**Topography and soil type**

The municipality of Valle de Chalco Solidaridad has a flat topography, its soil is formed by volcanic sediments, lacustrine or alluvial deposits, with high salt content (calcium and sodium carbonate) due to prolonged dry period suffered by the region. The slope found in the town is minimal (0.07%) from north to south, the existing soil type in most of the land is silt, clay and sandy. These soils have a high compressibility, showing an average resistance of two tons per square meter, these clays absorb large amounts of water, increasing to twice its original volume, which is reduced to a quarter when completely dehydrated, causing cracks in the ground.
Sewage network

The two open-air sewage canals crossing the municipality pose a great threat to the municipality. The contamination of agricultural soils with wastewater has caused soil erosion that results in dust storms causing respiratory diseases. Land slides from the two mountains (Cerro del Xico and Cerro del Marques) are also important risks.

Due to the lack of connection to the sewage system 62,119 inhabitants pour their sewage water to the Acapol river and the regulating lagoons.

The municipality pours 16.07 million m$^3$ per year to La Compañía open sewage canal. The overflowing of the canal has caused serious floods in the past years. The need to pump the sewage water out of the territory made necessary to build 14 pump stations (suction pits) along the Acapol and La Compañía open sewage canals. The risk of overflowing of those canals increases during the rain season.

Fresh water network

The fourteen regional wells from the Mixquic-Santa Catarina System causing the land subsidence of the area do not provide any water to the municipality. The water for the local consumption comes from 7 local wells at 400m depth, 710 lt/s are extracted and water is also brought from other municipalities. There are also 3 more illegal wells in the agricultural area. Fresh water supply is one of the major problems of the municipality, the wells functioning today have only 8 more years before they start being overexploited. The water supply covers 91% of the population, the dwellings which are not connected to the network are served by municipal pipes.

Fresh water network in VDC.
Source: Map by author based on H. Ayuntamiento de Valle de Chalco Solidaridad, 2005
Connectivity

For this research the analysis of the urban structure is a way of understanding the impact of the fragmented structure on the way inhabitants use and perceive the built environment to search for interventions that considers the importance of mobility and diversity (Sepúlveda, 2003).

Connectivity is understood as the way in which the area is connected to the rest of the city [the higher system]. Connectivity needs to be analysed to define problematic discontinuities and recognize possible linking opportunities.

The municipality shows a high dependence of large scale commercial services and sources of employment located in the Federal District and the west area of the State of Mexico. The map shows the location of those commercial functions (malls and supermarkets) on a larger scale that are most likely to be used by the inhabitants of the municipality of Valle de Chalco.

The main routes of public transport [buses, vans, minibuses and taxis] used by the population are the ones going to the nearest metro station to the north and to the neighbouring municipality Chalco, in order to get to their work places. The average commuting daily time is between one and two hours. There is one new metro line in construction going to Tláhuac borough at the west side of the municipality, it is planned to be finished in 2012, a potential connection for the area.

On the next page the map shows the area in relation with the regional level. The territory is crossed by a railway line for regional distribution of goods that is only used nowadays once a month going to the neighbouring state of Morelos at the south of the MCMA.

There are 3 regional roads connecting the municipality with the rest of the city. The most important one is the highway crossing the municipality at the north going to the State of Puebla.

Urban Structure Map
Source: Map by author based on H. Ayuntamiento de Valle de Chalco Solidaridad, 2005
Regional Exits of Mexico City.
Source: Map by author based on Raful, A., 2009
Local transport mobility

There are three types of local roads: main roads crossing the territory north-south, east-west, secondary roads dividing the neighbourhoods and neighbourhood streets. At the moment only 50% of the roads in the municipality are paved [main and secondary roads]. The sidewalks are too narrow and therefore the people usually walk on the streets. There are no bike lanes although bicycle is really used in the area. Only 30% of the population owns a car, therefore walking, bike, taxi-bike, small vans, and small buses are the most likely ways of moving inside of the municipality.

Source: Map by author based on H. Ayuntamiento de Valle de Chalco Solidaridad, 2005

Main road profile - Alfredo del Mazo

Secondary road profile

Neighbourhood street profile

Taxi-bike stop

Small van stop

Road network in VDC
Land use

The urbanized area has in total 2547.97 ha with predominantly medium density with commercial: one house each 120 m². More recent urban growth presents low density: plots of 200 to 300 m². The territory of the municipality is organized in 35 neighbourhoods and 1 municipal head. Existing housing in the municipality has been built through self-construction in most cases, there is only one middle-class development known as La Asunción at the north and 2 other are under construction at the moment at the south at the Cerro del Marques.

Housing types:
Independent houses 86.56%
Apartment buildings 1.53%
Enclosed popular dwelling 9.23%
Private housing developments in progress

The industrial area is located on the north part of the municipality. The rest of the territory has an agricultural use, in the southern part of the municipality from Tláhuac-Chalco highway, and the west area from the canal Acapol to the limit with Tláhuac borough.
Urban Facilities

There is a lack of public space in Valle de Chalco; the streets are intensively used as public space to host open markets and community parties. The municipality lacks of green infrastructure needed for a healthy environment. The total green and recreational areas in the municipality are 59.55 ha, only 1.52% of the territory. Those available public open spaces are concentrated in the centre of the municipality, therefore they are not easily accessible to all the people.

There is a need for more urban infrastructure for all levels of education and for more recreation areas and sport facilities. As shown on the map below urban facilities in the territory are well dispersed for each neighbourhood, however there are non physical connections between public spaces.

The urban centre where the Municipal Government’s offices are located act as the municipality’s urban centre. Commercial activities are highly integrated along main roads acting as urban corridors with higher density [3 stories maximum].

Urban Facilities in VDC.
Morphology and density

The municipality shows a very rigid and organized morphological structure. The spatial configuration shows no relation between the different levels of this structure: house, plot, block, street. The morphological structure of blocks does not include collective places.

The density per plot is still low 4.64 inhabitant per dwelling; although it is true that families have used an intergenerational densification strategy of ‘nesting’- building separate housing structures on their plot on an informal basis for additional extended household members. Second and third generations are building their houses on the same plot; not complying with the 20% minimum open space required by the municipality.

Each block has between 20 and 30 plots.

Plot sizes: 
- 7 x 17 = 120 m²
- 10 x 20 = 200 m² [more recent areas]
- 3 x 20 = 60 m² [housing developments]

Each plot has between 60% and 80% of built area. The open space of each plot is a ‘private patio’ surrounded by walls, therefore it is not part of the green structure of the Municipality.

Urban morphology in VDC.
Source: Map by author.
a. Age: The population aged between 1 and 24 is 57%, which shows an extremely young population structure, the percentage of people aged 25 to 49 years is 31%, resulting in a municipality with a slow aging process and increased demands for jobs and specialized services.

b. Education: In terms of education metropolitan expansion has meant a worsening in education levels of the population of these sub-centres. Two main hypotheses have been linked to this fact. First, most educated people moves away towards more central urban areas of Mexico City or other cities, being replaced by a more rural in origin and lower-educated migrants. Second, economic constraints have forced young people to leave school and start to work. The result of both processes is the deterioration of human resources of the population. The illiterate population in the municipality of Valle de Chalco accounts for 12,263 inhabitants.

Informality related to illiterate population in MCMA. Source: Map by author based on INEGI, 2005.
Job types:
Manufacturing industries 3,434 employees
Wholesale 903 employees
Retail Trade 10,871 employees
Media information 11 employees
Real estate, renting 332 employees
Professional, scientific and technical 200 employees
Educational Services 615 employees
Health and social care 558 employees
Temporary accommodation services and food preparation 1,613 employees
Other services except government activities 2,154 employees

Source: INEGI 2005

Economic: The dispersion of manufacturing activities from central city areas to the periphery and changes in the mix of dominant industrial activities are the two principal economic changes in the metropolitan periphery. From 1970 to 1990 the eastern periphery showed a substantial increment of industrial activities; however these activities are associated with the emergence of illegal large low income settlements. The latter was the case of Valle de Chalco, where small scale manufacturing activity was informal and part of economic survival strategies for the poor. The activity was concentrated in micro-enterprises located in households and workshops.

The level of income referred to in the municipality, is low relative to the State, the majority population receives an average of one to two minimum wages, this represents 43.47% of the economically active population, second are those who earn between two and five minimum wages 34.80%. Only 0.92% of the population receives more than 10 minimum wages. The educational levels of the population makes difficult to create better paid opportunities. It is important to say that the municipality is located in the economic region “C”, where the minimum wage is the lowest nationwide [56.70 MXN = 3.53 EUR].

With respect to labor market, it is estimated that one third of jobs in the east peripheries of Mexico City, where Valle de Chalco is located, are salaried, low-wage, unstable and unskilled. No pay, no steady job, no social security and no unemployment benefits, the poor in the peripheries are increasingly more isolated and more socially excluded. There is no enough industry or services, so that most residents have to travel to the city centre or to other parts of the metropolitan area for work, travel time varies from one to two hours. This lack of jobs suggests that many young people this municipality see international migration opportunities as a possible option, despite difficulties in crossing to the United States border illegally. However, international migration is not motivated by an idealization of the neighbouring country, but rather because of the urgency or need to leave Mexico for basically economic reasons.

Inactive population 32.39% [housewives working at their home 50.06%]
Economically active population [EAP] 114,066 inhab.
34.33% of the entire population
Primary sector - extraction and production of raw material 0.39%
Secondary sector - transformation of raw or intermediate materials into goods 52% (manufacturing and construction in other places)
Tertiary sector - provision of services to consumers and businesses 44%
Job deficit for economically active population 93,373 inhab. 81.86%

In regard to the distribution of the EAP per sector it appears that the primary sector is wasted in the municipality, there are currently 440 people dedicated to this activity, which means 0.39% of the EAP, but the 43.17% of the land is agricultural. The dominant sector in the municipality is the tertiary sector, focusing mainly on trade. It has now began to see the deterioration of this activity because most vendors sell the same products and there is no product that is representative of the municipality.

Local commercial activity and housing conditions in VDC
Source: Photos by author
In order to define strategies for the Municipality the first step was to conduct a SWOT analysis of the three previous analysis presented.

Based on the results, a matrix of the synergies from the three analysis helped me define potentials and constraints of the territory which are presented on the following pages.

Those potentials consider the existing conditions that may offer opportunities for transformation and may be turned into development strategies for the municipality.

<table>
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<th>Matrix Synergies</th>
<th>Constraints</th>
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<td>Forms of Production</td>
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### 4.4. Local Diagnosis

![Matrix of Synergies and Constraints](image)

- Topography
- Soil Type
- Land Cover
- Water Flows
- Connectivity
- Regional
- Local
- Urban Form
- Density
- Municipality
- Neighbourhood
- Block | House
- Public Space
- Land Use
- Age
- Education
- Income
- Forms of Production
SWOT TERRITORIAL ANALYSIS

STRENGTHS
- Remaining natural surroundings of the municipality

WEAKNESSES
- Flat topography
- Low permeability of soil

OPPORTUNITIES
- Open spaces and non paved streets
- The risk from the emerging lake to start transformation of the area

THREATS
- Flooding risk from the New Chalco Lake
- Flooding from rupture of open air sewage canals
- Air pollution and dust storms
- Land slides

SWOT MORPHOLOGICAL ANALYSIS

STRENGTHS
- Cohesive urban form at neighbourhood level

WEAKNESSES
- Low connectivity regional and local
- Lack of quality public space at all levels
- No spatial connection between existing public spaces
- No connection between blocks

OPPORTUNITIES
- Homogeneous urban pattern
- Empty spaces now related to crime
- Wide street profiles
- Railway crossing the municipality

THREATS
- Uncontrolled densification
- Spatial fragmentation from highway, railway and sewage canals

SWOT SOCIO-ECONOMIC ANALYSIS

STRENGTHS
- Self-building skills from the population
- 90% of VDC households have security of tenure on their properties

WEAKNESSES
- High dependency on jobs at city level
- Lack of local modes of production
- Worsening in education levels of the population
- Disaffection, lack of identity and no sense of belonging

OPPORTUNITIES
- Extremely young population structure
- Only 30% of the households owns a car - pedestrian and bike sustainable mobility

THREATS
- High unemployment rate and job insecurity

Natural surroundings, urban area and self-construction in VDC.
Source: Photos by author
Potentials

At city scale:

+ Existing railway crossing the municipality, nowadays it is only used once a month by freight trains.

+ Existing regional highways and close centralities.
Potentials

Based on a space syntax map from the Municipality, local integration of the street network was analyzed. The most integrated streets and roads have red and orange colours, followed by yellow colours, while the most segregated streets have blue colours.

Two potentials are:

+ Under utilized street network: only 30% of the households owns a car, there is potential for pedestrian and bike sustainable mobility.

+ Axis of local continuity crossing the municipality intersecting main commercial roads, those intersections are potential new centralities.
Potentials

Water strategies:

+ Open spaces at the borders and inside the municipality (schools) are potential areas for water strategies.

+ The streets are the spatial elements with more potential for water strategies, they are the only available open space within the urban area.

+ Security of tenure represents an advantage to convince people to capitalize on their own property [e.g. water tanks, water-saving bathroom fixtures and accessories].
Constraints

Morphology | Density

- Morphological structure without collective open spaces.
- Limitation of space for water related strategies [water retention] at plot and block level because of private property of the land.
- Uncontrolled plot densification, diminishing open spaces.

Environmental constraints

- Risk of pluvial flooding
- Risk of overflow and rupture of open-air sewage canals
- Land subsidence risk [expected growth of existing lake]

Socioeconomic constraints

- Difficult economic situation has a direct impact on the residents’ ability to invest in housing and infrastructure improvements.

Source: Map by author based on Ortega & Ortiz, 2007 and data from METROPOLI 2025, 2011.
<table>
<thead>
<tr>
<th>ASSET</th>
<th>OBSTACLE</th>
<th>OPPORTUNITY</th>
<th>POTENTIAL SOLUTION</th>
</tr>
</thead>
</table>
| LABOUR                | [-] Long commuting to working places because of limited and chaotic public transport  
[-] Very low level of income  
[-] Large part of the population is part of informal economy | [*] Manufacturing local industries  
[*] Existing railway line | [+ ] Provide adequate skills training for urban agriculture  
[+ ] Stimulate local entrepreneurship by micro-credit schemes by NGO’s  
[+ ] Reorganize local and regional transport systems and implement new Light Rail System towards closest metro station |
| HUMAN CAPITAL         | [-] Low education levels  
[-] Respiratory diseases related to open sewage canals and dust storms  
[-] Inability to provide safe, clean water, less consolidated areas without provision of sewage and water | [*] Improve quality of existing underpopulated schools and improve access to higher education | [+ ] Provide new educational infrastructure for new skills training program  
[urban agriculture, wastewater treatment]  
[+ ] Provide adequate, accessible low-costs health care  
[+ ] Provide credit for education expenditures  
[+ ] Rainwater harvesting and Decentralised stormwater and wastewater management [community based] |
| PRODUCTIVE ASSETS     | [-] Low quality self-construction housing                                  | [*] 90% of households hold tenure of their properties  
[*] Existing home-based enterprises | [+ ] Finish process of legalization  
[+ ] New housing typologies to promote organized and quality self-expansion  
[rental opportunity, home-based enterprises, small businesses]  
[+ ] Income generation from expropriation of properties from people at risk or demolished areas |
| HOUSEHOLD RELATIONS   | [-] Need to support weaker members  
[-] Overcrowding and lack of privacy because of intergenerational densification | [*] Cohesion of family members                  | [+ ] Provide community-based, community supported care for children and the elderly |
| SOCIAL CAPITAL        | [-] Lack of quality public space for social interaction  
[-] Escalation in levels of crime and violence attributed to increasing unemployment curtails community activities  
[-] Vandalism of few existing public spaces  
[-] Social segregation between areas with different level of consolidation | [*]                                      | [+ ] Promote and capacitate community based organizations for urban agriculture and water self-management  
[+ ] Externally managed NGO and government agency projects, with income or welfare components  
[+ ] Provide community facilities, especially for youth  
[+ ] Locate night schools close to residential neighborhoods  
[+ ] Enhance policing capacities |
Main problems of VDC Municipality:

1. Low connectivity with the rest of the city
2. Water related problems
   - 2.1 High risk of flooding from the growing lake
   - 2.2 No access to safe water
   - 2.3 Physical vulnerability from open-air sewage canals
3. Lack of good quality public space — collective places for social interaction
4. Lack of economic opportunities [local modes of production]

Needs of the community:

1. Improved regional connectivity [accessibility] & local mobility
2. Reduce environmental risks and improved access to basic needs
   - 2.1 Reduce risk of livelihood
   - 2.2 Fresh water supply
   - 2.3 Reduce risk to health problems
3. Improved housing stock and physical environment
4. Employ self-organisational capacities
5. Improve access to education and entrepreneurship possibilities

Strategy Challenges:

1. Create conditions for a water balanced system for VDC Municipality to improve environmental, urban and living qualities by ensuring water supply, promoting interaction with water and diminishing risks.
2. Create conditions to improve spatial integration of Valle de Chalco Municipality with the rest of the city.
3. Create conditions for a better mobility inside of the municipality.
4. Create conditions for good quality public space to promote social interaction and sense of belonging.
5. Create conditions for community development to reduce socioeconomic vulnerability [new economic opportunities].

Water pipe, housing conditions of less consolidated areas, taxi-bike system and existing urban agriculture program in the area
Source: Photos by author
5.1. General goals of the proposal

The proposed new water system is the catalyst for urban regeneration and local development. The land-use plan part of the territorial ordering plan for VDC Municipality responds to the environmental needs of the territory to create conditions for a more sustainable water resources management. Two concrete design proposals show how the strategies respond to the real and specific needs of the inhabitants, creating new opportunities for the development of the community. Interviews with inhabitants of VDC and local government’s authorities, and three site visits were part of this research. Those interviews and site visits provided me with the necessary data to make concrete design proposals fitting the inhabitants as well as the territory. [For a complete review of the interviews please refer to Appendix 7.2]

By acknowledging the relationship of Valle de Chalco Municipality with the rest of the Metropolitan Area, the municipality is recognized as a fragment; its functional (job) dependency with the city gives connectivity highest priority. By using potential infrastructure links and devising development opportunities, the integration of the area with the rest of the city is feasible. At the same time, recognizing the local risk that the area has because of the emerging lake is taken as an opportunity to start local transformation.

The idea is to deliver a flexible plan (guiding framework) to create spatial conditions for different possibilities, which will need different roles played by different stakeholders to attain the proposed transformation. The different scenarios are conceived based on the possible and desirable commitment from government institutions and other stakeholders on the one side and the willingness of the community for change on the other.

The proposal includes strategies not only for physical improvements but also include strategies that aim to reduce the socioeconomic vulnerability of the community. Therefore the proposal is a combination of spatial strategies that aim for the physical transformation of the area to create conditions for community development.

Five design concepts will be guiding the two proposed strategic interventions and will be further explained at the end of this chapter.

1. Permeability: Flows of people and flows of water [infiltration model]
2. Transformation of an homogenous area [peripheral sleeping town] into a more mix used area
3. Transit oriented development [TOD] : transport nodes related to mix-functional areas
4. Community development: economic opportunities for local people
5. Flexibility: the proposal will give the basis for future transformation
Xochimilco ecological park

Tlahuac forest

El Zapote ecological and sports park

Nativitas Park

Xochimilco chinampas area

Tlahuac parks

San Luis Tlactaltelco Park

Los Olivos Park

Tlahuac chinampas areas

Xochimilco chinampas area
VISION

The decentralisation of the water systems from the metropolitan structures will be the driver for the redevelopment of the area regarding ecological, economic and social criteria. The independency of VDC’s water systems can be feasible through the empowerment of the community with support from NGO’s and government to have self-managed water systems that respond to their actual needs: fresh water supply and safety from water risks.

A new water system provides multiple opportunities, one of them being the re-characterization of local streets. Structural axes will enhance the connectivity of the municipality with the rest of the city and create the basis for local transformation. At the local level they activate new centralities when intersecting with roads and streets of lower hierarchy. At those centralities as well as at every other intersection, public transport nodes will become urban space articulators with new functions that aim to activate the local economy. The new urban structure defined by a hierarchical traffic system for different types of mobility will be reinforced by the new water system.

Each type of street at the local level will provide different hierarchies of accessibility. The different hierarchies will define types of mobility and create new spatial units ‘clusters’ inside each neighbourhood. The streets with lowest hierarchy will create a new network of green-blue semi-public spaces for recreation and production [urban agriculture]. In a regional scale, this new green-blue structure in VDC may be connected to other existing natural areas through green corridors.
82 agriculture wholesale market
fruits|vegetables|flowers
manufacturing industry hub
densification areas
natural park
commercial hub
space for water
blue corridors [canals]
green corridors
green reservoir |
potential area for centralized wastewater treatment
new local centralities
centralities at regional scale
structural axes for local transformation - densification areas -
existing urban centre
regional roads
light rail train stop
existing railway line
Xochimilco ecological park
Tlahuac forest
El Zapote ecological and sports park
Tlahuac parks
Tlahuac chinampas areas
San Luis Tlactatemalco Park
Nativitas Park
Los Olivos Park
Xochimilco chinampas area
Tlahuac chinampas areas
Tlahuac parks
Xochimilco ecological park
1 km
agriculture wholesale market
fruits | vegetables | flowers
manufacturing industry hub
densification areas
natural park
commercial hub
space for water
floating agriculture
potential area for floating agriculture
potential area for natural park
blue corridors [canals]
green corridors
green reservoir |
potential area for centralized wastewater treatment
new local centralities
centralities at regional scale
structural axes for local transformation
- densification areas -

existing urban centre
regional roads
Xochimilco chinampas area
Xochimilco ecological park
El Zapote ecological and sports park
Tlahuac forest
Tlahuac parks
Tlahuac chinampas areas
San Luis
Tlactaltemalco Park
Nativitas Park
Los Olivos Park

Vision Map with context image.
Source: Map by author; image Google Maps, 2010
Challenge:

1. **Create conditions** for a water balanced system for VDC Municipality to improve environmental, urban and living qualities by ensuring water supply, promoting interaction with water and diminishing risks.

Strategy:

**DECENTRALISED MANAGEMENT OF WATER RESOURCES**  
**VDC INDEPENDENCY FROM METROPOLITAN INFRASTRUCTURES**

The starting point of the water strategy for VDC Municipality at city level is recognizing local risks caused by metropolitan mismanagement of water resources. Based on literature review the independence and empowerment of the community towards self-management of their water resources is considered the best strategy to overcome those environmental risks, fulfilling basic needs and creating opportunities for upgrading spatial and socioeconomic conditions.

By creating a new water system that includes physical interventions for rainwater and wastewater, living conditions from inhabitants in VDC can be considerably improved. Interventions at local level will require the involvement of metropolitan actors. In the first place to deal with the risks caused by metropolitan water resources mismanagement and secondly to maximize the potential of the area to become a Green Reservoir with numerous advantages for the whole metropolis.

There are three specific actions necessary for the transformation of the area in terms of the relation of the metropolitan and municipal water systems. The first three actions taken at a metropolitan level are also required for the local water strategies to take place.

Actions:

1. **Cease groundwater overexploitation at Chalco-Amecameca sub basin**

   The shutdown of the fourteen regional groundwater extraction wells from the Mixquic-Santa Catarina System is considered necessary as the first step for the redevelopment of the municipality. Therefore, the strategy is based on the best case scenario in which the overexploitation from those wells is ceased at some point during the following five years. In that way the ground subsidence would...
have limited effects on the area, making possible to recognize different levels of risk and develop strategies accordingly.

2 Removing the Acapulco open sewage canal
Nowadays the Acapulco open sewage canal limits the municipality to the west, along a dike up to two meters above the urban area directing wastewater to the north. This dike is currently holding up the emerging lake from coming inside the urban area. The black dashed line on the map below shows the area expected to experience vertical deformation as an effect of the overexploitation until now. This area is considered to be the area at higher risk, expected to be flooded in the following years since the protective dike will no longer be enough to retain the water. Therefore, the strategy is to provide more space to the water, turning current high risk urban areas into natural reservoirs that can serve for groundwater recharge and recreation areas. This can be done by removing the polluted wastewater that the Acapulco canal is conducting to the north to open up the dike and let the water in.

The water from the lake will be released gradually surrounding the highest levels of the dike which will become part of the new lakeside water park.

3 Wastewater treatment of polluted water coming from Ameacameca Open Sewage canal
In order to remove the Acapulco open sewage canal, the disconnection from the metropolitan sewage system is necessary. The disconnection is proposed to be made at the south of the municipality where the Ameacameca river intersects with the Acapulco canal. This disconnection will only be possible if the wastewater from both canals is either treated locally or redirected. The proposal therefore is the decentralised treatment of municipal wastewater to stop discharging it into the Acapulco Canal. This canal also receives wastewater coming from the Ameacameca Canal, therefore the strategy is to designate an area of 103 ha. at the agricultural fields at the south of the municipality for wastewater treatment [constructed wetlands]. The output from this naturally based treatment system may be reused at the high productivity agricultural areas or released to the new area proposed for floating agriculture. As the quantity of wastewater coming from the Ameacameca Canal may exceed the capacity of the proposed treatment facility, the surplus wastewater may continue its way to the west. It is proposed that the neighboring municipality [the Federal District’s borough ‘Milpa Alta’] would also implement a decentralised approach for wastewater treatment and reuse.

Groundwater overexploitation from the fourteen regional wells to limit the local risk. Source: Map by author based on Ortega and Ortiz, 2007 and H. Ayuntamiento de Valle de Chalco Solidaridad, 2005.
ACAPOL open-air sewage canal

AMECAMÉCA open-air sewage canal

existing surface water
open-air sewage canals
proposed point for disconnection from the metropolitan sewage network
Acapol open air sewage canal removed
proposed area for wastewater treatment for reuse in agriculture

Preliminary actions for the transformation of high risk area into lakeside waterpark.
Source: Map by author
4 City Scale Lakeside Waterpark
The possibility of the area to become an attraction at city scale comes from the decision to relocate the people at high risk from the emergent lake and to turn this area into a Natural Park. The Park will be complemented by a new area for traditional agriculture 'chinampas' to activate local economy with this kind of activity [this strategy is further explained on the next page]. The location of the city scale natural park is shown on the map below. The relocation and proposed densification will be explained in detail as part of the local scale strategy.

Stakeholders:
The park on the waterfront in combination with the new 'chinampas' area and other natural reservoirs around the Municipality will become an attraction at regional level and therefore the involvement of higher actors may be possible. The Mexico State government and Metropolitan institutions for environmental protection will be key actors for the transformation of this area. The community can also take an active role if they are well informed on the benefits on their living conditions and the economic opportunities that floating agriculture may also bring for them.
**Recovering traditions**

The idea is to expand the still existent areas of Xochimilco and Tláhuac [the municipalities to the east of the Municipality indicated on the map below] to the Municipality of VDC.

The chinampas represent a system of water management appropriate to the Valley of Mexico, which have lasted for more than seven centuries. This agricultural system can assimilate and soften the ups and downs in water levels. The roots of aquatic plants digest and recycle pollutants nutrients. This kind of agriculture also serve as the foundation for a wide diversity of flora and fauna.

Chinampas agricultural system provide between 3 and 4 food crops a year, they are considered one of the most productive agricultural systems in the world. These ‘floating gardens’ are still used in the south region of Mexico City for living and horticultural production - ornamental plants, flowers, maize, beans, etc. The recover of this tradition and the transition towards this sustainable agriculture activity can be proposed as a new economic opportunity for the municipality. Moreover the transformation of the area can become an attraction in relation to the city, as part of the new lakeside waterpark.
Images of the traditional agriculture system 'chinampas'.
Source: [Marin, 2008]

Existing areas of traditional agriculture system 'chinampas' in Xochimilco and Tláhuac. Source: [Google Earth, 2010]
Challenge:

2 Create conditions to improve spatial integration of Valle de Chalco Municipality with the rest of the city.

Strategy:

CONNECTIVITY

...the way in which the area is connected with the rest of the city [the higher level]...

Mobility is a factor that changes with the development of society because of transformations of the production factors, cultural changes and the development of information and communication technologies [Sepúlveda, 2003]. Mobility contains a physical dimension, that is CONNECTIVITY [the connection of two places with recognised functions, being here the central city the place of work and VDC Municipality the place of residence.

Improve spatial integration of Valle de Chalco Municipality with the rest of the city.

In informal settlements there are two elements that emerge from the macro-perspective of vulnerability. The first is social exclusion, and the second is settlement sustainability. Hence, while the primary objective of upgrading should be to reduce vulnerability, this should take place within a wider planning framework that seeks to achieve social integration and create a sustainable settlement [Abbot, 2002].

For a settlement to meet both of these goals it has to satisfy two distinct needs: firstly, it has to achieve internal cohesion and secondly it has to be integrated into the formal city. To deal with the issues of social exclusion and sustainability ‘the need is to turn the community outwards, spatially, socially and economically, in order to link it with the surrounding areas’ [Abbot, 2002 p. 323].
Following the latter ideas stated by Abbot, 2002 Valle de Chalco Municipality should not be longer perceived as an island; but as an integral part of the city of which it constitutes a physical part. Therefore the strategy at the city scale is to use infrastructure connections [public transport and roads] to improve economic and social exchange of the area with the rest of the city.

The strategy seeks to connect the area with the two closest centralities: the metro station ‘La Paz’ to the North and the centre of the neighboring Municipality of Chalco, in order to integrate the area to the city. Furthermore a new City Scale Lakeside Waterpark at the current risk area will become a touristic attraction for outside visitors activating the local economy.
Actions:

1 Light Rail Transit system using the existing railway crossing the Municipality to closest metro station to the North ‘La Paz’. Light rail or light rail transit (LRT) is a form of urban rail public transportation that generally has a lower capacity and lower speed than heavy rail and metro systems, but higher capacity and higher speed than traditional street-running tram systems. LRT system is proposed because it represents a sustainable transport system and because of the lower cost it may have compared to extending the existing metro lines to reach the area.

The implementation of this kind of new public transport would mean the reduction of the time that the inhabitants from VDC spend on a daily basis to reach their work places. The new train will run through the Municipality with seven stops along its way to the metro station. The stops are strategically positioned to serve the widest part of the population, the proposed fruit/vegetable & flowers wholesale market and the industrial area at the north. The LRT system will run along the new waterfront as a new green corridor. Therefore it will make easier the access to visitors to the new park proposed and explained later on.

2 New connections of regional roads with local structural AXIS inside of the municipality [see map on the next page]. Those connections are needed in order to improve the accessibility to the Municipality and the functional relation with the neighbouring municipalities. The new connections will make easier the commercial and social interchange between VDC, the city and surrounding municipalities.

The map on the next page shows the regional roads that connect with local axes and become the basis for local transformation. Once the regional highways and the two local axes are connected new routes for regional buses may be implemented, improving the connectivity of the municipality.

Stakeholders:

The implementation of the LRT system would need the involvement of the Municipality to receive the necessary permissions and financing from the State government. Since the people benefitted from this project exceeds at least 300,000 people the feasibility of the investment seems possible.
Regional connections and centralities.
Source: Map by author
RISK AS THE STARTING POINT FOR LOCAL TRANSFORMATION

The strategic plan for the Municipality is based on the best case scenario where the exploitation of groundwater from the Amecameca subbasin (where Valle de Chalco Municipality is located) stops within the next 5 years, so that the land subsidence would have limited effects on the area. This decision will need the involvement of municipal and federal governments together as explained on the city scale strategy.

The local strategy therefore starts by identifying the most feasible time wise phasing for the relocation of the people at risk. People living at high risk areas need to be relocated, not outside the municipality, not to the remaining natural areas but inside the municipality within the existing urban areas.

Densification of existing housing areas is therefore proposed as part of the strategy. Better spatial conditions need to be created as a starting step in order to densify chosen areas. Those areas will be the structural axes defined by the regional strategy that will also be the basis for a new hierarchical system for local mobility. At those areas better living conditions will be created with new open spaces and new functions. Transport nodes related to those mix functional areas will become the starting areas for transformation guiding the future redevelopment.
Actions:

1 Relocation: Two Phases

The relocation is proposed to take place in two phases. The area defined as high risk and therefore the necessary area to relocate within the next 5 years will be the area delimited by the -12m contour line of total vertical deformation of land surface that the New Chalco Lake is following (Ortega, 2010) [see map below]. The second phase proposed to be done within the next ten years is the area between the -12m contour line and the railway line. This relocation is needed in order to create the conditions for the city scale park which will bring multiple benefits for the Municipality.

1st Phase [2015]:
- Surface = 1.19 km²
- 8,500 inhabitants
- 1,840 dwellings

2nd Phase [2020]:
- Surface = 1.21 km²
- 8,670 inhabitants
- 1,870 dwellings

Stakeholders:

The relocation of people at risk will involve in the first place the municipal government to start the process of negotiating with higher levels of government to stop the extraction of water from the territory. Once this decision is taken, the Municipal government will need to let the community know about the risk so that they can have a word in the planning process. Expropriation of housing and commercial properties can take place once the people is aware of the risk. They need to be sure that the government will respond to their needs and provide them with a new house.
### 2 Demolishment: Two Phases

The demolishing and redevelopment processes are proposed along the two structural axes: the Mexico-Puebla Highway and the Isidro Fabela Road in a first phase. It is along these two roads where the worst housing conditions can be found within the Municipality [see photos to the right], therefore the necessity to relocate the people from the risk areas also brings the opportunity to improve living conditions at these areas. In a second phase the demolishment and redevelopment is proposed along the Adolfo López Mateos road shown on the last photo to the right.

The demolishing process is proposed to take place in two phases following the needs for new housing areas from the relocation process. The dwellings needed from the relocation and demolishing processes for each phase are given below. [Refer to Appendix 7.4 for complete calculations.]

#### 1st Phase [2015]
- Dwellings demolished: 2,650
- Dwellings Needed [Relocation + Demolishment]: 4,490

#### 2nd Phase [2030]
- Dwellings demolished: 1,840
- Dwellings Needed [Relocation + Demolishment]: 3,710

From the analysis on the existing urban facilities inside the municipality it can be concluded that cultural facilities are missing as well as communitary centres. Therefore apart from the facilities above mentioned I propose to include a series of libraries and cultural centres combined with community centres as part of the new area development.

**Urban facilities demolished:**
- 2 communitary centres [DIF - Desarrollo Integral de la Familia]
- 6 kindergarden
- 1 Primary and Secondary School
- 1 Highschool
- 4 Markets

**Stakeholders:**

Private developers need to be involved for the construction of new housing. Those developers should be elected by the local government once they agree to follow sustainable building principles. The government needs to provide high subsidies and financial help so that the people be able to buy a new house.
Phases for Demolishment.
Source: Map by author.
3 Redevelopment – Densification: Two Phases

The redevelopment process needs to follow the relocation and demolition processes therefore it is also proposed to take place in two phases. The densification strategy of existing housing areas also considers the expected population growth; both from natural growth of the population and new comers. The upgrading of the Municipality may also attract people from central areas of the city or neighbouring municipalities as it will offer better living qualities. Therefore the proposed building types need to provide enough space for people relocated from high risk areas and demolished areas and for future inhabitants.

The total urban area that VDC municipality will require if the population growth continues with an average growth of 3.11 (IGECEM 2000-2020), with an average density (average of 200 lots m²), will be 2.504 hectares. The total free surface today, taking into consideration agricultural areas and the natural park areas is 2.289 hectares (Plan de Desarrollo Municipal VDC, 2003). Re-densification of existing urban areas is the only option to cope with the growing population.

A sufficient density of activity and people has been regarded as a prerequisite of animation and vitality and for creating or sustaining viable mix use. Jacobs (1961:163) considered density as essential for urban life. For her densities ranging from 310 to 500 dwellings per net hectare of residential land, was the optimum environment. Recent debates about creating sustainable and compact cities argue that compact cities can offer a high quality of life while minimising resource and energy consumption. Higher densities are regarded as a prerequisite of more sustainable environments.

Floor space per person is an indicator that measures the adequacy of living spaces in dwellings. A minimum space of 21.5 m² per inhabitant in a high density typology is the minimum area required for a healthy living space. Therefore, the dimensions of the new building types are proposed following this principle.

With the building types proposed the average density attained will be 418 inhabitants per net hectare instead of the existing low density [71 inhabitants/ha] and medium density [150 inhabitants/ha], Hence, the densification strategy succeeds in providing not only enough and better quality housing for the people relocated as well as for the future inhabitants, but also creates favourable conditions for a more sustainable environment.

1st Phase [2015]

Dwellings Provided [Densification] 15,405

2nd Phase [2030]

Dwellings Provided [Densification] 10,720

BUILDING TYPE A
[MIX USED: COMMERCIAL, SERVICES & LIVING]

The proposed typology aims for the mixing of commercial, services and living functions. The morphology of the buildings will redefine the new public space surrounding them. The covered arcade on the groundfloor is meant to provide a physical space for people to meet and commercial functions to take place. The arrangement of the new buildings in the space will allow for permeability in two ways: the flow of people and the flow of water.

This type of building follows the existing typology of shop houses suitable for commercial activities and public services on the groundfloor and living space on the second level, but will include three more stories to increase the density of chosen areas.

Density: 396 inhab/ha
BUILDING TYPE A

Mix-use
[ GF Level ] Commercial & Services +
[ 4 Levels ] Living

[42 x 12 x 16m]
28 apartments
112 inhabitants

[36 x 12 x 16m]
25 apartments
100 inhabitants

BUILDING PARAMETERS

1. The separation of two main facades facing each other must be greater or equal to 12m.

2. The separation of a main facade facing a blind facade must be greater or equal to 6m.

3. Along main roads the separation of a main facade and a sidewalk must be greater or equal to 5m. [space for parking]

4. Along secondary roads and internal streets the separation of any type of facade and a sidewalk must be greater or equal to 2m.

5. The separation of a blind facade facing a blind facade must be greater than 4m or equal to 0m.

6. 50% of the surface of the block must be open space [semi-public collective space], more than 80% of this area must be permeable surface [green or pervious pavement].

7. 50% of the surface of the roof must be used for rainwater harvesting for reuse in the building and block's green spaces. The other 50% must have a public program for the block community [e.g. roofgarden].

8. Parking space for bicycles must be provided within the block for 70% of the number of households.

9. Car parking space must be provided within the block or within surrounding streets for 30% of the number of households and must be pervious pavement.
BUILDING TYPE B [SELF-EXPANDING HOUSING]

‘PRIDE IS THE COMMUNITY’S GREATEST ASSET’
- Elemental Architects

The proposed self-expanding typology is proven to be a method for social insertion and community participation. This typology fits with the context of Valle de Chalco Municipality, for their skills for self-building, their numerous family members and their need for community development. The idea is to provide people [relocated from high risk areas and people evicted from demolished areas] with a house capable of being a departing point with a broader horizon within which families can develop and express themselves. This typology offers a design prepared to change over time, just as the evolving family that is going to live in it needs and aspires to do. What is designed and given to the families is just the most difficult and costly part so that expansions can be done in an easy, economic, quick and safe way. The expansion is the space for the expression of the families’ own cultural and living traditions to eventually increase their assets thanks to a larger house. This typology creates an open system rather than a closed design, therefore the families can adapt and develop their homes to their own needs and aspirations.

The proposed typology offers also the possibility to change from a house on each plot to multiple houses; achieving enough density without overcrowding that would happen otherwise in the current process of self-organized densification. The row-housing typology provides a physical space for the ‘extended family’ to develop which has proved to be a key issue in the economical take off of a poor family. In between the private and public space, the new collective space, conformed by approximately 30 families becomes a common property; an intermediate level of association that allows surviving fragile social conditions [Elemental, 2010].

‘COMMUNITIES THAT ARE PROUD OF THEIR CULTURAL HERITAGE, ALWAYS HAVE A LEADING ROLE IN THE DEFINING OF THEIR OWN LIVES.’
- Elemental Architects

The process of completing their houses will give the people the chance to create sense of belonging and pride with their own houses and their intermediate level communities and the Municipality.

Areas:
Initial house: 36m²
Expanded house: 70m²
Initial duplex: 25m²
Expanded duplex: 72m²

Density: 440 inhab/ha

Note: See Appendix 7.3. For a complete review on Reference project [4] ‘Housing Project Quinta Monroy’.
BUILDING PARAMETERS

1. The separation between a main facade and any type of facade must be greater or equal to 6m.
2. The separation between two blind facades must be greater or equal to 4m.
3. The separation between any type of facade and a sidewalk must be greater or equal to 4m.
4. 60% of the surface of the block must be open space [semi-public collective space], more than 80% of this area must be permeable surface [green or pervious pavement].
5. Parking space for bicycles must be provided within the block for 70% of the number of households.
6. Parking space must be provided within the block for 30% of the number of households and must be pervious pavement.

BUILDING TYPE B

Living
Self-expanding housing
Row houses

[30 x 6 x 9m]
5 houses
5 duplex
40 inhabitants

[24 x 6 x 9m]
4 houses
4 duplex
32 inhabitants

[18 x 6 x 9m]
3 houses
3 duplex
24 inhabitants
Challenges:

1 Create conditions for a water balanced system for VDC Municipality to improve environmental, urban and living qualities by ensuring water supply, promoting interaction with water and diminishing risks.

4 Create conditions for good quality public space to promote social interaction and sense of belonging.

5 Create conditions for community development to reduce socioeconomic vulnerability [new economic opportunities].

Strategy:

VDC AUTONOMOUS AND SUSTAINABLE WATER SYSTEM

In order to attain the desirable disconnection of VDC Municipality from metropolitan hydraulic infrastructures the strategy at the local level is divided into three strategies. The different strategies correspond to the three different types of water according to their level of pollution: rainwater, stormwater runoff and wastewater. Each one of them proposes interventions for an specific type of water, although they interrelate with each other.

A. RAINWATER
B. STORMWATER
C. WASTEWATER

As mentioned before, the strategies proposed are meant to be a guiding framework and not a fixed solution; each strategy can work on its own; however, they take stronger meaning when they are combined.

After the evaluation of the current water system and being aware of all the existing problems and future demands. The next step for designing a new water system is making clear where do we want to go, which would be the most desirable and sustainable condition for the area. The literature review presented as part of my theoretical framework on planning and designing sustainable water systems with innovative approaches gave me the basis for the water strategies. The theories needed to be fitted into the specific climatic, cultural, social and economic context of the Municipality just as a sustainable approach suggests.

A well-developed awareness of the context and priorities of the community and other stakeholders and the social-cultural elements are key elements for planning and designing water systems both for rainwater and sanitation. Therefore the proposed strategies provide desirable and possible solutions, not as a fix answer but as a basic framework where different things can happen. The strategies are context specific based on the local environment (temperature, rainfall, etc.), culture and resources (human and material).
The design of an alternative autonomous water system for VDC Municipality was designed based on the following criteria:

1. Retention and storage of as much rainwater as possible
2. Reuse of water
3. Purification of water through natural sound processes [green infrastructure]
4. Protection of water quality
5. Minimization of pipelines; utilization of local hydrology [low-cost green solutions]
6. Minimization of external dependency
7. Flexibility to cope with future effects of climate change
8. Integration of visible water in urban design

Values

As part of the evaluation to get to the most appropriate strategy, the interventions were thought based on the values they could bring for the inhabitants [based on the Asset Vulnerability Framework conducted on the Diagnosis Phase of the area] and for natural ecosystems. Proposed rainwater harvesting strategy and sustainable decentralised management systems will include visible solutions which can be part of the urban space to include multiple functions and related values. This values are out spoken as part of each action to validate its relevance and possible benefits.

A new culture of water

It is important that equitable and responsible use of water become an integral part in the formulation of strategic approaches to integrated water management (UN 2003). The education of the population towards a responsible use and appreciation of the resource is a key element for change. The creation of a new culture for water saving and protection can be achieved through campaigns to inform the inhabitants on actions they can take such as leakage control at the household level, installation of bathroom fixtures and accessories of low water-saving in homes.

Calculations

In order to get a grip on water quantities and spatial requirements for each one of the water strategies, calculations were conducted as part of the research and design process. Those calculations also serve the purpose of validating the strategy and giving guidelines for the design part; concrete numbers show how the new water system can steer the redevelopment of the area in terms of water self sufficiency. Furthermore, these calculations are also part of the conclusions and findings of this research project, aiming to answer the second part of the research question:

How can local strategic urban interventions based on sustainable water management improve spatial and living qualities of informal settlements in Mexico City’s periphery?

To what extent those interventions can contribute towards the hydrological metropolitan regeneration?

For this the water footprint of the area needs to be clear as well as the achievements that the proposed interventions may have. Rainwater harvesting and the decentralised management of stormwater runoff will be a valuable supplement to the current sources of fresh water (the seven wells in the territory for local use). Therefore, these strategies may contribute to diminish the land subsidence risk in the area as the groundwater levels will be recharged and extraction will be reduced. The third water strategy, wastewater reclamation and reuse for urban agriculture will also contribute for freshwater conservation, therefore

In a later stage as part of the evaluation phase of the project, it will be assessed the transferability of the proposed strategies to realise how the whole south-east peripheral area could contribute on the metropolitan level if the delivered development model is implemented.
For the calculations it was necessary to take estimated values considering as the basic unit one of the defined clusters, part of the design area number one at the centre of the Municipality [See map on the following page]. Even if the calculations cannot offer exact quantities, this method seems accurate enough given the homogeneity of the area in terms of its morphological attributes.

For each part of the strategy only the main calculations and results are shown. The complete calculations conducted as part of the research and design process can be found on the Appendix 7.4. Complete calculations for strategies and design.

- 80,000 m²
- 0.3% of the total area of the Municipality
- 20 blocks
- 1.4 plots per block
- total = 280 plots
- on average 1300 inhabitants

Cluster as the unit for calculation for water strategies.
Source: Drawing by author.
Satellite image of cluster as the unit for calculation for water strategies.
Source: Google Earth, 2010
A. RAINWATER

Rainwater as a resource starting from the smaller scale
Rainwater has been viewed as a nuisance or hazard in terms of flood management and drainage conveyance. An alternative to this thinking is to view rainwater as a ‘resource’ to be harvested and used beneficially for broader community benefits. As a resource, rainwater can be collected in tanks and reused specifically for toilet flushing, laundry, garden watering, car washing and the like; potentially reducing potable use by up to 70% in an average household. Similarly rainwater tanks can assist in reducing stormwater runoff volumes during rainfall events, through temporary storage and reuse.

Actions:

1 Rainwater harvesting and reuse at household level
Rainwater harvesting systems have been used since antiquity, and examples abound in all the great civilizations throughout history. Rainwater harvesting is the process of capturing, purifying and storing rainwater for human use.

Seasonal fluctuation of precipitation and evaporation

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<td>33</td>
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<td>70</td>
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<td>Fluctuation</td>
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<td>-105</td>
<td>-74</td>
<td>-10</td>
<td>45</td>
<td>87</td>
<td>92</td>
<td>56</td>
<td>-20</td>
<td>-80</td>
<td>-103</td>
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</table>

Source: Data from Plan de Desarrollo Municipal Valle de Chalco, 2005.
Calculations

Rainwater calculations were made to demonstrate the soundness of the rainwater harvesting proposed strategy, concrete numbers show how the area receives enough rainwater on a yearly basis to serve almost one fourth of the total household water demand of VDC municipality.

Rainwater harvesting requires at least an annual rainfall of 100-200 mm. The area of study counts with rainfalls of about 640 millimetres per year. Rainwater harvesting is suitable even when the roof is small; in the case of Valle de Chalco Municipality the average roof area from which water may be harvested is about 140 square meters per house; with 640 mm annual precipitation, each house receives a rainfall of 89,600 litres on its roof.

- Number of houses = 87,500
- Average m² roof per house = 140
- Average rainfall in mm per year = 640
- Litres rainwater per house (roof) = 89,600
- Litres rainwater on all houses (roofs) = 7,840,000,000
- Brutto m³ rainwater on all roofs = 7,840,000
- Net m³ on all roofs per cluster [323 clusters in total] = 16,921.49
- Portion roof surface area (of total area) = 47%
- Total roof m² = 12,250,000
- Gross m³ rainwater on all roofs (per year) = 7,840,000
- Net m³ on all roofs (per year) = 5,465,640

* Runoff reduction value 0.697147959 (for calculation of net)

Peak precipitation event in mm = 79

Net peak m³ on all roofs (per day) = 677,425

Value of intervention:

Reusing rainwater can have a monetary value as people who are not connected to the water supply network will not have to buy water from water pipes as they do at the moment.

Stakeholders:

The idea is to provide a system to each household that collects the rain of their rooftop, stores the water in a cistern and purifies the rainwater for domestic uses. Those systems may be provided by an NGO’s program for low-income communities already in progress in Mexico City ‘Isla Urbana’. Isla Urbana is a collaborated project of the non-profits NGO’s, the International Renewable Resources Institute (IRRI), located in Mexico City, Mexico, and TEMO Foundation, located in Dallas, TX, USA. The project launched in 2009, the team of Isla Urbana has designed a sustainable, rainwater harvesting model that can be easily and inexpensively implemented on a large scale to ensure clean water throughout Mexico city and the developing world (ISLA URBANA, 2010).

For a complete description of the Isla Urbana Model see Appendix 7.5. [Isla Urbana Presskit].
B. STORMWATER

Evaluation of the current water system
Today the rainwater in the Municipality is combined with the sewage water. During the four months of high precipitation the area suffers of flooding because the drainage system is unable to cope with such amounts of water.

Strategy:

1 Decentralised stormwater management - Landscape drainage system at municipal level for VDC using the streets to create a new green-blue structure

Following the innovative Water Sensitive Urban Design approach, the strategy for VDC Municipality is to implement a decentralised stormwater management for its sustainable redevelopment regarding ecological, economical and social criteria. Based on past experiences it has been recognized that a decentralised approach can strengthen local people and the independency of communities from central infrastructures (Schuetze, 2006). A decentralised rainwater management system is proposed for the avoidance of flooding, the protection of freshwater resources and the harmonization of a natural water balance. Sustainable stormwater management will be used to create places that serve both the demands of urban drainage and urban planning. This concept aims to close the loop, recreating a natural-oriented water cycle while contributing to the amenity of the municipality (Hoyer, 2010).

The natural water cycle is characterized by high evaporation, a high rate of infiltration, and low surface runoff. The water cycle closes not through the earth but through the air. This is the basis of our scientific understanding of the water cycle, that has been defined as the ‘succession of stages through which water passes from the atmosphere to the earth and returns to the atmosphere: evaporation from the land or sea or inland water, condensation to form clouds, precipitation, accumulation in the soil or in bodies of water, and re-evaporation (UNESCO 2006). In the typical urban environment there is more runoff, less infiltration, and less evaporation. Consequently, all measures that increase evaporation and reduce the superficial drainage are suitable.

The goal of sustainable stormwater management is to reduce stormwater runoff by treating the stormwater as close to the source as possible. Treat does not mean to collect and discharge the stormwater to the public sewer system, as it would be treated conventionally, but to reduce runoff by using technologies for stormwater collection and to increase stormwater infiltration and evaporation. Because of the morphological conditions of VDC municipality described before, the strategy proposes to use the streets to provide space for surface water retention needed for a decentralized rainwater management.

Street Structure as Blue-Green Public Space

The existing street structure in VDC Municipality only serves a small percentage of the total population as it is completely directed towards car movement. The idea is to transform the existing paved network into soft, green and blue public spaces.
like promenades, parks and floodable squares for a decentralised stormwater management. Following infiltration model principles, the new landscape drainage system holds the rainwater on site for people to experience and enjoy it. Water quality is improved by biofiltration plants [reeds or bamboo crops] that purify water runoff before infiltrating it. Rainwater will slowly be drained contributing to groundwater recharge.

**Actions:**

1 **Separation of stormwater from sewage** to allow appropriate treatment is the first step towards a decentralised management of rainwater. Therefore the idea is to stop rainwater runoff to combine with the sewer system. The existing street strainers will need to be closed up in order to let the water flow within the urban area where it will find space within a new green structure.

2 **Measures on each type of street need to be implemented for landscape drainage system.** Following an infiltration model system, the stormwater may be collected to attenuate surface runoff through low-cost green infrastructure measures: ditches, canals, shallow pits, swales, raingardens, permeable pavement, etc. Those measures will provide the space needed to retain stormwater during the four months of high precipitation. The water will slowly be drained into the ground for a continual recharge of groundwater levels. Please refer to pages 113 to 115 for a description of measures on each street profile.
3 New Water Reservoir for High Peak Storage Retention
At the south-east of the Municipality between the limit with the urban area of the neighbouring Municipality of Chalco a new water reservoir is proposed to be constructed in order to provide enough space for rainwater during high precipitation events.

4 Local water retention basins
Along the four structural axes [main diagonal, railway line, Mexico-Puebla highway and Adolfo López Mateos road] a series of floodable green spaces will be planned as part of the development of the new mixed-use areas. Those gardens will provide space for leisure, recreation and sport activities during eight months of the year and transform into small ponds during the four months of heavy rains.

5 Reuse of groundwater from hand-dug wells

In the design of the system, surface water fluctuations are expected to create sufficient retention capacity for the urban area to pass dry periods without an inlet of water from other areas. As groundwater tables will be continuously recharged during rainy season, hand-dug wells can be the last part of the system to close the cycle. The reuse of groundwater may be used for irrigation of green areas and urban agriculture areas.

Calculations:
The proportion of evaporation, infiltration and runoff for the specific location is dependant on climate, duration and intensity of precipitation events, water permeability of the soil and type of quantity of vegetation [Schuetze, 2006]. From the total precipitation that Mexico City receives annually it is estimated that 73.2% returns to the atmosphere by evapotranspiration.

<table>
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<th>Average rainfall in mm per year</th>
<th>Peak precipitation event in mm</th>
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<th>Net m³ on all roofs per cluster</th>
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<th>Total roof m²</th>
<th>Gross m³ rainwater on all roofs (per year)</th>
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<th>Net peak m³ on all roofs (per day)</th>
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<th>Total sealed traffic area m²</th>
<th>Gross m³ rainwater on all sealed traffic areas (per year)</th>
<th>Net m³ rainwater on all sealed traffic areas (per year)</th>
<th>Net peak m³ rainwater on all sealed traffic areas (per day)</th>
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<th>Total gross m³ rainwater on the whole area (per year)</th>
<th>Net m³ rainwater runoff from whole area per year</th>
<th>Net peak m³ rainwater runoff from whole area per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>16,593,548.39</td>
<td>9,726,801.29</td>
<td>1,203,412.10</td>
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</tbody>
</table>

Calculations for stormwater runoff for average runoff and peak precipitation events.

Source: [Schuetze, 2011]
Calculation of sealed and unsealed areas on a cluster basis.

Source: Map by author.

- 80,000 m²
- 0.3% of the total area of the Municipality
- 20 blocks
- 14 plots per block
- total = 280 plots
- on average 1300 inhabitants

Unpaved streets
Green areas
Unsealed areas
Paved streets
Built areas
Open areas

Built area = 70% of each block
the surface runoff is 22.1% and only 4.7% is infiltrated into the subsoil naturally recharging aquifers [CONAGUA, 2010]. For designing a landscape drainage system for VDC municipality calculations were needed in order to evaluate the feasibility of the strategy because of climatic and territorial conditions [i.e. seasonal fluctuation between precipitation and evaporation and soil type]. The area has an almost complete flat area as described before and experiences long periods of drought (8 months) and high precipitation with increasing peak events during 4 months [see diagram on page 106]. Furthermore the area has a relatively water proof day soil.

The first step to start the design of the measures for water retention and infiltration was to map and quantify on the cluster unit the sealed and unsealed areas [see map on the previous page]. After having extrapolated those values to the total area, the total roof areas, sealed traffic areas and unsealed traffic areas were multiplied by the average rainfall in m3 [640mm average rainfall /1000]. The quantities obtained are the gross m3 of rainwater that the area will receive per year. The three different surfaces [roofs, sealed and unsealed] deal differently with the rainwater, therefore a runoff reduction value was used to calculate the net m3 of rainwater runoff for each surface. In this way the total net m3 received in one year on the total area can be estimated on: 9,726,801.29 m3.

The measures for retention of rainwater need to meet the required storage capacity for peak events (precipitation events with frequency one in 100 years) [79mm of precipitation per day]. The process of design and calculation was simultaneous, to estimate the storage capacity that each measure should have. The net peak m3 rainwater runoff from whole area per day was estimated in 1,203,412.10 m3. Only the storage capacity of ditches on every internal street [length= 70m on average x width 0.5m x deep = 0.5m] and canals on every secondary streets [length= variable x width=1.5m x deep = 1m] were considered. The sum of the retention capacity of those two retention measures provided enough capacity to storage 39.67% of the total net peak m3 rainwater runoff received on the total area i.e. almost 32mm. The remaining 47.66 mm were used to calculate the runoff for the total area. The resulting 1,229,953.55 m3 of rainwater runoff need to be stored elsewhere. This is the reason why bigger open reservoirs need to be included to allow for exceeding water on peak event to flow and store at those areas. Those peak storage areas are planned along the main axes as multifunctional and floodable green spaces. A bigger reservoir is planned to the south east of the Municipality as a natural floodable park [see map on page 109]. Calculations were also conducted to know how big peak storage areas should be, the results point out that the total required area for peak precipitation event storage (portion of total area) is 9.53% of the total area, with a depth of 50cm or 4.77% with a depth of 1m. When adding to this amount the 2.61% catchment portion of the total area (ditches and canals) the total area designated for water retention will be 31,328.10 m2 (12.14% of total area) or 19,028.57 m2 (7.37%) according to depth. The strategy suggests to stay on the safe side and designating 12.14% of the total area but with a depth of 1m. In this way the strategy will be more resilient to future changes.

**Value of intervention:**

Avoid flooding, recharge groundwater and improve microclimatic conditions, aesthetics and interaction with water are some of the added values from having a decentralised rainwater management. Decentralised stormwater management measures can improve not only the visual aesthetics but also the quality of life in the city. Green spaces and water are key factors for the quality of life in cities. Decentralised stormwater management helps to increase the occurrence of natural blue-green spaces, making a key contribution towards sustainable living (Hoyer et al., 2010).

Accordingly, decentralised stormwater solutions can ideally be used for upgrading distressed areas or improving new housing areas. When stormwater is used as a visible design element, it captures the attention of inhabitants. The flowing water invites residents to follow the natural processes of the water cycle, making daily and seasonal changes noticeable, and even enjoyable. When residents are living alongside the dynamic process of stormwater flow, they are more likely to appreciate and understand the importance of the water cycle in urban areas and can potentially become more aware and sensitive to the limitations of water as a resource (Hoyer et al., 2010).

**Stakeholders:**

As this strategy will require physical interventions of high investment the Municipality will need to provide the economic financing while the community may be involved in the labour process. This financial model may strengthen the success of the strategy as the inhabitants will be benefitted from the whole process. If residents take part on the construction process it will not only bring economic benefits for them but also will enhance the sense of community and care for the new urban space. The inhabitants will become then the key actors in the development of this strategy so acceptance and appropriate use and care of new urban spaces can be sustained. The threat for those spaces designed for stormwater retention may be that they become garbage dumps, therefore the community needs to have the complete knowledge of the new water system. Direct discussion with the community needs to be held during the planning process and implementation phase so that advantages and disadvantages of decentralised stormwater management are known and understood by the residents.

**Results of required storage capacity for peak events in VDC.**

Source: Excel table for calculations of all water strategies was provided by Dr. Ing. Thorsten Schuetze.

The table was modified by author based on Schuetze, 2011.
[i] Structural Axes
Measure: Bioswale - Wet Swale

The three structural axes are proposed to include a bioswale, that consists of depressed land that serves as linear drainage areas. Wet swales intersect the groundwater, and behave almost like a linear wetland cell. The design incorporates a shallow permanent pool and a base of gravel and wetland vegetation [reeds or bamboo] to provide stormwater treatment to prevent pollution of groundwater.

[ii] Main Roads [Green Commercial corridors]
Measure: Shallow Pit

The main roads will include a natural feature that will always be green but that can be flooded in rainy season. Shallow pits as well as infiltration ditches allow the complete retention of precipitation events, even in relatively waterproof soils such as the one in VDC. In general the construction costs of retention and infiltration systems may be more economic than the construction of technical rainwater utilization systems because of the avoidance of pumps and pipes for the service water supply (Schuetze, 2006).
[iii] Secondary Streets [Green-blue corridors]
Measure: Rain Gardens + Canal for stormwater water retention + Permeable pavement on taxi-bike circuit

Rain Gardens are landscaping features designed for stormwater quality treatment without foregoing aesthetic of ornamental values. Stormwater runoff will be filtered, through a sand/organic mulch medium, which subsequently slowly drains into the ground. Rain Gardens will provide detention and retardation of stormflows, providing an aesthetic water/pond feature during rainy season.

The canals along this types of streets are designed in order to comply with the retention areas needed.

The new bike lane designed for taxi-bike public transport service and normal bikes will be covered with permeable pavement instead of standard asphalt and concrete. Permeable pavement will also be used to re-paved all other roads that will need to be changed: for surfacing sidewalks, bike lanes, driveways and parking areas.
[iv] Internal Streets [Cluster alleys]
Measure: Ditch + Raingarden

During rainy season the water will be stored in infiltration ditches along internal streets. Reed plants or bamboo crops can be planted on those ditches to purify the water before it is infiltrated, bamboo may also be harvested and use as construction material or craftsmanship. This type of street will be normally used by residents of each cluster therefore those streets will become one way streets. The rest of the space will be transformed into raingardens combined with parking.

[v] Collective Semi-public Spaces for Recreation and Production

Community gardens for Urban agriculture

‘Urban agriculture’ is a recent concept, which refers to the activities linked to food production in cities. It has coincided with the recognition of the need to pursue social and environmental goals of sustainable development, and address the specific problem of cities as resource consumers and pollution producers (Newman and Jennings, 2008.) Continuous Productive Urban Landscape (CPUL) is a design concept advocating the coherent introduction of interlinked productive landscapes into cities as an essential element of sustainable urban infrastructure. Central to the CPUL concept is the creation of multi-functional open urban space networks that complement and support the built environment (Bohn, K. & Viljoen A., 2011). By transforming the clusters’ less accessible streets into productive places this urban space network be created.

Urban agriculture in the form of community gardens may provide a concrete opportunity for small scale food production for the inhabitants of Valle de Chalco. As explained on the mobility strategy, these linear parks where the productive open spaces are proposed will become semi-public spaces only for pedestrian and bike mobility.
Added values of urban agriculture

Cities need to revive their social, economic and environmental capital through local communities and economies. It is important for cities to build social and economic security at the local and bioregional level (Newmann and Jennings, 2008). Urban agriculture and community gardens is one strategy available to transform current economic and social relations at either local or regional scale. For VDC urban agriculture and community gardens are proposed to assist the municipality to become more community and bioregionally focused.

Making agriculture visible and creating a local food industry, will also create a bigger market for regional products, making agriculture a marketing tool and a window to the countryside. Accordingly, at the local level the strategy may be combined with local enterprise facilitation, because local businesses multiply local economic advantages since the money stays local and creates employment. Moreover, local businesses build up local social capital and sense of place through the promotion of local products. Community gardens also provide a chance for meaningful social interaction and contact with natural cycles, both helping to enhance communities. According to Newmann and Jennings (2008:5) closing nutrient cycles through urban agriculture is a key way to faster more sustainable urban ecosystems.

Urban agriculture in the form of community assisted city farming is significantly contributing today to world food production, addressing poverty and hunger specially in developing cities. The international research initiative called ‘Making the Edible Landscape’ by Canada’s McGill University and the International Development Research Centre (IDRC) suggested at the 2006 UN Habitat’s World Forum in Vancouver as one of their findings that ‘in the overcrowded slums of developing world cities, initiatives such as urban agriculture can make a huge difference to the quality of life’ (Newmann and Jennings, 2008).

City farming no matter how small in scale contributes to food security, sense of community and energy conservation. Therefore it is proposed as a strategy that will complement VDC Municipality’s upgrading process. Urban agriculture not only has to be spatially integrated into the urban fabric and viable in economic terms but also it needs to be interwoven into the social fabric of the city (De Graaf, P., in Several Authors, 2010). On the following diagram the ecological and social benefits of a closed food cycle strategy for VDC are illustrated.

Notes:
*The urban agriculture strategy is very much related with the wastewater strategy in order to attain a close water cycle in VDC Municipality.

*Sembradores Urbanos is a multi-disciplinary team of three mexican women promoting urban agriculture in Mexico City through workshops and projects around the city. This organization is considered a key stakeholder for the education process of the community in VDC.

Environmental and social benefits from closing the food cycle inside the city.
Source: (De Graaf, P., in Several Authors, 2010).
A new Green-Blue Structure for VDC

Green structure strategies offer a promising network perspective for growing cities. Supported by road and water network systems, green structures create conditions for urban quality and flexibility (Tjallingii, 2006). The strategy for VDC Municipality is to use an urban green structure network simultaneously as a network for infiltration, retention and drainage of rainwater. Development oriented green structure strategies perceive green areas as a part of urban quality of life and the identity of the urban landscape. Green structures create a basis for managing ecological, social and economic issues. This spatial frame of open spaces is an attractive element in urban design and creates conditions for choice and for interactive planning processes.

In a spatial perspective, green structure is more than the sum of green spaces. Speaking of green structure implies drawing attention to the spatial network that links open spaces, public and private gardens, public parks, sports fields, allotment gardens and recreation grounds within the city to the networks of green open spaces in the surrounding countryside. Thus green structure highlights the role of greenways for walkers and cyclists and stresses the importance of ecological corridors for wildlife (Tjallingii, 2006). Accordingly, on a larger scale these green spaces surrounding the municipality will connect to green corridors and existing green spaces within neighbouring municipalities as shown on the Vision Map.
WASTEWATER

According to Schuetze, 2007 some of the disadvantages from conventional central systems for wastewater treatment are that sewage streams with different characteristics and noxiousness are mixed and nutrients are lost. Leakages in the sewage system, overflows of mixed sewers and the discharge of treated sewage are leading to the pollution of ground and surface waters. Opposed to those disadvantages of centralized water systems, decentralized systems for sewage treatment, ecological sanitation (ecosan) and water supply provide multiple advantages and possibilities for positive changes. They allow the separation of waste water streams with different characteristics, which allow for an efficient treatment and high-quality utilization of nutrients.

Decentralised systems are adaptable to changing demographic structures, changing precipitation patterns. They have the advantage of short pipeline lengths, minimized water losses and close water cycles. This is especially true for areas which are not equipped with sufficient water and sanitation systems and are not connected to sewers or waste water treatment plants. But it can also be for already developed areas, with existing infrastructure and high population density (Schuetze, 2007).

In planning and implementing sanitation systems an analysis of the physical and environmental factors, combined with an assessment of the social groups and institutional structures within these domains, as well as the respective incentives for being involved in sanitation improvements, forms the basis for identifying opportunities for intervention. A well-developed awareness of the context and priorities of the community and other stakeholders and the sociocultural elements are key elements for sanitation planning. The choice for a specific sanitation system has to be context specific and should be made based on the local environment (temperature, rainfall, etc.), culture and resources (human and material) (Luthi et al., 2011).

Actions:

1. Wastewater reclamation and reuse for urban agriculture

In response to the deficiencies and risks affecting VDC Municipality of the current metropolitan centralized service delivery, the strategy for wastewater is adopting a decentralised approach to sanitation and wastewater management to be reused for urban agriculture, which is considered to be particularly appropriate for peri-urban areas. Contributing in this way to a food security strategy based on local production. The local analysis and diagnosis chapter gave the necessary insights to be completely aware of the potentials and constrains of the specific context of VDC Municipality. Those findings as well as the specific problematic regarding sanitation presented below, are the framework for the three scenarios and proposed phasing for the wastewater new system.

Problem identification:

+ The centralized metropolitan management of wastewater have had serious environmental and socioeconomic consequences for the inhabitants of Valle de Chalco Municipality in the past.
+ Currently a small percentage of households in the area lack of sewage connection, however the expected demographic growth in the area and the risks from existing infrastructures [wastewater open air sewage canals] require better and more sustainable solutions.
+ Stakeholder’s attitudes: community might think the responsibility to provide the service and solve the problems is only of the municipality and therefore might not be interested in participating.

Calculations:

Sewage collection

total VDC population 2010 (inhabitants) = 406,521
wastewater = 0.8 of water consumption

total water consumption = 60,978,150 litre per day
60,978 m3 per day
705.76 Lts/seg

total wastewater produced = 48,782,520 litre per day
48,782 m3
564.60 Lts/seg

Stakeholders:

Within the framework of a participatory approach it is important to share the knowledge and to involve stakeholders to make well informed decisions during the planning process for sanitation. The latter will allow choosing appropriate and sustainable systems and technologies that keep project costs affordable and acceptable. Stakeholders involved for each one of the scenarios are mentioned within the description, as their different degree of participation are the key element for the creation of such scenarios.

For the decentralised treatment of sewage and recycling of wastewater to reuse for urban agriculture, natural sound as well as technical solutions are available. According to the specific conditions of this project I propose a natural sound system, constructed wetlands. A brief description of the proposed ecological system is presented below, for a complete review on the technical data of constructed wetlands please refer to Appendix 6.6. Technical data of proposed technologies for water strategies.

Constructed wetlands can be defined as engineered water saturated areas in which the natural removal processes for the water pollutants are reproduced and enhanced in order to optimise the purification performances. A main part of the pollutants contained in wastewater are nutrients that can be removed in wastewater treatment plants by reproducing natural self-purification processes. Conventional treatment plants like activated sludge plants enforce biological organisms with energy-intensive mechanical equipment to decompose complex compounds, to incorporate the nutrients in biomass and finally to separate that biomass from the purified water. Thus such plants are energy intensive reactors with relatively small area demand that are suitable for centralized wastewater treatment.

Constructed wetlands are principally using the same natural degradation processes and nutrient uptake but they are acting as “extensive systems”. The high degree of biodiversity present in these systems allows multiple and various degradation mechanisms for several classes of compounds, and therefore higher performances in comparison with the technological treatment plants in which only few families of specialised bacteria are grown. The purifying
processes take place without input of ‘human produced’ energy by, for instance, oxygenating pumps. Furthermore there is no excess sludge to be removed since there is a balance of biomass growth and decomposition in the constructed wetland system. As a compensation to the low energy demand there is a relatively large area demand. Accordingly constructed wetlands are usually suitable and cost effective for small and medium size wastewater treatment.

Advantages:
• Less expensive to build than other treatment options
• Simple construction, operation and maintenance
• Low operation and maintenance costs
• High ability to tolerate fluctuations in flow and inlet quality
• High process stability (buffering effect)
• Sludge produced only by the primary treatment stage
• High pathogen removal – good water reuse and recycling options
• Optimal aesthetic appearance

Application:
- Treatment of domestic or municipal wastewater is currently a conventional application.
- Industrial wastewater

Horizontal Subsurface flow [SFS-h or HF]
The system consists in a properly designed basin that contains gravel or sand as substrate, wetland plants (normally Reeds) and microorganisms; the bed is fed with wastewater coming from a suitable primary treatment by a simple inlet device. The subsurface horizontal flow systems (commonly named reed beds when planted with Phragmites) are most appropriate for treating primary wastewater, because there isn’t an atmosphere/water interface, and this fact makes this technology particularly safe from the public health point of view. Therefore these systems are actually useful for on-site treatment of septic tank effluents and grey water, which will be the two cases on the project.

The water level remains always under the surface of the bed; the wastewater flows horizontally by a slope (about 1%) obtained by a sand layer under the membrane liner. The subsurface flow prevents odours and mosquitoes and permits public access in the wetland area. In the inlet and outlet zones is advised to use a large filling material, like as stones, in order to ensure an easy cleaning if clogging happens. The preferred values for the Width/Length ratio are \( W/L > 1 \), with 3 meters < \( L < 30 \) meters. For the design phase of this project the spatial requirement given was 1m² per inhabitant.

From the emergent plants that can be used the Phragmites australis, amongst all macrophytes, is the most used worldwide for its optimal performances, for its ability in developing deep roots (0.5-0.7 m), for its resistance to aggressive wastewaters and to diseases. For the local context bamboo as indigenous specie may also be used.

Treatment process scheme
The most common treatment scheme consists of a primary treatment by a filtration-sedimentation device, like as septic or Imhoff tanks and often grids and degreasers, followed by a subsurface flow constructed wetland as secondary stage and then by a Free Water Surface CW as polishing stage.

The primary treatment in the case of this project septic tanks should be sized with a volume per person of about 500-600 litres, or an hydraulic retention time of one day as it was calculated for the design intervention, following the scenario 3.

In a second treatment in the SFS-h the water flows under the ground, in a gravel bed located within a waterproof liner or layer, where vegetation species, usually the common reed, have been planted. In the third stage the FWS CW is represented by a series of shallow ponds containing different plants with various purification potentials (such as Phragmites, Scirpus, Tipha, submerged macrophytes).

Source: (GmbH, 2011)
Scenario 1 - Centralized treatment [Top-down]

1 Three sites at the borders of the municipality are proposed to treat the municipal waste water instead of discharging it to the open-air sewage canals as it does today. By treating the wastewater on these sites the disconnection from the metropolitan sewage system may be feasible. The investments for this centralized treatment can be high and therefore the municipality would be the main stakeholder involved. Those places can also be designed as municipal parks with recreation facilities [at the final stage of treatment] involving the community to learn from natural processes to treat and reuse wastewater. Community gardens for reusing the treated water may be introduced to provide social and economic benefits for the people. [See Appendix 6.3. for complete review on the reference project 1 Dicomano CW treatment for the proposed treatment system].

Scenario 2 - Pilot projects at schools [Bottom-up]

Cultural factors may have a restrictive role in the process of a self-managed approach; as most of the existing houses in the municipality are already connected to the sewage network, people might not see the benefits of a more self managed process. People need to be educated and convinced of the values that this kind of interventions might give them. The strategy in this case will be to start by involving and educating the population in pilot projects at schools. Those programs will need to involve NGO’s and the municipality to start a process of educating the population on natural-based wastewater treatment systems [constructed wetlands] for reusing the water in urban agriculture [See Appendix 6.3. for complete review on the reference project 2 Blackwater and greywater reuse system at Chorrillos School in Lima, Peru].

Scenario 3 – Decentralised treatment for new areas as part of the densification process [Top-down and bottom-up]

As part of the densification process of areas along the structural axis, as open space will become available, a decentralised treatment for wastewater and reuse in urban agriculture [community gardens] may take place. Those areas will become green open spaces joining the new areas with the existing urban tissue. This can be the first step towards further decentralization.

An adequate training skills program for wastewater management needs to start running as a first step. This could combine the second scenario, using the existing educational centres for this training of the community. Once the population has the knowledge required and the awareness of the benefits of decentralised wastewater treatment a further decentralization may take place. The implementation process will need to be managed by the municipality with support of NGO’s to provide technical and economic support but will involve the community to build and manage the facilities. Once knowledge from NGO’s is transferred to the community, the people may start having opportunities for entrepreneurship as they can use the organic waste from wastewater to produce fertilizer for agricultural use. In this way business opportunities may be created.

In this scenario the big open areas at the east and west borders proposed for centralized municipal waste water treatment would not be used. To protect open land from further invasions (extension of urbanization), multiple function parks may be created that also serve as environmental education centres and provide open space and recreation [See proposed landuse plan at the end of this chapter].
Three scenarios for decentralised wastewater management in VDC.

Source: Diagram by author
Challenges:

3 Create conditions for a better mobility inside of the municipality.

4 Create conditions for good quality public space to promote social interaction and sense of belonging.

5 Create conditions for community development to reduce socioeconomic vulnerability [new economic opportunities].

The new urban structure will be defined by a new hierarchical system for different types of mobility reinforced by the new water system, and the development of local nodes which represent the opportunity for endogenous development.

Strategy:

HIERARCHICAL MOBILITY STRUCTURE
AND NODE DEVELOPMENT
INTEGRATION AND REQUALIFICATION OF STREET NETWORK
FOR MULTI-LEVEL AND MULTI-MODAL MOBILITY
Actions:

1. Requalification of street network - Creating new public space

‘...streetspace forms the basic core of all urban public space – and by extension, all public space – forming a contiguous network or continuum by which everything is linked to everything else. This continuum is punctured by plots of private land. The plots of private land surrounded by public streets are like an archipelago of islands set in a sea of public space.’
- (Marshall, 2004)

The re-characterization of streets done to comply with the stormwater strategy, creates the opportunity for a new hierarchical street network for multi-level and multi-modal mobility. Hence, each type of street has a specific profile defined by spatial measures part of the new water system described before.

The proposed hierarchy is defined by five different types of roads: structural axes, main roads, secondary streets, internal streets and new collective semi-public space [see road and street hierarchy diagram]. Different types of streets provide different hierarchy of accessibility and define different types of mobility including specific public transport systems. The profile of each type of street also responds to the existing and new functions along them, those functions will give a special character to each street.
Hierarchical traffic system Map.

I. Structural axes
- Regional borders and local axes
- Light Rail Train
- Commercial
- Regional buses
- Transport hubs
- Taxi private service

II. Main roads
- Local corridors
- Local minibuses
- Mini vans
- Commercial

III. Secondary streets
- Local mobility - green|blue corridors
- Bici taxi
- Waterways
- Cluster borders

IV. Internal streets
- Cluster alleys
- Parking

V. Semi-public collective space
- Recreation + Sports
- Production

Road and street hierarchy diagram.

- new connections
- existing railway line
- new transport nodes
- existing local centrality
- centralities at regional scale

Hierarchical traffic system Map.
Source: Map by author
As shown on the map on the previous page, the first hierarchy 'structural axes' cross the entire Municipality and connect the area to regional exits. The second hierarchy, the 'main roads,' are the local commercial corridors. The third hierarchy, the 'secondary streets,' will define new spatial units 'clusters' inside each neighbourhood. This hierarchy is spatially the most important one as it structures a new network for local mobility. The internal streets will become alleys used only by local residents from each cluster for parking. The streets with lowest hierarchy will create a new network of green-blue semi-public collective spaces for recreation and production (urban agriculture). The use of the space is proposed based on the gradient of accessibility. Community gardens therefore are proposed on the most restrictive internal spaces.
One of the major tasks in urban planning and design to attain urban sustainability consist in an efficient co-ordination of land-use with effective public as well as private transport systems. Design to provide for different modes of movement starts with a recognition of the existence of those modes: motorised and non-motorised. Today there is much talk about green modes and sustainable mobility, as well as equity and accessibility for all ages and social groups. According to Marshall, 2004: 193 '...the purpose of transport hierarchies is to manage relationships between modes. A modal hierarchy should be able to help to identify which modes might be compatible for coexisting on the same road or street type, and which ‘favoured’ modes might be worthy of promotion through street type and network structure.’

The proposed spatial configuration of the new local-regional multimodal transport network generates sustainable means of movement, visibility and permeability for all types of residents. The strategy seeks to give priority to more sustainable travel modes such as walking, cycling, taxi-bike and the new light train. The proposed hierarchical system enhances the connection between different functions by organizing the public transport system inside the Municipality. The evaluation of routes for different uses, density of flows and diversity of mobility infrastructure to support the interrelation between local nodes and regional nodes made necessary the reorganization of the current public transport system.

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Public Transport System</th>
<th>Main Functions</th>
</tr>
</thead>
</table>
| I Structural axes  
[Regional borders and local axes] | Light Rail Train  
Regional buses  
Taxi private service | Commercial  
Local nodes |
| II Main roads  
[Local corridors] | Local buses | Commercial |
| III Secondary streets  
[Local mobility - green | blue corridors] | Taxi-bike | Waterways  
Cluster borders |
| IV Internal Streets  
[Cluster alleys] | | Parking |
| V Semi-public collective space | | Recreation + Sports  
Production |

Multi-modal transport new system.  
Source: Drawings by author.
Regional buses will only run along the structural axes, from there local buses will provide the service. The current mini vans transport system is taken out as local buses combined with taxi-bike provide enough capacity to serve the population.

A ten minutes walk is the desired comfort walking distance to move from one place to another [see walking diagram] therefore the stops for local buses have as catchment area a radius of 1km. Taxi-bike stops will be placed at every intersection of secondary streets, being therefore the most utilized public transport system activating local economy.

MOBILITY STRUCTURE INTEGRATION AND REQUALIFICATION

FLOWS
residents [commuters]  visitors  goods

USE
freight  agricultural logistics  manufacturing logistics

MULTILEVEL & MULTIMODAL TRANSPORT SYSTEM
railway  regional bus  local bus  taxi  taxi-bike  car  bike  pedestrian

LOCAL NODES
transportation interchanges
‘mobility environments’ Specialized activities: agricultural and manufacturing hubs Multi-functional areas

NODE DEVELOPMENT

- Strengthen the multimodal accessibility of activity places
- Increase the liveability of local nodes
- Release congestion and pollution [sustainable mobility]
- Integration of multi-transportation network
- Municipality development potential at regional level
- Social interaction

Based on: (Meijers, 2007), (Rooij, 2005), (Trip, 2007)
3 Node Development

‘Recognition of the increasingly borderless nature of the contemporary city does not mean that we should abandon the planning and design of physical urban places. Physical places still fulfil an essential role in our open urban systems.’

[BERTOLINI, L. & DIJST, M., 2003]

In particular, places where mobility flows interconnect or urban squares and parks, have the potential for granting the diversity and frequency of human contacts that are still essential for many urban activities. Bertolini and Dijst, 2003 refer to such places as ‘mobility environments’ stating that their quality depend on the features of each location and the characteristics of their visitors.

Existing functions [eg. commercial corridors] and proposed functions [eg. natural park and floating agriculture] were evaluated to identify local activators. Six ‘mobility environments’ activated by the new hierarchical system were identified at the local level as potential new centralities. By identifying correlated functions to transport nodes these areas become multifunctional areas where a variety of activities may take place: living, working, shopping, eating, etc. In VDC large number of commuters will use those created new environments when going to their work places or coming back, therefore local nodes need to accommodate multiple functions both for local and regional purposes.
Multimodal transport system and local nodes.
Source: Map by author
Two of the local nodes accommodate specialized activities: manufacturing industry hub and commercial hub; those nodes become part of the regional network.

At the north the existing industrial area is proposed to be expanded to attract more manufacturing industries to the Municipality. In this way new jobs can be provided to the large number of inhabitants who work in this kind of industry in surrounding municipalities.

At the central area a new fruit|vegetable and flowers wholesale market is proposed as a new commercial hub from where the local production may be transported. All agricultural local production from the new ‘chinampas’ area [traditional floating agriculture], high-production agriculture area and ‘surplus’ production from urban agriculture will come together at this point for local selling or regional distribution.

Design Challenge:

The design challenge for the local nodes is to accommodate and integrate multiplicity of functions to fulfill the spatial demands of regional and local networks. Those ‘mobility environments’ will take the advantages of multi-scalar mobility to improve local spatial conditions [housing conditions and mix-use] and in this way upgrade the living quality of inhabitants.
5 km/hr
100m/min
0 carbon emissions per travel mode pound/passenger/mile

20 km/hr
400m/min
0 carbon emissions per travel mode pound/passenger/mile

25 km/hr to 100 km/h
light train system = 0.25 carbon emissions per travel mode pound/passenger/mile

50 km/hr
20 km/hr
car = 1 carbon emissions per travel mode pound/passenger/mile
bus = 0.4 carbon emissions per travel mode pound/passenger/mile

Informal settlement upgrading programs that take a neighbourhood approach and in addition to local infrastructure improvements include social programs aimed at community development like the one proposed in this research and design project are most effective when coupled with policies that tackle difficult issues related to land (World Bank, 2011). There is a need for land use planning to consider flood and other hazard zones when determining where new development should be permitted. Efficient transport systems proposed by enabling access and mobility within the existing urban areas will reduce the possibility to develop in vulnerable locations or conservation areas.

Map of current land use and urban facilities in VDC. Source: Map by author based on 'Plan Municipal de Desarrollo Urbano de Valle de Chalco Solidaridad, 2005.
The proposal considers the risk as the starting point and combines the expected growth of the New Chalco Lake and surrounding lagoons of the Xico and el Marques hills caused by land subsidence with the parallel need of public space and economic opportunities in the municipality. The new land use plan proposes to give more space to the water, relocating housing areas in danger to areas inside the municipality. The opening of the dike gives the opportunity for new spaces for traditional floating agriculture ‘chinampas’ complementing the new recreational city scale park proposed as the new waterfront. To cope with the peak of rainfall, a new water reservoir at the east of the municipality is planned. This area together with the other three green reservoirs will be

1 The risk of the emerging lake is not taken into consideration, the Municipal government has no plan regarding the emerging lake or the other water related risks from open-air sewage canals or pluvial flooding.

The three maps on the following pages show the current land use of VDC Municipality, the proposed plan from the government and the project’s land use proposal.

The proposed land use map in contrast with the one proposed by the government has three main differences:

- **Map of proposed land use for VDC from government.**
  Source: Map by author based on ‘Plan Municipal de Desarrollo Urbano de Valle de Chalco Solidaridad, 2005.’
protected areas that in the future if not used for wastewater treatment as one of the scenarios proposes may be turned into urban parks with recreational as well as productive activities. The disconnection from metropolitan water systems will reduce the risk from open air sewage canals.

2 The plan from the government is to keep on urbanizing the remaining natural areas surrounding the Municipality.

The proposal considers the densification of existing urban areas as the best way to cope with the expected population growth.

3 The governmental plan includes new industrial and commercial areas at the south of the municipality foreseeing as the proposal the reuse of the existing railway.

The proposal agrees on expanding the existing industrial area at the north for more manufacturing industries that may come to the area offering new jobs. The area at the south is maintained as agricultural land for high productivity, below the proposed area for floating agriculture. The most eastern area is reserved for possible centralized waste water management in order to treat the polluted water coming from the Amecameca River. The new land use plan foresees the possibility of the municipality to turn

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**Proposed land-use map.**

Source: Map by author.
into an important agriculture producer at city scale and therefore proposes a new wholesale market at an strategic point inside the urban area, along the railway. The location of this commercial hub will allow for all products to come together at one point [crops from floating agriculture, high productivity agriculture and urban agriculture]. The three types of agriculture can be specialized in the production of different and complementary crops, so that they do not compete with each other. The urban agriculture is considered mostly for self consumption of households and commercialization inside the Municipality. On the following page a description of the possible crops for each type of agriculture is given.

Types of crops for each type of agriculture:

High production Agriculture

The main crops produced in this type of agriculture are:
- broccoli
- lettuce
- chard
- cauliflower
- rosemary
- chilacayote
- chile
- corn
- leguminous
- winter maize

Traditional Floating Agriculture ‘Chinampas’

Chinampas agricultural system provide between 3 and 4 food crops a year, they are considered one of the most productive agricultural systems in the world.

This type of agriculture specializes in horticultural production:
- ornamental plants
- flowers
- maize
- beans

Urban Agriculture in community gardens

The main crops produced in this type of agriculture are:
- chard
- beetroot
- pumpkin
- chile
- tomato
- lettuce
- radish
- carrot
- basil
- coriander
- mint
- parsley
- rosemary
- calendula
- onion
- cabbage
- spinach
- strawberries
- bean
- corn
- oregano
- potato
- cucumber

Source: http://agriculturaurbanamexico.blogspot
The phasing scheme for strategy implementation is developed based on different conditions: risk, community economic possibilities, government support, etc.

The phasing scheme shows the priorities of the process needed to initiate the redevelopment process. Each phase will involve specific actors and financial models to realise the physical interventions and social programs. The stakeholders were gathered in four different groups:

- PUBLIC
- PRIVATE
- COMMUNITY
- ORGANIZATIONS

The colors on the phasing scheme show the responsible actors for each one of the actions.

The last column of the scheme illustrates the interrelation between strategies making evident the integral design approach followed. In this way, the positive impacts of each strategy can be assessed and the relation between strategies can be better understood. For example it is clear how the water strategies create opportunities for mobility restructuring and how the risk creates the opportunity for housing improvement in other areas.

**City Level**

1. Cease groundwater overexploitation at Chalco-Amecameca sub basin
2. Removing the Acapol open sewage canal
3. Wastewater treatment of polluted water coming from Amecameca Open Sewage canal
4. City Scale Lakeside Waterpark & Floating agriculture
5. Light Rail Transit system
6. New connections of regional roads with local structural AXIS

**Local Level**

1. Relocation: Two Phases
   - 1st Phase [2015]:
     - 8,500 inhabitants
     - 1,840 dwellings
   - 2nd Phase [2020]:
     - 8,670 inhabitants
     - 1,870 dwellings

2. Demolishment and Redevelopment: Two Phases
   - 1st Phase [2015]:
     - 2,650 dwellings demolished
     - 15,405 Dwellings Provided [Densification]
   - 2nd Phase [2020]:
     - 1,840 dwellings demolished
     - 10,720 Dwellings Provided [Densification]

3. Rainwater harvesting and reuse at household level
4. Decentralised stormwater management
   a. Separation of stormwater from sewage
   b. Measures on each type of street need to be implemented for surface landscape drainage
   c. New Water Reservoir for High Peak Storage Retention
   d. Local water retention basins
   e. Reuse of groundwater from hand-dug wells

5. Wastewater reclamation and reuse for urban agriculture

Scenario 1 - Centralized treatment [Top-down]
Scenario 2 - Pilot projects at schools [Bottom-up]
Scenario 3 – Decentralised treatment for new areas as part of the densification process [Top-down and bottom-up]

6. Re-characterization of mobility structure
7. Integration of Public Transport Systems
8. Node development
Forecasted climate change scenario for VDC [2050]

“The poor are particularly vulnerable to climate change and natural hazards due to where they live within cities, and the lack of reliable basic services.”
- World Bank, 2011

Local governments play a vital role in financing and managing basic infrastructure and service delivery for all urban residents. Basic services are the first line of defense against the impacts of climate change and natural hazards.
- World Bank, 2011

In order to give stronger validation to the water system proposal, forecasted consequences of climate change and increasing populations are further developed as part of this research. An introduction to the current projects and institutions involved based on the World Bank, 2011 report: Climate Change, Disaster Risk, and the Urban Poor Cities Building Resilience for a Changing World is presented below.

Given the institutional and political complexities of the Mexico City Metropolitan Area, the Mexico City Climate Action Program (MCCAP) 2008-2012 requires a high level of coordination among multiple agencies and civil society. The MCCAP was developed as part of both the Green Plan and the Environmental Agenda of Mexico City. The Green Plan is a 15 year plan that lays out strategies and actions of sustainable development for Mexico City (described within Chapter 2). The Environmental Agenda of Mexico City is a 5 year plan that defines the city’s environmental policy (World Bank, 2011a).

The main objectives of the MCCAP are twofold: (i) reduce carbon dioxide emissions by seven million tons (or equivalent) in the period 2008-2012 and (ii) develop a Climate Change Adaptation Program for the Federal District and fully begin its implementation by 2012. To achieve these objectives, the government utilizes various policy instruments including direct investment from Mexico City, regulation, economic incentives, voluntary carbon markets, and education and information campaigns. The Inter-institutional Climate Change Commission of Mexico City is in charge of coordinating and evaluating the MCCAP. This commission includes representatives from all the administrative units of the Federal District. In addition, three deputies from the District’s Legislative Assembly are invited to attend each session. Among its specific responsibilities are: to design, encourage, and coordinate policies to mitigate climate change effects in Mexico City; to evaluate, approve, and disseminate related projects; to develop financial strategies that generate revenue; and to coordinate actions and policies with other programs linked to the MCCAP.

To facilitate coordination and provide support to the MCCAP, the Legislative Assembly of Mexico City is working on a proposal for a climate change law (not yet entered into force as of March 2011). Although the execution of the MCCAP has an estimated cost of approximately US$5 billion, most of which is budgeted for mitigation actions, there has been little translation into monetary transfers. The only instrument that could specifically provide resources for the MCCAP is the Environmental Public Fund, while the remaining identified actions would have to be financed through each respective agency’s annual budgets. The main challenge of the MCCAP is the lack of institutional coordination and cooperation. Even though the program was designed to cut across institutional boundaries, there is lack of ownership and it is mostly considered a program of the Secretary of Environment.

The MCCAP’s program of adaptation consists of a set of short and long-term actions that aim to reduce risks to the population and economy of Mexico City by taking the potential impacts of climate change into account. The lines of action regarding adaptation are: (i) identifying key threats and performing a vulnerability analysis, (ii) main streaming of adaptation to enhance existing capabilities in Mexico City’s Government, (iii) implementing adaptation actions.

There are multiple agencies involved in responding to extreme hydro-meteorological events, including: The Water System of Mexico City, the Civil Protection Agency, the Public Safety Agency, the Health Department, the Social Development Agency, the Social Assistance Institute, and the Urban Development and Housing Agency. Their main tasks are described on the following table:

<table>
<thead>
<tr>
<th>Institution</th>
<th>Headed by/Headed</th>
<th>Major function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water System of Mexico City</td>
<td>Secretary for the Environment</td>
<td>Responsible for public services related to water, sanitation, sewage, and water treatment. Also coordinates and operates the “México Green” during high precipitation emergencies.</td>
</tr>
<tr>
<td>Civil Protection Agency</td>
<td>Chief of the National Civil Protection Agency</td>
<td>Responsible for coordinating prevention efforts and response to natural disasters, mainly floods and earthquakes, using a “risk alert” that has more than 150,000 people reporting multiple hazards.</td>
</tr>
<tr>
<td>Public Safety Agency</td>
<td>Director of Public Safety</td>
<td>Responds to dangerous situations, both natural and human, and leads the operation of the Civil Protection Agency.</td>
</tr>
<tr>
<td>Health Department</td>
<td>Deputy Director of Health</td>
<td>Responds to sanitary and epidemiological events, and is responsible for public health policies.</td>
</tr>
<tr>
<td>Social Development Agency</td>
<td>Coordinator of the Social Development Program</td>
<td>Provides social services to low-income populations.</td>
</tr>
<tr>
<td>Social Assistance Institute</td>
<td>Coordinator of the Social Assistance Program</td>
<td>Provides assistance to those in need of social services.</td>
</tr>
<tr>
<td>Urban Development and Housing Agency</td>
<td>Coordinator of the Housing Program</td>
<td>Responsible for urban development and social housing programs.</td>
</tr>
</tbody>
</table>

Institutional Responsibilities Relating to Climate and Disasters.
Source: World Bank, 2011
Ongoing Programs and Projects Related to Disaster Risk Management or Climate Change Adaptation

Climate change adaptation programs focus on Early Warning Systems and medium-term response:
Programs on Early Warning Systems and upstream preventative action include the implementation of a hydrometeorological monitoring and forecasting system for Mexico Valley. Initiatives are in place for management of hillside risk, the protection of native vegetation to reduce erosion, and the establishment of processes to help vulnerable populations.

Regarding Medium-Term Response Mexico City is running projects on water and land conservation, land management for agricultural rural areas, reforestation with more resilient species, and green roofing in urban areas.

The main climate change adaptation projects in the context of Mexico City Climate Action Program are:

Program | Responsible Agency
--- | ---
1) Urban Hillsides Program | Environmental Agency
2) Monitoring and Prevention of Health Effects due to Extreme Weather | Health Department
3) Epidemiological and Health Monitoring of Climate Change | Health Department
4) Support to vulnerable populations during winter season | Social Assistance Institute
5) Risk Atlas of Mexico City | Civil Protection Agency
6) Preventive program for hydrometeorological risks | Civil Protection Agency
7) Storm Unit Program | Water System of Mexico City
8) Reduction of extreme precipitation impacts in “El Arenal” | Government Secretariat
9) Sustainable housing in the Federal District | Housing Institute of the Federal District

For emergency response in case of landslides or flooding the most relevant agencies are the Department of Civil Protection, Fire and Health, complemented by Brigades of the Ministry of Social Development, to provide shelter, hot food and psychological help to those affected, on the one hand, and the Ministry of Public Security to control access and prevent vandalism, on the other hand.

Projected impacts of climate change related to water issues in VDC and MCMA

In the case of Mexico, climate change is a process underway that will have important consequences on the availability of water resources. MCMA is exposed to increases in extreme temperatures, which with expanding urbanization, has contributed to a significant heat island effect for Mexico City. Projections reveal that the mean temperature is expected to increase by 2 to 3 °C towards the end of the 21st century. In recent years heat waves come to produce temperatures between 33°C and 35°C. Those heat waves result in a high risk mainly for older adults (sixty years or more), a segment of the population that has been increasing in Mexico City going from 5.1% in 1995 to 5.8% in 2000 and 6.8% in 2005 (INEGI, 1997; INEGI 2001, INEGI, 2006a) For Mexico City, the trend in the regions with rapid urbanization between 1963-2000 is an increase of about 0.7 °C per decade, while for regions close to vegetated areas the associated increase was about 0.1°C per decade (World Bank, 2011a).

Accordingly, the degree of vulnerability in Mexico City because of climate change is very high because of the relationship between temperature rise, increased evapotranspiration, reduced water bodies and reduced groundwater infiltration. Recent years have also shown the vulnerability of Mexico City to events of extreme precipitation. Precipitation projections for Mexico City seem to be consistent with the general projection made by the Intergovernmental Panel on Climate Change (IPCC) in 2007, which states that precipitation will increase in regions with high precipitation and decrease in regions with low precipitation.

Flooding to the west and south of the city indicate that the risk of intensive rains (over 30 mm/hr) has increased because of the increasing frequency of these events. Climate change projections indicate that with increasing temperature, evapotranspiration increases at the expense of infiltration and runoff. For many urban areas, including the MCMA, changes in land use also affect this ratio whereby as urbanization increases, less water is naturally absorbed into the ground and more runoff occurs. Past research have shown a noticeable increase in runoff in 2000 when compared with 1980 (World Bank, 2011a). The increased precipitation and resulting runoff will continue to increases flood risk in the city, particularly given the existing drainage system.

There are also indirect consequences from climate change and natural hazards on health via exposure to declining water, air and food quality, alterations in ecosystems, agriculture, industry and settlements and the economy (such as migration and poverty), and effects on food security. Under climate change, water availability would be reduced and competition for the resource might cause social problems. The more frequent appearance of drought conditions would cause great losses in the agriculture sector. Furthermore, changes in agricultural production will be reflected in prices, which affect the whole population. Those living in informal settlements are found to be most vulnerable to climate-related risks (World Bank, 2011).

Finally, another important aspect of climate change is its socioeconomic consequences for Mexico City Metropolitan Area. Past research (World Bank, 2011) on the economic costs of climate change in terms of GDP for the Federal District, have estimated that economic losses are not distributed equally among administrative units. Those that will lose the most are those that are currently in worse conditions. In other terms, if the temperature increases by 2 °C, Mexico City could lose up to 7% of its GDP and get 150,000 additional poor annually (World Bank, 2011a).
The previous background makes clear the vulnerability of the whole metropolitan area in a climate change scenario and in particular of areas where the urban poor live such as VDC municipality. In order to assess the proposed water system some figures are important.

**Renewable water:**

Renewable water per capita in MCMA, 2008
165 m³/capita/year
Renewable water per capita in MCMA, 2050
131 m³/capita/year

Source: [Conagua, 2010](http://www.imta.gob.mx)

**Annual precipitation and peak events:**

For a climate change scenario for 2050 it can be expected a precipitation for VDC Municipality of 847 mm. per year and increasing extreme events with peak precipitation of 124 mm. per day.

Source: Projections based on CONAGUA, 2010

**Population**

<table>
<thead>
<tr>
<th></th>
<th>MEXICO [million of inhabitants]</th>
<th>2005</th>
<th>2010</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>103 946 866</td>
<td>108 396 211</td>
<td>121 855 703</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MCMA [million of inhabitants]</th>
<th>2005</th>
<th>2010</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>21 582</td>
<td>23 673</td>
<td>26612</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>VDC [million of inhabitants]</th>
<th>2005</th>
<th>2010</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>332, 279</td>
<td>406,521</td>
<td>745,622</td>
<td></td>
</tr>
</tbody>
</table>

**Summary of Main Findings of City Level Risk Assessments: Mexico City**

Source: World Bank, 2011

Calculations were conducted to estimate rainwater runoff for climate change scenario (2050) per year and per day (precipitation peak events) and to evaluate proposed measures for rainwater storage for peak precipitation events under climate change scenario (2050). The main findings are shown on the opposite page. [For complete calculations please refer to Appendix 7.4.](http://www.imta.gob.mx) Under a higher peak precipitation expected for 2050, the proposed design can only storage 8.29% of the total runoff. The exceeding amount will flow towards the planned peak storage areas along the main axes and at the boundaries of the municipality. In order to be on the safe side, the strategy proposes to take the total required area for peak precipitation event storage from the climate change scenario:13.98% of the total area with a depth of 1m, providing enough storage capacity for peak events.

It has to be mentioned that the design capacity of measures for water retention and infiltration did not consider percolation of natural soil (considering it is a relatively waterproof soil and being...
out of the scope of this research project). However, it is an important variable that gives the design certain margin of safety for the future climate scenario. As part of further research, percolation calculations and more accurate knowledge on movement of water in flat areas could provide important insights for water urban planning.

<table>
<thead>
<tr>
<th>average rainfall in mm per year (2050)</th>
<th>peak precipitation event in mm</th>
<th>number of houses per cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>874</td>
<td>124</td>
<td>557</td>
</tr>
</tbody>
</table>

**NOTE: After complete design...**

<table>
<thead>
<tr>
<th>total gross m³ rainwater on the whole area (per year)</th>
<th>net m³ rainwater runoff from whole area per day</th>
<th>net peak m³ rainwater runoff from whole area per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>22,487,956.34</td>
<td>10,508,486.74</td>
<td>5,760,060.94</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>net storage capacity all ditches and canals in m³</th>
<th>storage capacity in relation to total gross runoff per year</th>
<th>storage capacity in relation to total net runoff per year</th>
<th>storage capacity in relation to total net peak runoff per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>477,419.35</td>
<td>2.12%</td>
<td>8.29%</td>
<td></td>
</tr>
</tbody>
</table>

**Results for Climate Change Scenario [2050]**

- **Required storage capacity for remaining rainwater (peak event) in m³ on total area**: 1,229,953.55
- **Net storage capacity for remaining rainwater (peak event) in m³ on total net peak event runoff per day**: 646,109.97

<table>
<thead>
<tr>
<th>portion of total area for peak precipitation event</th>
<th>required storage area for remaining rainwater (peak event) in m³ (depth=1m)</th>
<th>required storage area for remaining rainwater (peak event) in m³ (depth=50cm)</th>
<th>portion of total area for peak precipitation event storage (portion of total area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.77%</td>
<td>1,229,953.55</td>
<td>2,499,907.10</td>
<td>9.33%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total required area for peak precipitation event storage (portion of total area)</th>
<th>total required area for peak precipitation event storage in m³</th>
<th>total required area for peak precipitation event storage in m³ (peak event) in m³ (depth=50cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.37%</td>
<td>19,028.57</td>
<td>12.14%</td>
</tr>
</tbody>
</table>

**Results for current situation.**

<table>
<thead>
<tr>
<th>portion of total area for required storage area for peak precipitation event</th>
<th>required storage area for remaining rainwater (peak event) in m³ (depth=1m)</th>
<th>required storage area for remaining rainwater (peak event) in m³ (depth=50cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.97%</td>
<td>2,934,720.00</td>
<td>5,869,440.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total required area for peak precipitation event storage (portion of total area)</th>
<th>total required area for peak precipitation event storage in m³</th>
<th>total required area for peak precipitation event storage in m³ (peak event) in m³ (depth=50cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.98%</td>
<td>56,076.23</td>
<td>25.35%</td>
</tr>
</tbody>
</table>

**Results for Climate Change Scenario [2050]**

Source: Excel table for calculations of all water strategies was provided by Dr. Ing. Thorsten Schuetze.
The table was modified by author based on Schuetze, 2011.

Green-blue structure in VDC Municipality - Peak storage water retention area.
Source: Map by author.
5.6. Strategic Interventions

5.6.2. [Design 2: Lakeside Waterpark]
Two strategic interventions are chosen as design areas to show the integration between strategies. The two design areas are linked by the new water system and the new hierarchical mobility network.

Each design follows design concepts and sustainability principles described before, to create better living conditions and new opportunities for the development of the community.
Strategy and design guidelines are defined by the integration of
the three layers [Landscape, infrastructure and Function] to fulfil the
economic, social and environmental needs. The latter is illustrated
on the diagram on the next page.

For the redevelopment of the central axis the following design
concepts were followed:

1 **Permeability**: The new street profiles and local basins will
be integrated in the design following the infiltration model proposed
for the rainwater decentralised management strategy. In terms of
flows of people permeability is understood as a compositional
property, referring to the extent to which a two-dimensional plan
area is ‘permeated’ by accessible space (Marshall, 2004). All
the area around the main roundabout becomes accessible and
attractive by commercial and services functions surrounding.

2 **Transformation of an homogenous area [peripheral
sleeping town] into a more mix used area**: The design integrates
the two proposed types of buildings to attain a more mix-use used
area.

3 **Transit-oriented development (TOD)** is the functional
integration of land use and transit via the creation of compact,
walkable, mixed-use communities within walking distance of a
transit stop or station. A TOD brings together people, jobs, and
services and is designed in a way that makes it efficient, safe, and
convenient to travel on foot by bicycle or car. TOD concept will be
used to create a flexible plan for the area so it can respond to
changing conditions.

The following principles serve as a guide and provide an
understanding of the essential elements and characteristics of a
TOD. They serve as the foundation for the design of the transport
node in VDC Municipality.

+ Create a compact development within an easy walk of public
transit and with sufficient density to support ridership.
+ Create active places and livable communities that service daily
needs and where people feel a sense of belonging and ownership.
+ Make the pedestrian the focus of the development strategy
without excluding the auto.
+ Include engaging, high quality civic spaces (e.g. small parks
or plazas) as organizing features and gathering places for the
community.
+ Encourage a variety of housing types near transit facilities
available to a wide range of ages and incomes.
+ Ensure compatibility and connectivity between neighbourhoods.
+ Introduce creative parking strategies that integrate, rather than
divide the site and reduce the sense of auto domination.
+ Recognize that all TODs are not the same; each development is
located within its own unique context and serves a specific purpose
in the larger context.

4 **Community development: economic opportunities for
local people:**

In lower class neighbourhoods the green spaces tend to be ‘earth
spaces’, due to the lack of maintenance because of the distance
that exists between green spaces and the living spaces, which
makes it difficult for neighbours to take care of them. Therefore,
TRANSPORT NODE AREA STRATEGY

- FUNCTION -
  [NEW CENTRALITY - LOCAL NODE]

  S = Local activator
  - Local identity
  - Local flow articulator

  DG = Integrate extra functions related to flows
  - Integrate elements related to cultural identity & diversity
  - Densification residential mix-used with commercial: markets & food areas.

- INFRASTRUCTURE -
  [REGIONAL-LOCAL & MULTI-MODAL MOBILITY INTEGRATION]

  S = Permeability [people flows]
  - Flows connection and distribution

  DG = Roundabouts to open the grid
  - Open public space
  - Regional and local buses main stops, parking space cars and bikes, taxi-bike stops,
  - Public facilities: community centres, education and cultural centres, libraries, sports.

- LANDSCAPE -
  [CONTACT WITH NATURE AND BUILDING LOCAL IDENTITY]

  S = Permeability [water flows]
  - Open space for local water retention

  DG = Open mix-functional floodable green spaces to allow vertical water flow [permeability]
  - Open typologies and landscape elements to allow horizontal water flows [permeability]
the new housing areas are proposed to be surrounding the green space reducing the distance between communal space and the home to a minimum. This will give space to the social network and generate favourable conditions for maintenance and care. In this way all the houses and apartments will have direct access from the public collective space.

The new street hierarchy where internal streets become only for pedestrian and bike mobility allow for new productive activities to happen [urban agriculture] shaping a new network of public space. Public space is understood as a place that provides the conditions for social relations and participatory activities among local residents. Places to rest, to meet and practice different activities that make people feel more engaged with their community.

5 Flexibility: A concrete design is developed based on the specific needs of the community although the plan allows for flexibility for further transformation. Please refer to page 153.

Green structure plays an important role in improving water management, influencing urban climate and thermal comfort in streets. Urban growth goes with a dramatic increase of hard surfaces. Rainwater does not longer infiltrate into the soil causing sinking groundwater tables; instead the rainwater runs into sewers that are unable to cope with increased peak discharges from paved surfaces (Tjallingii, 2006). The concept of green structure is useful as a frame that is linked to the identity and ecology of the city and, at the same time, creates conditions for choice and for interactive processes that can make the city a healthier and more agreeable place to live. The green structure strategy will deliver those green collective places for residents to promote a healthier community but the focus must be on an interactive planning process rather than on delivering a general plan. Questionnaires and interviews with residents, combined with expert information, may lead to identify more integral solutions and social leaders that can act as an interface between community and planners. Sustainability principles must be included in long term planning policy to make the spatial structure of green spaces a basis for sustainable urban development.

Since the 1920s, researchers and planners have sought to determine the minimal green surface required for health and recreation in cities (Turner, 1992:366). Although it is difficult to substantiate these figures through research, most cities have adopted minimal green space standards for sustainable urban development, varying from 20 to 75 m² per person being aware of the 9m² per capita recommended by the World Health Organization. As mentioned on the city analysis, in Mexico the available open green space is 1.94 m² per inhabitant and in VDC Municipality this figure is even lower 1.42 m² per inhabitant. The proposed green structure strategy for VDC could have an enormous positive impact providing almost 25 m² of green open space per inhabitant.
(iv) Internal Street Profile.
Source: Impressions by author

(v) Semi-public Collective space for urban agriculture.
Source: Impressions by author
Decentralized Wastewater Strategy Implementation:

- Allotment gardens
- Septic tanks
- Disconnection
- Existing blocks
- Subsurface CW
- New blocks
- Existing sewage network
- Limit of area for decentralized wastewater treatment

**Septic tank**
- Volume: 3m x 4m x 1.4m = 16m³
- Capacity: 16,000 litres per day
- [1 day hydraulic retention time for 200 inhabitants]
- 6 septic tanks
- Total capacity = 96,000 litres per day

**Horizontal subsurface flow constructed wetland**
- Calculated with an area of 1m² per inhabitant for a maximum of 1,200 inhabitants

**Allotment gardens**
- Space for urban agriculture
- 20m² per allotment

**Limit of area for decentralized wastewater treatment**

---

Source: Impressions by author
80,000 m²
0.3% of the total area of the Municipality

Source: Drawing by author.
unpaved streets
unsealed areas
open areas
green areas
unpaved streets
sealed areas
built areas
paved streets

EXISTING BLOCK
16 blocks
14 dwellings per block
224 dwelling in total
4.64 inhabitants per dwelling
on average 1040 inhabitants

BLOCK - BUILDING TYPE A
2 blocks
42 apartments per block
82 apartments in total
on average 168 inhabitants per block
on average 336 inhabitants

7 blocks
42 apartments per block
294 apartments in total
on average 168 inhabitants per block
on average 1176 inhabitants

BLOCK - BUILDING TYPE B
1 block
22 expanding houses
22 expanding duplex
on average 176 inhabitants per block

8 blocks
176 expanding houses
176 expanding duplex
on average 1408 inhabitants per cluster

BLOCK - WASTEWATER TREATMENT & COMMUNITY GARDENS
1 block
capacity for wastewater treatment of
1200 inhabitants per block
26 allotments per block [20m² each]
space for food production [urban agriculture] for
86 families on average [1.5 m² per inhabitant]

5 blocks
capacity for wastewater treatment of
6000 inhabitants per cluster
130 allotments per cluster
space food production [urban agriculture] for
433 families on average [1.5 m² per inhabitant]

Total Population per cluster = 1 552 inhabitants | 337 families
Total Population per cluster = 2 584 inhabitants | 557 families

open space ≥ 50% from that pervious surface (green) ≥ 80%
roof surface:
50% rainwater harvesting
50% public program [green roof]
parking areas pervious pavement
bicycle parking + car parking

FLEXIBILITY FOR FUTURE TRANSFORMATION

Flexibility of design for future transformation.

Source: Drawings by author.
Strategy and design guidelines are defined by the integration of the three layers [Landscape, infrastructure and Function] to fulfil the economic, social and environmental needs. The idea is to redesign the limit between the lake and the urban as a new natural park with productive, commercial and recreational uses. The transition between the natural environment of the lake, the new area of traditional floating agriculture ‘chinampas’ and the new park with the urban area will create a green corridor on which the new LRT system will run. The existing dike will become part of the new waterfront park connected by wooden decks to the rest of the park.

The urban area and the lakeside waterpark will be connected through the [iii] hierarchy ‘the secondary roads’, the canals on this street profile will continue through the park until they intersect with the main canal running along the railway line. Pedestrian and bike paths will connect every other intersection of a secondary street running E-W with the rail line with connecting bridges to cross the main canal.

Commercial and services areas will also be part of the park offering entrepreneurial opportunities for the residents of VDC. One of the most important features of the park will be the fruit/vegetable and flowers wholesale market that will give the opportunity for local producers to sell their products on a regional scale.

5.6.2. [Design 2: Lakeside Waterpark]

Identity & Sense of place

Place is described by Susan Moore (1997:1) as 'the intersection of people's physical, biological, social, and economic world's. Sustainability then depends on the integration of those four worlds. Past research (Newmann and Jennings, 2008) argues as well on the need to search for sustainability down to the local arena, rather than focusing on global abstract solutions. The local is where physical interactions occur and joys and losses are experienced. Hence, local communities provide the most immediate expression of connections to place and people.

The literature emphasises the importance of the identity of the urban environment (Jacobs, 1961; Gehl,1978). It has been recognized that the attractiveness and individuality of the living environment also contributes to the identity of the residents and with that to self-respect. The idea then is that the inhabitants of VDC start feeling identified with its community, by providing them with a places which they can be proud of and attached it. In this way protection of natural environments can also be guaranteed. When inhabitants realise that the new Lakeside Waterpark may bring to them multiple benefits they will take care of it, therefore it is key to involve them in the planning process to let them know what are the plans for their own territory.
Bridges crossing the main canal running along the railway.  
Source: Sketch by author

Recreational activities related to water to attract tourism (boats and fishing).  
Source: Sketch by author

Impression of the Lakeside Waterpark in VDC.  
Source: Impression by author.
Impression of the Lakeside Waterpark in VDC | the new connection between the lake and the urban area.
Source: Impression by author.

Section C-C'.
Source: Section by author

Sightseeing points along the waterside for bird watching.
Source: Sketch by author

Wood decks connecting the park to the existing dike.
Source: Sketch by author
6.1. Three levels of evaluation

The evaluation of this research project is conducted on three different levels:

[a] Evaluation of the design and proposed strategies against the vision. A qualitative and as far as possible quantitative evaluation of the strategies and design proposals is conducted to answer some final questions and assess the positive contribution toward sustainability of the area for the metropolitan area.

[b] Evaluation of transferability of the proposed strategies. By defining parameters [model] used as part of the research in this project, the proposed strategies can be assessed to define their transferability. Ciudad Nezahualcóyotl a neighbouring municipality of Valle de Chalco is chosen as a case example to conduct this evaluation.

[c] Evaluation of the feasibility of the project. This evaluation is done by identifying the actors involved in the planning and decision making processes in Valle de Chalco. Via this stakeholder’s analysis, needed changes and opportunities can be recognized.

As an overall evaluation of the project final conclusions are given against the project’s hypothesis and research questions. Finally further research considerations are also pointed out.

[a] Qualitative and Quantitative

Is there a place for sustainability within marginalized peripheral areas of Mexico City?

This graduation project aims to give a positive answer to that final question by providing a sustainable redevelopment vision for Valle de Chalco Municipality as a reference case. An assessment of the proposed strategies and choices made is needed to validate their feasibility and to evaluate if the proposed future situation is more sustainable than the existing one.

In order to make this evaluation two concepts: ‘ecological footprint’ and ‘urban metabolism’ are explained and suggested as indicators to assess the ecological performance of VDC and MCMA.

Great cities are planned and grow without any regard for the fact that they are parasites on the countryside which must somehow supply food, water, air, and degrade huge quantities of wastes.

— Eugene Odum (1971)

Ecological footprint

Cities consume significant quantities of resources and have a major impact on the environment beyond their borders (Newman and Jennings, 2008). One way of describing the impact of a city is to measure its ecological footprint. The ecological footprint of a city or a country is defined as the area of land (and water) required by its population, given prevailing technology, to produce the resources it consumes and to absorb any wastes created. Ecological footprints are measured in ‘global hectares’ (gha). A global hectare encompasses the average annual productivity of all biologically productive land and ocean areas in the world. In 2005 the world’s population required the resources of 2.7 gha /person. Unfortunately, the world’s biocapacity (the amount of resources its ecosystems can supply each year) was only equivalent to 2.1 gha per person and is declining each year as population increases (Rhoda, R. & Burton, T. 2010). According to UNDP on 2007 the world’s biocapacity had already declined to 1.8 gha/person.

Ecological footprint of several countries.
The deficit between biocapacity and our ecological footprint causes damaging environmental changes to forests, fisheries, rivers, coral reefs, soil, water and air, and plays a major role in global climate change. The figures mean that current usage of the world’s resources is inherently unsustainable. The graph above shows how the ecological footprint of more developed countries are even higher. Mexico’s ecological footprint is on average 3.7 gha/person meaning that its population require almost double of its fair share of the world’s biocapacity.

The challenge of reaching a high level of human well-being while ensuring long-term resource availability is illustrated in the figure to the right [the situation of Mexico is pointed out]. The United Nations Development Programme (UNDP) defines a high level of development as an Human Development Index [HDI] score of 0.8 or above, while 1.8 global hectares is the average productive area available for each person on the planet. Countries with an HDI score of 0.8 or higher, and a Footprint of 1.8 global hectares per person or lower, meet two minimum criteria for global sustainable development: a high level of development and an Ecological Footprint per person that could be globally replicated to a level less than global biocapacity [lower right quadrant]. Despite growing adoption of sustainable development as an explicit policy goal, any country meet both minimum conditions.

The well-being of human society is intricately linked to the biological capital on which it depends. Accounting for the biological capacity available to, and used by, a society can help identify opportunities and challenges in meeting human development goals. The loss in human well-being due to ecological degradation often comes after a significant time delay, and is difficult to reverse once the stock of resources has been significantly depleted. Short-term methods to improve human lives – such as water purification, basic medicine, and electricity for hospitals – must be complemented by effective long-term resource management in order to address and reverse humanity’s cumulative ecological degradation (GFN,2010).

Mexico City Metropolitan Area creates an enormous ecological footprint. The city’s needs are not self-sufficient; rather, they are subsidised by other regions. The tension of this relationship is illustrative of a key issue in common pool resource management, the challenge of mediating between multiple and often competing interests. The city is dependent on other ecosystems to subsidise the vast amounts of food, energy and water that it requires, a subsidisation that is only possible because Mexico City is the hub of an immense concentration of economic and political power that permits it to concentrate resources as well (Aguilar et al, 1995). Mexico City Metropolitan Area needs to reduce its ecological footprint to match its bioregion, as a fundamental part of sustainability. The spatial and environmental strategies proposed in this research project aim to enable Valle de Chalco Municipality to minimize its ecological footprint as a step that could have a chain effect in other informal settlements if both local governments and citizens become committed. According to Newman and Jenning (2008:81), ‘In reducing the footprint, problems should be solved locally where possible, rather than shifting them to other geographic locations or future generations. Reducing the ecological footprint of VDC and further on of the whole MCMA means not only a necessary transformation of infrastructure but also a profound modification of citizens’ behaviour.

One recommendation of this project is that the ecological footprint or some other way of auditing the city’s consumption, needs to be regularly calculated and used as an indicator of progress toward sustainability. The ecological footprint is a tool for foreseeing global impacts from resource consumption. However, local ecological footprints or impacts need to be managed through careful ecosystems assessments that can determine the biocapacity of groundwater, soils, etc. and through instituting management regimes to accommodate human activity in a bioregion [Newman and Jennings, 2008].
Urban metabolism

A number of cities around the world are now developing sustainability visions as a basis for future planning instead of following fixed land use plans. According to Newman and Jennings (2008:26) ‘the formulation of more local visions provides the opportunity for greater community participation and engagement with issues at a practical level, which is likely to produce visions better matched to local ecological and social realities.’ New city visions apply sustainability principles to governance, global issues, natural resources, settlements, community and business. The extended metabolism model below [an ecosystem-based model developed by Newman and Kenworthy (1999)] has been used to guide those new sustainability visions. The model suggests how cities can become more sustainable by reducing their resources and wastes while increasing livability.

The term ‘urban metabolism’ was first coined in 1965, the conception of a city as a living organism that takes in energy and materials, transforms them through metabolic processes into usable goods and services, and excretes waste (Erickson and Kane, 2007). The notion of urban metabolism raises the question of the source of inputs and location of waste sinks for areas that are not self-sufficient, and is at the heart of questions of sustainability (Baccini, 1997).

The concept of ‘urban metabolism’ motivates discussion of urban dependence on geographic regions outside their borders for both sources of inputs and as waste sinks. Therefore, it may be useful for assessing the sustainability of major urban areas such as Mexico City, which encounter a unique set of problems in acquiring adequate supplies for their concentrated population. Like any living system a community consumes material, water and energy, processes them into usable forms and generates wastes. This is the ‘metabolism’ of the city, making this metabolism more efficient is essential to reducing the city’s ecological footprint (Newman and Jennings, 2008).

Many very large cities, throughout the world (for example, New York, Los Angeles, Seattle, Caracas, Mexico City, and Cape
Town, South Africa) acquire their supplies from distant sources, adding significant political challenges and often legal battles to water supply management. Many experts predict that the Basin of Mexico is now reaching not only its ecological limits, but also its technological and social limits to substitute or import needed resources (Aguilar et al, 1995). Mexico City is an acute example of uncontrolled urban expansion and environmental deterioration, but it is certainly not unique in its situation. ‘The combination of natural resource constraints, environmental impacts and the incapacity of governments to respond and solve rather complex problems can be found in both developed and developing countries’ (Tapia et al, 2000).

Currently as literature points out (Girardet, 2000) most cities are linear metabolic systems in which resources flow in and wastes flows out, unlike natural ecosystems where resources are cycled in the system. Thus, cities need to close materials cycles an adopt a circular metabolism maximizing recycling of paper, glass, metals and plastics, treatment and reuse of wastewater and composting organic wastes (Newman and Jennings, 2008). Inputs and outputs of cities should match bioregional capacities; inputs gained locally and bioregionally and wastes should be recycled at the local and bioregional scales. See figure below.
The current unsustainable centralized water systems are contributing to the pollution of ground and surface waters. As stated before, opposed to that proposed **decentralized systems for rainwater management, sewage treatment and ecological sanitation (ecosan) and water supply** provide multiple advantages and possibilities. They allow the separation of waste water streams with different characteristics, which allow for an efficient treatment and high-quality utilization of nutrients (Schuetze, 2007).

A comparison between the conventional centralised water systems and the decentralised systems part of the proposal of this research project is illustrated on the schemes below.
Water Strategy Evaluation
Analysis of water flows - Quantity

There is a wide range of EST’s [Environmental Sound Technologies] available for all parts of the water cycle and promising combinations of them already in practice in many countries. Selected EST’s should fit specific situations therefore understanding facts and uncertainties is key for the decision making process [UNEP and TU DELFT, 2008].

A similar graph for Valle de Chalco shows a completely different picture. Quantities and possibilities for EST’s vary considerably because of different climatic, cultural, economic and technological situations. For VDC the current average consumption is already higher than 150 litres per person and day. The average amount of rainfall per person per day is estimated on 52 litres per person and day, the consumption patterns are almost the same although the losses caused by pipeline leakages are bigger.

A first step towards strategies for sustainable water use and saving is to reconsider the balance of water use for different purposes. The illustration [a] shows a domestic level analysis using as an example quantities (in litres) used in the Netherlands in 1990. The 136 litres becomes 127 due to water losses caused by pipeline leakages. The quantity of piped water with drinking water quality metered on building level as well as the outflow of sewage are 127 litre per person and day. Water use is categorised as: kitchen, cleaning, bathroom, washing and toilet flushing. An extra potential input and outflow is the rainfall of average 30 litres per person and day that falls on the roof and leaves the building by drains. This analysis reveals the relative importance of the different domestic water flows and thus demonstrates where EST’s and water-saving policies may be most effective [UNEP and TU DELFT, 2008].

<table>
<thead>
<tr>
<th>required water quality</th>
<th>purpose</th>
<th>consumption pattern litres</th>
<th>person</th>
<th>day</th>
</tr>
</thead>
<tbody>
<tr>
<td>drinking water</td>
<td>cooking and drinking</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>washing kitchen</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>bath and shower</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>service water</td>
<td>laundry</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>cleaning and watering</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>toilet flushing</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>losses from leakages</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total water consumption</td>
<td>required litres</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>person</td>
<td>day</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[a] Example for the average water consumption in The Netherlands in 1990 of a domestic household in litres per person and day, separated in different uses. Display of resulting sewage streams and average amount of rainfall, also per person and day. Source: [UNEP and TU DELFT, 2008].

[b] Example for a water-saving household with applied EST’s for water use and savings in litres per person and day. Source: [UNEP and TU DELFT, 2008].

[c] Water consumption pattern for VDC and proposed reduction values. Source: [UNEP and TU DELFT, 2008 modified by author].
the whole area on a yearly and monthly basis were estimated. The results were used to assess the water balance of the area (total rainwater from all areas - total water demand). The water consumption in VDC per day was also calculated to analyse by which extend the stored rainfall would be reduced by consumption in the area, the result was that it would be reduced by 3.37% per day. Calculations were also conducted to estimate the water demand for irrigation on the whole area for the urban agriculture strategy. This calculation was made taking tomato crops as a reference. For normal climatic conditions in Mexico City it was estimated that tomato crops would need 544 litres per m2 for 32 weeks of irrigation per year. Considering the amount of allotment gardens proposed for each cluster it was estimated that each cluster would need 380, 800 litres for irrigation per year. That is translated into 380 m3 average per cluster, that amount multiplied by the total number of clusters in the area (323) results in the total water demand for irrigation on the whole area. Please refer to Appendix 7.4. for a complete review of all calculations.

To assess the estimated results on water flows for the area it is considered that for a sustainable water system the rainwater runoff should exceed the freshwater demand within the area (hence no water needs to be imported) [Schuetze, 2011]. In the case of VDC Municipality in the current situation [high water consumption: 150 litres per person per day], the freshwater demand exceeds the total rainwater runoff of the total area on a yearly basis.

The first step towards a sustainable water system would be to stimulate measures for efficient water use to reduce domestic freshwater consumption. With minimal investment and operating costs and without loss of comfort, by the installation of flow-control devices (water saving fittings), water saving household appliances and toilets the average freshwater demand may be reduced up to 1/3 (Schuetze, 2006). In the case of VDC that would mean that the average consumption could be reduced to 100 litres per person per day. Calculations were made for this strategy of water consumption reduction, however the result was still not positive. See [Table 1].

A further step may be taken, from research (Schuetze, 2006) it has been acknowledged that the proportion of the service water demand of water saving households in relation to the total water demand is on average 30%. While the service water demand varies depending on the types of toilets used, the drinking water demand remains constant. In the case of an area-wide implementation of water saving households and the utilization of irrigation as service water (water recycling) the freshwater demand could be reduced an extra 25% on average (Schuetze, 2006). In the case of VDC that would mean a reduction of almost 30 litres. Calculations for this strategy are presented on [table 2] with a new consumption value of 72 litres per person per day.

For further reduction of freshwater consumption at household level, sustainable sanitation (ecosan) for reuse of treated wastewater for irrigation may be implemented. Hence, the integration of the proposed strategy for decentralized wastewater treatment and reclamation for urban agriculture is key to attain water balance for the municipality [Scenario 3 wastewater strategy]. As it can be noticed on the calculations, when the wastewater treatment strategy is implemented since the first step of the reduction strategy water balance is attained.

On table three it is shown how without implementing the wastewater strategy the freshwater demand reduction strategy alone needs to be reduce to 65 litres per person per day to attain a sustainable water system because the rainwater runoff exceed the freshwater demand within the area and therefore it becomes self-sufficient.

As a last stage of the reduction strategy it needs to be also considered that freshwater demand can also be reduced by the reuse of recycled wastewater as service water. This concept of cascade use is further explained on the next page.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Calculations for domestic freshwater demand reduction strategy [1st Step]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water demand (liter per person per day)</td>
<td>100</td>
</tr>
<tr>
<td>Irrigation from rainwater runoff from whole area in liter per person per day</td>
<td>9,726,801.29</td>
</tr>
<tr>
<td>Total household water demand for irrigation in the whole area in liter per person per year</td>
<td>122,918.40</td>
</tr>
<tr>
<td>Water balance yearly basis in liter (Total rainwater runoff from all areas - Total water demand)</td>
<td>5,236,715.81</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Calculations for domestic freshwater demand reduction strategy [2nd Step]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water demand (liter per person per day)</td>
<td>72</td>
</tr>
<tr>
<td>Irrigation from rainwater runoff from whole area in liter per person per day</td>
<td>9,726,801.29</td>
</tr>
<tr>
<td>Total household water demand for irrigation in the whole area in liter per person per year</td>
<td>10,683,371.88</td>
</tr>
<tr>
<td>Water balance yearly basis in liter (Total rainwater runoff from all areas - Total water demand)</td>
<td>11,742,656.99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Calculations for domestic freshwater demand reduction strategy [3rd Step]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water demand (liter per person per day)</td>
<td>65</td>
</tr>
<tr>
<td>Irrigation from rainwater runoff from whole area in liter per person per day</td>
<td>9,726,801.29</td>
</tr>
<tr>
<td>Total household water demand for irrigation in the whole area in liter per person per year</td>
<td>122,918.40</td>
</tr>
<tr>
<td>Water balance yearly basis in liter (Total rainwater runoff from all areas - Total water demand)</td>
<td>40,907.83</td>
</tr>
</tbody>
</table>

Source: Excel table for calculations of all water strategies was provided by Dr. Ing. Thorsten Schuetze. The table was modified by author based on Schuetze, 2011.
Water conservation - Cascade Water Use and Closed-loop systems

At the new housing areas there are other opportunities for maximising water conservation such as applying closed-loop and water cascading systems in residential buildings. This strategy may also be implemented on existing houses with more financial and technical support for households.

Apart from rainwater harvesting, green measures for stormwater infiltration, and conventional approaches of water recycling/reuse for lower grade water usages such as for toilet flushing and irrigation; in new housing areas there should be an effort made to maximise water recovery through the design of closed-loop water systems as well as water cascading. Closed-loop water system aims towards a total re-use of all components in the wastewater [Wan Alwi, 2006]. The concept of closed loop in water demand management for a residential building is shown in the diagram to the right. The main idea is to match water quality with the appropriate water usage.

This closed-loop method can be applied at household, neighbourhood, community, industry or institution scale. After water is used, the generated wastewater is segregated into greywater and blackwater streams. Grey water and black water are produced separately, and ensuring that they remain separate can facilitate management of the two wastewater streams. The wastewater streams are treated accordingly before being reused or recycled for other applications. The basic principle of water cascading system is water quality cascade where water sources are matched with end uses in terms of the required water quality as shown on the table to the right [Wan Alwi, S.R. et al., 2006].

At new housing areas water conservation can be maximised through integration of the whole suite of measures: rainwater harvesting, installation of water efficient fixtures, effluent reuse and evaporation as well as productive reuse of treated effluent in spaces for urban agriculture. Those measures aim to bring the urban water cycle as close as possible to the natural water cycle. Past case studies have shown a reduction up to approximately 80% of freshwater consumption and 80% of wastewater discharge achievable via this technique [Wan Alwi, 2006].
In order to evaluate the feasibility to transfer the proposed strategies for VDC Municipality into other informal settlements, four parameters are defined:

1. Morphology and density: to assess the possibility for water retention.

2. Local and regional connectivity: to assess potentials to reconfigure urban structure [connections between local and metropolitan mobility network and centralities].

3. Socioeconomic profile of different groups: to assess constraints or potentials of the population.

Those parameters were used as part of the local analysis and therefore constitute part of the proposed methodology. The chosen informal settlement used as a case study for this evaluation is Ciudad Nezahualcóyotl, or more commonly known as Ciudad Neza, a city and municipality of Mexico State adjacent to the northeast corner of Mexico’s Federal District.
Parameters Assessment

1 Morphology and density: The morphological structure of Ciudad Neza resembles that of VDC Municipality as many of the informal settlements surrounding Mexico City. Ciudad Neza is a municipality with higher density than VDC because of its stage of consolidation. This municipality started as an informal settlement in the late 1940’s, thirty years before of VDC. The morphology of the blocks is in part different because of the internal collective space

2 Local and regional connectivity: the area is connected by public transport to the rest of the city. Four metro stations are close to the municipality as shown on the map below.

3 Socioeconomic profile of different groups: The situation in Ciudad Neza is very similar to the one in Valle de Chalco, most of its population belong to the same socio-economic group, that one being very low. However, Ciudad Neza has greater rates of criminality and migration to the United Stated associated to unemployment.

The possibility to assess each of the parameters in a different informal settlement demonstrates that the methodology followed by this research project may be transferable. The socio economic and environmental vulnerability of this and other informal settlements in Mexico City are very similar, therefore there is potential to model proposed strategies for VDC. However, the challenge would be on finding and exploiting unique territorial and social characteristics that bring different design proposals.

- metro stations
- open spaces with public facilities
- built areas
- municipal limit

average block size:
270x40 m
54 plots per block
average size of each plot 200m²
The challenges with respect to urban water supply and sanitation are huge all over the world but particularly in developing nations such as Mexico City. The rising demand on water supply because of the increasing urbanization needs to be addressed by innovative measures. The implementation of innovative measures for the development of an integrated water resource management in the context of Mexico City will require a multi-sectoral approach under a new institutional framework to enable negotiations between the several public and private stakeholders involved.

The water crisis in Mexico City is essentially a crisis of governance. The causes of this crisis include: lack of adequate water institutions, fragmented institutional structures (a sector-by-sector management approach and overlapping and conflicting decision-making structures). Water development and management should be based on participatory approach, involving users, planners and policy-makers at all levels.

The political-administrative boundaries in MCMA are the boroughs in the Federal District and the municipalities in the State of Mexico and Hidalgo. As most large metropolitan areas MCMA has a multijurisdictional administrative structure. There is no elected government institution in charge of administering the entire metropolitan area. Each municipality is autonomous to administer its local affairs, regulated by the government of the states they belong to. As MCMA spreads over three federal entities, two states and the Federal District, metropolitan projects have to be agreed upon by government officials of each federal entity and overseen by the federal government. The multiplicity of governments and jurisdictions in the MCMA leads to the disjuncture between entities and take away the opportunity for representative and participative democratic structures to emerge within and between them (Aguilar and Ward, 2003).

Stakeholder’s analysis

The legal and political entities from the Federal District and the municipal government from the State of Mexico and Hidalgo act separately and lack of coordination between them. Indeed, because of political and economic interests they are competitive with each other making more complicated the planning process for the metropolitan area as a whole. Since creating a single metropolitan government is not feasible, it is important to explore ways in which jurisdictions may corporate between them to create new levels of representation and participation across the metropolitan region. Accordingly, under this context of weak political structure and aiming to an opportunity to deal with the metropolitan problems of transport and roads, planning and development of hydraulic systems, public safety and law enforcement, human settlements and environmental benefits, the Federal District and the State of Mexico established coordination arrangements whereby metropolitan commissions were created since 1995.

Those metropolitan commissions are:
- Metropolitan Transportation Commission and Transit (COMETRAVI)
- Water and Sewer Commission of the Metropolitan Area
- Metropolitan Commission of Public Safety and Law Enforcement
- Metropolitan Commission on Human Settlements (COMETAH)
- Metropolitan Environmental Commission
Subsequently, in 2000 the Metropolitan Commission of Civil Protection was established, this commission aims at addressing, in coordination with other agencies, planning and execution actions related to the prevention and disaster relief of emergency situations that affect the metropolitan area.

Regarding water management faced with evidently intractable financial and ecological constraints, and confronted by increasing social resistance from competing water users, the government of Mexico has recognised that it is impossible to pursue the centralised, technologically growth-oriented water strategy of the past (LEAD, 2011). After decades of continuous hierarchical water management, the government and water authorities have begun to implement new regional and local approaches for the planning and management of water resources within a sustainable development framework (Paredes, 1997). As water is crucial to the economic and social development of Mexico, these new approaches were an integral component of the ‘Environment Policy for a Sustainable Development’, enacted by the Mexican government as part of the 1995-2000 National Development Plan.

The strategy of the government of Mexico is focused on reforms to the legal and institutional framework, effective decentralisation policies, and new financing schemes, resulting in greater private sector participation (Paredes, 1997). Its goal is to meet a number of objectives, both regional and local:

+ To achieve a sustainable and balanced use of the water resources
+ To increase the coverage of services related to potable water, sewage disposal and sanitation, and to increase the construction of infrastructures for flood control and irrigation
+ To ensure the quality of water supplied for human consumption and for other uses likely to affect public health
+ To clean up with an integral approach the hydrologic basins in order to restore the water quality
+ To promote more efficient uses of water for irrigation, domestic consumption, and industrial purposes
+ To decentralise and privatise the operation of conveyance and distribution facilities of water for all anticipated uses.

Mexico is now faced with the task of implementing and financing these changes. A review of the water projects by The World Bank estimated that the cost of development of each cubic metre of water for the next generation of projects is between two and three times higher than that of the present generation (The World Bank 1992, in Tortajada and Biswas, 1997). The estimated amount of resources needed to accomplish the goals of the Water Programme 1995-2000 is close to US $7 billion (Hazin, 1997). Like many other developing countries, Mexico cannot afford to finance these projects alone, and has sought international support from the World Bank, the Inter-American Development Bank (IDB) and Global Environmental Facility (LEAD, 2011).

After several immense water development failures, donors like The World Bank have also reoriented Mexico’s water management strategies to take greater account of the social and environmental implications of water projects. One example of Mexico’s international partnerships is the Water Resources Management Project (PROMMA) with The World Bank. This US $342 million project is executed by the National Water Commision [CONAGUA].

In keeping with the recently adopted sustainable development principles of both the Government of Mexico and international donors, the money is assigned to improve and modernise existing water facilities and establish sustainable planning, including training, technical assistance, and environmental monitoring (LEAD, 2011).

At the regional scale, one of the most significant examples of Mexico’s changing approach to water resource management is the establishment of River Basin Councils [Consejos de Cuenca]. The creation of basin councils was the result of the 1995-2000 Water Resource Plan in which the Federal government, through the CONAGUA, committed to form at least 13 river basin councils (Paredes, 1997). In 1995, the authorities of the Federal Government, the Federal District [D.F.], and the States of Hidalgo, Mexico, Puebla and Tlaxcala signed an agreement establishing the Council of the Valley of Mexico [CCVM] for its acronym in spanish Consejo de Cuenca del Valle de México to coordinate the actions of stakeholders in the Basin of Mexico, including the CONAGUA, all levels of government and private users in the basin.

The role of basin councils is to coordinate water management on a regional basis and to promote region-specific strategies and actions. As such, their establishment represented an important step in the government’s effort to decentralise. The councils identify the local, regional, and national needs of the basin, and their plural and participatory framework make it possible to include stakeholders such as NGOs, community organisations and municipal governments, that were formerly excluded in centralised decision-making processes. In this way, river basin councils represent a shift from a purely technocratic approach to one that encompasses economic, human and environmental dimensions of water resource management.

The CCVM includes the basins of Valley of Mexico and Tula River, which in turn also correspond to the Administrative Hidrological Region XIII. Aguas del Valle de México. This region occupies relatively a small portion of land [16 438 km2], it has a large population [21 258 911 inhabitants], low amount of renewable water [3 514 hm3/year]; and provides a large proportion of

Contrast between development and water availability on the thirteen administrative hydrological regions, 2008
The river basin council is an extremely complex experiment in common pool resource management. Due to its complicated structure (refer to image at the bottom of this page), the Council of the Valley of Mexico is still in the early stages of implementing change, and as yet, can report few great successes. It has, however, experienced many problems and challenges. Perhaps one of the most significant blocks to its successful operation is the too rapid transfer of authority and responsibility from the federal government to the state and municipal level. At the municipal level particularly, many municipalities lack not only the financial capacity to implement plans, but the management and planning capacity to adequately manage water resources and address the different needs of the users (LEAD, 2011).

Other problems encountered by the council is the question of how to effectively structure the diverse inputs from stakeholders, and how to reconcile their competing demands. Finally, the council, in some cases, is resistant to involvement from its newest participants; interests and bureaucratic inertia prevent truly participatory water resource management. Despite these problems, many authorities and water experts are optimistic that such councils are a crucial step in the transition toward an integrated and sustainable management of water resources. Although the planning, implementation and management capacities of innovative solutions (as the one proposed by this research project) would be augmented if international organisations would work together with local scale governments.

In this respect, at the local scale, efforts have been directed at reducing Mexico City’s inefficient water use. The city’s deficient distribution infrastructure and wasteful consumption practices in households are two priority areas for improved water management. To address the first aspect, a number of initiatives have begun as part of the PROMMA programme funded by The World Bank (LEAD, 2011). Mexico City’s water authorities are undertaking the important and arduous task of locating and repairing leaks, improving the efficiency of existing treatment facilities and enabling them to operate to capacity. Mexico City officials have also launched a water conservation project, involving the replacement of 350,000 old toilets with water efficient ones, in a public awareness and education campaign to make every drop of water count (Gleick, 2000).
Authorities and planners are already attempting to tackle inefficient water use in households through a combination of a) increased public education to explain the importance of water as a valuable natural resource, b) implementation of improved billing and water pricing procedures. Historically, Mexico City’s residents have not possessed a strong environmental consciousness about water conservation. For decades, the federal government subsidised water so there was no financial incentive to save water, and its use was taken for granted by many as something that was always free and always available. Mexico City is now introducing increased pricing and billing of water as part of its water management plan, and has taken the unprecedented step of contracting its collection and payment services to the private sector (LEAD, 2011). Many planners argued that the old system of irregular billing, or no billing, for water services was an obstacle to saving water. Until recently, a flat fee was charged regardless of how much water was used. Some people were charged very little, others none at all, which meant that water authorities had no control over how much water was consumed.

At the same time, this introduction of more stringent pricing and billing is controversial because it raises difficult issues of equity and access to water. For water pricing to be standardised, Mexico City must work to even out the service standards and quality of water delivered. It is also crucial that mechanisms are introduced to ensure access to water to the poor. Many analysts point out that the commodification of water and the move away from its status as a basic ‘human right’ or as ‘public property’, is a dangerous trend. Those critics say that the potential privatisation of water may represent the backside of some of the positive changes that the decentralisation of water management has introduced, most notably, more participatory decision-making.

Although the physical size and unique location of Mexico City intensify the issue of water scarcity, the questions and issues it faces are certainly not unique to the city. Undoubtedly, how Mexico City addresses these challenges will be instructive to urban areas, small and large, in other parts of the world that are facing, or will be facing, similar common pool management issues in the future. Mexico City is presently dealing with the hard realities of a closed ecological system [where every source of water is also a potential sink], and the unavoidable certainty that water is a finite resource. The latter means that there are no places to obtain water or to put waste that is not already utilised by other users. The second is that water allocation to one user means less water for another.

According to LEAD International (2011), ‘this ‘zero-sum’ proposition means that there is no easy ‘win-win’ solution for competing users.’ However, the connectedness of water, and the connectedness of water users, also offer the crucial possibility for stakeholders to cooperate together to devise creative solutions to common problems. This would be the starting point for the strategic plan for the redevelopment of VDC Municipality to take place.
6.2. Final conclusions

The findings and final conclusions from this research and design project are listed below:

> The relation described within my theoretical framework between risk, vulnerability and assets as means for resilience of marginalised populations, are taken as the starting point of the strategy. The self-management [independence from unsustainable centralised metropolitan structures] of water resources at municipal, community and household level is thought as an asset for the inhabitants of Valle de Chalco. Through this their basic needs: fresh water supply and safety from environmental hazards (flooding) will be fulfilled. Furthermore, a decentralised management of water as part of their human capital will enable inhabitants to increase their other assets; for instance through rainwater harvesting their household relations may be improved and through urban agriculture in community gardens their social capital assets will be augmented. Consequently, the protection and sustainable management of ecosystems [water] is an appropriate approach for informal settlement upgrading; to reduce their vulnerability and turn present risks into opportunities.

> The replacement of conventional central water service systems by distributed systems that account for sustainability and pay attention to environmental concerns is feasible in developing cities such as Mexico City. Low-cost ‘green solutions’ might be a more affordable solution instead of big infrastructure projects. Large scale city-wide infrastructure investments for flood protection or measures to make roads and facilities more resilient to extreme events may be necessary over time, but they are expensive and will not improve conditions for those living at risk. Smaller-scale investments in drainage and improvements in basic infrastructure need not be expensive, and are catalytic in building resilience for the urban poor. In order to accomplish the proposed strategic plan for VDC municipality significant financial support is needed, therefore the local government need to work in association with multilateral development banks to get resources ensuring a more successful management of existing and new resources at local level.

> The integrated design approach followed to develop the strategic plan for VDC Municipality becomes visible from the overlapping of the water strategies and the mobility strategies. On the phasing scheme it is shown how the actions proposed to accomplish the water strategies bring opportunities to restructure the street network. The integration of multiple disciplines and stakeholders during an early stage in the planning process will also be reflected on the economic feasibility of strategies as costs could be shared. Therefore, an integrated rather than sectoral upgrading approach is essential for the implementation of the proposed strategies. Only in this way important interactions between different branches of infrastructure may be recognized allowing for a simultaneous and cost-effective upgrading of all different types of infrastructure.

> Local solutions proposed within this research project have better possibilities to be accomplished by partnerships between local government and community. It is clear that much of what is needed to reduce risk in low income urban communities depends on the availability of infrastructure that residents cannot provide themselves. [storm and surface drainage, road and path networks, links to water networks, and health care services require specialized skills and substantial resources that communities may not have]. Importance of involvement of NGO’s as sociotechnical support groups as they can open new avenues for participation [education and continuity] becomes clear. There are obvious benefits of partnerships between local governments and communities, successful examples exist around the world (e.g. veredas participativas project in Chile, where the people provide labour force and local government provides resources). Such cooperation can be facilitated through mutual recognition of the role that each group plays; improving the dialogue and discussion to understanding and recognizing what is happening at the local level and forming partnerships with local organizations. For the poor, understanding what the city can and cannot provide is a first step. Strong community groups and detailed community-level information systems can be extremely effective for initiating engagement in such partnerships. For local governments, the challenge is to recognize the contribution that the urban poor make to a city’s economy and society and involving them in discussions about needs and priorities. Local participation is crucial to ensure that the approach taken suits the needs of residents, and satisfy quality standards. Reference cases around the world [see Reference Project 3: The Guarapiranga Program, Brazil] show how a community based upgrading approach can succeed by the empowerment of the people to take part on the decision-making process to plan and design their territory according to their real needs.

> By integrating in the project employment and income generation activities such as urban agriculture, the constraints from a difficult economic situation caused by the increasing unemployment (e.g. residents’ ability to invest in housing and infrastructure improvements and their willingness to participate) may be overcome.

> Climate change adaptation and disaster risk reduction can be best addressed and sustained over time through integration with urban planning practice. Better urban planning and management is imperative to reducing disaster risk and climate change impacts on the urban poor. Policies to mitigate such risks have links to multiple sectors and thus can come with important synergies (e.g. urban policies can have positive impacts on poverty reduction policies and poverty reduction policies can be designed to have co-benefits with climate change mitigation policy goals.) On the next page the table outlines some of the policy choices and actions that can be considered when addressing climate change, disaster risk and the urban poor, positive co-benefits and possible negative consequences of each one are also mentioned. According to the World Bank (2011) from an operational perspective, governments
Because of inconsistencies on data from the different governmental agencies in Mexico it is difficult to provide accurate design solutions to respond for future scenarios. For example in regard to extreme meteorological events the lack of institutional coordination and cooperation becomes evident as multiple agencies are executing a series of actions but with limited communication or information exchange among them. Each agency has its own information platform. Therefore, there is a strong need to develop a single common interface which all government agencies and researchers can use for data storage and use. Relevant and up to date information can allow all stakeholders to assess risk and make informed policy and investment decisions.

The proposed strategy for wastewater treatment gives multiple scenarios for implementation. One of the constraints of the proposed natural system of constructed wetlands is the need for big open spaces. After further research on community’s acceptance and economic feasibility studies on other wastewater systems, other more technological systems which require less space should be explored.

**6.3. Further research considerations**

Consequences of Risk Reduction Policies in Urban Areas

Source: (World Bank, 2011)
Living with Water and its Risks
Integrating natural and human dynamics in urban ecosystems

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Abstract – Natural ecosystems are currently threatened by urban development but at the same time the human habitat is every time facing more risks caused by dynamic natural forces. Is it possible for natural and human processes to coexist and benefit from one another? Can natural ecosystems be integrated into our urban living? Fortunately for the future of our planet a shift has begun in the view towards the relationship between man and nature, in an attempt to answer these questions. In the past years a new mindset and increased knowledge of ecological processes has lead to ecologically oriented innovative development approaches for planning, urban design and architecture. The method of ‘Designing with nature’ created by Ian McHarg can be considered the first approach applied into urban design that evolved from the idea that humans are an integral part of ecosystems and that cities cannot be fully understood outside their ecological context. More recently institutional initiatives and ideas have also been developed viewing cities as ecosystems in themselves, with material, energy flows, and complex information systems like any other ecosystem. In terms of water, the emergence of a new view has announced a long term transition from historic self protection to industrial engineered defence to the need to work with nature in developing more sustainable methods for managing the most precious resource for humans. Over recent years flooding and scarcity episodes have become commonplace around the world; the notions of risk and resilience related to spatial planning have emerged as key concepts to assist in the development of more safe and flexible cities by improving the ability to manage water more effectively. Furthermore, the new idea of ‘Water Sensitive Urban Design’ in the planning and design of urban environments that is sensitive to the issues of water sustainability and environmental protection offers a possibility to reveal the applicability of past research. These theories and new approaches provide new opportunities for a mutually beneficial relationship between urban development and natural ecosystems for developing cities as their continual growth increases their environmental and social problems and their vulnerability to water related risks. The context of developing cities offers a unique set of challenges that claim for a new mindset, a new way for planning and designing cities, directed to create sustainable urban habitats. This paper gives as a conclusion that current water challenges in developing cities can be turned into opportunities for sustainable development when an understanding of the natural processes is applied into design guidelines and spatial planning frameworks.

Key words – designing with nature; water challenges; risk; resilience; water sensitive urban design; developing cities.

1 Introduction: The relation between natural and human dynamics

An urban future is a reality of our changing world. According to UN estimates half of humanity now lives in cities, and within two decades, this amount will raise to nearly sixty per cent of the world’s population. Urban growth is most rapid in the developing world, where cities gain an average of five million residents every month (UN-HABITAT, 2008). As a result of urban growth, cities in the developing countries are facing great challenges in terms of sustainable use of natural resources, environmental degradation and quality of life of inhabitants. Particularly in terms of water it has become increasingly difficult to satisfy growing water demand, deal with increasing amounts of wastewater and fight against effects of environmental problems such as climate change. Urban infrastructure and spatial organization in developing cities have not followed satisfactory transformations in order to cope with present needs; as a result, the spatial quality of the space and inhabitants’ safety had become compromised.

Concerns about water scarcity and climate change, urban decay, car dependence and the related issues
of smog and traffic congestion are the reality of every city. However, cities in the developing world are struggling with these issues to an even greater degree. As cities grow in size and population the tendency has been to expand in land area, consuming important natural ecosystems and agricultural land. In this way harmony among the spatial, social and environmental aspects and between their inhabitants becomes more complicated. From a sustainable development perspective, the welfare of future generations depends on how well present generations tackle the environmental problems associated with urban living, social and ecological components of these problems are inseparable.

The last decades have been remarkable for the increasing literature, research and intensity of debate about sustainability problems of cities and their global impact. While cities provide expanding economic opportunities in the new global economy, they are the biggest contributors to environmental disruption. With the trend toward globalization, cities are having a major impact on natural ecosystems and the biosphere as a whole, as they are drawing resources from across the globe and exporting wastes beyond their boundaries (Newman and Jennings, 2008). The implications of urban growth and cities’ urban lifestyles in terms of global use of resources and of human living conditions have been deeply discussed in the past and are now well recognized. Moreover, the importance of development that focuses on positive contributions to the local ecology, economy and society is increasingly recognized and gaining support from those involved in the design, planning, development and management of urban areas. Finally, it has been realized that the transition towards sustainable development is our only option; the way in which the urban need for food, water and shelter are met and the way in which natural processes are integrated with urban processes will determine the future of our planet (Girardet, 2008).

The previous anthropocentric view of man as separate from nature has greatly influenced human acts towards nature, especially in terms of urban development. Fortunately for the future of our cities, a new view towards the relationship between man and nature emerged some decades ago and has been getting stronger in the past years. The anthropocentric view assuming man as all that matters and therefore creating a culture set against nature, with the desire to conquer and control the environment has been replaced with an eco-centric view (McHarg, 1969). The accumulation of evidence of the unsuccessful early ways of planning and designing urban space has made clear the need for a new way of thinking planning and designing our cities. Instead of protecting natural ecosystems against the city the aim should be to make the city itself more ecological, to look the city itself as an ecosystem. The focus must be not on defending nature against the city but to take the opportunities that the synergism between conditions for natural ecosystems and for vital human aspects of urban life can bring (Tjallingii, 2000).

The notion that human’s life is bound up with the forces of nature, and that nature, so far from being opposed and conquered, must rather be treated as an ally and friend is determining a new path towards attaining sustainable habitats. In the past years research and environmental policies in some countries have advocated an ecosystem approach in light of the growing importance of ecological issues and the recognition of the interconnectedness of social, economic, and environmental systems (UNA/IAS, 2003). It has been recognized that the concerns of development and those of environment and social welfare demand integrated development approaches for their resolution. The delicacy of natural ecosystems and our dependence on them has been acknowledged. Moreover it has become clear that one of the main forces challenging all cities but to an even greater extent developing cities is the environmental challenge. Climate change will create more extreme hydrological conditions, rising sea levels, increased rainfall and longer periods of drought, having a great impact on cities. Therefore, this paper aims to make a review on innovative approaches which entail the integration of natural ecosystems dynamics with the urban dynamics for reducing vulnerability and increasing community resilience to water threats.

This paper takes as the starting point the recognition of the interdependence between city and nature and its application into the context of urban planning and design with a review on Ian McHarg’s method of ‘designing with nature’. Later on the focus of the paper turns specifically on water and the current challenges cities are dealing with. Water is considered the most valuable natural resource, essential to life in every form and the basic condition for the human habitat. Yet, water can also be a destructive element, capable of threatening entire communities. Consequently, this paper will also review the more recently emerged notions of risk and resilience related to spatial planning as key concepts to assist in the development of more safe and flexible cities by improving the ability to manage water more effectively. From all the theory built in the last few years there is still not so much of these knowledge applied in design. As a way to uncover the applicability of past research, the last part of this paper makes a review on the transition from traditional urban water management towards a more sustainable Water Sensitive Urban Design (WSUD) approach that cities are starting to follow.
From the theory of innovative approaches reviewed conclusions will be derived in order to deliver a set of recommendations for developing cities to help them follow a transition towards an integrated management of the urban water cycle to steer their future development. At the final part of this paper some recommendations for the applicability of the theory reviewed into my own graduation project will be delivered.

2 Recognizing interdependence between city and nature: Designing with nature

‘Where you find people who believe that man and nature are indivisible, and that survival and health are contingent upon an understanding of nature and her processes, these societies will be very different from ours, as will be their towns, cities and landscapes’ (McHarg 1969: 27).

Nature has historically been seen as a factor to be managed, as a superficial embellishment or an optional luxury within cities. This idea has been challenged and the view that by strategically working with nature we can increase sustainability, provide environmental benefits and limit environmental risks is gaining currency (White, 2010). At the root of this new view towards a better relationship between man and nature is a deep understanding of natural ecosystems. It is necessary to increase our knowledge of ecology and the evolution of physical and biological processes before making changes on the land (McHarg 1969).

According to McHarg (1969), an eco-centric view evokes a deeper understanding and acceptance of nature as an interacting process, responsive to laws, constituting a value system, offering intrinsic opportunities, limitations and even prohibitions to human use. In his book ‘Design with Nature’, McHarg provides an ‘ecological method’ as a way of analysing and understanding natural processes to guide regional planning and development.

In essence the method consists on identifying both social and natural processes as social values. As land and building values do reflect a price value system that reflects a hierarchy, so too should be with natural processes. McHarg (1969) argues that it is possible to evaluate and rank values by critical factors such as uniqueness of resources, productivity, natural phenomena and cultural manifestations. Identifying components of the natural identity of the city as a value system is critical to understand how these natural processes can be beneficial to society as offering opportunities for human use (McHarg, 1969). The method suggests that if physical, biological and social processes can be represented as social values, then any intervention will affect them. Therefore, the method requires identifying the area of concern as consisting of processes in land, water and air which represents values that can be ranked from the most valuable to the least valuable. In this way the optimum solutions can be identified as the ones with the maximum physical and social benefits at the least physical and social costs, the most suitable areas for conservation and development will consequently be revealed (McHarg, 1969).

McHarg’s ecological approach requires an understanding of natural processes such as topography, subsurface geology, groundwater and surface. Each of these processes interacts with the others creating restraints and opportunities inherent in the landscape. Interactions therefore, need to be evaluated to establish the degree in which the land is permissive or prohibitive to certain land uses (McHarg, 1969). The method states as a proposition that certain lands are unsuitable for urbanization and others intrinsically suitable, being the lands that best perform work for man in a natural condition the least suitable for urbanization. Consequently the method proposes to select eight natural features and rank them in order of value to the operation of natural processes and their degree of intolerance to human use; this group reversed will constitute a gross order of suitability for urban use. These are: surface water, floodplains, marshes, aquifer recharge areas, aquifers, steep slopes, forests and woodlands, and flat land.

Each natural feature is best suited for certain uses as they can absorb different degrees of development, while some are intrinsically unsuitable for urbanization. Water related and water using industries may be in riparian land and may occupy floodplains. Surface water, floodplains and marshes may be used for recreation, agriculture and forestry. Aquifer recharge areas may absorb development in a way that does not seriously affect percolation or pollute groundwater resources. Steep slopes, when forested may absorb some housing, while forests may support a relative density of development (McHarg, 1969). By understanding the nature of the place, its intrinsic suitability for different land uses such as agriculture, recreation, and urbanization becomes clear. The analysis of the present natural ecosystems in a specific region will reveal the best relation for man and environment, by using the ‘ecological planning method’ the nature of a place may be learned, understood and consequently be used and managed well (McHarg, 1969).

The method seeks to optimize not for single but for multiple compatible land uses. Figure 1 shows a matrix developed to examine the first place the degree of compatibility of different land uses. Next to this is another matrix to identify the resources necessary for those land uses and a third matrix shows the consequences of the operation of those
land uses. McHarg (1969) sustains that when the results of the matrix are applied, the maximum potential conjunction of coexisting and compatible land uses may be revealed.

Alongside with all the understanding of natural processes mentioned above, there is a need for regulations which ensure that society protects the values of natural processes as a way of protecting itself, regulations should serve a double purpose: ensuring the operation of vital natural processes and employing lands unsuited to development leaving them unharmed of the violent process of urbanization. According to McHarg (1969) there is a need to bring natural sciences into the planning process, only in this way development would occur in areas intrinsically suitable, were dangers are absent and natural processes unharmed.

3 Recognizing current water challenges in the city

During recent years it has been recognized that population growth, urbanization and climate change are powerful drivers that will amplify the exposure and vulnerability of cities to natural hazards. Water, as a vital human need is critical for cities’ growth and living quality of inhabitants. Today at the forefront of challenges for cities are concerns over water; we both need continual availability and protection from its potential impacts as either too much or too little water can have devastating consequences (White, 2010). The relationship between cities and water is complex; secure safe fresh water supply and an urban environment protected from flooding are the two main goals that need to be met simultaneously. These goals are becoming every day harder to reach; what is more, cities are conceived today as the hub of modern risks as they have evolved increasingly disconnected from their natural constraints with very high levels of human interference with natural processes. White (2010) suggests that there may be no such thing as a ‘natural disaster’ because unfortunate events threatening cities today are ‘man-made hazards’, they are the result of human interventions on natural ecosystems.

It is known that problems with management of urban rainfall have their roots in concentration of
population on small areas, as a consequence from constructing larger impervious areas to make living and transportation possible. This result in a change of the hydrological cycle as infiltration and groundwater recharge decreases and patterns of surface runoff are changed imposing high peak flows and accelerated transport of pollutants from urban areas. Thus, the city influences the state of the ecological systems creating hydro-ecological imbalance. Furthermore, the gradual and largely unplanned urban extensions of cities have been made towards land in less safe areas, hence it can be stated that today’s exposure and vulnerability of cities worldwide is related to urban sprawl. Therefore decisions on the use of land can have a great influence on the management of risk (White, 2010). White (2010) asserts that as the potential of the city to alter its form is limited, land use decisions are more likely to diminish a hazardous inheritance far into the future.

Water today can be a real threat to the success of urban areas, we must understand that we cannot master the weather and therefore cities need to change their behaviour in order to cope with climate change. Until today environmental risks have been addressed from a technocratic perspective, with the perception that natural risks can be effectively managed and that engineering can remove any environmental constraint. This perspective has rightly been questioned in the face of rising incidence of exposure to natural risks such as flooding and drought affecting urbanities all over the world (White, 2010).

During recent years a new narrative has emerged recognizing the limits of technocentricity and the need to work with nature in developing more sustainable methods of management of water. Consequently, the importance of spatial planning¹ has been widely realized, as it has been identified as the most sustainable and effective method of intervention over the long term in order to limit impacts and minimize costs. It seems logical that if the risks and impacts are becoming more powerful, the tools for intervention should respond accordingly. In this way, just as urban processes increase exposure to risks, they can equally facilitate a beneficial decrease by an effective analysis of risk leading to a coherent and appropriate land use response (White, 2010).

3.1. Risk and resilience towards a framing concept within spatial planning

As population grows and climate changes with regard to managing water modern notions as risk and resilience and related terms as hazard, vulnerability, adaptation and mitigation can be particularly useful to better understand and address future hazards. In this paper the concepts of risk and resilience will be further discussed. Risk is the key concept with regard to managing water hazards however it is a subjective and complex issue in itself. Therefore there is a need to be aware of the constraints of the concept and how it can assist in decision making so that planning systems may be effective agents of risk management. According to White (2010) the risk of flooding or drought can be viewed as a function of both the existence of a hazard (the potentially damaging event) and vulnerability (the susceptibility to its impacts); the intersection of both, an area at risk and a population variably subject to its impacts. Vulnerability in this instance does not only focus on land use or physical environment but also incorporates social, economic and cultural factors such as wealth, access to resources, social networks and ethnicity (White, 2010).

There are also alternative views to define risk; elements as exposure, consequences and the recognition of the capacity to respond have been included in different definitions of the concept. The addition of the exposure constituent provides a stronger spatial element than vulnerability in itself cannot provide. Considering consequences for people and natural and built environments provides a useful slant for spatial planning. The recognition of the capacity to respond component introduces a human and institutional element that has linkages with concepts of resilience and adaptation, key concepts of a city more resilient to water hazards (White, 2010). White (2010) maintains that deconstructing risk into component parts can bring insights with regard to framing the concept within spatial planning and facilitate the design of tailored and effective management responses.

Resilience is viewed as a key idea to tackle risk, the concept has been recently advocated to describe the way in which cities can attempt to recover from disasters and to the effective implementation of contingency features into planning, governance and response systems (White, 2010). This term has been widely appropriated within urban risk management and the built environment professions as it offer promise in moving towards cities less exposed to flooding and water stress. The roots of the notion lie

¹ Spatial planning according to White (2010) is the first modern planning system that established the move from ad hoc past approaches to a formalized and structured way to intervene and address environmental impacts. It is an inclusive term that encompasses an ever-expanding array of topics: from housing and transport provision to modern objectives such as designing out crime or improving health.
in the field of ecology relating to the ability of a system to return to equilibrium after disturbance; later on the notion was linked with a system able to absorb shocks and still continue, considering the dynamic relationship between environment and the city (White, 2010).

According to White (2010) resilience has a strong human element which focuses on the ability of a society to meet future challenges incorporating social and cultural aspects. Therefore a key feature of modern understanding of the concept is its ability to connect not only physical and social systems with each other but also connecting those to natural systems; through this, vulnerability of ecosystems to human or natural threats can be acknowledged and strategies may be adopted to preserve resources. Recently resilience has been understood as process orientated, as a wider and encompassing process through which the resilience capacity of communities can be enhanced and augmented; this contemporary perception provides a key link to the escalating reality of risks in our cities. Based on the idea that resilience is not an unconnected aim but rather is embedded in the concept of risk and can be seen as a mechanism to manage the consequences of risk on people and places via spatial planning, White (2010:97) suggests: ‘risk = (hazard-resilience) x (vulnerability-resilience) x (exposure-resilience)’.

As shown in the model in Figure 2, concepts such as adaptation and mitigation can also help manage water in the city; this diagram provides a further insight into how all these concepts can be potentially useful for spatial planning. Risk is determined by the interaction between hazard, vulnerability and exposure, the level of uncertainty informs the policy response, which is centred on the need to pursue adaptive or mitigation options. These two pathways incorporate the differing descriptions of resilience. Finally these interventions feed back into the model to influence the three elements of risk and then the cycle continues (White, 2010).

According to White (2010:110) this ‘flexible methodology of managing water in the city can ensure a consistent approach and potentially provides a framework for cities to design their own strategies dependent upon their own drivers and constraints’. The next step would be to consider how best to use this framework within spatial planning to enable cities to become more resilient to flooding and drought.

As both cities and climates are evolving, urban areas alter their relationship with the natural environment and subsequent exposure to risk. The process of development so far has been driven by short term socio economic processes such as income generation, property development or job creation. This process lacks of a long term environmental overview and has been aided by a protective and techno-centric methodology to control nature. In this way the degree of exposure to water risks has increased.

Although the spatial exposure to water risks is every day better understood, the scope of hazards and vulnerability of communities are not yet influencing decision making. White (2010) states that the current risks of flooding and water scarcity are the result of historical development paths and governance processes and that the exposure and vulnerability of our cities to these threats nowadays depends on how we act today. Therefore, institutional structures, governance processes and the role of science and technology are all key pieces for the effective management of water in society (White, 2010). The spatial nature of water risks affecting urban areas need a focus on flexible and transferable principles that can provide a basis for decision making. Utilizing the concept of risk as a basis for interventions offers a possible solution as it is a mechanism able to integrate complex social, environmental and economic goals although its effective application by planners still needs time to mature (White, 2010).

4 Transition to Water Sensitive Urban Design

Water Sensitive Urban Design reflects a new paradigm in the planning and design of urban environments that is sensitive to the issues of water sustainability and environmental protection (Brown and Clarke, 2007). As defined by Wong (2006), WSUD is focussed on the synergies within and between the urban built form and landscape, and the urban water cycle, recognizing that community values and aspirations play an important role in urban design decisions and water management practices. Therefore it challenges conventional urban water provision by linking the management of urban water streams (fresh water supply, wastewater
and stormwater) with the goals of minimising and treating pollution discharges, reducing potable water use, and efficiently matching different water sources (such as recycled water and treated stormwater) to ‘fit for purpose’ uses. These aims are met through the urban design process by the provision of integrated urban water management infrastructure; reintroducing the aesthetic and intrinsic values of waterways back into the urban landscape; and promoting new forms of urban design and architecture within the built environment (Brown and Clarke, 2007).

As shown in Figure 3, WSUD concerns to the interactions between the urban built form and the integrated management of the urban water cycle defined by the three urban water streams. Integrated urban water cycle management includes objectives for water conservation, pollution control of wastewater and stormwater, and mitigation of the effect of increased flow as a result of urbanization. There are a number of natural synergies in achieving individual urban water management objectives. For example installing water efficient appliances has the benefit of reducing potable water usage and generation of wastewater. Rainwater harvesting has benefits in achieving water conservation and stormwater management. Water reuse and water treatment are essential elements, therefore efforts to reduce the import of water and the export of wastewater and stormwater pollutants can increase the overall sustainability of an urban area. The harvesting of stormwater as an alternative water resource is clearly an initiative that would address both the potable water conservation and stormwater quality objectives (Wong, 2006).

One of the most significant challenges facing urban water managers and policy makers today is the shortage of reliable knowledge and guidance on how to effectively institutionalise, and therefore mainstream the WSUD approach. According to Brown and Clarke (2007) the mainstreaming of WSUD requires a complex multi-sectoral governance approach that is dedicated, proactive and strategic in its pursuit; it is not an approach that requires a simple adaptive technological change from the current practice. The transition to WSUD requires new technologies and approaches that are often radical, demanding fundamental changes in institutional capacity at various levels including new knowledge and skills, organisational systems and relationships, policy frameworks and regulatory rewards and penalties (Brown and Clarke, 2007).

Water Sensitive Urban Design has evolved into a framework for integrating the holistic management of the three urban water streams with the practice of urban design. This new paradigm aims for integration at a number of levels: the integrated management of the three urban water streams of potable water, wastewater and stormwater; the integration of the scale of urban water management from individual allotments and buildings, to precincts and regions and integration of sustainable urban water management into the built form (incorporating building architecture, landscape architecture and public art); and integration of structural and the non-structural sustainable urban water management initiatives (Wong, 2006).

While there have been successful projects involving one or more elements of WSUD, the overall success in implementation are however varied. Institutional reforms, construction and maintenance practices can be identified as impediments to the effective implementation of conceptual designs of WSUD. In spite of these obstacles, the implementation of innovative practices of WSUD can be seen as a possible path towards sustainable urban water management for cities around the world.

5 Conclusions: Relevance of innovative water management approaches for developing cities

Nowadays developing cities in Latin-America are facing new spatial and environmental challenges as they intend to manage local urban development within a globalization world. As social and economic inequities abound and the environmental harm to natural ecosystems increases apace, the need to achieve sustainable development is becoming critical. At the same time of the rapid urbanization, developing cities simultaneously need to expand and modernize their infrastructure while dealing with profound internal socio-economic inequalities as well as severe environmental
deterioration, therefore the pathway towards sustainability for developing cities is even harder.

Cities that have not been properly planned, governed and managed can easily threaten the quality of the air, the availability of water, the capacity of waste processing and recycling systems and many other qualities of the urban environment that contribute to human well-being. Low-income groups, particularly those living in the informality, are particularly vulnerable to environmental and health risks associated with lack of safe water, flooding, poor air quality and poor sanitation (UN-HABITAT, 2008). Even the present challenges are great, especially in developing cities, yet there is hope; if urbanity is envisioned in more positive ways such as reducing per capita impact and by creating a symbiotic relationship between cities and their bioregions to attain ecological regeneration (Newman and Jennings, 2008).

The aim of the paper was to make a review on innovative approaches to manage water in order to provide a theoretical framework for developing cities for reducing vulnerability and increasing community resilience to water threats. In conclusion an ecological approach involves in the first place understanding natural processes to identify areas for protection and restoration as well as areas suitable for urbanization. By the recognition of the ecological processes as social values and by understanding the nature of the place, its intrinsic suitability for different land uses and compatibility between them can be revealed. From the review carried out with this paper it can also be concluded that land-use decisions have great influence on the management of risk, therefore an effective analysis of risk can lead to a coherent land-use response. The notions of risk and resilience and related concepts can be potentially useful for spatial planning as they are flexible and transferable principles that can integrate complex social, environmental and economic goals.

Finally from the review on the Water Sensitive Urban Design approach it can be concluded that the application of innovative principles to manage water demonstrates that when water is integrated with urban processes it can add environmental, aesthetic, economic, cultural and recreational values to cities. Thus, while enhancing urban spatial qualities water can help in attaining environmental, social and economic sustainability. As a final point, it can be concluded that flooding and water scarcity events cannot be disassociated from the socio-economic context within which they occur, they are directly related to the way of living, the geo-climatic context and forms of government. Therefore the understanding of the natural processes is crucial and needs to be applied into design guidelines and spatial planning frameworks in order to develop tailored technical solutions and organizational methods to deal with present urban water management challenges, to turn present problems into future opportunities.

6 Recommendations: Applicability of innovative water management approaches for developing cities

Current urban and environmental challenges make more obvious the necessity to integrate environmental, social and economic issues within urban design, management and planning frameworks in Latin-American cities. The destruction of natural ecosystems means not only an environmental harm but also a lost development asset and a threat for the well being of inhabitants. The challenge for spatial planning and urban management in developing cities is to bring together natural and urban dynamics, to work with an integrative framework where spatial, social and economic issues interact. By bringing natural sciences into the planning process, development would occur in areas intrinsically suitable, were dangers are absent and natural processes unharmed. Developing cities must focus on investigating the potential for spatial planning and land use preventive policies to assist the development of more resilient cities to water related risks. Moreover, the equality aspect must have highest priority in order to satisfy basic needs and safety for all to diminish social disadvantage.

It has been recognized that social, economic and political factors influence the vulnerability and exposure to water risks. Consequently these aspects offer potential avenues for intervention, as opposed to a narrow focus on hard infrastructure. In the context of developing cities the design of future water and wastewater infrastructures is a question of integrated planning and management of local land, water and other resources taking into account local potentialities and restrictions. Therefore, planning and development of urban areas and water management measures and infrastructures in developing cities should be based on local conditions, culture and traditions.

It is also important to remember that technological advances, while important, are ineffective if not well implemented or if not adequately managed or monitored when implemented. Besides as the performance of technical solutions depends on climate as well as on social, economic and cultural conditions; local hydrological studies and environmental impact assessments are needed for an integrated water resources management. In addition, the analysis of local governance and legal frameworks will provide the basis for developing
improvements in the socio-economic management of the resource.

6.1 Recommendations: Applicability of innovative water management approaches for the redevelopment of informal settlements in Mexico City

Mexico City Metropolitan Area, the largest urban agglomeration in Latin-America, accommodating over twenty one million inhabitants nowadays exemplifies a fragmented urbanity that cannot sustain itself anymore. Its uncontrolled urban growth and inappropriate planning framework has put at risk both its natural ecosystems and its inhabitants. While urban development threatens to destroy natural ecosystems, natural forces such as floods and landslides pose a threat to the city. The denial for interaction between the city and its natural ecosystems will continue to produce more risks both for the nature and the people.

The theories and approaches reviewed on this paper will be used as part of my theoretical framework for developing spatial strategies for my graduation project. The application of an ecological approach to understand the natural processes on my site will help me to make better land-use decisions according to the place suitability. After having recognized the current water challenges within cities, understanding and incorporating the notions of risk and resilience will assist me to define tailored and effective spatial interventions. From the review on the applicability of Water Sensitive Urban Design principles, my proposal will aim to implement practices according to the three objectives of this approach: water conservation, pollution control of wastewater and stormwater and mitigation of increased flow. By understanding the synergies between strategies for the different objectives, the interventions that I propose will search for an integrated management for water conservation and aquatic ecosystem protection to increase the overall sustainability of the area.

In the context of my graduation project, an informal settlement vulnerable to water related risks, it is of great importance to realize that natural ecosystems can also be considered as productive ecosystems for the economic benefit of inhabitants and can also serve as cultural identity carriers for those communities that experience alienation. Making visible ecological processes within the urban fabric can be used as a strategy for fostering sense of place, shape a unique identity and create a new way of life for the inhabitants of marginalised areas. If inhabitants experience, learn about and appreciate those processes, the connection with natural ecosystems may be rebuilt and strengthen the capacity to care about them. A water-sensitive design approach is needed in order to provide not only essential infrastructural services but to combine those with educational and recreational sites for the community. The aim must be to learn to live with water and convert the water risks into opportunities to promote sustainable development of communities while diminishing their vulnerability to water scarcity and flooding.

Bibliography


GIRARDET, H. 2008. Cities People Planet - Urban development and climate change Chichester, John Wiley & Sons, Ltd.


7.2. Interviews with Valle de Chalco Municipality’s inhabitants

<table>
<thead>
<tr>
<th>Name</th>
<th>Age</th>
<th>Gender</th>
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<tr>
<td>Luisa</td>
<td>47</td>
<td>M F</td>
</tr>
<tr>
<td>Julia</td>
<td>19</td>
<td>M F</td>
</tr>
<tr>
<td>Jesús</td>
<td>30</td>
<td>M F</td>
</tr>
<tr>
<td>Jonathan</td>
<td>23</td>
<td>M F</td>
</tr>
<tr>
<td>Victor</td>
<td>18</td>
<td>M F</td>
</tr>
</tbody>
</table>

How do you get to your job?

1 Bicycle
2 Bus
3 Car
4 Bus
5 Bus

If you use some form of public transportation, what route do you take and how long it takes to get there?

1 I do not use public transport
2 I always use the bus and it takes me two and a half hours
3 I always use my car
4 I use the bus, it takes me two hours
5 I take the bus to go to the centre, it takes me about two hours

What is your occupation?

1 Housewife
2 Self employee
3 Civil engineering (contractor)
4 Military
5 Student

Do you live in this neighborhood? Where? Mark it on the map.

1 Yes
2 Yes
3 Yes
4 Yes
5 Yes

How long have you lived there?

1- 24 years
2- 19 years
3- 30 years
4- 5 years
5- 18 years

Where do you buy your food? market, supermarket? Where are these places? Mark it on the map.

1
2
3
4
5

How do you move from one place to another within your neighborhood and inside the municipality? (Eg walking, cycling, minibuses, taxi-bike, etc.).

1 Walking
2 Walking
3 Bicycle
4 Walking/Bicycle
5 Bicycle
What do you do in your spare time?
1 Stay at home
2 Relax
3 Spend time with family
4 Go out
5 Skate

What places do meet with friends or family? (Eg park, cinema, bar, etc.) Where are these places?
1 Their home
2 Their home
3 Park / cinema
4 Their home
5 Park (Chalco or Toluca)

Do you own your home?
1 Yes
2 No
3 No
4 Yes
5 No

Who built it?
1 Myself
2 The owner
3 My family
4 My family
5 My parents

What materials is it made of?
1 Hollow ceramic bricks and zinc roofing
2 Concrete structure and hollow ceramic bricks
3 Concrete structure and hollow ceramic bricks
4 Concrete structure and hollow ceramic bricks
5 Concrete structure and hollow ceramic bricks

How many people live in your house and how many rooms do you have?
1-3 / 1
2-4 / 2
3-4 / 2
4-4 / 2
5-5 / 3

Do you have any free space or garden?
1 Concrete patio
2 No
3 Patio
4 Patio
5 Patio

If you could move to another municipality or improve your current house, what would you prefer?
1 Renovate current house
2 Move
3 Renovate
4 Renovate
5 Move

Are there any parks near your home? Do you use them? What activity do you use them for (relax, read, play soccer, other)?
1 No
2 Yes (about 10 minutes walking), I do not use it
3 Yes / Practice sports
4 Yes / Practice sports
5 Yes / practice sports

What areas or streets of the town consider the most dangerous?
1 All of them
2 All of them
3 All of them
4 Main roads
5 Sur 8

What areas or streets of the town consider more secure?
1 None
2 None
3 None
4 None
5 Where I live

What’s in these streets (shops, parks)? Are there many or few people?
1 Few people
2 There is nothing in the street, it’s quiet and alone
3 Neither many nor few
4 Few people
5 Many people

What is your relationship with water? Why you use it?
1 I take care of it
2 Shower
3 I use it every day
4 For almost everything
5 For everything

Do you have drinking water and drainage at home?
1 Yes
2 Yes
3 Yes
4 Yes
5 Yes
<table>
<thead>
<tr>
<th>Question</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
<th>Option 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are you aware of the problem of flooding in the area?</td>
<td>Yes</td>
<td>No</td>
<td>I do not feel identified with it</td>
<td>I do not feel identified with it</td>
<td>I do not feel identified with it</td>
</tr>
<tr>
<td>Are there special occasions or important holidays in your community?</td>
<td>No that I know</td>
<td>Do not know</td>
<td>Yes, regional and religious celebrations in local churches</td>
<td>Religious celebrations are popular</td>
<td>No</td>
</tr>
<tr>
<td>What do you know about the new Chalco lake west of the municipality?</td>
<td>No</td>
<td>It's being forming</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Would you be willing to invest in transforming your home for added security against floods?</td>
<td>Yes</td>
<td>No since I rent it</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Would you be willing to collect and reuse rainwater in your home for your own consumption?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Would you be willing to practice urban agriculture in your own garden or collective spaces near your home?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Would you like to have more contact with water? for example, fountains, canals, ponds, lake?</td>
<td>Yes it was clean</td>
<td>No because it might be polluted</td>
<td>Yes</td>
<td>Yes</td>
<td>No because it could be threatening for hygiene</td>
</tr>
<tr>
<td>Are there benchmarks in the countryside near your home which you use to find your way?</td>
<td>No</td>
<td>Train track</td>
<td>No</td>
<td>No</td>
<td>Chapel, train tracks</td>
</tr>
<tr>
<td>What traditions within your community are important to you?</td>
<td>None</td>
<td>I have not time for those matters</td>
<td>All traditions I can help with</td>
<td>15 September</td>
<td>Market day</td>
</tr>
<tr>
<td>What are the 3 most important elements that give identity to your community?</td>
<td>Confidence, safety, education</td>
<td>Quietness, distance, periphery</td>
<td>Respect, honesty, hard work</td>
<td>1 I do not feel identified with it</td>
<td>2 I do not feel identified with it</td>
</tr>
<tr>
<td>What are 3 things would you change in your community?</td>
<td>Felony, unfinished pavement works, garbage</td>
<td>Education, public infrastructure, public servants honesty</td>
<td>Safety is my biggest concern</td>
<td>Pavement work, better/friendlier neighbours, safety</td>
<td>1 I would only change parks</td>
</tr>
<tr>
<td>If Valle de Chalco was a color, odor, sound, material, object and landscape ... What would it be?</td>
<td>Green, blue, green, red, red</td>
<td>Canal, disgusting, fetid, flowers, flowers</td>
<td>Cars, trucks, avenue, quiet, drums</td>
<td>Lake, lake, pirate ship, lake, cars</td>
<td>Lake, lake, pirate ship, lake, cars</td>
</tr>
<tr>
<td>Thank you very much for your help!</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.3. Reference Projects

[1] Constructed wetlands treatment plant for the treatment of Dicomano (Florence province) municipal wastewater
Special Area of Conservation (SAC) Orbetello Lagoon

Technical data:
Number of Person Equivalent: 3.500
Application: treatment of urban wastewater
Type of CW: Hybrid system (SFS-h + SFS-v + SFS-h + FWS)
Area (m²): 6080
Year of realization: 2003

Description:
The wastewater, after a primary treatment (grid followed by a septic tank), flows into the Constructed Wetland treatment plant constituted by an horizontal subsurface flow system (1st stage), followed by a vertical subsurface flow system (2nd stage) and then by an horizontal subsurface flow system (3rd stage). Finally, wastewater is received by a free water system functioning as tertiary treatment (4th stage). The free water system is conceived in order to obtain a high-biodiversity area (16 Tuscany’s autoctone species of vegetation have been planted).

Main features of Dicomano CW treatment plant
Surface area 1st stage SFS-h (m²) 1000
Surface area 2nd stage SFS-v (m²) 1680
Surface area 3rd stage SFS-h (m²) 1800
Surface area 4th stage FWS (m²) 1600
SFS-v beds depth (m) 0.90
SFS-v filling media (m) Top 5 cm gravel Ø 10 mm 5 cm sand 15 cm gravel Ø 10 mm 15 cm gravel Ø 20 mm
Bottom 30 cm gravel Ø 40-70 mm
SFS-h beds depth (m) 0.80
SFS-h Gravel size (mm) Ø 5-10

Source: http://www.constructedwetland.co.uk/files/file_manager/42/IRIDRA%20Dicomano.pdf
**[2] Blackwater and greywater reuse system at Chorrillos School in Lima, Peru**

Type of project:
Urban upgrading - school demonstration project

Project period:
Start of planning: February 2007
Construction period: July 2007 - October 2008
Start of construction:
Grey- / blackwater treatment: July 2007
Urine diverting dehydration toilets (UDDTs): May 2008
Start of operation:
Greywater treatment system: September 2007
Blackwater treatment system: November 2007
UDDTs: May 2008

The objectives of the project:
1. Reduction of the water consumption (and the cost for it).
2. Reduction of the dusty areas by creating more extensive planted areas (which need irrigation and fertilization) to improve aesthetics and micro climate.
3. Demonstration of a closed-loop system with reuse of treated wastewater, nutrients and organics, adapted to the environmental necessities of a populated desert area and the technical possibilities.
4. Showcasing a dry sanitation system (urine-diversion dehydration toilets - UDDTs).

For the purpose of treatment and irrigation, two independent treatment systems were built:

**Constructed wetland for greywater treatment:** Greywater (wastewater without faecal matter) from the laundry, bakery and kitchen is treated in a vertical flow constructed wetland (sub-surface), also called reed bed. The greywater passes a grease trap and is pumped in intervals (time regulated) to the papyrus reed bed.

**Compost filter for blackwater treatment:** Blackwater from the flush toilets mixed with greywater from two private kitchens, showers and washing basins of all bathrooms is treated separately. It is led to a well ventilated double-chamber compost filter. The two chambers are used alternately in intervals of 6 months. This compost filter acts as a solid-liquid separation device. Solids are retained in a special (custom-made) filter bag which is filled with straw. During the six months in use and the following 6 months, where the second chamber is in use, some composting of the solid material in the filter bag is achieved. After removing the filter bag from the chamber, a secondary treatment for the retained solids is realized in a separate vermicomposter. Here earth worms (taken from the already existing compost system) break down the organic matter and improve the composting process. The liquid passes the filter bag to the bottom of the chamber and is pumped to the constructed wetland.

**Double-vault urine diversion dehydration toilets (UDDTs):** The UDDTs which are constructed as outdoor toilets with ventilated vaults for dehydration of faeces. When one faeces vault is full, the content (then already dehydrated for about one year) will be composted in the vermicomposter (together with the solid material filtered from the blackwater). Urine and greywater (water from...
hand washing) are collected separately. Greywater from the hand washing facilities is infiltrated directly into a gravel filter bed with bamboo plants. Urine is collected in two 25 litre jerricans. The dried faeces and the liquid urine are used as fertilizers for gardening.

The main impact of the project is the reduction of potable water consumption by 50% through complete grey- and blackwater reuse and therefore reduction of costs. The higher production of vegetables and fruits for sale helps to increase the income of the school and to give scholarships to poor families with handicapped children. Furthermore, the children benefit from greener surroundings (50% of the school area) and more outdoor activities.

It is an important demonstration project for environmental education purposes. Schools, teachers, students, public authorities, architects, engineers and private persons are invited to see that saving water through dry sanitation methods, reuse of treated wastewater and the use of composted organic waste can improve the quality of life. Before the start of the project, wastewater from 12 flush toilets (15 litres per flush), from bathrooms with showers and 3 kitchens, 1 laundry and 1 bakery was disposed to the public sewer system.

Source: Sustainable Sanitation in Cities (2011) and Compilation of 31 case studies on sustainable sanitation projects (2010)
[ Sao Paulo, Brazil ]  
Informal Settlement Community Based Upgrading Approach

This World Bank urban water quality management project is often described as a ‘model urban development project.’ The Guarapiranga Program is a project jointly developed by the Government of the State of São Paulo and the Municipality of the City of São Paulo, with resources from IBRD - International Bank for Reconstruction and Development. The Guarapiranga reservoir meets 20 percent of São Paulo’s water needs, for a population 3.2 million people. The water catchment area occupies 639 km2 and is home to 622,000 people from which 170,000 live in squatter settlements. Informal occupation in the surrounding land of the water catchment area caused the deterioration of the reservoir’s water quality. Initially the primary objective of the Guarapiranga program was to ensure the quality of the water supply for the metropolitan São Paulo but during the formulation stage the program range of program actions were expanded.

Two main courses of action were undertaken: corrective action to reduce degradation of the water source; and institutional capacity building action helped develop a legal, regulatory and management framework to improve and maintain water quality. Five specific objectives were established to accomplish these goals generating a specific project. The first and the third one of these objectives are the ones relevant as a case study for this research project:

1. Expand and improve water supply, sewerage, and wastewater treatment services.
2. Upgrade informal settlements and provide alternative housing solutions to people living in risk areas (floods or landslides).

The Guarapiranga program’s primary purpose was to improve the water quality of the reservoir, but the presence of informal settlement in the catchment area made it necessary to shift priorities. In São Paulo, as in other developing country cities, environmental degradation and the lack of basic infrastructure and services in the informal city are intertwined. This issue was directly addressed by the program so that environmental sanitation became the entry point for catalyzing investment in upgrading and addressing the problems of risk areas.

The initial idea evolved into a comprehensive intervention that included infrastructure for water supply, drainage of wastewater and storm runoff, access roads, paving, and electricity supply as well as socio-technical support during construction, as well as the need for relocation of families. An integrated rather than sectoral upgrading approach was taken in recognition of the important interactions between wastewater collection and other branches of infrastructure. Since upgrading of all different types of infrastructure took place simultaneously this project has been considered as an example of a comprehensive upgrading approach.

From the review on this case study some conclusions relevant to my project are given below:

- The participatory process is needed in order to integrate diverse interests and priorities into a coherent set of actions. The population may participate in the process of architectural design and civil works by offering suggestions on the most suitable design solutions. Community leaders may act as mediators between local residents and contractors.

- Distrust, apathy and submission can undermine participation of local residents of informal settlements. People have very little trust in governments; either people feel satisfied with the mere fact that the municipality is doing something in the area or they generally agree with community leaders without giving their own opinions.

- Even in patriarchal societies, women can take a lead role in issues related to neighbourhood management and problems in their community.

- Socio-technical support groups can open new avenues for participation. These groups provide ready access to the project for residents, as well as information and technical issues, and served as an avenue for requests and complaints. Socio-technical support introduced since the beginning of the program may enhance the project’s sustainability. Environmental education and community development activities and post-implementation socio-technical support may have a great impact at the cultural level or to change collective behavior.

- A chain reaction may be unleashed by upgrading, as residents of informal settlements begin to feel like ordinary citizens. The sense of normality increases the people’s self-esteem and strength their sense of belonging to a physical and social environment. It also stimulates residents’ economic investment in their community. If there is a community organization, improvements may participate in the process of architectural design and civil works by offering suggestions on the most suitable design solutions. Community leaders may act as mediators between local residents and contractors.

- Difficult economic situation caused by the increasing unemployment has a direct impact on the residents’ ability to invest in housing and infrastructure improvements, and affect their willingness to participate. This constraint may be overcome by integrating in the project employment and income generation activities.

- A broad horizontal partnership of public sector actors in
comparison with the traditional hierarchical structure commonly associated with government projects brought good results and contributed to continuity of effort and the creation of joint initiatives. Each of the main actors was responsible for a project under a general coordination unit which was established at the state government level.

The participation of private sector organization was an important innovation in project management in the upgrading component of the Guarapiranga program. Large-scale interventions in the informal city introduce new actors to the process. The intervention of private sector may influence project management style which previously was directed by the bureaucracy of public administration.

As an overall conclusion from the review on the Guarapiranga project, I understood that even the improvement of the physical environment can produce a very positive impact, the engine of change is the community, which must be mobilized to continue the development process. Without a strategy for long-term participation, no project can be truly sustainable.

For a complete review on the case study see (Imparato and Ruster, 2003) p. 329-364
The Chilean Government asked Elemental to resolve the following equation: To settle the 100 families of the Quinta Monroy in the same 5,000 m² site that they have illegally occupied for the last 30 years; located in the very centre of Iquique, a city in the Chilean desert. They had to work within the framework of the current Housing Policy, using a US$ 7,500 subsidy with which they had to pay for the land, the infrastructure and the architecture.

If to answer the question, one starts assuming 1 house = 1 family = 1 lot, they were able to host just 30 families in the site. The problem with isolated houses is that they are very inefficient in terms of land use. In order to make a more efficient use of the land, they worked with row houses. The problem with this typology is that whenever a family wants to add a new room, it blocks access to light and ventilation of previous rooms. Moreover, it compromises privacy because circulation has to be done through other rooms, instead of efficiency, overcrowding comes as a result.

They think that social housing should be seen as an investment and not as an expense to make sure that the initial subsidy could add value over time. Elemental identified a set of design conditions through which a housing unit can increase its value over time, without having to increase the amount of money of the current subsidy.

First, they needed to achieve enough density - without overcrowding - in order to be able to pay for the site, which because of its location was very expensive.

Second, the provision of a physical space for the "extended family" , to develop has proved to be a key issue in the economical take off of a poor family. In between the private and public space, they introduced the collective space, conformed by approximately 20 families.

Third, due to the fact that 50% of each unit’s volume will eventually be self-built, the building had to be porous enough to allow each unit to expand within its structure.

Finally, instead a designing a small house they provided a middle-income house, out of which they gave just a small part in the beginning. This meant a change in the standard: kitchens, bathrooms, stairs, dividing walls and all the difficult parts of the house had to be designed for final scenario of a 72m² house.

‘That is how Elemental firm expect to contribute using architectural tools, to non-architectural questions; in this case, how to overcome poverty.’

Source: http://www.elementalchile.cl/viviendas/quinta-monroy/quinta-monroy/#
### A. Calculations for relocation and demolishing processes.

#### RELOCATION HIGH RISK

<table>
<thead>
<tr>
<th>Phase</th>
<th>km²</th>
<th>Inhabitants</th>
<th>inhab/dw</th>
<th>dwellings</th>
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#### DEMOLISHED

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#### RELOCATION HIGH RISK

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#### DEMOLISHED

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#### TOTAL DWELLINGS NEEDED

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3,710.00</td>
</tr>
</tbody>
</table>

7.4. Complete calculations for strategies and design.
B. Calculations for rainwater runoff for the current situation per year and per day (peak precipitation events).

Source: Excel table for calculations of all water strategies was provided by Dr. Ing. Thorsten Schuetze. The table was modified by author based on Schuetze, 2011.

<table>
<thead>
<tr>
<th>number of houses</th>
<th>m² roof per house</th>
<th>total population 2010 (inhabitants)</th>
<th>average rainfall in mm per year</th>
<th>peak precipitation event in mm</th>
<th>liter rainwater per house (roof)</th>
<th>liter rainwater on all houses (roofs)</th>
<th>brutto m³ rainwater on all roofs</th>
</tr>
</thead>
<tbody>
<tr>
<td>8,000</td>
<td>140</td>
<td>406,021</td>
<td></td>
<td></td>
<td>89,600.00</td>
<td>7,840,000,000.00</td>
<td>7,840,000.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>peak precipitation in mm</th>
<th>total traffic area in m² (53% of total)</th>
<th>portion roof surface area (of total area)</th>
<th>total roof m²</th>
<th>gross m³ rainwater on all roofs (per year)</th>
<th>net m³ on all roofs (per year)</th>
<th>net peak m³ on all roofs (per day)</th>
<th>runoff reduction value for calculation of net</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>13,556,451.61</td>
<td>47%</td>
<td>12,250,000.00</td>
<td>7,840,000.00</td>
<td>5,465,640.00</td>
<td>677,425.00</td>
<td>0.697147959</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>cluster size in m² (including 20 blocks)</th>
<th>portion sealed traffic area</th>
<th>total sealed traffic area m²</th>
<th>gross m³ rainwater on all sealed traffic areas (per year)</th>
<th>net m³ rainwater on all sealed traffic areas (per year)</th>
<th>net peak m³ rainwater on all sealed traffic areas (per day)</th>
<th>runoff reduction value for calculation of net</th>
</tr>
</thead>
<tbody>
<tr>
<td>80,000.00</td>
<td>23%</td>
<td>5,935,483.87</td>
<td>3,798,709.68</td>
<td>2,279,225.81</td>
<td>281,341.94</td>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total area in m² (323 cluster = 6452 blocks)</th>
<th>portion unsealed area</th>
<th>total unsealed traffic area m²</th>
<th>gross m³ rainwater on all unsealed traffic areas (per year)</th>
<th>net m³ rainwater on all unsealed traffic areas (per year)</th>
<th>net peak m³ rainwater on all unsealed traffic areas (per day)</th>
<th>runoff reduction value for calculation of net</th>
</tr>
</thead>
<tbody>
<tr>
<td>25,806,451.61</td>
<td>30%</td>
<td>7,741,935.48</td>
<td>4,954,838.71</td>
<td>1,981,935.48</td>
<td>244,645.16</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total gross m³ rainwater on the whole area (per year)</th>
<th>net m³ rainwater runoff from whole area per year</th>
<th>net peak m³ rainwater runoff from whole area (per day)</th>
<th>net storage capacity all ditches and canals in m³</th>
<th>storage capacity in relation to total gross runoff per year</th>
<th>storage capacity in relation to total net runoff per year</th>
<th>storage capacity in relation to total net peak runoff per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>16,593,548.39</td>
<td>9,726,801.29</td>
<td>1,203,412.10</td>
<td>477,419.35</td>
<td>2.88%</td>
<td>4.91%</td>
<td>39.67%</td>
</tr>
</tbody>
</table>
C. Calculations for dimensioning measures for rainwater storage for peak precipitation event for the current situation.

<table>
<thead>
<tr>
<th>Area ditches (depth = 50 cm) per cluster (m²)</th>
<th>Portion ditches in relation to cluster total area</th>
<th>Total area ditches (depth 50cm) in m²</th>
<th>Net storage capacity ditches (depth 50cm) in m³</th>
<th>Net storage capacity all ditches and canals in m³</th>
<th>Storage capacity in relation to total gross runoff per year:</th>
<th>Storage capacity in relation to total net runoff per year:</th>
<th>Storage capacity in relation to total net peak runoff per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1216</td>
<td>1.32%</td>
<td>392,258.06</td>
<td>196,129.03</td>
<td>477,419.35</td>
<td>2.88%</td>
<td>4.91%</td>
<td>29.67%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area canal ss (depth = 1m) per cluster (m²)</th>
<th>Portion canals ss in relation to cluster total area</th>
<th>Total area canals ss (depth 1m) in m²</th>
<th>Net storage capacity canal ss (depth 1m) in m³</th>
<th>Total catchment portion in relation to cluster total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>870</td>
<td>1.09%</td>
<td>281,290.32</td>
<td>281,290.32</td>
<td>2.61%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total area for water retention per cluster (m²)</th>
<th>Cluster area in relation to total area (%)</th>
<th>Required storage capacity for remaining rainwater (peak event) in m³ on total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>2086</td>
<td>0.31</td>
<td>47.66</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Portion of total area for required storage area for required peak precipitation event</th>
<th>Required storage area for remaining rainwater (peak event) in m² (depth=1m)</th>
<th>Required storage area for remaining rainwater (peak event) in m² (depth=50cm)</th>
<th>Portion of total area for required storage area for peak precipitation event</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.77%</td>
<td>1,229,953.55</td>
<td>2,459,907.10</td>
<td>9.53%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total required area for peak precipitation event storage (portion of total area)</th>
<th>Total required area for peak precipitation event storage in m²</th>
<th>Total required area for peak precipitation event storage in m³</th>
<th>Total required area for peak precipitation event storage (portion of total area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.37%</td>
<td>19,028.37</td>
<td>31,328.10</td>
<td>12.14%</td>
</tr>
</tbody>
</table>
D. Calculations for rainwater runoff for climate change scenario [2050] per year and per day (precipitation peak events).

<table>
<thead>
<tr>
<th></th>
<th>average rainfall in mm per year [2050]</th>
<th>peak precipitation event in mm</th>
<th>number of houses per cluster</th>
<th>total number of clusters</th>
<th>total population (inhabitants)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>874</td>
<td>124</td>
<td>557</td>
<td>323</td>
<td>745,622</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>liter rainwater per cluster (roof)</th>
<th>liter rainwater on all houses (roofs)</th>
<th>brutto m3 rainwater on all roofs</th>
<th>net m3 on all roofs per cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>8,400,888.00</td>
<td>2,713,486,824.00</td>
<td>2,713,486.82</td>
<td>5,856.66</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>roof area per cluster in m2</th>
<th>total roof m2</th>
<th>gross m3 rainwater on all roofs (per year)</th>
<th>net m3 on all roofs (per year)</th>
<th>net peak m3 on all roofs (per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9612</td>
<td>3,104,676.00</td>
<td>2,713,486.82</td>
<td>1,891,701.80</td>
<td>269,485.88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>sealed traffic area per cluster in m2</th>
<th>total sealed traffic area m2</th>
<th>gross m3 rainwater on all sealed traffic areas (per year)</th>
<th>net m3 rainwater on all sealed traffic areas (per year)</th>
<th>net peak m3 rainwater on all sealed traffic areas (per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,522.00</td>
<td>4,044,606.00</td>
<td>3,534,985.64</td>
<td>2,120,991.39</td>
<td>1,351,707.33</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>unsealed traffic area per cluster in m2</th>
<th>total unsealed traffic area m2</th>
<th>gross m3 rainwater on all unsealed traffic areas (per year)</th>
<th>net m3 rainwater on all unsealed traffic areas (per year)</th>
<th>net peak m3 rainwater on all unsealed traffic areas (per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>57,525.22</td>
<td>18,580,645.16</td>
<td>16,239,483.87</td>
<td>6,495,793.55</td>
<td>4,139,767.74</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total gross m3 rainwater on the whole area (per year)</th>
<th>net m3 rainwater runoff from whole area per year</th>
<th>net peak m3 rainwater runoff from whole area per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>22,487,956.34</td>
<td>10,508,486.74</td>
<td>5,760,960.94</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>net storage capacity all ditches and canals in m3</th>
<th>storage capacity in relation to total gross runoff per year:</th>
<th>storage capacity in relation to total net runoff per year:</th>
<th>storage capacity in relation to total net peak runoff per day:</th>
</tr>
</thead>
<tbody>
<tr>
<td>477,419.35</td>
<td>2.12%</td>
<td>4.54%</td>
<td>8.29%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>portion roof surface area (of total area)</th>
<th>12%</th>
</tr>
</thead>
<tbody>
<tr>
<td>portion sealed traffic area</td>
<td>16%</td>
</tr>
<tr>
<td>portion unsealed area</td>
<td>72%</td>
</tr>
</tbody>
</table>

| open green space per person in m2 | 24.92 |
E. Calculations for evaluating proposed measures for rainwater storage for peak precipitation events under climate change scenario [2050].

<table>
<thead>
<tr>
<th>required storage capacity for remaining rainwater (peak event) in mm</th>
<th>required storage capacity for remaining rainwater (peak event) in m³ on total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>113.72</td>
<td>2,934,720.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>portion of total area for required storage area for peak precipitation event</th>
<th>required storage area for remaining rainwater (peak event) in m² (depth=1m)</th>
<th>required storage area for remaining rainwater (peak event) in m² (depth=50cm)</th>
<th>portion of total area for required storage area for peak precipitation event</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.37%</td>
<td>2,934,720.00</td>
<td>5,869,440.00</td>
<td>22.74%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total required area for peak precipitation event storage (portion of total area)</th>
<th>total required area for peak precipitation event storage in m²</th>
<th>total required area for peak precipitation event storage in m²</th>
<th>total required area for peak precipitation event storage (portion of total area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.98%</td>
<td>36,076.23</td>
<td>65,423.43</td>
<td>25.35%</td>
</tr>
</tbody>
</table>
F. Calculations for rainwater runoff for the current situation on a monthly basis [august].

<table>
<thead>
<tr>
<th>peak precipitation in mm</th>
<th>total traffic area in m² (53% of total)</th>
<th>portion roof surface area (of total area)</th>
<th>gross m³ rainwater on all roofs (in august)</th>
<th>net m³ rainwater on all roofs (in august)</th>
<th>runoff reduction value (for calculation of net)</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>13,556,451.61</td>
<td>47%</td>
<td>1,531,250.00</td>
<td>1,067,507.81</td>
<td>0.697147959</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>cluster size in m² (including 20 blocks)</th>
<th>portion sealed traffic area</th>
<th>gross m³ rainwater on all sealed traffic areas (in august)</th>
<th>net m³ rainwater on all sealed traffic areas (in august)</th>
<th>runoff reduction value (for calculation of net)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80,000.00</td>
<td>23%</td>
<td>741,935.48</td>
<td>445,161.29</td>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total area in m² (323 cluster = 6452 blocks)</th>
<th>portion unsealed area</th>
<th>gross m³ rainwater on all unsealed traffic areas (in august)</th>
<th>net m³ rainwater on all unsealed traffic areas (in august)</th>
<th>runoff reduction value (for calculation of net)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25,806,451.61</td>
<td>30%</td>
<td>967,741.94</td>
<td>387,096.77</td>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total gross m³ rainwater on the whole area (in august)</th>
<th>net m³ rainwater runoff from whole area (in august)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,240,927.42</td>
<td>1,899,765.88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>storage capacity in relation to total gross runoff per year:</th>
<th>storage capacity in relation to total net runoff per year:</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.73%</td>
<td>25.13%</td>
</tr>
</tbody>
</table>


G. Calculations for VDC's water flows to assess water balance.

<table>
<thead>
<tr>
<th>Household Water demand per day and year</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>water demand (liter per person per day)</td>
<td>household size (inhab. per house)</td>
</tr>
<tr>
<td>150</td>
<td>4.64</td>
</tr>
<tr>
<td>number of houses</td>
<td>total household water demand (liter per day)</td>
</tr>
<tr>
<td>87500</td>
<td>60,900,000.00</td>
</tr>
<tr>
<td>number of inhabitants</td>
<td>total household water demand (liter per day)</td>
</tr>
<tr>
<td>406521</td>
<td>60,978,150.00</td>
</tr>
</tbody>
</table>

Water balance yearly basis (Total rainwater from all areas - Total water demand)

<table>
<thead>
<tr>
<th>net m3 rainwater runoff from whole area per year</th>
<th>total household water demand (m3 per year)</th>
<th>m3 water demand for irrigation on the whole area (per year)</th>
<th>Water balance yearly basis in m3 (total rainwater from all areas - total water demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9,726,801.29</td>
<td>22,257,024.75</td>
<td>122,998.40</td>
<td>-12,653,221.86</td>
</tr>
</tbody>
</table>

Water balance monthly basis (Total rainwater from all areas - Total water demand)

<table>
<thead>
<tr>
<th>net m3 rainwater runoff from whole area in august</th>
<th>total household water demand (m3 per month)</th>
<th>m3 water demand for irrigation on the whole area (per year)</th>
<th>Water balance yearly basis in m3 (total rainwater from all areas - total water demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,899,765.88</td>
<td>1,829,344,500.00</td>
<td>0.00</td>
<td>-1,827,444,734.12</td>
</tr>
</tbody>
</table>

Daily water demand in relation to peak events

<table>
<thead>
<tr>
<th>net peak m3 rainwater runoff from whole area per day</th>
<th>total household water demand (m3 per day)</th>
<th>rainfall reduced by consumption in the area (m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,203,412.10</td>
<td>60,978.15</td>
<td>1,142,433.95</td>
</tr>
</tbody>
</table>
H. Calculations for quantitative evaluation of proposed decentralized rainwater and sewage treatment [Implementation of strategies for water consumption reduction]

<table>
<thead>
<tr>
<th>Water consumption reduction strategy</th>
<th>Household Water demand per day and year</th>
<th>1st STEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water demand (liter per person per day)</td>
<td>household size (inhab. Per house)</td>
<td>water demand per household (liter per day)</td>
</tr>
<tr>
<td>100</td>
<td>4.64</td>
<td>464</td>
</tr>
<tr>
<td>number of houses</td>
<td>total household water demand (liter per day)</td>
<td>total household water demand (liter per year)</td>
</tr>
<tr>
<td>87,500</td>
<td>40,600,000.00</td>
<td>14,819,000,000.00</td>
</tr>
<tr>
<td>number of inhabitants</td>
<td>total household water demand (liter per day)</td>
<td>total household water demand (liter per year)</td>
</tr>
<tr>
<td>406,521</td>
<td>40,652,100.00</td>
<td>14,838,016,500.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>net m3 rainwater runoff from whole area per year</th>
<th>total household water demand (m3 per year)</th>
<th>m3 water demand for irrigation on the whole area (per year)</th>
<th>Water balance yearly basis in m3 (total rainwater from all areas - total water demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9,726,801.29</td>
<td>14,838,016.50</td>
<td>122,998.40</td>
<td>-5,234,213.61</td>
</tr>
<tr>
<td>-16,853,881.60</td>
<td>11,742,666.39</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total wastewater produced from the total area in m3 per day</th>
<th>m3 wastewater treated and reclaimed for irrigation on the whole area (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48,782.00</td>
<td>16,976,880.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total wastewater treated with 1 constructed wetland per cluster for maximum 1200 inhabitants in litres</th>
<th>total wastewater treated with 1 constructed wetland for maximum 1200 inhabitants per cluster in m3</th>
<th>total number of clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>144,000.00</td>
<td>144.00</td>
<td>323.00</td>
</tr>
</tbody>
</table>
## Water consumption reduction strategy
### Household

### Water demand per day and year (2nd STEP)

<table>
<thead>
<tr>
<th>water demand (liter per person per day)</th>
<th>household size (inhab. Per house)</th>
<th>water demand per household (liter per day)</th>
<th>water demand per household (liter per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td>4.64</td>
<td>334.08</td>
<td>121,939.20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>number of houses</th>
<th>total household water demand (liter per day)</th>
<th>total household water demand (liter per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>640</td>
<td>213,811.20</td>
<td>78,041,088.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>number of inhabitants</th>
<th>total household water demand (liter per day)</th>
<th>total household water demand (liter per year)</th>
<th>total household water demand (m3 per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>406521</td>
<td>29,269,512.00</td>
<td>10,683,371,880.00</td>
<td>10,683,371.88</td>
</tr>
</tbody>
</table>

### Water balance yearly

<table>
<thead>
<tr>
<th>net m3 rainwater runoff from whole area per year</th>
<th>total household water demand (m3 per year)</th>
<th>m3 water demand for irrigation on the whole area (per year)</th>
<th>Water balance yearly basis in m3 (total rainwater from all areas - total water demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9,726,801.29</td>
<td>10,683,371.88</td>
<td>122,998.40</td>
<td>-1,079,568.99</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>total wastewater produced from the total area in m3 per day</th>
<th>m3 wastewater treated and reclaimed for irrigation on the whole area (per year)</th>
</tr>
</thead>
<tbody>
<tr>
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<table>
<thead>
<tr>
<th>total wastewater treated with 1 constructed wetland per cluster for maximum 1200 inhabitants in (litres)</th>
<th>total wastewater treated with 1 constructed wetland for maximum 1200 inhabitants per cluster in (m3)</th>
<th>total number of clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>144,000.00</td>
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### Water consumption reduction strategy Household

#### Water demand per day and year [3rd STEP]

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<table>
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<table>
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<td>9,644,710.73</td>
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#### Total wastewater production and treatment

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<th>m3 water demand for irrigation on the whole area (per year)</th>
<th>Water balance yearly basis in m3 (total rainwater from all areas - total water demand)</th>
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<td>-16,853,881.60</td>
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<table>
<thead>
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<th>total wastewater produced from the total area in m3 per day</th>
<th>m3 wastewater treated and reclaimed for irrigation on the whole area (per year)</th>
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<td>17,805,430.00</td>
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#### Total wastewater treatment and land use

<table>
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<tr>
<th>total wastewater treated with 1 constructed wetland per cluster for maximum 1200 inhabitants in (litres)</th>
<th>total wastewater treated with 1 constructed wetland for maximum 1200 inhabitants per cluster in (m3)</th>
<th>total number of clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>144,000.00</td>
<td>144.00</td>
<td>323.00</td>
</tr>
</tbody>
</table>
The unsustainable management of water resources in Mexico City is causing a crisis that threatens to leave 22 million people without water in the near future. Isla Urbana is dedicated to developing a practical and affordable solution to this crisis. The Isla Urbana team has designed a sustainable, rainwater harvesting model that can be easily and inexpensively implemented on a large scale to ensure clean water throughout Mexico City and the developing world. Isla Urbana is a collaborated project of the non-profit NGO's, the International Renewable Resources Institute (IRRI), located in Mexico City, Mexico, and TEMO Foundation, located in Dallas, TX, USA.

The project launched in 2009 in a marginalized region of Mexico City, where Isla Urbana worked closely with the Cultural Maya community to ensure an accessible water supply for people of varying economic levels. As they strive to promote sustainability in every aspect of the project, Isla Urbana uses readily available materials from local stores and trains local personnel to construct and install the systems. To ensure a future with access to clean water, it is imperative for innovative water saving technologies to be enacted on a larger scale and Isla Urbana is committed to making rainwater harvesting an integral component of Mexico’s water management system.

Our mission

At Isla Urbana, we believe there exists a better system of water management than the traditional methods currently employed. We plan to mitigate the city’s flooding problems while providing water to the millions of people living without it. Our vision provides a source of water that is economically, environmentally and socially beneficial to all individuals.

What is Isla Urbana?

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**What is Isla Urbana?**

**Our mission**

**Revolutionizing Water Sustainability**

**Water crisis**

- Currently, 36% of houses lack adequate access to water, with the number predicted to rise dramatically in the coming years.
- While Mexicans turn on their faucets to find not a single drop of water, major floods occur throughout the city during the rainy season.
- Most of the families suffering from the water crisis are also families with the least amount of resources to deal with the scarcity.
- In a city that averages more rainfall than London, rainwater harvesting is a sustainable solution that could circumvent future water catastrophes.
- Rainwater harvesting, implemented on a large scale throughout the city, could provide 50% of the city’s water supply.

**What is rain water harvesting?**

Rainwater harvesting is the process of capturing, purifying and storing rainwater for human use. The system created by Isla Urbana collects the rain on a household’s rooftop, stores the water in a cistern, and purifies the rainwater for domestic uses.

**A third of the water for the city travels up a 1000 meter mountain and comes from 200km away, using vast quantities of fossil fuels to pump that water. Rainwater harvesting uses nature’s free transport system by collecting water as it falls on rooftops then storing and filtering the rainwater for household use.**

**In Mexico City, rainwater harvesting is an economically, environmentally and socially sustainable design solution that works with the valley’s natural processes to provide a clean water supply to everyone living in the valley.**

Isla Urbana works closely with the particular communities to ensure the project is culturally sensitive and self-sustaining. The cost of materials for each system is approximately 350 USD and all materials are bought from local hardware stores. The local focus not only supports the local economy, but it also ensures that the homeowners can build and fix the systems on their own, without having to purchase unavailable items.

We are currently training professional plumbers from each neighborhood in the region in an effort to pool local knowledge on the installation and maintenance of the systems.

**How is rain water harvesting addressing the city’s problems?**

- **Creating green collar workers in low-income communities**
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Creating green collar workers in low-income communities

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“We just hope that everyone can have the opportunity to have a system like I do.”
- Clara

Unique value of isla urbana

Social Entrepreneurship of the 21st Century
Even though Mexico City, one of the largest cities in the world, is running out of water, Isla Urbana is the only non-profit NGO providing rainwater harvesting systems in low-income neighborhoods.

Isla Urbana’s rainwater harvesting systems promote sustainable water management practices by mitigate the city’s flooding problems, relieve the burden of poverty, reduce carbon emissions and also provide a reliable source of water for the people of Mexico City.

The project stresses social service as a way for the beneficiaries to give back to the community. Isla Urbana organizes reforestation and cleaning of green spaces, and also hosts free events for children including mural painting, movies and soccer games in the effort to promote unity in the neighborhood.

Collaboration between local government & communities empowers both
When Clara Gaytan and her daughter arrived in Mexico City thirty years ago, they started a life on the mountainside of Ajusco. There she built a modest house, which did not have water or electricity. Clara came from Oaxaca with the goal to make money to support her growing family. She found a job as a housekeeper in a nice apartment in the valley. While looking down into the Valley of Mexico from her house Clara said, “How is it possible for so many people to be taking from the same water sources?” Clara worked diligently to build a comfortable house for her family, but they did not have enough water to bathe during the dry seasons of the year. Even after her house was connected to the city’s water system, her family received an inconsistent and vastly insufficient water supply.

In 2009, Clara became the first beneficiary of Isla Urbana’s rainwater harvesting system and says that the system has vastly improved her quality of life. During the spring of 2010, Clara’s cistern was almost empty since she had not received water from the city in weeks. She did not have enough money to buy water and was left without options. Just as she was using the last drops in her water supply, a rainstorm hit Mexico City which filled her cistern completely. The next day she crossed the street to the Isla Urbana office to hug and thank us.

Through Isla Urbana’s rainwater harvesting systems, Clara has access to water throughout the year and truly understands the value of water for day-to-day living. She has potable filters, enabling her to drink the water. When washing clothes, Clara washes her whites first, uses that same water to wash her darks, and uses that same water to wash the floors. She bathes with a bucket of hot water to use as little water as possible and flushes the toilet only with reused water.

The story behind the idea

The isla urbana team

The design and implementation of this sustainable form of water management has brought five people from different corners of the world together in Mexico City to create Isla Urbana. Isla Urbana was initiated by a thesis project of Enrique Lomnitz, while attending the Rhode Island School of Design. Enrique studied industrial design and having many roots in Mexico, decided to focus his efforts on a design solution an environmental and humanitarian problem facing Mexico City.

He found that water scarcity is a vast humanitarian crisis in Mexico City, and the water management systems are exceedingly detrimental to the environment; however, Mexico City has the infrastructure necessary to make rainwater harvesting a sustainable solution to the water management problems.

Jennifer White studied urban geography at Penn State University with the goal of enhancing urban systems to function more efficiently for the betterment of the environment and the citizens.

Carmen Hernandez has lived most of her life in Mexico City. She studied cultural anthropology at UAM (Universidad Autónoma Metropolitana) and is passionate about making water accessible to all of Mexico City.

David Vargas, also born in Mexico City, received a Master’s Degree in Civil Engineering at Penn State University with a focus on rainwater harvesting, engineering leadership, and global entrepreneurship. He moved back to Mexico City to use his creative skills to improve human lives.
Our achievements!

As of October 2010

• Isla Urbana has installed 110 rainwater harvesting systems in Mexico City.
• Approximately 740 people are now collecting rainwater.
• 4,165,000 liters of water have been harvested thus far.

The municipal government of Delegation Tlalpan is investing 7 million pesos into Isla Urbana to implement our rainwater harvesting systems on a large scale in the Ajusco-Medio region of Mexico City.

Awards

The Deutsche Bank Urban Age Award - Honorable Mention - 2010
BBC World Challenge Finalist 2010 - Winner to be determined

Grants

• Instituto Nacional de Desarrollo Social, INDESOL [National Institute of Social Development (Part of the Secretariat for Social Development, SEDESOL)] - 2010. Installed three cisterns and three rainwater harvesting systems in a remote indigenous Huichol community in Jalisco, Mexico.
  www.indesol.gob.mx/web/Index.php
• “Genera” a project of Pase Usted (Genera = Generate) Transforming Mexico Through Ideas - 2010. Ten week incubator and $100,000 peso seed money for new projects/businesses which are working on social and/or environmental projects in Mexico City.
  http://paseusted.org/index.php/contenido/genera/
• Instituto de la Juventud INJUVE (The Youth Institute) Grant entitled “Creación Joven” (“Young Growth”). Grant money to be used for the installation of one rainwater harvesting system followed by water sample analysis, subsequent system updates, and the installation of another rainwater harvesting system.
2.3 Definition and terminology

Constructed wetlands (CWs) are "engineered systems, designed and constructed to utilise the natural functions of wetland vegetation, soils and their microbial populations to treat contaminants in surface water, groundwater or waste streams" (ITRC, 2003).

Synonymous terms of CWs include: Man-made, engineered, artificial or treatment wetlands.

There are also a number of terms used for subsurface flow CWs, which can be confusing for novices:

- Planted soil filters: Their vegetation is composed of macrophyte plants from natural wetlands and this sets them apart from the unplanted soil filters, also called subsurface biofilters, percolation beds, infiltration beds or intermittent sand filters.
- Reed bed treatment system: A term used in Europe resulting from the fact that the most frequently used plant species is the common reed (Phragmites australis).
- Vegetated submerged beds, vegetated gravel-bed and gravel bed hydroponics filters.

This great number of terms is confusing for novices who are searching for information.

In this document, the terms “bed”, “filter” or “filter bed” are used interchangeably, denoting the sand filled main body of the subsurface flow CWs.

We use the term "pre-treatment" in this document to denote the treatment step before the wastewater reaches the subsurface flow CW filter bed. Other authors call this step "primary treatment", and the treatment in the CW would in that case be called "secondary treatment".

2.4 Historical development

Historically, natural wetlands have been used as convenient sewage and wastewater disposal sites. This led to many wetlands, such as marshes, being saturated with nutrients and experiencing severe environmental degradation.

The German scientist Dr. Seidel conducted the first experiments on the possibility of wastewater treatment with wetland plants in 1952 at the Max Planck Institute in Germany (Seidel, 1965). A major increase in the number of CWs took place in the 1990s as the application expanded to treat different kinds of wastewater such as industrial wastewater and storm water.

The use of constructed wetlands for wastewater treatment is becoming more and more popular in many parts of the world. Today subsurface flow CWs are quite common in many developed countries such as Germany, UK, France, Denmark, Austria, Poland and Italy. Constructed wetlands are also appropriate for developing countries but they still have to become better known there (Mohamed, 2004; Heers, 2006; Kamau, 2009).

2.5 Classification of constructed wetlands

Constructed wetlands are classified according to the water flow regime (see Figure 1) into either free water surface flow (FWS CWs) or subsurface flow CWs, and according to the type of macrophyte plant as well as flow direction. Constructed wetlands used macrophyte plants which are aquatic plants that grow in or near water.

Subsurface flow CWs are designed to keep the water level totally below the surface of the filter bed. They can even be walked on. This avoids the mosquito problems of FWS CWs.

Different types of constructed wetlands may be combined with each other to form hybrid systems in order to exploit the specific advantages of the different systems.

The coarse sand used in subsurface flow CWs contributes to the treatment processes by providing a surface for microbial growth and by supporting adsorption and filtration processes. This results in a lower area demand and higher treatment performance per area for subsurface flow CWs, compared to FWS CWs. Subsurface flow CWs are the predominant wetland type in Europe.

There are two different types of filtering material, i.e. sand or gravel. Gravel bed systems are widely used in North Africa, South Africa, Asia, Australia and New Zealand. The sand bed systems have their origin in Europe and are now used all over the world.

This publication only deals with subsurface flow CWs with coarse sand as filter media.

![Classification of constructed wetlands](image)

Figure 1. Classification of constructed wetlands (modified from Vymazal and Kroepfelová, 2008). The dashed ellipse signifies the focus of this document. HFB and VFB are abbreviations for horizontal and vertical flow bed, respectively. Hybrid systems are also possible. "Emergent plants" are a type of macrophyte where the leaves are above the water level.
2.6 Range of applications

Constructed wetlands can be used for a variety of applications:\1:
1. Municipal wastewater treatment
2. Treatment of household wastewater or greywater
3. Tertiary treatment of effluents from conventional wastewater treatment plants
4. Industrial wastewater treatment such as landfill leachate, petroleum refinery wastes, acid mine drainage, agricultural wastes, effluent from pulping and paper mills, textile mills.
5. Sludge dewatering and mineralisation of faecal sludge or sludge from settling tanks.
6. Storm water treatment and temporary storage
7. Treatment of water from swimming pools without chlorine

This publication only deals with the first two applications of the list above. Note that pre-treatment of some form is required in most of the applications.

2.7 Technology selection

Subsurface flow CWs offer significant potential for decentralised wastewater treatment, but they are not the only available technology. The right treatment technology for a given application should be carefully selected taking into account a whole range of aspects and sustainability indicators.\2.

Figure 2. Urban decentralised greywater treatment with a subsurface flow CW in Klosterenga in Oslo, Norway (photo by L. Ulrich, 2008).

2.7.1 Space requirements as a selection criterion

The high space requirement compared to high-rate aerobic treatment processes can limit the use of subsurface flow CWs especially for urban applications.

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1 For an overview of these applications see this presentation: http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=1035.


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In warm climates, horizontal flow beds have approximately the same area requirement as facultative ponds which are another "low tech" wastewater treatment option, whilst vertical flow beds need about 20% less space than ponds.

In most urban situations neither HFBs nor ponds can be implemented for wastewater treatment because of the space requirement. VFBs for decentralised applications may however be small enough to fit into available urban spaces, especially in warm climates.

In order to save space in urban applications, subsurface flow CWs could be constructed on roofs of buildings. This is an interesting research area for the future but currently has a lot of practical drawbacks.

Further details on the required area of subsurface flow CWs are provided in Section 3.2.4.

2.7.2 Comparison of subsurface flow CWs with high-rate aerobic treatment processes

High-rate aerobic treatment processes require less space than constructed wetlands. Process examples are: activated sludge plants, trickling filters, rotating discs, submerged aerated filters or membrane bioreactor plants.

The main argument in favour of subsurface flow CWs compared to high-rate aerobic treatment processes is their operational robustness which is very important in the case of developing countries and countries in transition.

Another important aspect is the lack of secondary sludge production in constructed wetlands, whereas excess secondary sludge is produced in high-rate aerobic treatment processes and needs to be managed. In developing countries, this excess sludge is often discharged in an uncontrolled manner to the environment, leading to pollution and health risks.

Constructed wetlands are very effective as a tertiary treatment system after activated sludge or trickling filter plants:\3.

- The constructed wetland can serve to compensate temporary variations of effluent quality.
- Constructed wetlands achieve more pathogen removal than conventional high-rate aerobic processes (see Section 8.2 in the Appendix).

2.7.3 Comparison of subsurface flow CWs with ponds

Constructed wetlands and ponds both score high in terms of process reliability and simplicity since no special equipment is required. The main arguments to choose subsurface flow CWs over ponds include:

- Subsurface flow CWs do not have open water bodies; therefore they do not encourage mosquito breeding.
- Subsurface flow CWs produce clear water, whereas ponds have a high algae production which influences the effluent quality.
- Due to their open water surface, mosquitoes and odour, ponds are much more difficult to integrate in a neighbourhood, particularly an urban neighbourhood.

---

3 The lower organic load entering the CW in that case (after secondary treatment) significantly reduces the area requirement for the CW.
- Well-functioning constructed wetlands have no odour generation, whereas in most ponds odour generation is common.
- Constructed wetlands do not produce sludge except for the sludge produced from the pre-treatment step upstream of the filter beds. In ponds on the other hand, sludge accumulates over time, and the sludge has to be removed after about ten years. This is often neglected in developing countries and instead the ponds are abandoned.

And what are the advantages of ponds over subsurface flow CWs? They are easier to design and construct, do not need a substrate (sand) and have lower capital costs for large-scale plants (see Section 2.7.4).

2.7.4 Cost considerations

The capital costs of subsurface flow CWs are highly dependent on the costs of sand since the bed has to be filled with sand. Secondly the capital costs are also dependent on the cost of land.

Financial decisions on treatment processes should not primarily be made on capital costs, but on net present value or whole-of-life costs, which includes the annual costs for operation and maintenance.

The following points can be made when comparing costs for constructed wetlands and high-rate aerobic treatment processes:
- Constructed wetlands do not exhibit economies of scale to the same degree that high-rate aerobic treatment plants do. For small plants of up to 500 p.e., constructed wetlands are usually cheaper to build than high-rate aerobic plants but for larger plants, they are usually more expensive in terms of capital costs.
- Constructed wetlands have significantly lower operation and maintenance costs compared to high-rate aerobic processes for energy use and operator time.

For large scale treatment plants of more than 10 000 person equivalents (p.e.) in areas where land is available cheaply, ponds have lower capital costs than constructed wetlands. But there is a range of other aspects which have to be taken into account when making the decision between the two different treatment processes, as shown above.

We argue that the capital costs argument should be less important than the reliability and long-term sustainability of the treatment plant, including its financial sustainability which is strongly influenced by annual operation and maintenance costs.

2.8 Reuse aspects

2.8.1 Reuse for irrigation

Subsurface flow CWs treat wastewater to a standard fit for discharge to surface water or fit for various reuse applications according to WHO guidelines (WHO, 2006). The legal requirements for the effluent quality vary depending on the specific regulations of each country and also on the intended reuse or disposal pathway. The design of the subsurface flow CW should be in line with the desired effluent quality for disposal or reuse.

The most common type of reuse is irrigation, such as drip irrigation or subsurface irrigation, for lawns, green spaces or crop production. In this case, utilisation of nutrients contained in wastewater rather than nutrient removal is desirable.

Relevant guidelines must be followed to ensure this practice is hygienically safe for the consumers of the crops as well as for workers who can be in contact with treated wastewater. International standards for reuse and an explanation of the important multiple-barrier concept can be found in WHO (2006).

2.8.2 Hygiene aspects (pathogens)

Humans excrete many different types of disease causing pathogens if they are infected or carriers of a disease. The human intestinal tract contains coliform bacteria which are discharged with the faeces. These coliform bacteria are not pathogens but if present in environmental samples indicate that intestinal pathogens may also be present.

Greywater which has been treated in subsurface flow CWs usually meets the standards for pathogen levels for safe discharge to surface water without further treatment. In the case of domestic wastewater, disinfection by tertiary treatment might be necessary, depending on the intended reuse application.

For further information on pathogen types and pathogen removal by various treatment processes please see the Appendix.

For large scale treatment plants of more than 10 000 person equivalents (p.e.) in areas where land is available cheaply, ponds have lower capital costs than constructed wetlands. But there is a range of other aspects which have to be taken into account when making the decision between the two different treatment processes, as shown above.

We argue that the capital costs argument should be less important than the reliability and long-term sustainability of the treatment plant, including its financial sustainability which is strongly influenced by annual operation and maintenance costs.

2.8.3 Quantity aspects

Horizontal flow beds in warm climates can lose all the wastewater due to evapotranspiration. This needs to be considered in the water balance. The larger the surface area, the more significant are the effects of precipitation (rain) and evapotranspiration, especially in warm and dry climates.

Figure 3. The treated effluent (left) of the vertical flow constructed wetland in Haran Al-Awamed, Syria, is collected in this storage tank (right) before its reuse for irrigation in agriculture (photos by E. von Muench, 2009; project supported by GIZ).
If water loss is regarded as a problem, VFBs are preferable to HFBs, because they have an unsaturated upper layer in the bed and a shorter retention time than HFBs.

## 2.8.4 Colour aspects

The effluent from any biological wastewater treatment process such as a constructed wetland can have a yellowish or brownish colour. This is caused by humic substances, such as humic acids or humins (Figure 4). The colouration may reduce the social acceptance of wastewater reuse.

Humic acids originate from the biological degradation of organic matter, being the unbiodegradable fraction of organic matter. Humic acids are a natural compound of soil, lake and river water. They are not harmful to the environment but they have a negative impact on disinfection processes with chlorine or UV radiation.

When treated wastewater is used for toilet flushing, it is easier to use coloured porcelain for the toilet bowl than to attempt to remove the coloration, since humic substances can be only removed by advanced technologies such as activated carbon, ozone, photo catalytic oxidation (Guylas et al., 2007; Abegglen et al., 2009).

From the main authors’ experiences, greywater after treatment in a constructed wetland tends to have no colour. On the other hand, domestic wastewater or blackwater after treatment in a constructed wetland is often, but not always, slightly yellow or brown (see for example Figure 4).

![Figure 4. Wastewater samples before and after treatment in a VFB. Left photo: pre-treated greywater (left bottle) and effluent of the CW which is reused for irrigation of crops (right bottle). Right photo: pre-treated blackwater (left bottle) and effluent of the CW which has the typical brownish colouration caused by humic acid (right bottle) (photos by: H. Hoffmann, 2008).](image)

### 3 Design criteria for subsurface flow CWs

#### 3.1 Treatment principles

##### 3.1.1 Overview of main processes

Subsurface flow CWs achieve the removal of the following pollutants (see Table 1 for details):

- Organic matter measured as “biological oxygen demand” (BOD) or “chemical oxygen demand” (COD)
- Suspended solids measured as “total suspended solids”, TSS
- Nutrients, i.e. nitrogen and phosphorus
- Pathogens, heavy metals and organic contaminants.

Constructed wetlands are often referred to as “simple, low tech systems”, but the biological, physical and chemical treatment processes involved are actually far from simple. They occur in different zones in the main active layer of the constructed wetland, the “filter bed”. These zones include:

- Sediment, sand bed
- Root zone, water in pores
- Litter, detritus (non-living particulate organic material, such as leaf litter)
- Water
- Air
- Plants and plant roots
- Biomass zones, such as bacteria growing in sand and attached to roots

The wastewater treatment in the filter bed of constructed wetlands is the result of complex interactions between all these zones. A mosaic of sites with different oxygen levels exists in constructed wetlands, which triggers diverse degradation and removal processes.

### Table 1. Overview of pollutant removal processes in subsurface flow CWs.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Process</th>
</tr>
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</table>
| Organic material (measured as BOD or COD) | • Particulate organic matter is removed by settling or filtration, then converted to soluble BOD.  
• Soluble organic matter is fixed by biofilms and removed due to degradation by attached bacteria (biofilm on stems, roots, sand particles etc.). |
| Suspended solids (TSS)    | • Filtration  
• Decomposition by specialised soil bacteria during long retention times |
| Nitrogen                  | • Nitrification and denitrification in biofilm  
• Plant uptake (only limited influence) |
| Phosphorus                | • Retention in the soil (adsorption)  
• Precipitation with calcium, aluminium and iron  
• Plant uptake (only limited influence) |
| Pathogens                 | • Filtration  
• Adsorption  
• Predation (“feeding”) by protozoa  
• Die-off due to long retention times |
| Heavy metals              | • Precipitation and adsorption  
• Plant uptake (only limited influence) |
| Organic contaminants      | • Adsorption by biofilm and clay particles  
• Decomposition due to long retention times and specialised soil bacteria is possible |

* Nutrient removal is not necessary when treated wastewater shall be reused for irrigation purposes (see Section 2.8).
The filter bed acts as a mechanical and biological filter. Influent suspended solids and generated microbial solids are mainly retained mechanically, whereas soluble organic matter is fixed or absorbed by a so-called biofilm. All organic matter is degraded and stabilised over an extended period by biological processes. The biological treatment in the filter bed is based on the activity of microorganisms, mainly aerobic and facultative bacteria. These microorganisms grow on the surface of the soil particles and roots, where they create a highly active biofilm.

Subsurface flow CWs are designed for aerobic and facultative treatment. Aerobic processes always need the presence of oxygen (air). Facultative processes can occur under temporary oxygen limited conditions or in the absence of oxygen, when nitrate (NO₃⁻) is used by specialised bacteria for the oxidation of organic matter. This is then called an anoxic process.

CWs are not designed for anaerobic treatment (which occurs in absence of oxygen) but some small anaerobic zones may still exist in CWs, particularly for free water surface flow CWs and HFBs. The possible biogas emissions due to these anaerobic processes are however negligible compared to other sources.

A low organic load to the CW allows for the degradation of less degradable organic matter (organic contaminants), which will be decomposed by specialised natural soil bacteria. These specialised bacteria have very low growth rates. All organic matter, suspended solids and also bacteria. These specialised bacteria have very low growth rates. All organic matter, suspended solids and also generated microbial solids are finally reduced by aerobic and anaerobic processes into CO₂, H₂O, NO₃ and N₂.

The uptake of heavy metals by plants in constructed wetlands has been reported. The physiological reasons for heavy metal uptake are not yet fully understood and probably depend strongly on the plant species. Nevertheless it has to be pointed out that heavy metals do not disappear, but still remain in the plant tissues. In greywater and domestic wastewater heavy metals are usually not an issue, because their concentration is low in such types of wastewater.

### 3.1.2 Pollutant removal ratios for greywater treatment

The removal efficiencies for greywater treatment with two types of subsurface flow CWs are summarised in Table 2. It is obvious that different removal ratios exist for HFBs and VFBs as well as for the different parameters. The removal ratios for BOD and TSS are up to 99%, while total nitrogen removal ratios are only up to 40% (but higher for hybrid systems). The values can be expected to be similar for domestic wastewater treatment.

The effluent concentrations of pollutants can be calculated by multiplying the influent concentrations in the flow to the filter bed (i.e. after pre-treatment) with the removal ratio.

### Table 2. Removal ratios (in %) of HFBs and VFBs (subsurface flow CWs) for greywater treatment. The values are similar for domestic wastewater treatment.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>HFB (Morel and Diener, 2006)</th>
<th>VFB (Ridderstolpe, 2004)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (biological oxygen demand)</td>
<td>80-90</td>
<td>90-99</td>
</tr>
<tr>
<td>TSS (total suspended solids)</td>
<td>80-95</td>
<td>90-99</td>
</tr>
<tr>
<td>TN (total nitrogen)</td>
<td>15-40</td>
<td>30</td>
</tr>
<tr>
<td>TP (total phosphorus)</td>
<td>Phosphorus removal rates depend on the properties of the filter material and on the length of time the CW has been operating for.</td>
<td></td>
</tr>
</tbody>
</table>

### 3.1.3 Nutrient removal

Plant growth leads to removal of nutrients such as nitrogen and phosphorus: The reduction of ammonia and phosphate from domestic wastewater by growing plants is about 10-20% during the vegetation period. More important for nitrogen removal are however the nitrification/denitrification processes carried out by bacteria.

#### Nitrogen removal:

- **HFBs:** As the oxygen transport into HFBs is limited, enhanced nitrification cannot be expected. On the other hand denitrification can be very efficient, even at very low carbon to nitrogen ratios (Platzer, 1999). The produced nitrate can be reduced under anaerobic conditions by heterotrophic bacteria to nitrogen (N₂); this is called denitrification.
- **VFBs:** In VFBs with sufficient oxygen supply, ammonia can be oxidised by autotrophic bacteria to nitrate; this process is called nitrification. An almost complete nitrification with 90% ammonia oxidation is commonly reported for VFBs. Nevertheless nitrification depends strongly on the oxygen supply. For the dimensioning it is essential to calculate the oxygen consumption in the VFB (Platzer, 1999; Cooper, 2005; Platzer et al., 2007). On the other hand, since VFBs do not provide much denitrification, the nitrogen remains as nitrate in the effluent and the total nitrogen removal ratio is therefore only around, 30%.
- **Combination:** Often a combination of a VFB followed by a HFB and flow recirculation is used when nitrogen removal is required. For details see Section 5.4.

#### Phosphorus removal:

Most CWs are not designed primarily for phosphorus removal and in developing countries they are practically never designed for phosphorus removal since this is generally not a requirement there. Phosphorus removal is not such an important issue in those countries compared to the other health risks from untreated wastewater discharge. If excess phosphorus in receiving water bodies such as lakes and rivers became an important problem, a first step could be to ban detergents which contain phosphorus, as has been done for example in Switzerland.

A reliable design for phosphorus removal has not yet been developed although many subsurface flow CWs do present a relatively high phosphorus removal rate for a period of time.
Phosphorus removal can be achieved in CWs by adsorption and precipitation, and a small amount is also taken up by plant growth.

The authors estimate that a phosphorus removal ratio by plant growth of up to 10% is possible depending on the climate, plants, type of wastewater, etc. The capacity of chemical phosphorus binding, and thus the phosphorus removal efficiency, decreases during the lifetime of a subsurface flow CW. This is due to limited adsorption sites of the sand.

If phosphorus removal is indeed required, a separate unplanted soil filter can be used downstream of the subsurface flow CW, where the substrate can be replaced once its phosphorus adsorption capacity has been reached. Exchange of substrate is theoretically also possible for subsurface flow CWs but in practice it is not economically feasible.

3.1.4 Role of plants in subsurface flow CWs

Subsurface flow CWs are planted with macrophyte plants which are commonly found in natural wetlands or non-submerged riverbanks in the region. The plants are an essential part of a constructed wetland. They are aesthetically pleasing and add greenery to a built-up area. They serve as a habitat for animals like birds and frogs, and act as a local “green space”.

Most significant in comparison to unplanted filters is the ability of the subsurface flow CWs – which are by definition with plants – to maintain or restore the hydraulic conductivity of the filter bed. Unplanted soil filters on the other hand have to be treated to regain their hydraulic conductivity, for example by removing the top few centimetres of substrate.

The plants also play an important role in the treatment process. They provide an appropriate environment for microbial growth and significantly improve the transfer of oxygen into the root zone, which is part of the filter bed. Furthermore, in cold climate zones dead plant material provides an insulation layer, which has a positive effect for the operation of subsurface flow CWs in winter.

For example, in the case of reed, there is a massive network of roots and rhizomes, which maintain a high biological activity in the constructed wetland, due to their ability to transport oxygen from the leaves to the roots (see Figure 5). For HFBs a uniform distribution of roots in the entire filter bed is important, whereas for VFBs only the uniform distribution of roots in the upper layer (the first 10 cm) is essential.

The characteristics of plants such as papyrus or bamboo, which are adapted to growth conditions in temporarily submerged natural wetlands, are probably similar. In the case of bamboo, its roots may however reach too far down and therefore destroy the liner at the base of the constructed wetland.

In summary, the effects of plants which contribute to the treatment processes in subsurface flow CWs include:

- The root system maintains the hydraulic conductivity of the coarse sand substrate.
- The plants facilitate the growth of bacteria colonies and other microorganisms which form a biofilm attached to the surface of roots and substrate particles.
- The plants transport oxygen to the root zone to allow the roots to survive in anaerobic conditions. Part of this oxygen is available for microbial processes, although the exact contribution is still a point of discussion.

3.2 Basic design considerations

3.2.1 Necessary conditions and basic setup

The necessary conditions to be able to use constructed wetlands for wastewater treatment are listed below:

- Enough space must be available because it is a low-rate system with a higher space requirement than high-rate systems (Section 2.7.1).
- Climates without longer freezing periods are preferable, even though subsurface flow CWs with adjusted designs do work in cold climates (Jenssen et al., 2008).
- Full sunlight situation is preferable and full shadow conditions need to be avoided. Especially for subsurface flow CWs it is very important that the surface area can regularly dry out completely because otherwise the risk of clogging rises due to excessive biofilm growth in wet conditions.
- Plants used must be adapted for growth under partially submerged conditions, the local climate and the sunlight/shadow conditions of the respective wetland location.
- As for all biological treatment processes the wastewater should not contain toxic substances, although the high retention time makes constructed wetlands more robust to toxic events compared to more highly loaded systems.
- Well trained maintenance staff to carry out the basic maintenance tasks is needed.

Urbanisation and future population development have to be considered when calculating the expected wastewater flowrate to the constructed wetland.
There are some general considerations about constructing subsurface flow CWs, which are usually adhered to:

- **A 15 cm freeboard for water accumulation is recommended.**
- **The surface must be flat and horizontal to prevent unequal distribution or “surface run-off” (which means in the case of HFBs that wastewater is flowing across the surface of the CW to the outlet but not infiltrating and hence not receiving treatment).**
- **The design of the inlet area and distribution pipes has to assure uniform distribution of the wastewater, without allowing short circuits of the flow.**
  - The right selection of filter material is crucial (see Section 3.3 for details).
  - The wastewater is applied to the bed via distribution pipes which have small holes equally distributed along the length of the pipes.
- **Drainage pipes** collect treated wastewater at the base below the filter bed.
- **Liner at the base:** Plastic PVC lining, a clay layer or a concrete base is used to seal the filter bed at the base (see Figure 9). For HFBs this is always necessary. For VFBs it is only necessary when the effluent will be reused or when the groundwater table is high and groundwater is used for drinking water purposes. Sometimes the authorities also stipulate the sealing of the base.
  - The lining prevents contact of wastewater with groundwater but otherwise does not improve the effluent quality nor prevent clogging.
  - Disadvantages of lining are the additional costs, the difficulties with finding a local supplier (especially in rural areas), environmental pollution during production of PVC lining and the need for specialists to lay the PVC sheets properly in the hole.

Details on the design of subsurface flow CWs are given in Section 5. Special attention should always be paid to the pre-treatment (see Section 4).

### 3.2.2 Major components and design life

The major components of a constructed wetland are an influent pump (for VFBs; this is not required for HFBs), plastic pipes, plastic lining underneath the drainage pipes, gravel and sand. Therefore, the design life is determined by the design life of these major components. The pumps and feeding pipes can easily be replaced if necessary. The gravel and sand is in practice never replaced. The design life of the plastic lining is difficult to predict and the condition of the plastic lining is unfortunately impossible to assess in a constructed wetland while it is in use.

There are no theoretical reasons to indicate that constructed wetlands would stop removing organic matter, nitrogen and pathogens after a certain length of time. If a constructed wetland ever has to be abandoned, it is easy to use the space for other purposes, or to just let the plants grow wild.

Constructed wetlands can be expected to have a design life at least as long as other wastewater treatment systems, such as high-rate aerobic processes or ponds. Some constructed wetlands have now been in continuous operation for over 20 years and these plants are still producing good treatment results.

### 3.2.3 Design parameters

There are several design parameters for designing subsurface flow CWs which are used at different points in the design calculations, depending on the type of wastewater and climate:

- **Area per person in m²/p.e., where p.e. stands for “person equivalent”;**
- **Organic loading per surface area in gBOD/(m²·d) or gCOD/(m²·d);**
- **Hydraulic load in mm/d or m³/(m²·d);**
- **Oxygen input and consumption (kg/d).**

There is no commonly accepted design approach which uses the **retention time** to size a subsurface flow CW.

The best method to minimise the size of a constructed wetland is an efficient pre-treatment (see Section 4) and the precise calculation of the actual load. The organic load to a CW (in g/d) equals the flowrate (in m³/d) multiplied by the BOD concentration in the pre-treated wastewater (in mg/L).

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7 The situation is different for phosphorus removal, see Section 3.1.3.
3.2.4 Typical values for area requirements

The simplest design parameter for constructed wetlands is the area required per person, but this design parameter on its own is not sufficient for properly sizing constructed wetlands. This parameter can only be used for a basic assessment in order to obtain a first indication of the space requirement (see Section 5 for detailed design information).

Table 3 shows how the climate and the type of constructed wetland (HFB versus VFB) influence the area requirement of constructed wetlands. This table can be used as a guide and should be read as follows: if a constructed wetland is smaller than the recommended value in Table 3, then an overload situation can occur which would cause serious operational problems and reduced treatment performance. Oversized constructed wetlands on the other hand, do not have problems with treatment efficiency and are more robust, but are unnecessarily large and expensive.

To give an example: a VFB to treat wastewater of 3 000 people needs about 3 000 to 12 000 m² depending on the climate and design. A HFB would need at least twice as much space.

It should be noted that the required pre-treatment is the same for HFBs and VFBs. But the pre-treatment for wastewater is different than the pre-treatment of greywater, as the wastewater characteristics differ (see Section 4 for details).

Table 3. Approximate design values to estimate the area requirement for subsurface flow CWs in different climate conditions for domestic wastewater (after pre-treatment)\(^8\).

<table>
<thead>
<tr>
<th>Design value</th>
<th>Cold climate, annual average &lt; 10°C</th>
<th>Warm climate, annual average &gt; 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area per person (m²/p.e.)</td>
<td>HFB</td>
<td>VFB</td>
</tr>
<tr>
<td>---------------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

3.2.5 Design differences between CWs for domestic wastewater versus CWs for greywater

Domestic wastewater and greywater have different characteristics and these have to be considered when dimensioning a CW. The characterisation of domestic wastewater and greywater is outlined in the Appendix.

The main differences between the design of constructed wetlands for treating greywater compared to treating domestic or municipal wastewater include:

- **Nitrogen and phosphorus** removal are much easier to achieve for greywater than for domestic wastewater treatment since the nutrient loads and concentrations are much lower in greywater due to the lack of urine and faeces.
- **Pathogen** removal is not a design consideration for greywater treatment since the pathogen levels are very low in greywater, but it is an important consideration for domestic wastewater.

3.3 Substrate used in subsurface flow CWs

The selection of a suitably permeable substrate in relation to the hydraulic and organic loading is the most critical design parameter for subsurface flow CWs. Most treatment problems occur when the permeability is not adequately chosen for the applied load.

This publication refers only to the use of **coarse sand** as a substrate for filtration. In our view, this is the most suitable substrate for the application of subsurface flow CWs for wastewater or greywater treatment in developing countries or countries in transition (with a warm to moderate climate).

The drainage pipes at the base are covered with gravel. On top of this gravel layer, there is a sand layer of 40-80 cm thickness which contains the actual filter bed of the subsurface flow CW. On top of this sand layer there is another gravel layer of about 10 cm thickness, in order to avoid water accumulating on the surface. This top gravel layer does not contribute to the filtering process.

![Figure 8. Example of filter material used for VFBs for municipal wastewater treatment in Brazil: coarse sand from river, containing neither loam nor silt (photo by C. Platzer, 2008).](image)

It is not recommended to construct layers with different grain sizes such as larger grains on top, smaller grain sizes at the base — as this design approach has led to poorly performing constructed wetlands in the past.

It is also not recommended to use a layer made of fabric between the lower gravel layer and the sand layer. This had been included in some constructed wetlands in Germany and led to clogging in deeper zones of the VFBs which was impossible to revert. Also in the case of HFBs such a fabric separation layer would have a negative impact on the hydraulic conductivity.

Design recommendations regarding the substrate to be used in subsurface flow CWs are listed below:

- The sand should have a hydraulic capacity (kₐ value) of about 10⁻³ to 10⁻² m/s.
- The filtration sand layer needs to have a thickness of 40 to 80 cm.
- The recommended grain size distribution for the substrate is shown in Figure 32.

\(^8\) The values are the same for greywater treatment if the pretreatment unit has resulted in the same effluent concentrations (the pretreatment unit can be smaller for greywater treatment when the calculation is done on a per person basis).
The substrate should not contain loam, silt nor other fine material, nor should it consist of material with sharp edges. Figure 8 illustrates the visual appearance of suitable sand.

Figure 9. Left: VFB during construction in Palhoça, Santa Catarina, Brazil: drain pipes situated on top of the PE liner are being covered with gravel. Right: VFB in Lima, Peru during filling with sand (photos by H. Hoffmann, 2007).

3.4 Types of plants used

For the selection of plants to be used in constructed wetlands (mostly macrophyte plants i.e. aquatic plants which grow in or near water), the following recommendations can be made:

- Use local, indigenous species and do not import exotic, possibly invasive species.
- Use plant species which grow in natural wetlands or riverbanks because their roots are adapted to growing in water saturated conditions.
- Plants with an extensive root and rhizome system below ground are preferable (see Figure 5).
- Plants should be able to withstand shock loads as well as short dry periods.
- Plants should not require permanent flooding but be able to cope with temporary flooding and waterlogged soils.

Whether the wetland plants should be harvested or not is discussed in Section 6.4 as part of the operational tasks.

Plants used in subsurface flow CWs in cold climates of Europe, Southern Australia and North America include for example:

- Common reed (Phragmites australis): this is the most common plant used in Europe and in countries with a cold climate.
- Broad-leaved cattail (Typha latifolia), reed sweet grass (Glyceria maxima), reed canary grass (Phalaris arundinacea) and yellow iris (Iris pseudacorus).

The types of plants used in subsurface flow CWs in warm climates of South America, Africa, and Asia are summarised in Table 4.

<table>
<thead>
<tr>
<th>Plant name</th>
<th>Characteristics</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Papyrus sedge (Cyperus papyrus)</td>
<td>Decorative (see Figure 11).</td>
<td>3 m high, forms a layer on the CW surface, roots are only formed from the mother plant.</td>
</tr>
<tr>
<td>Umbrella sedge (Cyperus alostiaus and Cyperus alternifolius)</td>
<td>Very robust plants, excellent also for highly concentrated or salt containing wastewater.</td>
<td></td>
</tr>
<tr>
<td>Dwarf papyrus (Cyperus haspens)</td>
<td>Excellent when it is the only plant.</td>
<td>Does not survive in the shadow of larger plants.</td>
</tr>
<tr>
<td>Bamboo, smaller ornamental species</td>
<td>Decorative.</td>
<td>Slow growth especially in the first 3 years and if the plant is not well adapted to the climate.</td>
</tr>
<tr>
<td>Broad-leaved cattail (Typha latifolia)</td>
<td>Is often more resistant in warm conditions than common reed.</td>
<td></td>
</tr>
<tr>
<td>Species of genus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heliconia: lobster-claws, wild plantains</td>
<td>Decorative</td>
<td>Some plants of these species prefer half shadow, others full sunlight conditions.</td>
</tr>
<tr>
<td>Canna: Canna lily</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zantedeschia: Calla lily</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Napier grass or Elephant grass (Pennisetum purpureum)</td>
<td>Species of grass native to the tropical grasslands in Africa. It has a very high productivity, both as forage for livestock and as a biofuel crop.</td>
<td></td>
</tr>
<tr>
<td>Vetiver (Chrysopogon zizanioides, previously called Vetiveria zizanioides or cuscus grass)</td>
<td>It can grow up to 1.5 m high and forms an efficient root system. This grass is used in warm climates for erosion control and for producing essential oil which is distilled from its roots. The grass is also used as fodder plant or for handicraft material.</td>
<td>The roots do not grow so well when the plant is used for wastewater treatment in constructed wetlands, but the roots are still sufficient to maintain the functionality of a VFB. Hence, vetiver is only recommended for VFBs, but not for HFBs.</td>
</tr>
</tbody>
</table>

The types of plants used in subsurface flow CWs in warm climates of South America, Africa, and Asia are summarised in Table 4.
4 Pre-treatment of wastewater before subsurface flow CW treatment

4.1 Overview of processes

Constructed wetlands can be called a secondary treatment step since suspended solids, larger particles including toilet paper and other rubbish as well as some organic matter need to be removed before wastewater can be treated in subsurface flow CWs. The technology used for pre-treatment (also called primary treatment) depends on the type and quantity of wastewater. Table 5 provides a general overview.

Pre-treatment is extremely important to avoid clogging of subsurface flow CWs, which is an obstruction of the free pore spaces due to accumulation of solids (see Section 5.2.2 for details).

This section provides only general guidance on pre-treatment processes. Specialised literature or local experts should be consulted to design the pre-treatment process. See for example Gutterer et al. (2009) for design equations for septic tanks, baffled tanks and Imhoff tanks.

Small household treatment plants (less than 1 000 p.e.) are usually designed without screens. In this case septic tanks, baffled tanks or compost filters carry out the screening function.

About 60% of suspended solids in the wastewater is removed in the pre-treatment step. As a basic rule, the aim is to have less than 100 mg/L TSS in the influent to a SSF CW (i.e. after pre-treatment).

Table 5. Overview of available pre-treatment processes and their suitability for different wastewater types: GW stands for greywater, WW stands for wastewater (X means: can be used).

<table>
<thead>
<tr>
<th>Pre-treatment process</th>
<th>GW with low organic load</th>
<th>Domestic WW or GW with high organic load</th>
<th>Scale (p.e.)</th>
<th>Biogas production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screens (mechanically operating)</td>
<td>X</td>
<td>X</td>
<td>&gt; 1000</td>
<td>No</td>
</tr>
<tr>
<td>Sand and grit removal</td>
<td>X</td>
<td>X</td>
<td>&gt; 1000</td>
<td>No</td>
</tr>
<tr>
<td>Grease trap</td>
<td>X</td>
<td>X</td>
<td>At household level</td>
<td>No</td>
</tr>
<tr>
<td>Compost filter</td>
<td>–</td>
<td>X</td>
<td>Up to 70</td>
<td>No</td>
</tr>
<tr>
<td>Septic tank</td>
<td>–</td>
<td>X</td>
<td>5-200</td>
<td>Yes</td>
</tr>
<tr>
<td>Baffled tank</td>
<td>–</td>
<td>X</td>
<td>200-2 500</td>
<td>Yes</td>
</tr>
<tr>
<td>Imhoff tank</td>
<td>–</td>
<td>X</td>
<td>500-20 000</td>
<td>Yes</td>
</tr>
<tr>
<td>UASB</td>
<td>–</td>
<td>X</td>
<td>&gt; 5 000</td>
<td>Yes</td>
</tr>
</tbody>
</table>
4.2 Biogas emissions during pre-treatment

In most of the pre-treatment facilities, anaerobic degradation processes occur in the accumulated sludge (see Table 5). These anaerobic processes lead to the emission of biogas, which contains typically around 66% methane. Methane (CH₄) in the earth’s atmosphere is an important greenhouse gas with a global warming potential of 25 times higher compared to CO₂ over a 100-year period.

Unfortunately the organic load in communal wastewater is in most cases not high enough for the economical usage of biogas for cooking, lighting or heating. Sometimes the distance between the point of biogas generation and the point of possible biogas use is also too large. In these cases the biogas should at least be burnt (also called “flared”). When biogas needs to be burnt, there are additional costs for safety equipment. The flare for a household plant has nearly the same costs as a flare for a large plant of 20,000 inhabitants – thus the specific costs per person are relatively high for flares implemented in small systems.

Due to the fact that septic tanks, baffled tanks, Imhoff tanks and UASBs lead to biogas emissions and since flares are neither economical nor practical at the small scale, the designer should be aware of the negative impact on climate change of these pre-treatment methods.

It is recommended to always check the possibility of flaring of biogas or of using other available pre-treatment methods which do not produce biogas. Whilst the greenhouse gas (methane) emissions from anaerobic processes within pre-treatment processes are relatively small compared to other sources of greenhouse gases, they should still be minimised as much as possible.

4.3 Grease trap

Fats, oil and grease (FOG) are removed by floating this material, which is lighter than water, in a container downstream of the kitchen sink before this wastewater is mixed with other wastewater streams. The outlet in the sink and/or the inlet to the grease trap should be equipped with a removable screen which retains pieces of food and sand.

The floating scum layer has to be removed periodically before it gets so thick that it would mix with the grease trap effluent. The frequency for the removal depends on the use of fat in the kitchen.

For household units, commercial plastic traps with removable buckets can be bought (see Figure 14) which simplify the cleaning. Larger grease traps (as a guideline: for more than 20 p.e.) must be cleaned with a pump.

Further recommendations regarding grease traps include:

• Common pre-treatment methods for municipal wastewater (for instance septic tanks) also eliminate a fraction of FOGs, but at least for restaurants and large kitchens it is important to have a grease trap because concentrated fats cause problems in the pre-treatment as well as blockages in the sewer. The grease traps are installed downstream of the kitchen sink.

• If the grease trap is the only pre-treatment step for greywater before it enters a constructed wetland, it may be necessary to combine it with a sedimentation tank or to have an outlet in the bottom of the trap. This enables removal of sludge/sediments which can be formed by sand, soap and pieces of food which would otherwise pass onto the wetland.

• The removed scum has to be treated, for instance by composting or by transporting it by tanker to a centralised treatment plant if there is one nearby. The high energetic value of FOGs means that the removed scum could also be used for anaerobic digestion (biogas generation).

4.4 Septic tank

Some basic facts about septic tanks are listed below:

• Widely used for decentralised ("on-site") domestic wastewater treatment due to their simple construction. Many countries have standards for septic tank design.

• Common in many developing countries but also in sparsely populated regions of developed countries.

• Can be used for pre-treatment of wastewater from 5 to 200 inhabitants.
- Consist of two or three chambers (see Figure 14) which have a depth of 1.4 m or more from the point of the inlet pipe.
- Chambers are made of concrete or are installed as prefabricated plastic tanks.
- Removal ratio for organic matter, measured as BOD, is typically 30%.
- In warm climates, septic tanks are designed with 1-2 days hydraulic retention time. In cold climates up to 5 days may be required.
- The treatment process is based on sedimentation and flotation of scum, with partial anaerobic degradation of the sludge. This process leads to undesired biogas emissions (see Section 4.2).

In a three-chamber system the first chamber is designed with 50% of the total volume. It is connected to the second chamber from a level of 60-80 cm above the bottom of the tank. With this arrangement, settled solids and floated scum are mainly retained in the first chamber. The third chamber is used as reservoir for the pre-treated wastewater.

Septic tanks have to be desludged regularly when the sludge in the first chamber almost overflows. The duration between emptying events varies with the design and number of users but may be in the range of 1-5 years.

The removed faecal sludge should be properly managed and treated but is unfortunately often simply dumped anywhere in the environment. The faecal sludge from the septic tank cannot be reused without further treatment.

The process functions as follows:
- The raw wastewater passes through a filter bag which is made of plastic material into a chamber with a ventilation pipe.
- The liquid effluent from the compost filter is collected below the filter bags and normally needs to be pumped to the constructed wetland, as the hydraulic head loss in compost filters is about 1.5 m.
- The solid components of the wastewater, i.e. faeces, food and toilet paper, are retained in the straw bed which is contained in the filter bag. Once a week dry straw has to be added to obtain a suitable carbon to nitrogen (C/N) ratio and also to act as a filtering and bulking material for better aeration of the compost.
- 2-4 filter bags are used in an alternating mode in two separate chambers. The dimensions of the chambers depend on the number of users. The retained solids are composted during the resting phase of six months, during which time the second bag is being used. During this time the volume reduction can be up to 75%.

The final product, after it has been fully aerated and left without addition of new material for six months, is black, compact material which looks and smells like black soil or humus. Nevertheless, the material still needs further treatment in another composting unit as it still contains pathogens such as helminth eggs (see Section 2.8.2).

Advantages of the compost filters include:
- The effluent or filtrate from a compost filter has no objectionable odours – at least not in warm climates – according to extensive experience of the main authors.
- There is no biogas production since it is an aerobic process. This is an advantage for the reasons described in Section 4.2.

Disadvantages of compost filters include:
- They need more "hands-on" maintenance than other pre-treatment methods.
- Their use is limited to small units.
- Compost filters only work with highly concentrated wastewater (such as blackwater from low-flush toilets), because otherwise too much solids may be washed from the filter bags.
- Blockages may occur, although this is usually due to having selected the wrong filter bags where the filter pores are too small.

Overall, the process appears to work reliably in warm climates, but possibly less so in cold climates, based on experiences in Linz, Austria and Berlin, Germany.

4.5 Compost filter

A "compost filter" is a novel pre-treatment method particularly when there is a desire to avoid biogas emissions. Up to now this aerobic process has only been used for single households or up to 70 p.e. for example in ecological sanitation projects where concentrated blackwater requires pre-treatment (Gajurel et al., 2004; Hoffmann, 2008; Hoffmann et al., 2009).

The process functions as follows:
- The raw wastewater passes through a filter bag which is made of plastic material into a chamber with a ventilation pipe.
- The liquid effluent from the compost filter is collected below the filter bags and normally needs to be pumped to the constructed wetland, as the hydraulic head loss in compost filters is about 1.5 m.
- The solid components of the wastewater, i.e. faeces, food and toilet paper, are retained in the straw bed which is contained in the filter bag. Once a week dry straw has to be added to obtain a suitable carbon to nitrogen (C/N) ratio and also to act as a filtering and bulking material for better aeration of the compost.
- 2-4 filter bags are used in an alternating mode in two separate chambers. The dimensions of the chambers depend on the number of users. The retained solids are composted during the resting phase of six months, during which time the second bag is being used. During this time the volume reduction can be up to 75%.

The final product, after it has been fully aerated and left without addition of new material for six months, is black, compact material which looks and smells like black soil or humus. Nevertheless, the material still needs further treatment in another composting unit as it still contains pathogens such as helminth eggs (see Section 2.8.2).

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Overall, the process appears to work reliably in warm climates, but possibly less so in cold climates, based on experiences in Linz, Austria and Berlin, Germany.

4.6 Imhoff tank

The Imhoff tank is a two-stage anaerobic system where the sludge is digested in a separate compartment and is not mixed with incoming sewage. It can be used in moderate to cold climates. It is a compact and efficient communal system for pre-treatment of municipal wastewater from 500 up to 20,000 habitants. It removes about 30-40% of the organic matter of the raw wastewater.

In the German wastewater literature, the term "Emscherbrunnen" is used for this type of tank.
The Imhoff tank is designed with three compartments:
1. Upper compartment for sedimentation
2. Lower section for sludge digestion
3. Gas vent and scum section

The sludge which is settled and stored in an Imhoff tank has to be removed periodically by a pump. It is stabilised and can be dried, composted or used directly in agriculture, as long as hygienic aspects are considered and relevant safety precautions taken (see Section 2.8.2).

There is more biogas production than in septic tanks, but unfortunately the organic load in communal wastewater is usually not high enough for the economical usage or flaring of biogas.

4.7 Baffled tank

The baffled tank is an improved septic tank and is used for instance by BORDA\(^\text{14}\) for primary wastewater treatment in communities with 200 to 2 500 inhabitants as part of their “DEWATS - decentralised wastewater treatment systems” (see Gutterer et al. (2009) for details). This type of system is also called anaerobic baffled reactor.

Characteristics of the baffled tank are:
- The baffled tank has 4-6 compartments instead of the 2 or 3 compartments of septic tanks. The total retention time is much shorter than in a septic tank: in warm climates 10-12 hours are used compared to 24-48 hours for septic tanks.
- The removal ratio for organic matter measured as BOD is about 40% in cold climates and 60% in warm climates; consequently the biogas production is higher than in septic tanks and the biogas should be burnt or used. Again, this is unfortunately not commonly done in practice due to the additional costs of the flare or gas pipework and biogas burner.
- The sludge is stabilised and can be used in agriculture as long as hygienic aspects are considered and relevant safety precautions are taken (see Section 2.8.2).

Baffled tanks have a higher removal ratio for organic matter (40-60% BOD removal) compared to septic tanks (typically 30%) due to the more efficient clarification and sludge retention in the baffled tank.

Also, a constructed wetland treating wastewater which has been pre-treated in a baffled tank needs only about 60% of the area of a constructed wetland which is treating wastewater after pre-treatment in a septic tank. Therefore, the higher costs of pre-treatment for the baffled tank are partially or fully offset by the lower cost for the constructed wetland.

4.8 UASB reactor

The upflow anaerobic sludge blanket (UASB) reactor is a technology for anaerobic treatment of wastewater developed by Mr. Lettinga from the Netherlands (van Haandel and Lettinga, 1995). It is often used in warm climates for municipal wastewater treatment and for industrial effluents with high organic loads such as bakery or brewery effluent. There are also many applications in Brazil for municipal wastewater.

The influent enters at the base of the UASB reactor and flows upwards. Due to the high loading and special design, the anaerobic bacteria form sludge granules, which filter the wastewater biologically and mechanically. The outlet for the treated wastewater and biogas caption is in the upper part of the reactor.

The UASB reactor is a very compact technology which achieves up to 80% organic matter reduction (measured as BOD). UASB reactors are only suitable for larger plants (> 5 000 p.e.) as they have a relatively high technical complexity. They have a low sludge production and the integrated biogas capture allows utilisation or flaring of biogas.

Sludge can be lost from the UASB reactor with the pre-treated wastewater and enter the CW filter bed. Therefore, the proper dimensioning of the decantation section in the UASB reactor is very important. The high efficiency of the pre-treatment with UASBs allows relatively small constructed wetland areas.

5 Design principles for subsurface flow CWs

This section explains general design principles for horizontal flow beds (HFBs) and vertical flow beds (VFBs), which are two types of subsurface flow constructed wetlands (SSF CWs). The filter bed consists primarily of sand and plant roots. The gravel in the bed does not have a filtering function, but is there to cover the influent distribution pipes and the drainage pipes, and to avoid puddles on the surface.
5.1 Horizontal flow beds (HFBs)

As the initial designs of subsurface flow CWs were for HFBs, these are still the most common type of subsurface flow CW. In the beginning HFBs often had poor effluent quality mainly due to inlet areas which were too small, but nowadays well-designed HFBs are widely accepted as a robust treatment system with low maintenance requirements. HFBs are an interesting option especially in locations without energy supply and low hydraulic gradient, whereas VFBs require pumps.

In HFBs the wastewater flows slowly through the porous medium under the surface of the bed in a horizontal path until it reaches the outlet zone (see Figure 18). At the outlet the water level in the HFB is controlled with an adjustable standpipe. For continuous operation the submerged height of the bed should be less than one third of the total height of the filter bed to avoid anaerobic conditions in the bed.

The organic matter in the wastewater is removed by bacteria on the surface of soil particles and roots of the plants. Oxygen supply plays an important role for the efficiency of the treatment process. Unlike for VFBs, the HFBs have very little additional external oxygen transfer. This is one of the reasons for the larger area requirement of HFBs.

The second reason is the smaller available inlet area: the inlet area consists of the width of the bed multiplied by the bed depth, whereas in VFBs the entire surface area is used as an inlet area.

Even in warm climates, there is little scope for area reduction of HFBs. They are thus less suitable than VFBs for urban applications where space is expensive.

If wastewater reuse is an objective, HFBs are not recommended in hot climates due to their very high evaporation rates in such climates.

Basic design recommendations for HFBs treating domestic wastewater are:

- While the surface of the filter is kept level to prevent erosion, the bottom slope should be 0.5-1% from inlet to outlet to achieve good drainage (Morel and Diener, 2006).
- The depth of filter beds is normally around 60 cm with an additional 15 cm freeboard for water accumulation.
- The required specific surface area is about 3-10 m²/p.e. depending on temperature and other factors. In warm climates less area is required due to the higher biological activity. In cold climates the minimum design value should not be below 5 m²/p.e. (for example in Germany).
- The organic loading per surface area should not exceed 4-10 gBOD/(m²·d) in cold climates (Wood, 1995; Morel and Diener, 2006) or 16 gCOD/(m²·d) (DWA, 2006). No data is available for warm climates with coarse sand substrate.
- The hydraulic loading should be 60-80 mm/d for greywater (Wood, 1995; Ridderstolpe, 2004; Morel and Diener, 2006) and 40 mm/d for wastewater (DWA, 2006). However, the limiting factor is the organic load, which means that greywater with low organic load (from showers or laundry) can probably be applied to the HFB with even higher hydraulic loads.

HFBs are simpler to design and build than VFBs, nevertheless they can still fail because of design errors. The most important point for proper design is the inlet zone which acts as a filter and removes a significant portion of suspended solids.

In HFBs clogging mostly occurs as an obstruction of the inlet area by suspended solids or accumulation of a biofilm (sludge). It is caused by insufficient pre-treatment, high loading, an undersized inlet area or filter material which is too fine.

Figure 18. Schematic cross-section of a HFB (source: Morel and Diener, 2006).

Figure 19. Schematic cross-section of a HFB showing pre-treatment with a septic tank on the left (source: Fehr, 2003).

Figure 20. Inflow zone with stones in a HFB near Leiria, Portugal (photo by J. Vymazal, 2003).

15 In general, the design parameter “area requirement per person” is lower when treating greywater from an average person. But since greywater characteristics vary widely (e.g. kitchen greywater versus shower greywater), it is better to use the BOD loading as a design parameter. For greywater with low BOD concentrations, the hydraulic loading can be used for the design.
Incorrectly designed HFBs may also exhibit “surface run-off”. This occurs if the inlet area is too small or clogged, and the wastewater accumulates at the inlet area, floods the wetland and flows to the outlet without infiltration and hence without treatment.

To prevent clogging and surface run-off the following actions are recommended:

- The best method to avoid clogging and infiltration problems is to optimise the efficiency of the pre-treatment.
- The inlet zone can be filled with small rocks or coarse gravel and should have multiple vertical riser pipes to ensure that the wastewater is distributed evenly over the entire width and depth.
- Another possibility is to introduce a small dam after 2 m of the bed so that the first part of the HFB’s surface serves as an inlet zone (Figure 21).
- It is absolutely necessary to carry out a hydraulic dimensioning by Darcy’s law to ensure a sufficient hydraulic gradient in the filter bed16.

The following points provide basic guidance for the design of HFBs with filter material of coarse sand:

- An efficient use of the filter area is given by a filter length (distance of inlet to outlet) of about 5-8 m (DWA, 2006). Longer filter lengths would lead to hydraulic problems.
- An inlet length (or bed width) of more than 15 m is uncommon in Germany; other design approaches use lengths up to 25 m. Certainly an inlet length of more than 30 m is not recommended as it leads to uneven flow distribution. Rather, the inlet area should be divided into several compartments with separate inlets.
- The grain size of the filter media should be large enough to allow continuous flow of the wastewater without clogging, but it should not be too large to reduce the efficiency of treatment.

![](image)

Figure 21. Left: Side view of the liquid level in a HFB showing inlet dam to control clogging and prevent surface run-off of the wastewater. Left vertical arrow is influent and right vertical arrow is effluent. Right: Top view of correct geometry of larger HFBs where filter length (see vertical arrows) is 5-8 m, and bed width (see horizontal arrows) is maximum of 30 m (source: Platzer, 2000).

5.2 Vertical flow beds (VFBs)

5.2.1 Basic design recommendations

VFBs are more suitable than HFBs when there is a space constraint as they have higher treatment efficiency and therefore need less space.

In VFBs wastewater is intermittently pumped onto the surface and then drains vertically down through the filter layer towards a drainage system at the bottom. The treatment process is characterised by intermittent short-term loading intervals (4 to 12 doses per day) and long resting periods during which the wastewater percolates through the unsaturated substrate and the surface dries out. The intermittent batch loading enhances the oxygen transfer and leads to high aerobic degradation activities. Therefore, VFBs always need pumps or at least siphon pulse loading, whereas HFBs can be operated without pumps.

Basic design recommendations for VFBs treating domestic wastewater are:

- The top surface of the filter has to be kept level and the distribution pipes are often covered with gravel to prevent open water accumulation during the pumping periods.
- The distribution pipes should be designed in such way that they achieve an even distribution of the pre-treated wastewater on the entire constructed wetland bed (see Figure 6). This is ensured by selecting the right diameter of the distribution pipes, length of pipes, diameter of holes and spacing between holes in the distribution pipes.
- The distance between drainage pipes is based on the detailed design but may be around 5 m. The drainage pipes are covered with gravel to enable good drainage.
- A bottom slope of 0.5-1% in direction to the outlet is important for large VFBs.
- The depth of the sand filter beds should be at least 50 cm, with an additional 20 cm of gravel at the base to cover the drainage pipes, 10 cm gravel on the top of the bed and 15 cm freeboard for water accumulation. The gravel on top prevents free water accumulation on the surface, and could in fact be omitted if there is no access to the CW for members of the public.
- The required specific surface area is usually 3-4 m²/p.e. in cold regions and 1-2 m²/p.e. in warm regions17. However, this may also vary depending on the reuse option and local legislation. The authors have good experiences with designing VFBs in warm climates with about 1.2 m²/p.e. (Platzer et al., 2007).
- The organic loading per surface area should be limited to 20 gCOD/(m²·d) in cold climates (DWA, 2006; ÖNORM, 2009). This applies to greywater and wastewater. The authors have made good experiences with designing VFBs in warm climates with about 60-70 gCOD/(m²·d), corresponding to approximately 30-50 gBOD/(m²·d).
- The hydraulic loading for VFBs in cold climates should not exceed 100-120 mm/d (DWA, 2006). The authors’ experiences showed that in warm climates hydraulic rates up to 200 mm/d of pre-treated wastewater could be applied without negative influence. During rain events, a short-term hydraulic loading of up to 500 mm/d can be applied.
- The key factor in warm climates is dimensioning according to oxygen availability, see Section 5.2.2.

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16 In fluid dynamics and hydrology, Darcy’s law is a phenomenologically derived equation that describes the flow of a fluid through a porous medium (source: [www.wikipedia.org](http://www.wikipedia.org)). See design manuals for details, such as Metcalf and Eddy (2003).

17 In general, the design parameter “area requirement per person” is lower when treating greywater from an average person. But since greywater characteristics vary widely (e.g. kitchen greywater versus shower greywater), it is better to use the BOD loading as a design parameter. For greywater with low BOD concentrations, the hydraulic loading can be used for the design.
5.2.2 Soil clogging and soil aeration in VFBs

The development of VFBs has been very rapid since the publication of first results at the IAWQ conference in Cambridge, UK (Cooper and Findlater, 1990). Due to their high treatment capacity for organic matter removal and nitrification, VFBs became “state of the art” during the past 20 years (Platzer, 1999; Philipi et al., 2006, Platzer et al., 2007).

Suspended solids and organic matter removal is around 90-99%. Almost complete nitrification with 90% ammonia oxidation is commonly reported. More information on nitrogen removal is provided in Section 3.1.3.

5.2.2 Soil clogging and soil aeration in VFBs

An extremely important aspect of VFBs is the potential risk of soil clogging which results in a general failure of the system (Cooper and Green, 1994; Platzer and Mauch, 1997; Winter and Goetz, 2003). “Temporary” soil clogging occurs regularly in VFBs and is part of the process. Regular resting of the beds reverses the temporary soil clogging.

In VFBs clogging occurs as an obstruction of the surface area by suspended solids or due to a fast growing biofilm (sludge). It is caused by poor pre-treatment, high loading or too fine filter sand. The term used in the literature is “soil clogging” even if the term “bed clogging” may be better.

Clogging is a normal reaction caused by the biological activity of the microorganisms. Therefore the system has to be designed large enough so that resting periods in parts of the filter bed can occur. Another possibility to avoid clogging is to keep the load low enough so that it does not occur due to the natural degradation processes.

The experiences with soil clogging in constructed wetlands differ widely since the problem depends on many factors. Sufficient soil (or bed) aeration is the main factor for the proper functioning of VFBs, and therefore the following design aspects are very important:

- Wastewater needs to be pumped onto the VFBs intermittently (4-12 times per day).
- VFBs treating municipal wastewater should have at least 4 beds in order to be able to rest the beds on a regular basis: 6 weeks in operation and 2 weeks of rest.
- A uniform distribution of the wastewater is required.
- The filterable solids loading should be less than 5 g/(m²·d) and this requires efficient pre-treatment.
- Adequate plants with well developed rhizome/root systems play an important role in maintaining and restoring soil conductivity.
- The hydraulic and organic load to the VFBs need to be checked regularly and should not exceed the design values given in the previous section.

In VFBs oxygen supply is the key consideration for efficient degradation of organic matter, for nitrification and to avoid clogging. That is why the commonly used design parameter “area per person equivalent” is not sufficient to guarantee good treatment results.

The dimensioning of VFBs based on oxygen demand was first developed by Platzer (1999). The design depends on the oxygen demand for oxidation of organic matter and for nitrification as well as the oxygen input (loading frequency, loading volume, roots and surface area).

The intermittent batch loading is most significant for oxygen input: an adequate oxygen transfer in VFBs is only guaranteed when application and infiltration occur in a short time with sufficient time lag to the next application.

There is still a lack of knowledge about the total impact of all the factors which can influence the treatment efficiency of the constructed wetland: The climate conditions, wastewater characteristics, plant influences and microbial degradation processes. Their interactions between each other are not yet fully understood. Every well planned, operated and monitored constructed wetland can give us important information to gain a better understanding of the treatment process.

5.3 The French System for combined primary and secondary treatment of raw wastewater

Since around 1990, a special vertical flow subsurface flow CW for treating raw wastewater has been used in France called the “French System”. A very interesting aspect about this system is that it does not require a pre-treatment step, hence it avoids the associated problems of sludge production and unintentional biogas generation. The pre-treatment is instead performed within the first stage of the French System, which is also a VFB.

The following description of this two-stage VFB system is mainly based on a publication by Molle et al. (2005).

The first stage of the French System is a VFB filled with gravel and is designed for pre-treatment of raw wastewater. The raw wastewater, after screening or even without screening, is pumped onto this bed through pipes of typically 100 mm diameter. These distribution pipes have no holes along the pipe length, unlike those of conventional VFBs.
which have small holes. The pre-treated effluent then passes through the second stage for further treatment, which is a VFB filled with coarse sand.

Molle et al. (2005) recommend dividing the first stage for raw wastewater treatment into three VFBs, and the second stage for secondary treatment into two VFBs as can be seen in Figure 24.

![Figure 24. French System, from left to right: three VFBs (filters) for pre-treatment and two VFBs for secondary treatment in Albondón, Spain, with 800 inhabitants. The plant needs no electricity supply as it is built on a slope (photo by T. Burkard, 2005).](image)

The first stage is operated in alternating phases to control the growth of biomass and maintain aerobic conditions in the VFB. Each VFB receives all raw wastewater for 3-4 days, and then is rested for 6-8 days while the other filter beds are used.

The raw wastewater is treated (or "filtered") in the first stage in vertical flow: it passes first through a 30 cm fine gravel layer (2-8 mm particle size), then through a 10-20 cm transition gravel layer (5-20 mm particle size) and then reaches the drainage layer (gravel with 20-40 mm particle size or even 30-60 mm particle size) in the bottom of the filter bed (see Figure 25). The solids are retained on the surface where they are mineralised19 (see Figure 26).

![Figure 25. Pre-treatment of raw wastewater in the first stage (VFB) of the French System (source: Molle et al., 2005). Wastewater flows out of the end of the distribution pipes (without small holes along the pipe length).](image)

The two VFBs used in the second stage can be operated in parallel with the option to rest one filter or to alternate the operation. The VFBs of the second stage have a 30 cm sand layer (d10 of 0.25 mm to 0.4 mm)20. In France all the filter beds are usually planted with common reed (*Phragmites australis*).

![Figure 26. Distribution pipes for raw wastewater in first stage (VFB) in French System in Albondón, Spain (photo by T. Burkard, 2007).](image)

For dimensioning of the French System for municipal wastewater treatment, Molle et al. (2005) recommend:

- For the first stage: 1.2 m²/p.e. (equivalent to an average loading of 100 gCOD/(m²·d); 50 gTSS/(m²·d); 10 gTKN/(m²·d) and 120 L/(m²·d) divided over three identical alternately fed units.
- For the second stage: 0.8 m²/p.e. divided over two parallel or alternately fed filter beds. This results in a very low average load of 25 gCOD/(m²·d).

Molle et al. (2005) reported for the very highly loaded gravel bed (first stage) a removal efficiency of 80% COD, 86% TSS and 50% TKN, which is more efficient than any conventional pre-treatment process. In some countries these results would even be sufficient for river discharge. The retained solids form a sludge layer, which limits the infiltration and improves the water distribution on the surface.

The sludge accumulation on the filter bed of the first stage is about 1.5 cm per year. The sludge mineralises on the surface of the filter bed and has to be removed after 10-15 years, when a layer of up to 20 cm has accumulated. The reuse of the sludge for agricultural purposes is possible but, as always, depends also on the heavy metals content of the wastewater.

The second stage is needed to complete nitrification and to achieve pathogen removal and for further reduction of COD and TSS (this is called "polishing"). The French system for raw wastewater treatment typically removes 90% of COD, 96% of TSS and 85% of TKN.

This system is an interesting option for small communities as it is simple and low-cost. It avoids the disadvantages of conventional pre-treatment, namely primary sludge production and biogas emissions (see Section 4.2). The French System has been used since over 20 years, and approximately 500 constructed wetlands of this type exist in France. Some plants are now also in use in Germany, Portugal and Spain.

In general the space requirement of the French System in comparison to conventional VFBs and HFBs is as follows (as the French system already includes the pre-treatment, the}

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19 In biology, mineralisation refers to the process where an organic substance is converted to an inorganic substance.

20 The d₁₀ is the grain diameter which corresponds to the grain size where 10% of the grains are smaller than that grain size (see Appendix for further details).
area requirement for pre-treatment would still need to be added in the case of VFBs and HFBs):
- for warm climates: HFB > French system > VFB (meaning VFBs require the least space)
- for cold climates: HFB > VFB > French system (meaning the French System requires the least space)

Disadvantages of the French System include:
- Due to the necessity of intermittent loading for each of the two stages, two pumping stations are necessary. A self priming siphon for the intermittent batch loading of the filter beds can sometimes be used to avoid pumping. Siphons need sufficient difference in height between the level of influent and the surface area.
- The French System is not suitable for small household level systems due to potential hygienic problems of having open access to raw wastewater in the garden or near the house.
- Many experts hesitate to build the French System because they fear lack of acceptance due to raw wastewater application onto the filter beds. The system should therefore not be built in densely populated areas in order to avoid problems with the social acceptance.

In our view, the French System has significant potential for the future for domestic wastewater treatment plants at community level which are fenced off to avoid uncontrolled access.

5.4 Hybrid systems
Various types of subsurface flow CWs can be combined in order to achieve higher treatment efficiencies especially for nitrogen and pathogen removal. In these systems, the advantages of the HFB and VFB systems are combined to complement each other. There has been a growing interest in hybrid systems, although they are more expensive to build and more complicated to operate than non-hybrid systems.

5.5 Project examples
Table 6 contains examples of constructed wetlands for treating greywater and domestic wastewater. In hot climates, the specific area can be relatively low, as the biological activity is high. It is however risky to build wetlands that are too aggressively designed with a low specific area, as there is a higher risk of process failure.

<table>
<thead>
<tr>
<th>Specific area (m²/p.e.)</th>
<th>CW size parameters (measured values)</th>
<th>Location and type of wastewater</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>7 000 p.e.; 2 992 m³; 300 m³/d; (42 L/(cap·d))</td>
<td>Haran Al-Awamied, Syria (domestic wastewater after settling tanks)</td>
</tr>
<tr>
<td>0.9</td>
<td>3 000 people; 2 680 m³; 150 m³/d; (50 L/(cap·d))</td>
<td>Bayawan City, Philippines (domestic wastewater after septic tanks)</td>
</tr>
<tr>
<td>1.7</td>
<td>140 people; 240 m³; 10-13 m³/d; (82 L/(cap·d))</td>
<td>Hamburg Allermoehe, Germany (greywater after settling tank)</td>
</tr>
<tr>
<td>1.7</td>
<td>460 p.e.; 771 m²; flowrate not known</td>
<td>SolarCity Pichling Linz, Austria (greywater and filtrate from brownwater compost filter)</td>
</tr>
<tr>
<td>1.9</td>
<td>270 p.e.; 500 m²; 25-30 m³/d; (102 L/(cap·d))</td>
<td>Dubai, United Arab Emirates (greywater after settling)</td>
</tr>
</tbody>
</table>

Table 7 shows how the separated loads from greywater and blackwater were calculated for a school in Lima (Hoffmann, 2008; Hoffmann et al., 2009). Both wastewater streams are treated separately in two constructed wetlands and are subsequently used for irrigation purposes.

The school uses about 200 m³ potable water per month. 18 persons are constantly living in the school area and some 40 persons come from outside. The daily occupation was calculated with 70 p.e. As all sanitary installations already existed, greywater separation was only possible for the commercial school bakery, laundry and two kitchens (the school kitchen and a private one). In the school’s kitchen around 60 meals per day are prepared.

21 http://www.susana.org/lang-en/case-studies
22 Wetland type: VFB followed by HFB
23 Brownwater is a mixture of faeces and water.
25 For more information about this project in English please see SuSanA Case Study: http://www.susana.org/lang-en/case-studies?view=ccbktypeitem&type=2&id=70
The effluent from all bathrooms (with toilets, showers and sinks) and from two private kitchens is mixed together and called “blackwater”. The specific blackwater load per person had to be estimated in advance, which is a common challenge in sustainable sanitation projects. It is always recommended to use adequate safety factors in the calculations in order to avoid overload situations.

Table 7. Example of the load calculation of greywater and blackwater streams and the resulting area occupation of the two CWs for a school in Lima, Peru (design basis was 70 p.e.). Italic text in brackets provides the reduction rates.

<table>
<thead>
<tr>
<th>Units</th>
<th>Totala</th>
<th>Greywater</th>
<th>Blackwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>L/d</td>
<td>7 000 (100%)</td>
<td>2 100 (30%)</td>
<td>N/A</td>
</tr>
<tr>
<td>gBOD/d</td>
<td>3 500 (100%)</td>
<td>700 (20%)</td>
<td>630 (-10%)</td>
</tr>
<tr>
<td>m² for VFB in warm climate with 30 g BOD/(m²·d)</td>
<td>N/A</td>
<td>21</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Notes: N/A = no effect

a Wastewater flowrate was calculated by the known potable water use per month, BOD was based on Peruvian norm (see Table 8).
b Blackwater is pre-treated in a compost filter (see Section 4.5), 25% BOD reduction was estimated.

Results after two years of operation:
- The BOD removal in the VFBs for greywater (21 m²) and blackwater (70 m²) is about 95%.
- The removal of suspended solids is about 90% in the greywater VFB, and 86% in the blackwater VFB.
- The number of thermotolerant coliform bacteria is in the effluent less than 1 000 per 100 ml.
- All treated water is used for irrigation of crops, trees and green areas (Hoffmann, 2008).

6 Operation and maintenance

6.1 Operational tasks for HFBs and VFBs

Whilst constructed wetlands are “low tech” systems they still require adequate maintenance by a trained person with basic skills.

The pre-treatment unit requires maintenance as indicated in Section 4 depending on the type of technology. The efficiency of the pre-treatment units has to be checked on a regular basis. The larger the system, the higher the required frequency. The effluent from the pre-treatment system should be analysed for settleable solids by using an “Imhoff cone” in order to know the quantity of solids being transferred to the wetland. The sludge of the pre-treatment systems has to be removed regularly.

The operational tasks required for the constructed wetland filter bed includes regular checking of:
- pumps
- inlet structures for obstructions and for the water level
- outlet structures for the water level
- hydraulic loading rate and pollutant loads, i.e. influent and effluent concentrations of BOD and SS as well as influent flowrate
- wetland vegetation for disease, insects, etc. (remove weeds and predatory plants until the wetland vegetation is fully established).

If maintenance is ignored, the following consequences will occur sooner or later:
- uneven flow distribution
- local overloading and odour
- deterioration of treatment efficiency.

6.2 Tasks for the operation of HFBs

It is very important to check the filter bed for clogging. Clogging occurs for example in HFBs which were built too long, i.e. where the horizontal distance between inlet and outlet is too long. Such HFBs have a high hydraulic load in a relatively short inlet zone.

A possible refurbishment step for such HFBs is to split the HFB in the middle after half of the horizontal length, by digging a trench and placing drainage pipes there. The new trench will thus become an inlet or “feeding” trench as well. With this modification, the inlet zone doubles and the flow distance is halved.

Another possibility is to introduce a small dam after 2 m of the inlet to the bed (see Figure 21). With this measure, the first part of the HFB serves as an inlet zone.

Further tasks for the operator and thus considerations for the designer include:
- When sludge accumulates in the inlet zone of the HFB, the filter bed has to be taken out of operation so that it can dry out. In the worst case, all affected filter material in the inlet area has to be exchanged. Until the filter
material is exchanged, the CW cannot operate and treat wastewater.

- Especially in the case of HFBs it is recommended to have the possibility to occasionally dam up the filter bed completely in order to be able to control the growth of the wetland plants.
- In order to guarantee sufficient aeration of the filter bed it is recommended to have the option to lower the water level down to the bottom of the HFB.

6.3 Tasks for the operation of VFBs

VFBs need more operation and maintenance than HFBs. The following operation and maintenance activities should be performed for VFBs:

- The even distribution of pre-treated effluent on the entire surface is important for VFBs and has to be monitored. Valves at the front of the distribution pipes and removable caps at the end allow the cleaning of the pipes during the pumping phases (see Figure 29). In case a filter bed, or areas of the filter bed, is affected by clogging and has to rest, the valves can be closed.
- Wastewater feeding intervals have to be maintained by an automatic system with pumps or siphons. However, VFBs for the treatment of greywater of households can be designed without a pump or siphon, if the production of greywater has suitable and regular intervals.
- The surface has to have the possibility to dry out between each charging with wastewater.
- Immediate action has to be taken in the case of clogging (see Section 5.2.2 for details). A VFB can recover well after a resting period of two weeks where the filter bed can dry out. However, in cold climate zones with low temperature and freezing periods (temperature 0-8°C) a VFB cannot recover so quickly. That is why VFBs have to be designed much larger in cold climate zones (see Table 3).
- It is better to overload one part of the filter bed in order to give the other part a rest than to expect the entire system to recover at the same time. Once clogged, the system does not recover without resting periods. It has been shown that a VFB can almost completely regain its efficiency after longer resting periods (Platzer and Mauch, 1997). Such a resting period is needed to completely dry out the clogged layer and may be as short as three weeks in a dry, sunny climate to about six months in a cold, wet climate.

6.4 Should wetland plants be harvested or not?

Whether plants from constructed wetlands should be harvested or not is a question of debate. A general answer cannot be given, but plants need to be harvested if they affect the operation or the maintenance activities. Experiences in warm climate zones showed that in VFBs plants should be removed every two years to enable a visual check of the distribution system.

Also, there is a difference between a “hot and dry” and a “hot and humid” climate. For example, in Dubai with a hot and dry climate, the decay rate of the accumulated dead reed on the surface is very slow while in Brazil with a hot and wet climate it is very fast. Hence, a constructed wetland in Dubai will need more frequent harvesting than one in Brazil (see Figure 30 and Sievert and Schlick (2009)).

Benefits of harvesting plants from constructed wetlands include:
- Nutrients which have been taken up by the plants will be removed from the system.
- Less plant biomass can make maintenance tasks easier in the case of VFBs.
- It might be possible to use the plant material as fodder crop or straw.

Benefits of not harvesting plants from constructed wetlands include:
- Creation of an isolating layer of dead plant material – this is only important for moderate climate zones.
- Provision of a carbon source for denitrification if nitrogen removal is important.
- No alteration of the ecological functioning of wetlands.
- Less work for the maintenance staff.
6.5 Basic trouble-shooting

An indication of the performance of the filter bed can be obtained by checking the effluent of the constructed wetland for visual appearance and odour:

- Turbidity and/or greyish colour is an indicator for insufficient oxygen supply. The reaction should be:
  - In the case of VFBs, a uniform distribution should be ensured. It might be that the intervals between the influent pumping events are too short. Thus the surface cannot dry out and this may lead to clogging.
  - In case of HFBs the effluent drainage should be lowered in order to allow more oxygen supply within the filter bed.

- An unpleasant smell like foul eggs indicates anaerobic conditions within the filter bed. This is a very critical situation. The filter bed should be rested and the load to the filter bed should be lowered in order to increase the oxygen supply (see Section 5.2.2).

- Clear effluent but slightly yellowish or brownish colour due to humic acids is a normal situation in biological treatment systems, especially wetlands (see Figure 4).

- Oily matter in the effluent sometimes occurs especially in HFBs; this effect can also be caused by humic substances.

If possible, effluent samples should also be analysed professionally in a water laboratory from time to time, especially when the effluent is reused for irrigation.

7 References and further resources

Note: For all documents which are copyright-free, a URL link is provided. For journal articles use the websites www.sciencedirect.com or www.iwaponline.com to view the abstract and to see instructions for purchasing the article.

Articles from the “Water Science and Technology” journal can be viewed using www.sciencedirect.com up to volume 40, and from volume 40 onwards they are available on www.iwaponline.com.

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Infiltration Swale System Design Principles
Source: www.gvrd.bc.ca

**DESIGN PRINCIPLES**

- Literature suggests swale areas of about 10-20% of upstream impervious area. For GVRD, calculate swale area by continuous flow modelling.

- Flow to the swale should be distributed sheet flow, travelling through a grass filter area at the swale verges. Provide pre-treatment and erosion control to avoid sedimentation in the swale.

- Provide a 25mm drop at the edge of paving to the swale soil surface, to allow for positive drainage and build up of road sanding/organic materials at this edge.

- Swale planting is typically sodded lawn. Low volume swales can be finished with a combination of grasses, shrub, groundcover and tree planting.

- Swale bottom - flat cross section, 600 to 2400mm width, 1-2% longitudinal slope or dished between weirs.

- Swale side slopes - 3(horizontal) : 1(vertical) maximum, 4:1 preferred for maintenance.

- Weirs to have level top to spread flows and avoid channelization, keyed in 100mm minimum.

- Maximum ponding level - 150mm. Drawdown time for the maximum surface ponded volume - 24 hours.

- Treatment soil depth - 450mm desirable, minimum 150mm if design professional calculates adequate pollutant removal.

- Design stormwater conveyance using Manning’s formula or weir equations whichever governs with attention to channel stability during maximum flows.

- Drain rock reservoir and underdrain may be avoided where infiltration tests by a qualified professional, taken at the depth of the proposed infiltration, show an infiltration rate that exceeds the inflow rate.

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An Infiltration Swale is a shallow grassed or vegetated channel designed to capture, detain and treat stormwater and convey larger flows. It takes surface flows from adjacent paved surfaces, holds the water behind weirs, and allows it to infiltrate through a soil bed into underlying soils. The swale and weir structures provide conveyance for larger storm events to the storm drain system. Variations on designs include an underlying drain rock reservoir, with or without a perforated underdrain.

**Full Infiltration**

Where water entering the swale is filtered through a grass or groundcover layer, and then passes through sandy growing medium and a sand layer into underlying scarified subgrade. Suitable for sites with small catchments and subsoil permeability > 30mm/hr.

**Full Infiltration with Reservoir**

Designed to reduce surface ponding by providing underground storage in a drain rock reservoir. Suitable for sites with small catchments and subsoil permeability > 15mm/hr.

**Partial Infiltration with Reservoir and Subdrain**

Where a perforated drain pipe is installed at the top of the reservoir, providing an underground overflow that removes excess water before it backs up to the surface of the swale. Suitable for sites with larger catchments and low infiltration rates into subsoil permeability < 15mm/hr. Provides water quality treatment even if infiltration into subsoils is limited.
For the purposes of this research, the following concept definitions are used throughout this document.

> Aquifer. An aquifer is a wet underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, or silt) from which groundwater can be usefully extracted using a water well. The study of water flow in aquifers and the characterization of aquifers is called hydrogeology. Related terms include aquitard, which is a bed of low permeability along an aquifer.

> Bioregion: A bioregion is literally and ethimologically a ‘life-place’ a unique region definable by natural (rather than political) boundaries with a geographic, climatic, hydrological, and ecological character capable of supporting unique human and non-human living communities. Bioregions can be variously defined by the geography of watersheds, similar plant and animal ecosystems and related, identifiable land forms (e.g. particular mountain ranges, prairies, or costal zones) and by the unique human cultures that grow from natural limits and potentials of the region. Most importantly the bioregion is emerging as the most logical locus and scale for a sustainable regenerative community to take root and to take place.


> Bioswale: Bioswales are shallow, naturally or artificially formed ditches that are filled with vegetation, compost or another natural water filter. They are designed to maximize the time water spends traveling through them, which allows more contaminants to be trapped. Bioswales are different from traditional swales because a fabricated soil bed replaces the native soil with a sand/soil mix that meets permeability requirements. They also include native grasses and plants with deep root structures. These plants slow the flow of water and enhance filtration.

Source: http://www.crd.bc.ca/watersheds/lid/swales.htm

> Ecological sanitation (ecosan): Ecological sanitation (ecosan) offers a new philosophy of dealing with what is presently regarded as waste and wastewater. Ecosan is based on the systematic implementation of reuse and recycling of nutrients and water as a hygienically safe, closed-loop and holistic alternative to conventional sanitation solutions. Ecosan systems enable the recovery of nutrients from human faeces and urine for the benefit of agriculture, thus helping to preserve soil fertility, assure food security for future generations, minimize water pollution and recover bioenergy. They ensure that water is used economically and is recycled in a safe way to the greatest possible extent for purposes such as irrigation or groundwater recharge.


> Environmentally Sound Technology (EST). Environmentally Sound Technologies (ESTs) encompass technologies that have the potential for significantly improved environmental performance relative to other technologies. These technologies protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes. EST’s are not just ‘individual technologies, but total systems that include know-how..., goods, services, and equipment as well as organizational and managerial procedures”. Consequently, when considering technology transfer, UNEP-IETC’s approach incorporates both the human resource development (including gender relevant issues) and local capacity building aspect of technology choices. The need to ensure that Environmentally Sound Technologies are compatible with nationally determined socioeconomic, cultural and environmental priorities and development goals need to be recognized.


> Permeable pavement, also known as pervious or porous paving, is a type of hard surfaces that allows rainfall to percolate to an underlying reservoir base where rainfall is either infiltrated to underlying soils or removed by a subsurface drain.

> Renewable water. Maximum quantity of water that is feasible to exploit annually. Renewable water is estimated as the annual virgin runoff, plus the average annual recharge of aquifers, plus water imports from other regions or countries, minus water exports to other regions or countries.


> Stormwater. Stormwater is rainwater that has touch the ground and therefore in urban areas becomes contaminated. Stormwater that does not soak into the ground becomes surface runoff, which either flows directly into surface waterways or is channelled into storm sewers, which eventually discharge to surface waters.

> Wastewater: Domestic wastewater consists of ‘black’ water, the mixture of water and faeces flushed from WCs and pour-flush toilets, and ‘grey’ water, the sullage from kitchens and bathrooms. Grey water contains much lower pathogen levels and has a lower oxygen demand than black water and therefore represents a much smaller health and environmental threat.

> Water management: Refers to operational, on-the-ground activities to align water resources, supply, consumption and recycling.

> Water Governance: Rules and practices for decision-making about water policy and their implementation, i.e. the range of political, institutional, and administrative processes through which stakeholders articulate their interests, their concerns are considered, decisions are taken and implemented, and decision-makers are held accountable in the development and management of water resources and
delivery of water services.

> Multi-level Governance: This term is used to characterise the relationship between public actors situated at different administrative and territorial levels. This creates layers of actors who interact with each other: 1) across different levels of government (vertically); 2) among relevant actors at the same level (horizontally at central or at subnational level); or 3) in a networked manner. This relationship exists regardless of constitutional system (federal or unitary) and impacts the implementation of public policy responsibilities.

> SEDUVI stands for Secretaría de Desarrollo Urbano y Vivienda [Ministry of Urban Development and Housing]. Is the dependence responsible for generating and implementing policies and strategies to guide urban dynamics, also of holding the bases for land use planning in a fair, sustainable and inclusive way.

Different scales:

> Supranational: formal legal authority, decision-making power, soft law (guidelines, recommendations etc.) or conditional transfers from an institution or international body (World Trade Organisation, OECD, World Bank etc.) to member states.

> National or Central : central or federal government

> Regional : state, region, province, canton, or autonomous community government

> Local : Valle de Chalco Municipality or other municipalities.

NOTE: The glossary is a compilation from various sources to illustrate the various concepts used in this document. No definitions are therefore strongly legal.
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