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ASSESSMENT of STRUCTURAL STORMWATER MEASURES in TEHRAN through INDICATORS of SUSTAINABLE DEVELOPMENT

by
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Für meine Mama

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Keywords: Indicators, Stormwater Management, Structural Measures, Sustainable Development, Tehran;

ABSTRACT

This thesis suggests structural stormwater measures that should prevent negative impacts of stormwater evolved from Tehran´s drastic expansion. These measures should incorporate the concept of sustainable development in stormwater management. The study selects four structural sustainable stormwater measures appropriate for the 22nd district of Tehran. These are: extended detention basin, infiltration trench, sand filter and pervious pavement. The measures are assessed for their contribution to sustainable development in stormwater management in Tehran. In order to compare sustainable and conventional measures in respect to their contribution to sustainable development in stormwater management one conventional stormwater measure, a storm sewer, is also included. For the assessment one indicator set is developed that should describe the measures. The indicators are split into economic, environmental and social ones and thus represent the concept of sustainable development in stormwater management. By applying the scoring method final scores of the measures are gained. The final scores state to which extent each measure – relative to the other selected measures – incorporates the concept of sustainable development in stormwater management. One major finding is that a combination of extended detention basins and pervious pavement is proposed to tackle the problems due to stormwater in Tehran in a sustainable way.

ABSTRACT IN GERMAN

In dieser Arbeit werden bauliche Maßnahmen vorgeschlagen, die die negativen Auswirkungen durch Regenwasser, ausgelöst durch die drastische Expansion von Teheran, vermindern sollen. Die Maßnahmen sollen das Konzept der nachhaltigen Entwicklung involvieren. Vier bauliche nachhaltige Regenwassermaßnahmen, die den Bedingungen im 22. Bezirk von Teheran angepasst sind, werden ausgewählt. Diese sind: „erweitertes Rückhaltebecken“, „Infiltrationsgraben“, „Sandfilter“ und „durchlässiges Pflaster“. Die Bezeichnungen der Maßnahmen wurden aus dem Englischen frei übersetzt. Der Beitrag zur nachhaltigen Entwicklung im Regenwassermanagement soll von jeder dieser Maßnahmen gemessen werden. Um die nachhaltigen Maßnahmen mit konventionellen Maßnahmen zu vergleichen, wird der Regenwasserkanal als konventionelle Maßnahme miteinbezogen. Für die Bewertung der Maßnahmen werden Indikatoren entwickelt, die die Maßnahmen im Detail beschreiben. Nach dem Konzept der nachhaltigen Entwicklung sind die Indikatoren in ökonomische, ökologische und soziale unterteilt. Durch die „Scoring“ Methode erhält jede Maßnahme einen Gesamtwert, der angibt, in wieweit jede einzelne Maßnahme relativ zu den anderen Maßnahmen zum Konzept der nachhaltigen Entwicklung im Regenwassermanagement von Teheran beiträgt. Es werden zwei nachhaltige Maßnahmen, das „erweiterte Rückhaltebecken“ und das „durchlässige Pflaster“, für ein effektives und modernes Regenwassermanagement von Teheran vorgeschlagen.

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1 Introduction

1.1 Tehran: a megacity

Over two hundred years as the capital of Iran, Tehran has developed from a 7.5 square kilometer city with 15.000 inhabitants into a tightly packed city with 8 million people sprawling over 868 square kilometers. Today Tehran marks a gigantic Iranian metropolis in approximately equal distance from eastern (Afghanistan) and western (Turkey, Iraq) boarders in the Middle East. The city is located at latitude 35.40 N and longitude 51.26 E in the Central Iranian Plateau and is bordered by the Alborz mountains in the north and by the Kavir desert in the south (Municipality of Tehran, 2009). Representing all of Iran´s urban and pastoral nomadic population Tehran defines the politically and socially forefront of Iran. Zoroastrians, Jews, Armenians and Assyrian Christians fight for their right in daily chaotic traffic. Tehran is a city with contrasts, from broad, palm tree lined boulevards in the north to waste filled concrete river beds running through slum areas in the South. The modern, westerly rich areas are dwarfed to the north by the stunning Albruz mountains whereas the southern districts only glimpse a mirage of the Albruz mountains through the dense smog. Tehran is spread out over flatlands and mountain slopes, having an elevation difference of 800 meters from north to south. Parallel to the topographical variation there is a great gradient of wealth and life-style for Teheran´s inhabitants. This gives a picture of Tehran ranging from a loud, bold, fashionable, yet also ugly megacity (Amanshauser, 2006) (Burke & Elliott, 2008) (Shahshahani, 2003).

In terms of climatic conditions precipitation varies at the same time with altitude and wealth, namely from 200 mm in the south to 500 mm in the north (Faber et al., 2008). Having an average annual rainfall of 218 mm Tehran´s climate is classified as semi-arid with low rainfall and humidity. The average annual temperature is 16.9 °C [Figure 1]. Subsequently natural surface water flows are very low in summer and fresh spring water is an exclusive good. This is why Tehran water supply systems rely mainly on groundwater (Jahani & Reyhani, 2006) (Mühr, 2007) (Gibb A. & Partners, 1975) (Faber et al., 2008).

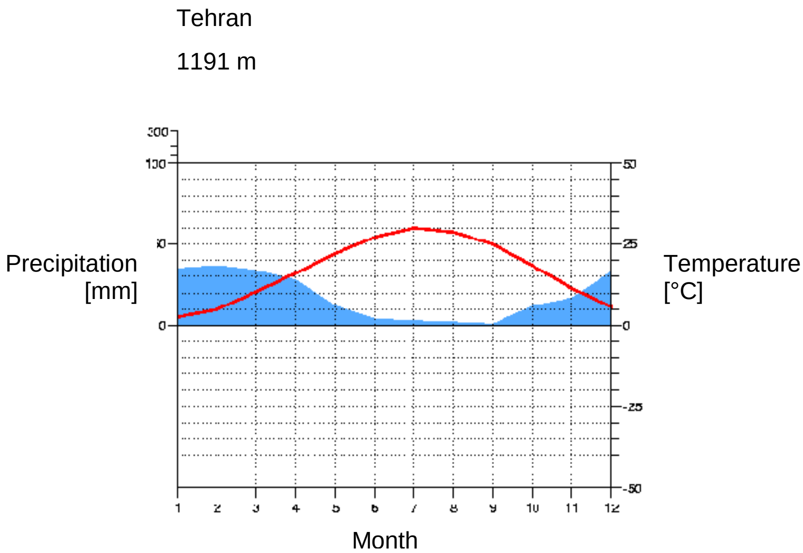

Figure 1: Tehran climate chart (Mühr, 2007)

The groundwater acquifer below Tehran area is big and has to serve more people than ever in Tehran. It was from the 1960ies on that Tehran experienced a drastic increase in population numbers. The White Revolution[1] aftermath in the 1960ies contributed to a migration to the Iranian cities. Land reforms failed so that people were searching for more prosperous jobs and new homes in the cities. The beginning of the Iran-Iraq war marked another massive migration wave to urban areas. Whereas 3 million people had lived in Tehran city in 1980, Tehran city counts about 8 millions in 2008 and this number is still rising [Figure 2]. High property prices in the center lead to urbanization of the outer regions [Figure 3]. That is why 13.4 millions are living in the urban catchment area of Tehran, today (Seiß, 2009) (ILF & Parsconsult, 2008) (Encyclopaedia Britannica, 2009).

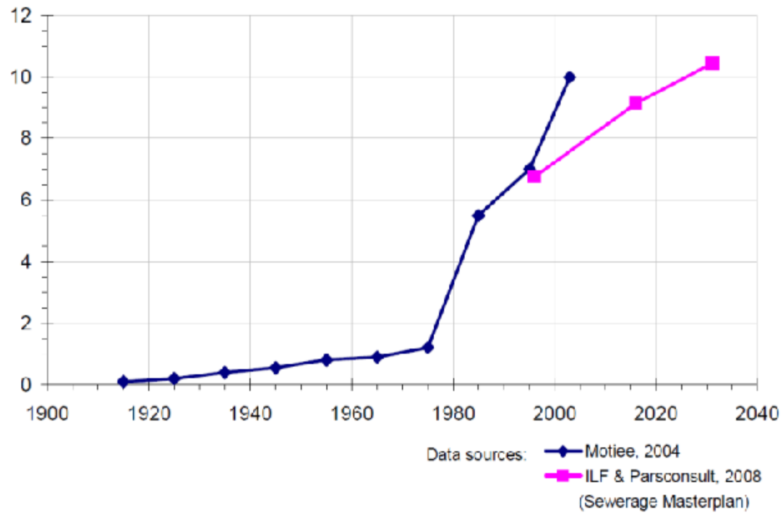

Figure 2: Tehran population in millions (ILF & Parsconsult, 2008)

Hence Tehran established itself as a megacity within the last two decades. However, infrastructure has not kept pace with this continuing enormous development and growth of Tehran. Especially the stormwater infrastructure system is not able to cope with the requirements of 8 million people anymore.

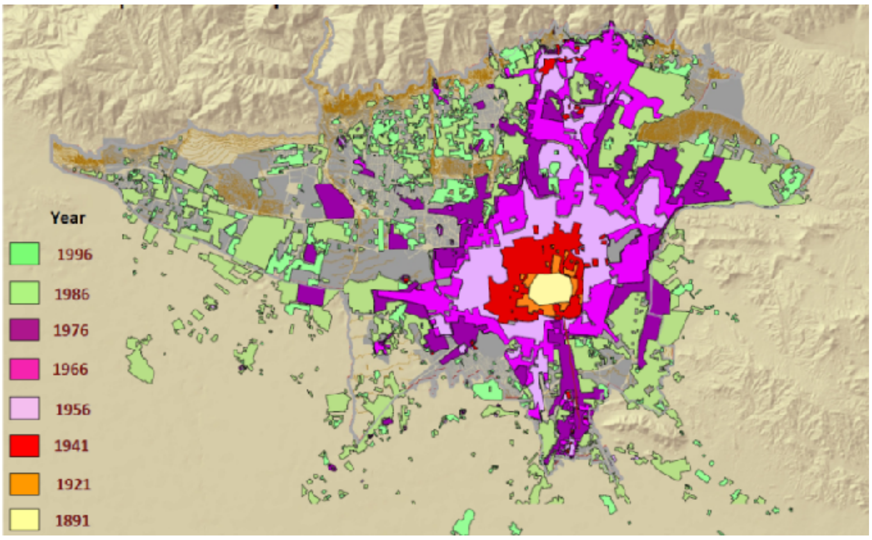

Figure 3: Rapid development of urban areas in Tehran (Pöyry, 2008)

Tehran´s population explosion raised various problems, also in respect to stormwater infrastructure systems. Actually the stormwater system did not keep pace with the speed of

[1] White Revolution was a program of reforms impeded by Shah Mohammad Reza Pahlavi from 1962, primarily to abolish the feudal system (Encyclopaedia Britannica, 2009).

urbanization at all and therefore stormwater is negatively affecting the urban life and the environment today.

1.2 Problem definition

Generally speaking the expansion of urban areas leads to the change from natural landforms and vegetative covers to unnatural and impervious areas. Regarding stormwater this has two major effects: effect on stormwater runoff quantity as well as on stormwater runoff quality. With the urbanization the sealed surfaces (streets, roofs, ect.) expand. At the same time the stormwater runoff volume is altered because stormwater cannot infiltrate into the ground any more [Figure 4]. Stormwater runoff volumes and peak runoff discharges are increased, as well as flows are discharged faster. Although Tehran has a semi-arid climate and an annual precipitation of 218 mm the existing drainage facilities face constrictions and lack of freeboard today. This is primarily because they were not designed for such altered stormwater runoff. Therefore Tehran is struggling with floods that occur mostly in the southern and central regions where flows are biggest. Gibb A. & Partners (1975) recognized a frequency of floods with a variation between 10 and 60 cm 4-5 times a year. Normally increased stormwater volumes also lead to channel erosion and channel incision. In Tehran this is not the case because most open surface waters are constructed as concreted riverbeds (AMEC Earth and Environmental et al., 2001) (Auckland Regional Council, 2003).

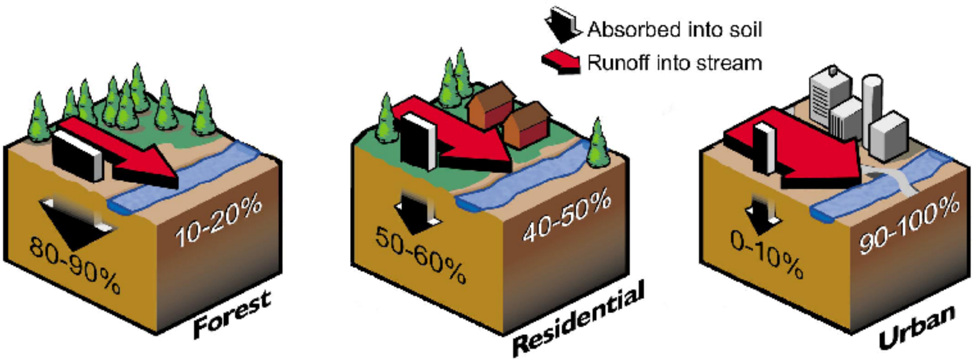

Figure 4: Changes in hydrology and runoff due to development (AMEC Earth and Environmental et al., 2001)

Apart from increasing stormwater runoff quantities the rise of population numbers, urban expansion and incline of impervious areas also affect the stormwater runoff quality. On impervious areas debris, litter and other particles accumulate that are collected by stormwater runoff in the case of a rain event and are discharged into receiving waters. Stormwater runoff acts like a “large street sweeper” by flushing everything that accumulates on roads, streets and pavements. Therefore the concentration and types of pollutants in runoff are increased, leading to contamination of receiving waters. The pollutants in stormwater originate only from non point sources. Non point sources are sources that have no exact point of origin. In comparison to non point sources point sources are direct discharges from sewage or waste water at one specific point (e.g. industries, waste water treatment plants, housing areas). Examples for constituents of non point sources are: suspended solids, nutrients, microbes, organic material, metals, toxic substances and litter [Table 1]. How much concentrations one liter of stormwater runoff actually contains is presented by Claytor et. al (1996) [Table 2].

The runoff pollution concentrations are very high especially in semi arid climates, like Tehran, because pollutants accumulate over a longer time and thus quantity gets bigger (Auckland Regional Council, 2003). Therefore the concentration of non point sources in receiving waters shortly after a rain event is relatively high compared to more humid climates. The actual situation of the quality of receiving streams in Tehran looks not very pleasant [Figure

5]. Especially the central and southern waters are polluted very much. However, in Tehran not only non point sources from stormwater but also point sources from direct discharge of waste water are the reasons for bad water quality of streams. In fact the pollution loads of point sources overweigh the pollution loads in most of Tehran. These pollution loads of point sources often contain very harmful substances and therefore water quality of streams and rivesr turns to be a hygienic issue for the city. In the case of flood events the situation turns worse as the “hazardous” water contaminates the surrounding areas. This can even lead to threatening of human lives. For example, children can be affected when playing on the playgrounds.

Table 1: Summary of urban stormwater pollutants (AMEC Earth and Environmental et al., 2001)

Pollutant groups	Constituents
Sediments	Suspended solids, dissolved solids, turbidity
Nutrients	Nitrate, nitrite, ammonia, organic nitrogen, phosphate, total phosphorus
Microbes	Total and fecal coliforms, fecal streptococci viruses, e.coli, enterocci
Organic matter	Vegetation, sewage, other oxygen demanding materials
Toxic pollutants	Heavy metals (cadmium, copper, lead, zinc), organics, hydrocarbons, pesticides/ herbicides
Thermal pollution	
Trash and debris	

Table 2: Runoff concentrations from streets and highways (Claytor & Schueler, 1996)

Parameter	Residential street	Commercial street	Urban highway
TSS (mg/l)	172	468	142
Cadmium (µg/l)	1.0	6.7	1.0
Copper (µg/l)	25	73	54
Lead (µg/l)	51	170	410
Zinc (µg/l)	173	450	329
Oil grease (mg/l)	2.0	3.7	ND

Another negative effect of the urbanization in Tehran is the fact that the impervious areas prevent the stormwater from infiltrating into the ground. Hence the groundwater aquifer is not recharged as much as before urbanization. Tehran relies for the major part on groundwater as fresh water resource. The lack of recharge and the increase in water demand lead to a decline of the groundwater table. The huge aquifer below the city of Tehran has begun to shrink. Besides the increased stormwater runoff and the incline of pollution concentration of stormwater this is the third important effect on the hydrological cycle due to the explosive development of Tehran. The problems that these changes raised, are floods, water and urban pollution and a diminishing groundwater aquifer.

These problems regarding stormwater issues have to be addressed. Adverse impacts of stormwater must be minimized and the current problems shall be answered. The state of urbanization cannot be revised but the infrastructure can be adapted to the new conditions. Actually the stormwater management master plan for Tehran is currently being updated by the municipality of Tehran. Within this master plan the latest developments should be regarded. This thesis is conducted in cooperation with the new master plan for Tehran.

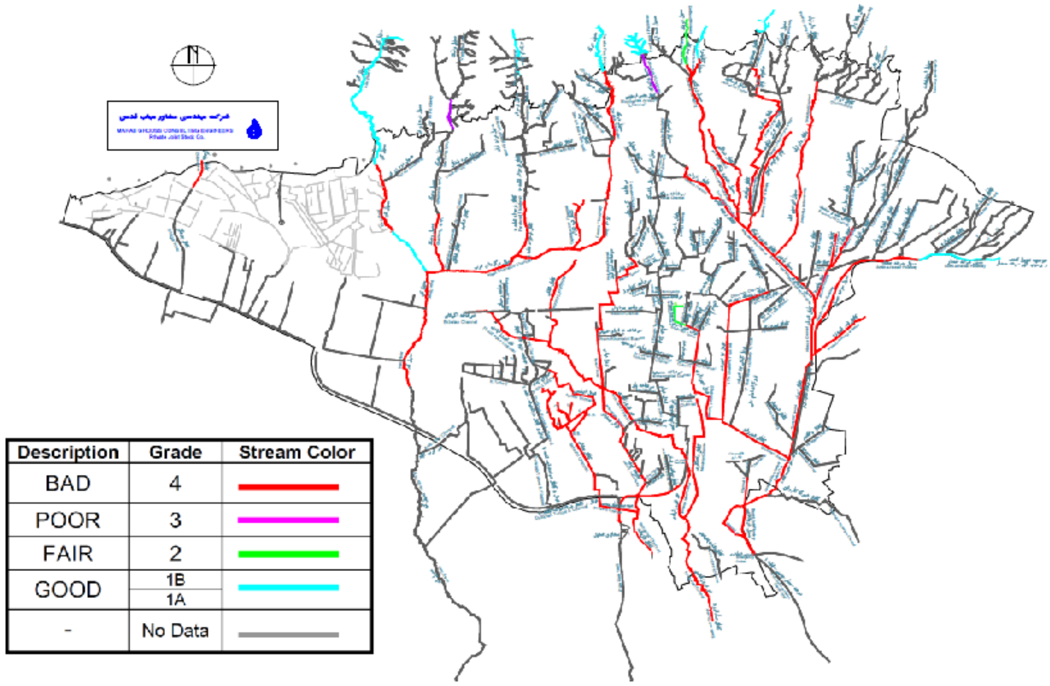

Figure 5: Streams water quality classification in Tehran – worst case (Municipality of Tehran, 2009)

2 Objectives and content of the thesis

2.1 Objectives

The aim of this study is to tackle the current stormwater problems due to rapid urbanization of Tehran. In other words stormwater needs an effective management in the city of Tehran that includes appropriate measures to diminish the current problems. New ideas, hence measures shall be elaborated for the new stormwater management master plan that is currently elaborated for Tehran. This master plan should include the concept of sustainable development which cannot be disregarded in any subject any longer, looking at the global situation. Therefore this concept is also imposed in this study. The study should suggest effective stormwater measures that involve the concept of sustainable development and decrease current negative stormwater impacts.

Thereafter the first objective of this thesis is:

1. Selection of stormwater measures relevant to the concept of sustainable development in stormwater management for Tehran

The concept of sustainable development is very site specific and therefore the selected measures should be assessed for their actual contribution to sustainable development in Tehran´s stormwater management. Therefore indicators of sustainable development in respect to stormwater must be elaborated. The assessment should involve a comparison among the measures and reveal how well each measure incorporates the concept of sustainable development relative to the others. This is done by quantifying the indicators that describe the measures.

Thereafter the second and third objectives of this thesis are:

2. Elaboration of indicators of sustainable development for stormwater measures
3. Assessment of selected measures through these indicators to state their contribution to sustainable development

The final result forms a ranking of the selected measures by their contribution to sustainable development of stormwater management. For this study it is also important to reveal the difference of sustainable and conventional stormwater measures in their contribution to sustainable development. This is why the conventional storm sewer is included in the assessment and in the general description of the measures. However the storm sewer is not a preferred and suggested measure.

Tehran is a tremendous city with large differences in any kind of subject within the city boarders. Therefore the study area is limited to the 22nd district of Tehran that is located in the west of Tehran. The reasons why exactly this area was chosen, is explained in the chapter 6.1.2.

Apart from the size of the study area, another constraint must be determined. The field of stormwater measures is spread very largely. Therefore only structural measures, measures with physical construction, should be looked at. This means that the first objective has changed to

1. Selection of structural stormwater measures relevant to the concept of sustainable development in stormwater management for the 22nd district of Tehran.

The structural measures shall improve water quality and water quantity aspects in Tehran area. Water quality of stormwater runoff should be increased and thus receiving waters should have lower pollution concentration. Furthermore measures should control water quantity of stormwater runoff and be able to retain small to medium storms (5 year return period). Besides these two main objectives structural measures should have a groundwater infiltration component, in order to recharge the Tehran aquifer.

Summing up the key target of the master thesis is the selection of sustainable structural stormwater measures for Tehran and the assessment of their contribution to sustainable development in stormwater management through appropriate indicators in the 22nd district of Tehran for the future.

2.2 Overview

After problem definition and objectives the thesis starts with a general part in which the terms stormwater, stormwater management, sustainable development, sustainable stormwater management and measures, and indicator are described. The most modern practices concerning structural stormwater measures will be presented in chapter 4. A description of a conventional stormwater system follows. Then the current situation of Tehran in terms of environmental, economical and social criteria is described in chapter 6.1. This will provide the background data for the assessment through indicators related directly to the study area. How the data was acquired, the measures and indicators selected and the assessment conducted is explained in the chapter 6.2 methods. The first result of the study includes appropriate stormwater measures which are designed and calculated in detail. Indicators are selected for the assessment of their contribution to sustainable development. The final result involves a ranking of the selected measures. At the end an analysis of the results of the study is given, future steps for implementation are proposed and the concluding remarks are presented

3 Theoretical fundamentals

3.1 Stormwater and stormwater management

Stormwater is water that originates from precipitation, either from rain or snow. So to say stormwater is runoff from rain. It can either infiltrate into the ground or create surface flow. Stormwater can cause extreme pollutant wash off and at the same time floods when the sewers or natural waterways are overspilled. Management of stormwater deems to be a necessary tool. Stormwater management primarily comprises different practices and strategies which mitigate adverse impacts (Akan & Houghtalen, 2003). Thus stormwater management can be referred to as the conceptualization, planning, design, construction and maintenance of stormwater control facilities in urban drainage basins. In other words stormwater management is the planned set of public policies and activities undertaken to regulate runoff under various specified conditions (Urban Water Resources Council of the American Society of Civil Engineers & the Water Environment Federation, 1992).

Since ancient times stormwater runoff has been an issue in infrastructure systems. First stormwater engineered systems were found in Greece or even in the Mesopotamian Empire. Stormwater runoff systems underwent various changes until sewer network system were established in the 19th century. Their concept was to collect waste and stormwater in urban areas and dispose it outside as fast and as fully as possible (Chocat et al., 2001). The sewer network evacuated both waste water and stormwater into the receiving water body. But then a combined sewer network was established in order to mitigate impacts of waste water and to separate both flows. Although the combined sewer network represents the best solution globally both systems still remain.

The problem with stormwater is that flow quantity varies extremely and first flush runoff contains high loads of sediments and other pollutants. First flush describes the washing effect on accumulated pollutants. This is why the adoption of new practices became necessary: detention basins were among the first measures to regulate stormwater runoff at source before it flows further downstream. Detention basins are basins that store stormwater for a certain time and release the stormwater thereafter constantly. Examples for those alternative techniques are “porous pavement” - pavement that infiltrates water through into the soil-, “detention ponds” (similar to detention basins) and “swales” - vegetated ditches with the purpose of collecting, storing and infiltrating stormwater- (Alfakih & Miramound, 2003). Source control is one of three principles listed by the Australian Environment Protection Agency et al. (1999) for effective stormwater management. Near the source quantity and quality of stormwater should remain unchanged. The others are:

- Preservation: Natural elements such as wetlands and stream-side vegetation should be preserved.
- Structural control: Structural measures such as detention basins should be constructed in order to improve water quality and control streamflow.

Evidently major changes in the design of stormwater systems have been taking place since the beginning of engineered stormwater systems; Chocat et. al (2001) point out the following reasons for this development:

a. *Introduction of the sustainable development concept,*
b. *Acceptance of the ecosystem approach to water resources management,*
c. *Improved understanding of drainage impacts on receiving waters, and*
d. *Acceptance of the need to consider the components of urban drainage and wastewater systems (drainage, sewage treatment plants, and receiving waters) in an integrated manner.*

At this point the concept of sustainable development comes into the play with stormwater management. It can be seen that including this concept is not only objective of this study but also a new principle of stormwater management. Therefore the next chapter deals with the definition of this new paradigm.

3.2 Sustainable development

Looking at literature reviews sustainable development is a concept applied in all kinds of context. For instance Murcott (1997) has compiled a list of 57 definitions of sustainable development based on the investigations of Pearce (1989) ranging from 1979 until 1997. More recent definitions of the concept of sustainable development are included by Elliott (2006), whereas Baker (2006) and Rogers et al. (2008) even trace back the term “Sustainable Development” to the 18th century. As the aim of this study is not the history and meaning of this concept the author will only give the most common existing definition and prevailing interpretation of sustainable development.

In 1987 the term “Sustainable Development” was explicitly defined for the first time by the World Commission on Environmental Development in their report “Our Common Future”. Hence, sustainable development was defined as

> *“development that can meet the needs of the present generation without compromising the ability of future generations to meet their own needs”* (WCED, 1987).

The report “Our Common Future”, also known as Brundtland Report, laid the foundation for every further definition and interpretation of the paradigm “Sustainable Development”. At that time Gro Harlem Brundtland was chairman of the WCED and Norwegian Prime Minister (Baker, 2006). Sustainable development means to fulfill environmental, economical and social objectives at the same time and same amount [Figure 6] (Rogers et al., 2008) (Elliott, 2006).

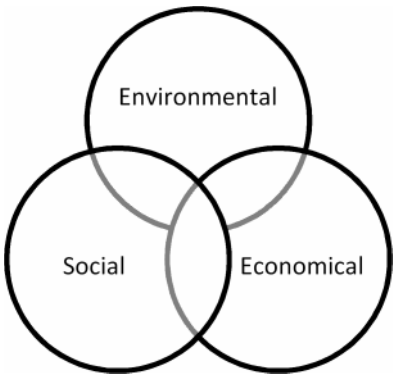

Figure 6: The objectives of sustainable development – Intersection of 3 circles

The concept was specified further through the United Nations:

> *“Sustainable Development requires taking longer-term perspectives, integrating local and regional effects of global change into the development process, and using the best scientific and traditional knowledge available.”* (UN, 1992)

Furthermore the UN proclaimed at their conference on Environment & Development in Rio de Janeiro that

> *“the protection of the environment and social and economic development are fundamental to sustainable development, based on the Rio Principles.”* (UN, 2002)

At the same conference the UN developed a global programme “Agenda 21” together with the Rio Declaration on Environment and Development that set new fundamental principles for sustainable development (UN, 2002). Also at the World Summit on Sustainable Development in Johannesburg the UN targeted further internationally agreed development goals, including those comprised in the United Nations Millennium Declaration. The Millennium Declaration includes the Millennium Development Goals that should be targeted in 2015. Goal Number 7 is most linked to the sustainable development concept because its aim is to ensure environmental sustainability (UN, 2009).

Summing up, the idea of sustainable development reaches far back but it was only since the 1980ies that the concept was specified through the WCED and the UN. In non technical language the idea behind the concept was expressed as non-declining human wellbeing over time by Atkinson et al. (1997). For this thesis sustainable development means to meet the objectives of the project by maximizing the social, environmental and economic pillar and to keep the balance among all three. On the basis of these three dimensions, also referred to as triple bottom line, the success of a particular development project is evaluated. In this study the appropriate stormwater measures for Tehran should be assessed on the basis of these three dimensions by indicators of sustainable development. It should be measured how much the measures contribute to sustainable development in stormwater management.

3.3 Sustainable stormwater management

Globally and in the case of stormwater management as well the paradigm “sustainable development” has become an important concept. It can be said that a “sustainable developed stormwater management” has recently evolved. From here on the term “sustainable developed stormwater management” will be replaced by “sustainable stormwater management” for the sake of the readability. The definition of sustainable development in general has been quoted but the link between sustainable development and sustainable stormwater management is missing. Therefore the most important perceptions and objectives for stormwater management are withdrawn from the WCED and UN reports on sustainable development:

- Water resources should be protected for present and future generations. In other words pollution on receiving waters, such as streams and groundwater, must be prevented (WCED, 1987).
- Modern water resource approaches should use the best scientific and traditional knowledge available (UN, 1992).
- Sustainable water resources systems should be designed to protect the environmental and social and economic development on the long-term perspective (UN, 1992).

3.3.1 Objectives of sustainable stormwater management

These ideas are clearly reflected in the common objectives of sustainable developed stormwater management. The objectives give an idea of sustainable stormwater management as no clear definition exists yet. The objectives are:

1) Use an integrated approach for planning and implementation (Pöyry, 2008) (Land of Sky Regional Council, 2008)
2) Minimize the generation of runoff and the risk of flooding in urban areas (Pöyry, 2008) (Crabtree, 2001)
3) Reduce pollution in receiving water bodies (Pöyry, 2008) (Crabtree, 2001)
4) Protection of groundwater recharge (Crabtree, 2001)
5) Minimize the impacts on humans and environment (Crabtree, 2001)

6) Improve urban amenities by optimum site planning (Pöyry, 2008) (Crabtree, 2001)
7) Collection and retention of stormwater for re-use (Pöyry, 2008)
8) Reduction in the use of resources in construction, operation and maintenance of stormwater infrastructures (Pöyry, 2008) (Crabtree, 2001)

These objectives can be divided into the three dimensions of sustainable development [Table 3]. It is clear that the most objectives match more than one pillar of the concept. However, the objectives, the criteria and indicators must be assigned to a certain pillar in the final result of this study.

Table 3: Objectives for sustainable stormwater management (Patawalonga Catchment Water Management Board et al., 2002)

Objective	**Social**	**Environ-mental**	**Economic**
Use an integrated approach for planning and implementation	✓	✓	✓
Minimize the generation of runoff and the risk of flooding in urban areas	✓		✓
Reduce pollution in receiving water bodies	✓	✓	✓
Protection of groundwater recharge	✓		✓
Minimize the impacts on humans and environment	✓	✓	✓
Improve urban amenities by optimum site planning	✓		✓
Collection and retention of stormwater for re-use	✓		✓
Reduction in the use of resources in construction, operation and maintenance of stormwater infrastructures		✓	✓

Looking at those objectives makes evident that stormwater is no longer only conveyed downstream but measures are set rather at source to protect humans and the environment. The basis for this current trend forms the "entanglement" of quantity and quality of runoff and amenity value of surface waters whereas quantity is the only characteristic feature of the traditional urban storm drainage [Figure 7] (Stahre, 2004).

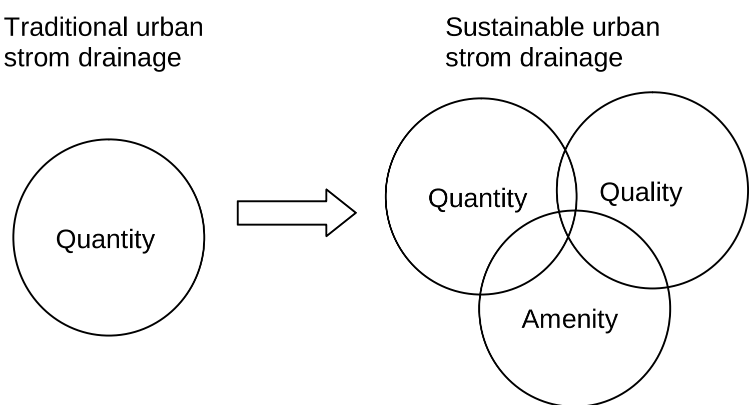

Figure 7: Towards a more sustainable urban storm drainage (Stahre, 2004)

Shaver et al. (2007) assign this entanglement to the ´Sustainable Urban Drainage Systems´ (SUDS) that is one out of several terminologies for sustainable stormwater management worldwide. SUDS derive from the UK and have spread all over Europe. The synonym for SUDS in Europe could be Low Impact Development (LID) for the USA: a very similar system that takes into account stormwater management as stormwater control throughout the landscape. Significantly for modern development of stormwater management are Best Management Practices (BMPs)[2] which promote the long term success of sustainable systems. A stormwater BMP comprehends a combination of various technologies that are thought to be the most effective and feasible. BMPs are accounted in any of the approaches worldwide. Originally BMPs have been first developed with the focus on stormwater quality by reducing the amount of pollution generated by non point sources. Nowadays they have a much broader application, including water quantity and amenity value of surface water (Urban Stormwater Initiative, 2002) (Peluso & Marshall, 2002).

Generally speaking sustainable stormwater management is mostly referred to the systems of SUDS, LID and BMPs, but other approaches include:

- Water sensitive urban design (WSUD)- based on holistic water resource approach to cycle management and regional natural resource management, designed in Australia (Urban Stormwater Initiative, 2002) (Shaver et al., 2007),
- Low Impact Urban Design and Development (LIUDD), used in New Zealand – especially Erosion and sediment control, permanent stormwater management (Shaver et al., 2007),
- Experimental Sewer System in Japan (Argue, 2004),
- Conservation design, approach to incorporate only natural site features (Shaver et al., 2007),
- Integrated Catchment Planning (Stahre, 2004) and
- Ecological stormwater management (Stahre, 2004)

Basically all approaches have a similar background in achieving sustainable urban stormwater management, consistent with the objectives mentioned above. All systems aim towards minimzing the hydrological impacts of urban development on receiving waters and surrounding environment (Shaver et al., 2007). In addition they offer very similar practices and measures for sustainable stormwater management which are explained in the next chapter.

3.3.2 Sustainable stormwater measures

Sustainable stormwater measures encompass structural and non structural measures. This study focuses only on structural measures, but also non structural measures are presented here. Non structural measures involve policies, laws, public awareness strategies, educational aspects and much more [Table 4] whereas structural measures involve any physical construction or engineering technique [Table 5].

All these measures are practices that are applied on site. On site means that the stormwater is treated before reaching the receiving waters. For example a detention basin collects stormwater from a large catchment area, stores it and releases it after some time to flow downstream. In this way stormwater is treated at the beginning but not at the end of the pipe (Stahre, 2004).

[2] In literature the term BMPs is often mentioned as a synonym for SUDS, however in this study BMPs only comprehend reasonable methods taking into account best available technology and economic factors for managing stormwater, not an complete approach (Scholes et al., 2003) (Water Council of Georgia, 2008).

Table 4: Non- structural practices for sustainable stormwater management (Taylor & Wong, 2002)

Category	Non-structural practice
Town planning controls	Better site design Reduction of impervious areas
Strategic planning and institutional controls	Land use restrictions Routine management practices
Pollution prevention procedures	Litter control Recycling programs
Education and participation programs	Public education Awareness campaigns Training programs
Regulatory controls	Street cleaning Catch pit/ gully cleaning Storm channel and ditch/creek maintenance

Table 5: Structural practices for sustainable stormwater management (Center for Watershed Protection, 2002) & (Middlesex University, 2003) & (Auckland Regional Council, 2003)

Practise Group	Detailed description	Practise examples
Storages	Permanent pools (or shallow marsh areas or extended detention storage) that treat water	Detention basin Retention pond Constructed wetland
Infiltration	Capture (and temporal storage) of water before infiltration into soil	Infiltration basin Infiltration trench Soakaways Sand filter
Biofiltration	Capture (and temporal storage) of water before passing it through a vegetation filter	Swales Filter strip Filter drain
Alternative surfaces	Hard Surfaces that can infiltrate rainwater through	Porous pavements Porous asphalt
Evaporation	Capture rainwater before evapotranspiration through plants	Green roofs
Harvesting and re-use	Temporal storage of water by technical means	Rainwater tanks (Rainwater harvesting) Cisterns and rain barrels
Pollutant traps	Traps for interception of coarse particulate matter and trash and debris by various means	Gross pollutant traps
Combined Systems	Combination of two or more of measures	Raingarden

Overall effective sustainable stormwater measures should reduce adverse impacts of stormwater runoff by utilizing natural procedures such as infiltration and utilizing technological features such as storage, and by introducing regulatory controls to prevent litter and enhance vegetated areas.

3.4 Assessment through indicators

> *"Given that as yet it is not possible to define what may or may not be a sustainable system, moves toward greater sustainability in water services can only be achieved using criteria and indicators,(…)"* (Matos et al., 2003)

Also this study aims for determining if and to which extent a system is sustainable. The assessment should reveal the contribution to sustainable development of each single measure.

It was the UN at their conference in Rio de Janeiro in 1992 that demanded for the development of sustainability indicators. These indicators should assess the interactions between environmental, economic and social development. Moreover, the global programme Agenda 21 calls to do so:

> *"Governments and international organizations should develop criteria and methodologies for the assessment of environmental impacts and resource requirements throughout the full life cycle of products and processes. Results of those assessments should be transformed into clear indicators in order to inform consumers and decision makers."* (UN, 1992)

Thereafter the assessment process can be interpreted as a two step development: Definition of criteria and definition of indicators. Criteria should include general description of the impacts and resource requirements whereas the indicators specify the assessment through the criteria. Concerning criteria and indicators there is often confusion in literature about the differentiation. It is very important to note that indicators are not synonym for criteria, but describe relevant properties of the given criteria. On the other hand criteria describe the characteristics of the main subject. In other words, in the decision making process the definition of criteria is the first step before choosing the right indicators.

Generally speaking sustainable development indicators provide statistical measures to indicate the grade of sustainability of all three dimensions. An environmental indicator, for example, is a parameter that describes the state of the environment (OECD, 2009). The European Environmental Agency defines an indicator as a measure that illustrates complex phenomena (European Environmental Agency, 2005). Apart from that an indicator can be either a quantitative variable, a qualitative (nominal) variable or a rank (ordinal) variable according to Moldan et al. (1997). Simple examples of everyday life indicators comprise the Dow Jones Index or the temperature next day (Hák et al., 2007) (Hák, Moldan, & Dahl, 2007).

For this study it is very important to choose the right indicators. Therefore a good indicator should fulfill the following five characteristics (Moffatt et al., 2001). An indicator should be:

- Readily available
- Easy to understand
- About something that can be measured and is believed important
- Internationally comparable
- Based on information comparable of different geographical areas

All in all it can be said that an indicator must be at least policy relevant, analytically sound and measurable, thus quantifiable (Atkinson et al., 1997).

In this study the indicators must not only fulfill a certain profile but also represent the three pillars of sustainable development. Hence the indicators are assigned to the environmental, economic and social dimension. These dimensions are represented through different criteria that illustrate the objectives of sustainable stormwater management. Thereafter a three step assessment process takes place [Figure 8]. First the objectives for stormwater management have to be elaborated. Then the objectives must be defined more closely through criteria.

Finally these criteria must be measured through indicators which are quantified by threshold values and units. To get a clearer picture, an example is presented for the assessment of stormwater measures [Figure 9].

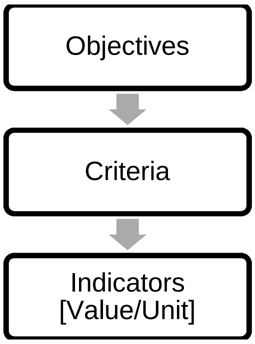

Figure 8: Assessment process of sustainable development

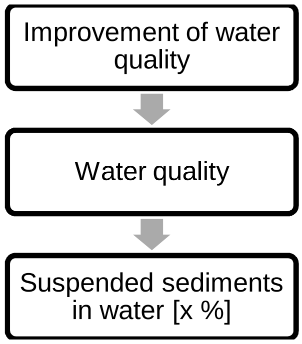

Figure 9: Example for assessment of stormwater measures

This assessment process is also relying on the hierarchic system of the ISO 24511 “Service activities relating to drinking water and wastewater” (ISO, 2006) [Figure 10]. The ISO 24511 defines clearly the order of the different steps of assessing and improving services related to drinking water and wastewater.

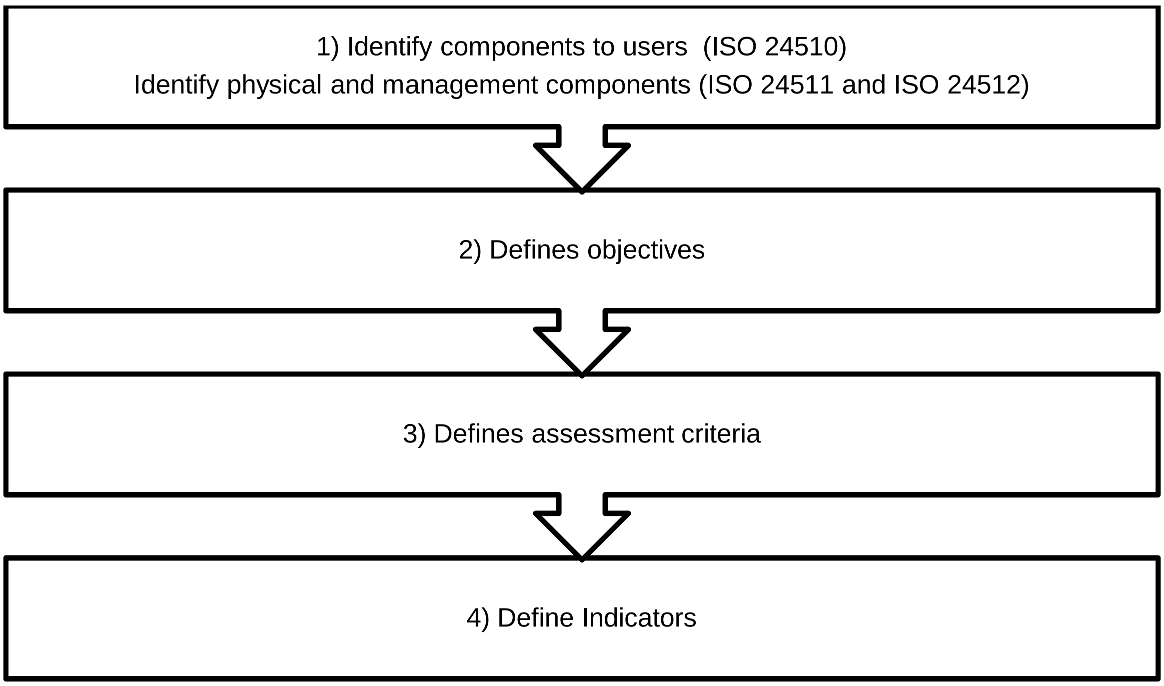

Figure 10: Step-by-step process from objectives to the indicators (ISO, 2006)

The structure of this process provides the basis for this study. In this study the objectives of the sustainable stormwater management are already defined. The objectives for the sustainable stormwater management in general are decisive for the elaboration of the criteria and indicators. Criteria should specify these objectives and finally indicators should be elaborated to assess the measures for their contribution of sustainable development. The assessment of the measures should provide the stormwater management with well conceived measures.

4 Sustainable structural stormwater measures

The most common sustainable structural stormwater measures found in Europe, the USA, Australia and New Zealand are now described and compared among each other in detail. Literature from Iran and Asian countries upon sustainable structural stormwater measures would have been preferred but has not been available yet.

The sustainable structural measures presented here are primarily based on the project under the EU RTD 5th Framework Programme: “Adaptive Decision Support System (ADSS) for the Integration of Stormwater Source Control into Sustainable Urban Water Management Strategies” by DayWater. Various reports have been published. The most important literature for this chapter includes:

- Report 5.1: Review of the Use of stormwater BMPs in Europe (Middlesex University, 2003)
- 1st draft of “Methodology for adapting hydrological impacts and adapting hydrological model to risk assessment” (Missa et al., 2005).

In addition the following guidelines and manuals provided complementary information for the compilation of this chapter:

- USA: AMEC Earth and Environmental et. al (2001), Peluso & Marshall (2002), Schueler et al. (2007)
- Australia: Urban Stormwater Initiative (2002), Melbourne Water (2005)
- New Zealand: Auckland Regional Council (2003)

In order to achieve methodological structure, the measures have been arranged in groups of storage, infiltration, filtration, biofiltration, pervious surfaces and other measures. The storage, infiltration, biofiltration and pervious surfaces are compiled of all 8 reports mentioned above. The filtration measures are based on information from AMEC Earth and Environmental et. al (2001) and Peluso & Marshall (2002) whereas the data for the other measures derives from single reports mentioned above. Which reports, will be stated explicitly.

At the end of each group the features determining the site restrictions, the size of the catchment area and the space that is required for the measure are presented in a clearly arranged table. It is important to note that restrictions are either described in the text or in the table. Besides that a general table at the end of the whole chapter compares all measures according to water quality, water quantity and groundwater recharge. For the water quality the removal rates of the following parameters are crucial: total suspended solids (TSS), nitrogen (N), bacteria, hydrocarbons and dissolved metals. It can be said beforehand that the removal rates depend on the hydraulic detention time. Regarding water quantity the measures are compared for the 2, 5, 10 year storm event capability. In the case of groundwater recharge it is indicated if the measure is designed and thus suitable for infiltrating water back into the soil and groundwater.

4.1 Storage measures

Storage facilities include detention basins - also known as water quality ponds in New Zealand -, retention ponds, constructed wetlands and sedimentation tanks. Lagoons are storage facilities too but are very similar to a detention basin and a retention pond. That is why lagoons are not included here. Generally speaking processes that determine these facilities are sedimentation and adsorption, precipitation and volatilization. Constructed wetlands include further microbial degradation, filtration and plant uptake due to their complex nature.

The advantage of storage systems is that they temporarily store stormwater runoff while pollutants are settling out and water is evaporating. Thereafter stormwater is released through a fixed and reduced opening and discharged to receiving waters. At the same time stormwater may infiltrate from the bottom of the measure into the soil. If infiltration into the ground is undesired a membrane can be installed. Another big advantage of these measures is that they can cope with high sediment input.

In comparison to detention basins and sedimentation tanks, retention ponds and constructed wetlands have a permanent open water body. Hence they can only be applied in humid climates or wet conditions. Detention basins store the water for a limited time after the rain event whereas sedimentation tanks can either have a permanent or a temporary water level. Sedimentation tanks are the only artificial measures among the storage practices. All other measures form natural conditions. Thereafter they have amenities for public and environment but can provoke odor, stagnant water or trophic state due to temporary or permanent water level and accumulation of sludge at the bottom.

Summing up storage systems protect the stream against erosion from peak flows, decrease the water pollution in the outflow and less volume is conveyed downstream.

4.1.1 Detention and extended detention basin

Detention basins are dry depressions that collect and temporarily store stormwater in the case of rainfall event. The stored water must be released totally after 72 hours. Because of the change from wet to dry conditions the suspended solids can lead to a clogging of the bottom and outlets. Also re-suspension of sediments after rainfall events is a problem. Both problems can be tackled by removal of accumulated trash and debris at least semi-annually.

Detention basins are primarily designed for reducing peak flows and have minor impact on water quality, however detention basins with a detention time of 24 hours perform much better regarding the removal of substances. These basins are called extended detention basins and meet not only attenuation objectives but also water quality criteria.

In comparison to retention ponds and wetlands detention basins require less space because there is no permanent water volume. Nevertheless detention basins are measures designed for rather large catchment areas and hence require sufficient area for construction. That is why they are not applied in densely developed urban areas.

Detention basins are also called detention ponds or retardation basins.

4.1.2 Retention pond

In comparison to detention basins retention ponds have a permanent pool of standing water. The permanent pool prevents re-suspension of sediments and clogging of the base. Furthermore retention ponds have longer stormwater detention times due to the permanent pool. That is why removal rates of the retention ponds are high. During rainfall events stormwater is stored above the permanent pool and then slowly released through a proper outlet.

Retention ponds are often designed with plants although plants make the maintenance more difficult. Plants at the banks of the pond can act as additional cleaners through aerobic decomposition and adsorption of contaminants and can increase removal rates.

Generally retention ponds require a lower frequency of maintenance than detention basins but slightly higher construction costs due to their bigger storage volume. Problems with retention ponds are not recorded.

4.1.3 Constructed wetland

Wetlands are not only naturally vegetated impounding systems but are ecological systems with flora and fauna. The integral component of wetlands, the plants, removes contaminants through various ecological processes (adsorption, plant uptake, filtration, decomposition, adhesion, etc.). Residence time can be several days to weeks and therefore removal rates are very high. Like retention ponds inflowing stormwater is stored above the permanent pool and released constantly afterwards.

Due to the vegetation in and around the pool the constructed wetland has to be maintained properly. Vegetation harvesting is necessary to guarantee performance and prevent problems like silting.

Compared to detention basins and retention ponds the construction of a wetland is the most expensive, also because constructed wetlands require the most space. Like detention basins and retention ponds they are designed for rather large catchment areas.

4.1.4 Sedimentation tank

A symmetrical and artificial structure for the storage of stormwater is called sedimentation tank. The sedimentation tank is also known as silt trap. Here stormwater is collected and released partially while pollutants are settling out. Tanks are only determined by sedimentation because the artificial closed structure makes adsorption, precipitation and volatilization impossible.

The man made construction can be applied everywhere, also underground, which is advantageous regarding space consumption. The underground system is much more common as it saves space and does not attract anything. Furthermore sedimentation tanks are good measures to prevent odor from stormwater.

In comparison to all other storage measures the requirements for maintenance are very low but the construction costs are higher due to the use of concrete as building material.

In the table below [Table 6] the site considerations for storage systems are summed up.

Table 6: Site considerations for storage systems

Option	Site restrictions	Size of catchment area	Space require (%) of catchment area
Detention basin (Extended detention basin)	Slope gradient 10% (Slope gradient 10%)	Min. 4 ha (Min. 4 ha)	2 - 3 % (2- 3%)
Retention pond	Slope gradient 15 %	Min. 5 ha	2 - 3 %
Constructed wetland	Poorly drained soils Slope gradient 8 %	Min. 10 ha	3 - 5 %
Sedimentation tank	None	Max. 8 ha	Low

4.2 Infiltration measures

Infiltration measures can be infiltration basins, infiltration trenches or soakaways. As the name implies these measures are designed to encourage the infiltration of stormwater into surrounding soils. Infiltration measures contain layers of soil or stone that have a minimum hydraulic conductivity of 10^{-5} m/s. Stormwater is drained to the infiltration measure where it is percolating to the bottom. Hence infiltration measures provide also a stormwater storage for the time of percolation.

Pollutants are removed from stormwater by filtration, microbial degradation and adsorption. Infiltration measures work best with relatively unpolluted stormwater. Therefore runoff from hotspot - a very polluted runoff - is not accepted. Out of the same reason the risk of groundwater contamination can be very high with polluted stormwater. To decrease the risk a filter fabric or a layer of sand can be installed at the bottom and the sides of the measure. Apart from that, clogging can be a problem too, especially due to seasonal changes.

The great advantage of infiltration measures is that the total stormwater volume is infiltrated into the ground and there is not produced any outflow. Hence the groundwater is recharged at full rate (like before urbanization). Infiltration into the ground is only recommended when the groundwater table is at least one meter below the bottom of the measure and the soil has a high permeability of at least $7*10^{\wedge -6}$ m/s. Regarding applicability infiltration measures work in humid as well as in arid climates.

Infiltration trenches are linear versions of infiltration basins whereas soakaways are underground infiltration trenches. All measures require the same space and have similar operation and maintenance schedules. Maintenance works are recommended regularly and every 2^{nd} month to prevent clogging. The single measures do not differ much from each other. Therefore the description of the single measures is short and comprehends only additional crucial aspects.

All in all infiltration measures are designed for reduction of sediment and pollution loads, decrease of stormwater runoff volume and groundwater recharge. They may be applied as pretreatment steps before detention basins and other more quantity oriented measures.

4.2.1 Infiltration basin

Infiltration basins are excavated pits filled with soil, stone or other material that detain surface water runoff. At the same time the stormwater is percolating through and further into the soil.

It must be noted that AMEC Earth and Environmental et al. (2001) list infiltration basin as “not recommended” structural control because of its low system reliability. The infiltration basin is not recommended for the use in Georgia because it does not meet the stormwater management objectives. Thus the infiltration basin have very high rates of failure due to clogging and require unacceptably high maintenance burden. This will be considered for the selection of the measures for Tehran.

4.2.2 Infiltration trench

Infiltration trenches are very similar to infiltration basins though they are designed in linear form and filled with stone or rubble. Infiltration trenches are very similar to soakaways too, however infiltration trenches provide higher infiltration surface area and hence higher treatment efficiencies. It is recommended that stormwater is discharged to the infiltration trench over a vegetated area acting as a pretreatment step.

The infiltration trench can also be laid out as a filter drain where stormwater is not infiltrated into the ground but intercepted by a perforated pipe. The perforated pipe is laid out in a trench backfilled with gravel. The main function of a filter drain is conveying stormwater to an outlet point. Filter drains are not discussed any further because they are similar to the infiltration trench regarding site considerations and removal rates.

4.2.3 Soakaway

Soakaways are designed as underground structures that let stormwater soak into the ground via the base and the side. Therefore their visual impact is low and they are often preferred as a less space consuming measure.

In the table below [Table 7] the site considerations for infiltration systems are summed up.

Table 7: Site considerations for infiltration systems

Option	Site restrictions	Size of catchment area	Space required of catchment size (%)
Infiltration basin	Deep permeable soils Slope gradient 0 %	1- 20 ha	2-3 %
Infiltration trench	Deep permeable soils Slope gradient max. 6%	Max. 2 ha	2-3 %
Soakaway	Deep permeable soils Slope gradient 0 %	Max 2 ha	2-3 %

4.3 Filtration measures: Sand filter

Filtration measures filter the runoff through an engineered media and collect the treated stormwater in an underdrain to pass it back to the conveyance system though exfiltration into surrounding soils is also possible. Filtration measures are primarily sand filters. Sand filters remove contaminants out of stormwater through adsorption, microbial degradation and filtration. They also store stormwater runoff in the filter media. Filter media can be sand but also topsoil or even compost. The height of the filter media depends on the general design; most often sand filters are constructed as two chamber structures and therefore the filter media volume is rather small.

The biggest advantage of filtration measures are their high removal rates due to the small particle size of the filter. On the other hand the small particle size makes the sand filter prune to clogging. Therefore maintenance is required monthly and the filter bed must be exchanged every 5 years approximately.

Concerning catchment size filtration measures are applied for treatment of small stormwater volumes and small catchment size. In addition filtration measures do not require much space and therefore can be applied in densely populated areas.

In comparison to infiltration devices the stormwater must pass a specific depth of sand media whereas in infiltration trenches the stormwater only passes through the void storage space.

Summing up filtration measures are primarily designed for improving water quality and can be applied in humid as well as in arid climates.

The most common example for a filtration measure is a sand filter. Sand filters are also referred to as filtration basins and most often consist of two chamber structures. Stormwater runoff is first treated in a sedimentation chamber for the removal of floatables and heavy sediments. Then the stormwater is passed to the filtration chamber. In the filtration chamber the stormwater is collected and at the same time passed through a bed of sand which acts as filter. Normally the treated runoff is collected in an underdrain system that is connected to the conveyance system; but it also can be exfiltrated into the surrounding soils when high soil permeability is granted. Concluding, stormwater is stored for the time of percolation not only in the filter bed, but also above the filter and in the sedimentation chamber.

Sand filters can be hotspot applications and achieve very high removal rates although they require a high frequency of maintenance (monthly). In addition they are very costly and are prune to clogging.

There are three different forms of sand filters: surface, perimeter and underground sand filter whereas the surface sand filter is the original sand filter design and this design is applied throughout this study.

In the table below [Table 8] the site considerations for filration systems are summed up.

Table 8: Site considerations for filtration systems

Option	**Site restrictions**	**Size of catchment area**	**Space required of catchment size (%)**
Sand filter	Deep permeable soils Slope gradient <6 %	Max 4 ha	2-3 %

4.4 Biofiltration measures

Biofiltration systems comprehend all those measures that pass stormwater through or over vegetation. These can be swales and filter strips. The vegetation removes stormwater pollutants through adsorption, sedimentation, volatilisation and precipitation. Plants absorb, take up and detain pollutants while stormwater is flowing across. At the same time biofiltration systems provide a small storage volume and reduce stormwater volume through uptake and soil infiltration.

Advantages of biofiltration systems are that the velocity of stormwater runoff is lowered through the vegetation. This enhances plant uptake of water and pollutants. At the same time groundwater is recharged though it can also be contaminated. Therefore biofiltration measures should receive rather low pollutant concentrations. Low pollutant concentrations are also favoured because failure due to clogging and sediment suspension can be prevented. Otherwise biofiltration systems need short maintenance intervals.

Regarding on site applicability, biofiltration measures do not require much space but wet climates are preferred due to the most important compound (vegetation).

Comparing the different measures among each other it can be said that the performance is similar but the layout and construction design is different. Overall biofiltration systems use the abilities of plants to reduce stormwater pollution and are best applied in residential areas.

4.4.1 Swale

Swales are vegetated open channels that are constructed to capture and transport stormwater. Besides the main function as stormwater conveyance measure they also meet water quality objectives. In comparison to filter strips swales have lower removal rates because the hydraulic detention time is higher with filter strips. At the same time the flow velocitiy across swales is higher. Therefore swales require less space than filter strips.

Swales can be either wet or enhanced dry swales, depending on the level of groundwater and the subsoil. As wet swales they are not as prune to clogging as dry swales. Generally clogging is a major problem if the stormwater is highly polluted.

Summing up swales are modern approaches for drainage systems that combine stormwater treatment with runoff conveyance systems. Thus they are less costly than traditional curb and gutter systems.

4.4.2 Filter strip

Filter strips are vegetated strips of land. While the stormwater is flowing across the strip pollutants are removed. Filter strips shall meet the objectives of water quality. The effect on water quantity is very low too.

However filter strips have medium removal rates and are favoured as measure in residential areas because of landscape enhancement. As already stated filter strips are designed for low pollution concentration and provide pretreatment of stormwater and groundwater recharge.

In the table below [Table 9] the site considerations for biofiltration systems are summed up.

Table 9: Site considerations for biofiltration systems

Option	Site conditions	Size of catchment area	Space required of catchment size (%)
Swale	Slope gradient max. 4% Low density areas	Max. 2 ha	10-20%
Filter strips	Slope gradient max. 4% Low density areas	Max. 1 ha	20-25 %

4.5 Pervious surface measures: Pervious pavement

Pervious surface measures are measures with permeable surfaces. Similar to infiltration and filtration measures they capture stormwater through permeable surface layers and let it percolate through. This means that pervious surface measures store temporarily stormwater runoff and release it either through infiltration into the underlying soil or collect it in a pipe. Therefore the most important processes taking place in the measure are filtration, adsorption and microbial degradation.

Pervious surface measures can cope with storm events with a probability less than 1% ($T \geq 100$) and may be applied in urban as well in rural situations. Furthermore those measures can have beneficial effects on traffic, as streets keep less water on the surfaces. Traffic security is improved through continuous infiltration so that less or no runoff is created.

Disadvantages include the high maintenance requirements and high workmanship. Pervious surfaces must be swept regularly to prevent failure. Moreover pervious surface measures have 20% higher costs compared to conventional surfaces though they require no additional space compared to all other structural stormwater measures.

If the stormwater should discharge by infiltration into the surrounding soils the soil infiltration must be greater than $7*10^{\wedge -6}$ m/s .This is also valid for all other measures that infiltrate stormwater into the ground.

The most common examples for pervious surface measures are pervious pavement and porous asphalt. Both measures are very similar but feature different kind of surfaces. Pervious pavement is a continuing surface laid out with porous blocks whereas porous asphalt is a special asphalt with a porous and thus permeable structure.

Both measures have high removal rates although they are not recommended for the removal of suspended solids because pores are very small and are immediately clogged. Clogging causes especially a high failure rate of porous asphalt because here the pores are even smaller. Therefore the measures require maintenance and inspection every second month.

Such pervious surfaces are primarily used for large car parking facilities and as side streets. They can be applied in high as well as in low residential areas. In other words pervious surface measures save treatment area by using parking area or side streets.

According to AMEC Earth and Environmental et al. (2001) pervious asphalts are not recommendable because of the very fine pores. These pores provide high risk of clogging. Therefore pervious pavement is preferred and porous asphalts are not included in the progress of this study.

In the table below [Table 10] the site considerations for pervious surface systems are summed up.

Table 10: Site considerations for pervious surface systems

Option	Site conditions	Size of catchment area	Space required of catchment size (%)
Pervious pavement	Permeable soil Slope gradient max 5 %	Max. 2 ha	Varies

4.6 Other measures

There are other sustainable structural stormwater measures that are not always referred to as sustainable structural stormwater measures globally but represent considerable side measures.

4.6.1 Green roof

Green roofs consist of a deep layer of soil that is planted with grass and other vegetation. This structure absorbs stormwater and stores it temporarily until it is transpirated and evaporated through the vegetation into the atmosphere.

As the name implies green roofs are constructed on roof tops and are most suited for high density areas. This measure is already applied worldwide. Green roofs collect and treat stormwater from rooftops. Thereafter the stormwater does not contain any pollutants from impervious surfaces but pollutants from the atmosphere which are accumulated in the soil and vegetation mainly through adsorption and microbial degradation.

Due to the very low pollutant concentration in the collected stormwater, problems like clogging are not recorded. However green roofs need regular maintenance, especially during dry periods.

In the 22nd district of Tehran the infiltration of rooftop runoff is mandatory. This can be done by green roofs or infiltration through manholes.

4.6.2 Rainwater tank (Rainwater reuse)

Storage of stormwater can be provided by rainwater tanks, cisterns and rain barrels and is commonly referred to as rainwater harvesting. It is a perfect tool to capture water for other uses than drinking water, however only stormwater with very low pollution concentration such as stormwater runoff from rooftops, is used.

Rainwater tanks are very similar to sedimentation tanks regarding constructional issues, although the stormwater of rainwater tanks is further used, and the stormwater of sedimentation tanks is only further conveyed. Moreover the primary aim of a sedimentation tank is to remove sediments whereas the primary aim of a rainwater tank is to collect water for further utilization.

Rainwater tanks are commonly used in humid as well as in arid climates though in humid climates rainwater tanks are never dimensioned to store the total stormwater rooftop runoff. Problems with rainwater tanks can be contamination or sludge accumulation through particles from the atmosphere. This is why cleaning of rainwater tanks is recommended whenever needed.

4.6.3 Gross pollutant traps

Gross pollutant traps are known as structural stormwater measures in New Zealand and Australia. They are often installed for quality management in streams and rivers and pretreatment of stormwater. These traps hold back large pieces of litter and vegetation in order to improve downstream water quality. In other words they act as screen for particulate solids in stormwater.

The trap has to be emptied or cleaned regulary in order to maintain the performance. As screens gross pollutant traps are very useful in line with other stormwater management practices.

Similar practices to gross pollutant traps are gully pots with filters (deriving from Germany) and oil and water separators (deriving from New Zealand) which are also assigned a pretreatment function.

4.6.4 Raingarden

Raingarden, often known as bioretention area in the USA, is an example for a combined system: filter strips, small ponds and vegetation may be components of a raingarden. Combined systems can be designed in any other form or of any other components and are most useful when pollutant concentration of stormwater and peak volumes are high. For infiltration, filtration or biofiltration measures a pretreatment step like a small sedimentation pond can be useful in order to avoid clogging. Two measures form already a combined system, although the measures are not designed parallel but in series.

Raingarden are very aesthetic small fields that represent recreational areas. Such landscaping islands are only applicable for small catchment areas. They do not require much maintenance but can only be applied at flat slopes.

In the table below [Table 11] the site considerations for other systems are summed up.

Table 11: Site considerations for other systems

Option	Site conditions	Size of catchment area	Space required of catchment size (%)
Green roof	Max roof slope 5 % Rooftop runoff	Varies	100 %
Rainwater tank	Rooftop runoff	Varies	1-2 %
Gross pollutant trap	None	Varies	Varies
Raingarden	High soil permeability No extreme slope	Max. 2 ha	5 %

4.7 Comparison of sustainable structural stormwater measures in terms of water quality, water quantity and groundwater recharge

From the information obtained in the reports (Middlesex University (2003), Missa et al. (2005), AMEC Earth and Environmental et. al (2001), Peluso & Marshall (2002), Schueler et al. (2007), Urban Stormwater Initiative (2002), Melbourne Water (2005), Auckland Regional Council (2003)) a comparison of the removal efficiencies, peak attenuation capability and groundwater recharge option is provided here [Table 12]. It must be noted that this configuration should help to select the appropriate structural measures for the 22nd district in Tehran. The measures listed under “Other measures” are not included in the list because their removal rates and peak attenuation capability cannot be defined clearly. Furthermore green roof and rainwater tank are designed only for rooftop runoff whereas gross pollutant traps are constructed for screening of solids. A raingarden consists of various measures that are found below.

Table 12: Comparison of sustainable structural stormwater measures

	Removal efficiency [%]					**Peak attenuation**		**Ground-water**
	TSS	**Total N**	**Bact-eria**	**Hydro-carbon s**	**Dis-solved Metals**	**1:2**	**1: 10**	**Recharge option**
Detention basin (Extended detention basin)	40 – 80 (50–90)	20 – 40 (20–40)	20 – 40 (60–75)	30 – 60 (50–75)	5 – 10 (10–25)	●	●	○
Retention pond	80 – 90	20 – 40	40 – 60	30 – 40	10 – 20	●	●	○
Constructed Wetland	70 – 95	30 – 50	75 – 95	50 – 85	15 – 40	●	●	○
Sedimentatio n tank	50 – 85	10 – 20	45 – 80	60 – 90	20 – 30	●		
Infiltration basin	60 – 90	20 – 50	70 – 80	70 – 90	20 – 35	●	●	●
Infiltration trench	60 – 90	20 – 50	70 – 80	70 – 90	20 – 35	●		●
Soakaway	60 – 90	20 – 50	70 – 80	70 – 90	20 – 35	●		●
Sand filter	80	25	40	Insuffic.	50	●		●
Swale	10 – 40	10 – 35	30 – 60	60 – 75	15 – 25	○		○
Filter strip	50	20	Insuffic.	Insuffic.	40	○		○
Pervious pavement	25	80	Insuffic.	Insuffic.	90	●		●

● Provide ○Slightly provided,

TSS – Total suspended solids, N – Nitrogen, Insuffic.- Insufficient data

5 Conventional structural stormwater measures: Storm sewer

The most common conventional stormwater measure is an ordinary storm sewer system. Storm sewer system is a pipe based system for carrying stormwater. This basically involves the conventional conveyance approach. The advantage of this conventional system is that the water is collected and discharged directly. The disadvantage is that storm sewers do not treat stormwater runoff, nor minimize the stormwater runoff volume In comparison to sustainable structural stormwater measures.

Storm sewers are designed as underground pipes, though they sometimes can be engineered as open ditches if stormwater runoff volume is very small.

Storm sewers are pipes that are placed below surface. The depth depends on the slope gradient and general urban design. The pipe diameter varies with the total runoff volume. The pipe length is in accordance with the total catchment area and basically pipes are located below all streets and roads.

The stormwater is entering the storm system over storm sewer inlets on or besides the impervious areas. Storm sewers convey the stormwater either to a treatment plant or directly to receiving waters. In this study the construction of storm sewers does not include gully pots or any mechanical filters. Storm sewers are not designed for attenuation of stormwater neither for groundwater recharge.

Storm sewers are systems with great life times and do not require much operation and maintenance. Generally speaking storm sewers are inspected every 5 years and maintained as required. Problems with storm sewers are not recorded (Butler & Davies, 2000) (Moberg, 2009).

6 Materials and methods

6.1 Study area

This study is about sustainable stormwater management in Tehran: appropriate measures and indicators shall be developed for the 22nd district in order to tackle the negative impacts of stormwater in Tehran. All relevant information about the selected zone is described in this chapter and why the 22nd district seems the right place for implementation of this latest development in stormwater management.

6.1.1 22nd District of Tehran: Khargoosh darreh

The 22nd district is one out of 22 districts of Tehran, named Khargoosh darreh. It is a very young district as it has recently been added in 1991 due to decentralization and urbanization since the 1960ies [Figure 11].

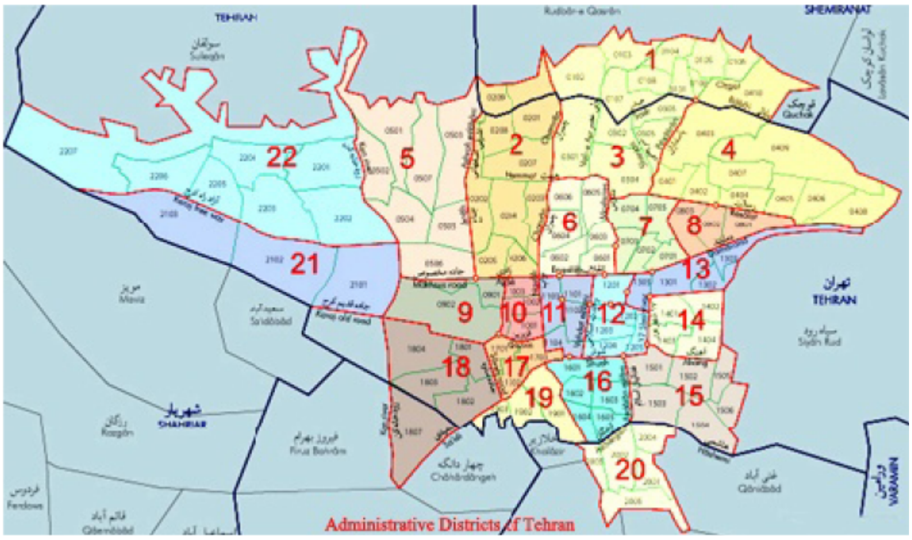

Figure 11: Administrative districts of Tehran (Municipality of Tehran, 2009)

The 22nd district is located in the outer north-western end of Tehran at the average altitude of 1200 - 1600 m above sea level. It is surrounded by the Alborz mountains in the north, by Kan river in the west, by Tehran Karaj highway in the south and by Karavan-Sara in the east [Figure 12] (Municipality of Tehran, 2009).

The 22nd district counts a population of 108 674 according to the census of 2006 which inhabit an area of 6140 ha (ILF & Parsconsult, 2008). It is noticeably that the literacy rate is more than 99%. The population is young and the life expectancy high (normal for western standards). The unique characteristics of the 22nd district comprehend low population density, calm traffic movement and a green belt area of Tehran (WHO, 2009). Moreover the 22nd district has a large green area per capita (272 m²) and several fields with a size exceeding 1 km² free of construction [c.f Figure 12 and 13].

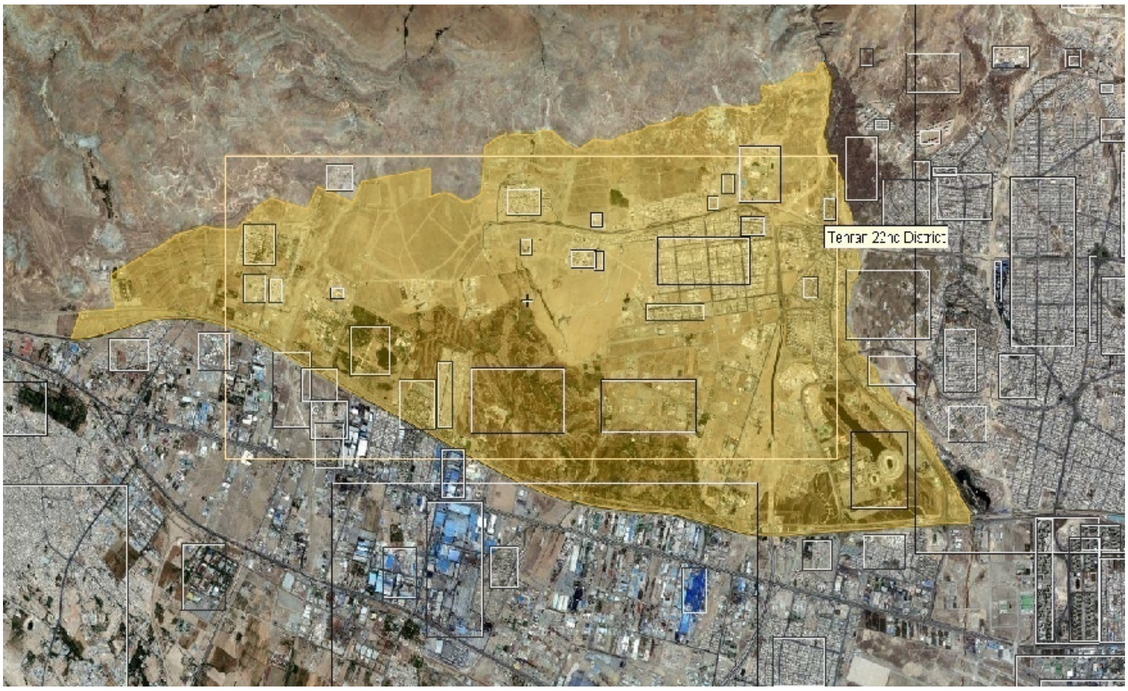

Figure 12: 22nd district of Tehran from above (Wikimapia, 2009)

Khargoosh darreh has been established in 1991 and is therefore a very young district with young development. The municipality is very strict concerning new standards of buildings and hence presents that all new constructed houses must feature rooftop infiltration and must connect to the local separated drainage system. Sink holes are dammed from new development and overall the 22nd district tries to live up to a western standards. Also in 2009 it became the first safecommunity district in Tehran by the WHO which means that it is a modernly developing district. Safecommunity is a concept of the WHO for global health and safety (WHO, 2009).

In order to gain input data and restrictions for the indicator set describing the stormwater measures environmental, social and economic issues are discussed in the following chapters.

6.1.1.1 Environmental issues

Besides the general information of the 22nd district special information is needed in order to elaborate the appropriate sustainable stormwater measures and indicators. Environmental site specifications must be known that may restrict stormwater measures.

Therefore maps of the seismic study report by JICA et al. (2000) have been analysed. According to the geology map [c.f Map "Geology and groundwater table" – Appendix A] the 22nd district is mostly grounded on conglomeratic young alluvial fan deposits which have high permeability rates. The permeability rate, thus the infiltration rate of the soil is estimated to be higher than 10^{-5} m/s. This type of geology layer is said to be the major aquifer of Tehran. The groundwater table of the aquifer is approximately located 100 m at the minimum below surface level [c.f. Map "Geology and groundwater table" – Appendix A] (JICA, et al., 2000).

The slope gradient is estimated [c.f Map "Slope gradient" – Appendix A] to an average of 5 %. Approximately two thirds of the area have a slope gradient of 2 % and the other third a 12 % gradient (JICA, et al., 2000).

For this study also the quality of stormwater is important. However, no data could be found regarding stormwater pollution concentrations in the 22nd district. Therefore the following assumption has been considered: the concentrations must be similar to the average concentrations of residential areas that have been estimated by the United States Environmental Protection Agency (2005) [Table 13].

Table 13: Pollutant concentrations for urban stormwater (United States Environmental Protection Agency, 2005)

Typical pollutants found in urban stormwater runoff	Units	Residential	General urban*
Total suspended solids	mg/l	101	80
Total phosphorus	mg/l	383	0.3
Total nitrogen	mg/l	-	2.0
Total Kjeldahl nitrogen	mg/l	1.9	-
Nitrate + Nitrite	µg/l	736	-
Total organic carbon	mg/l	-	12.7
Biological oxygen demand	mg/l	10	-
Chemical oxygen demand	mg/l	73	-
Fecal coliform bacteria	MPN/100ml	-	3 600
Coli bacteria	MPN/100ml	-	1 450
Petroleum hydrocarbons	mg/l	-	3.5
Oil and grease	mg/l	-	2 to 10
Cadmium	µg/l	-	2
Copper	µg/l	33	10
Lead	µg/l	144	18
Zinc	µg/l	135	140
Chlorides (winter only)	mg/l	-	230
Insecticides	µg/l	-	0.1 to 2.0
Herbicides	µg/l	-	1 to 5.0

*These concentrations represent mean storm concentrations measured at typical sites and may be greater during individual storms. Also note that mean or median runoff concentrations from stormwater “hotspots” are 2 to 10 times higher than those shown here.
Units: mg/l = milligrams/liter, :g/l = micrograms/l, MPN = most probable number, µg/l = micrograms/liter.

It can be seen that the pollutant concentration of urban runoff from residential areas is rather high compared with the general concentrations. Therefore the pollutant concentrations in stormwater are assumed to be high in the 22nd district of Tehran as well.

6.1.1.2 Social and economic issues

Having studied the most important environmental data a brief description of the area regarding economic and social situation would deem necessary; especially because the final result, the assessment, should include indicators describing social and economic criteria. However it was not possible to find specific information on the 22nd district of Tehran. Therefore the indicators must rely on the basis facts of Tehran in general.

For Tehran´s economic situation high inflation, high cost of living and over-crowding are major issues for Tehran. With a population density of 105.5 pph (persons per hectar) Tehran marks the 16th densely populated city of the world (City Mayor, 2007). Especially the central areas are highly populated but when it comes to the new districts in the west the population density sinks below 20 pph.

Overall people of Tehran form a young population of about 8 million inhabitants where two thirds work in the service sector and more than half are employed in the public sector. Most of the Tehran population are Persians and follow the Twelver Shia Islam which is the state religion. Family is still a strong and social unit although households enumerate 4.3 persons in average. Regarding education the Greater Tehran Area offers 50 major colleges and universities to choose from.

Remarkably for a metropolis nor vast slums, neither major shanty towns can be found throughout the city. However Tehran suffers from a north south dichotomy which means that rich people are conglomerated in the preferred conditions of the north whereas the southern regions are populated by poorer people (Municipality of Tehran, 2009). The population in the 22nd district forms a mixture from all over Tehran and Iran of young people as it has recently been established.

6.1.2 Choice of study area

Tehran is a city with a population of 8 million that spread over 22 districts over an area of 868 km². It is obvious that analyzing and tackling the problems of the whole city would go beyond an ordinary master thesis. This is why the extent of the thesis was lowered by choosing a the 22nd district as study area.

The 22nd district was chosen because it forms a semi-urban area where development is under way. This means that structural stormwater measures can be easily integrated in the establishment and construction of the urban surroundings. Obviously an area had to be selected where implementation of such measures is possible and meaningful in the long run. As mentioned previously the 22nd district is a residential area with low population density (17.7 persons per hectare) and large open space [Figure 13]. Therefore construction of space consuming structural measures is possible now.

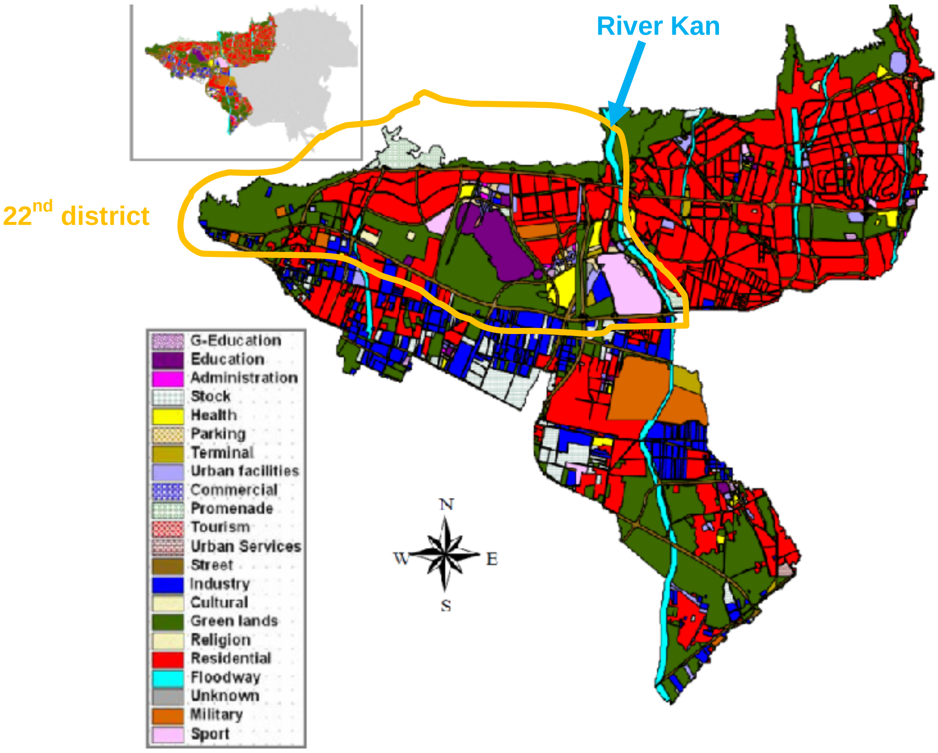

Figure 13: Land use of 22nd district (Pöyry & Mahab Ghodds, 2009)

Another important factor for the 22nd district as study area is that the strongest effect of the implementation of sustainable structural stormwater measure can be expected in western districts of Tehran, thus in the 22nd district. Stormwater quality is defined by the concentration of non point sources. If stormwater quality is very bad it will affect negatively the receiving waters. In most of Tehran the amount of point sources, discharged to receiving waters, is higher than the amount of non point sources. The only part of the city where the situation is the other way round is the western area [small picture in Figure 13]. There the ratio of non point source versus point source pollution of total suspended solids is 400%. Hence high quality of stormwater can positively affect the quality of streams and rivers (Pöyry & Mahab Ghodds, 2009). Good river quality is especially important for the river Kan that is located in the east of the 22nd district and which plays a very important role for groundwater recharge.

Overall the 22nd district was chosen to be study area for implementation of new stormwater technologies because it will have high development in future: According to ILF & Parsconsult (2008) the 22nd district has the highest population growth in the next years [Table 14]. This is another important reason that effective and sustainable stormwater management is needed.

All these facts point out that the 22nd district is a suitable area for application and implementation of sustainable structural stormwater measures.

Table 14: Population growth of the 22 districts in Tehran from 1996 to 2016 (ILF & Parsconsult, 2008)

Region Nr.	Area [ha]	Population in year 1996	Population in year 2016	Growth rate from 1996 to 2016 [%]
1	3 454	250 000	536 000	114.40
2	4 956	458 000	679 000	48.25
3	2 983	259 000	412 000	59.07
4	7 243	663 000	907 000	36.80
5	5 901	428 000	634 000	48.13
6	2 144	220 000	296 000	34.55
7	1 537	300 000	375 000	25.00
8	1 324	336 000	409 000	21.73
9	1 955	174 000	197 000	13.22
10	806	282 000	312 000	10.64
11	1 187	226 000	252 000	11.50
12	1 356	190 000	221 000	16.32
13	1 389	245 000	284 000	15.92
14	1 456	395 000	455 000	15.19
15	2 846	623 000	701 000	12.52
16	1 645	298 000	334 000	12.08
17	827	287 000	302 000	5.23
18	3 785	296 000	333 000	12.50
19	1 149	227 000	264 000	16.30
20	2 028	356 000	389 000	9.27
21	5 196	189 000	360 000	90.48
22	*6 140*	*56 000*	*483 000*	*762.50*
Population in total		6 758 000	9 135 000	35.17
Growth rate/ year				1.52

6.2 Methods

Generally speaking this study is conducted in four steps: all necessary literature is reviewed, the characteristics of the selected area are evaluated, structural stormwater measures are selected, appropriate indicators are elaborated and final step is the assessment of the measures through the indicator set. These steps are described in detail in the next chapters.

6.2.1 Review of literature

The fundamental method of this thesis is the literature review which gathers information upon the initial question of research. This means that neither practical investigations in Tehran and nor experiments on site were conducted during the study. On the one hand the thesis is based on the most important literature that is available for this topic; on the other hand it used reviews and reports about the environmental situation in Tehran. The reviews and reports are gained from a company that is currently enrolled as consultant in the adaption of the stormwater management master plan for Tehran. This thesis was developed in cooperation with the new stormwater management master plan for Tehran. Any other special information concerning Tehran or the decision maker within this stormwater management master plan was provided by the company involved in the new stormwater management master plan for Tehran. Therefore the access to real original data is guaranteed and local information is provided. The aim of this study was to get a broad and holistic view of the topic sustainable stormwater management and apply the concept for Tehran.

The search for literature included libraries, electronic databases, the world-wide-web and newspapers whereas most information was withdrawn from articles of electronic databases and library books. Electronic databases provided the most modern and state of the art knowledge whereas library books completed with standard and profound data. This also reflects the two very different aspects of the topic: the very well known paradigm of sustainable development and the very young concept of sustainable stormwater management. Both topics had to be screened. Reports that deal with both topics were preferred.

The principle search was done in a certain order: after searching for keywords new obtained data modified the keywords and the search started all over again. Search continued until repetitions of authors, arguments and concepts were noticed.

The most important keywords are sustainable development and stormwater management. Other keywords are structural measures, indicators and Tehran/ 22nd district. Modified keywords are sustainable stormwater management measures and environmental, economical and social situation in Tehran and in its 22nd district.

Searching for keywords and sub-keywords resulted in different output: while the search in electronic databases supplied relative exact and useful data, the search in library catalogues brought very general answers. Therefore a certain method for checking the significance of the obtained data is necessary. Overall the content and the summary was screened, then single chapters and headlines for usefulness; not to forget the reference list that gives clear information upon how scientific the source is.

Useful literature sources were then summarized and core ideas were excerpted. At the same time the author interpreted the main arguments and added criticism and own thoughts. After all the literature was ranked according to their real significance to the research question and classified into the four categories: (1) sustainable development (2) stormwater management and structural measures (3) indicators (4) Tehran/ 22nd district.

Overall all received information had to be proofed for their authentity and truth. A general rule was to dismiss all literature that does not follow the rules of scientific writing (e.g. citing). Thus world-wide-web pages were only used from well known authors or organizations (e.g. WHO). Regarding books and articles the form, style and language, the author (wellknown) and the number of cited literature were criteria for the quality of the source.

Finally all obtained literature had to be assessed in terms of consistency among the arguments concerning the research question. If arguments are based on single texts and are only mentioned once it will be stated explicitly in the thesis. Generally all gained information was compared throughout to avoid mistakes, misunderstandings and misinterpretations.

6.2.2 Selection and design of structural measures

The first result should comprehend the most appropriate sustainable stormwater structural measures for the 22nd district of Tehran. There are a set of strategies worldwide which are considered to be sustainable stormwater strategies. With the help of the obtained information the measures were compared among each other.

The most important factor that rules the selection of the right structural measure is the local climate in Tehran. The measure must operate in arid climates. Therefore the general design, such as wet or dry, and vegetated or not vegetated, is important. Obviously wet and vegetated measures are not recommended as they would require irrigation in dry times. However, the measures should fulfill the objectives for stormwater management in Tehran:

water quality and water quantity and supply of groundwater. Those measures are selected which fulfill these objectives and perform best regarding the removal rates.

In order to quantify the indicators and to find values the selected measures need to be described in detail. A calculation of the measures is conducted. In the calculation, the measures are dimensioned for a rainfall event occurring every 5 years (RI = 5) that was constituted by the decision maker. The decision maker for this study is represented by the consultant of the stormwater management master plan for Tehran that is currently elaborated. The exact rainfall data originates from Mahab Ghodds (2009) which presented a preliminary Intensity-Duration-Frequency (IDF) formula that derives from analyses of more than 40 stations in Tehran and its vicinity [c.f. Appendix B]. The actual value that is most important for the dimensioning of the measure is the treatment volume:

$$TV = \frac{R \cdot I \cdot Ac}{1000}$$

TV….. Treatment Volume [m^3]

R ….. Design Rainfall [mm],

$R = i \cdot t_D$, i … Intensity of rainfall event [mm/hr], t_d … Duration of rainfall event [hr]

I ….. Impermeability Index, 0,4 for low density residential areas (Indiana Geological Survey, 2004)

Ac….. Catchment area [m^2]

The measures are designed following the instructions of specific literature and dimensioned in respect to the most crucial rainfall duration. For the assessment and comparison of sustainable and conventional measures also the conventional measure ´storm sewer´ is described, designed, and calculated. All calculations are found in detail in the Appendix C.

6.2.3 Selection of appropriate indicators

The second result should contain an indicator set that is selected exclusively for the measures and the site. The elaborated indicator should be the basis for the assessment of the contribution to sustainable development of the single measures.

As explained in chapter 3.4 the assessment process contains three steps: definition of objectives, definition of criteria and definition of indicators. In the context of this report objectives of sustainable stormwater management in general have already been analysed [c.f chapter 3.3.1]. These objectives define sustainable stormwater management and these are further specified by criteria and indicators. Indicators and criteria are tools to reach a final judgement whereas criteria describe the subject in general and indicators define these criteria through quantified values. In this study criteria and indicators should be elaborated to assess the measures that fit best into the concept of sustainable stormwater management for Tehran. Basically criteria classify the stormwater measures and indicators define these criteria and quantify them through values.

The profound literature of Revitt et al. (2003) is the basis for the selection and definition of the criteria and indicators. This report is a crucial paper about indicators and criteria of sustainable stormwater management. However, the indicator and criteria set has to be adapted to this study.

At first the nomenclature was set to international standards. Revitt et al. (2003) use a different nomenclauture compared to the ISO (2006) [Table 15]. Comparing both it can be seen that Revitt et al. (2003) use “Secondary Indicator” for the “Criteria” of ISO. Further, ISO indicates “Performance Indicators” instead of “Benchmarks”, of Revitt et al. (2003).

Table 15: Comparison of indicators and criteria: Revitt et al. (2003) vs. ISO (2006)

Report source	**Revitt et al. (2003)**			
	Primary indicator	Secondary indicator	Benchmarks	Threshold values/ units
	System performance	Storage and flood control	Number of floods/ year within catchment	1….n
Report source	**ISO 24 511 (ISO,2006)**			
Objective	Criteria		Performance indicator	Value
Protection of the built/public environment	Minimize the effects of flooding		Flooding of properties from sewers	n.º/1000 properties/year

It can be seen that the ISO criteria fit the primary and secondary indicator of the report of DayWater, and the performance indicator equals the benchmarks. To be on the general side, the nomenclauture of the ISO is used in this report. It seems obvious to choose the ISO definitions because ISO represents a higher institution than Revitt et al. (2003) In addition the ISO 24 511 is the most recent publication among the stated ones. Moreover out of the author´s opinion, the ISO terms seem more logic than the terms in the DayWater report by Revitt et al. (2003). Benchmarks are supposed to be based or reference values, however Revitt et al. (2003) add another column with threshold values/ units. This thesis uses the nomenclauture of the ISO as follows: the terms primary and secondary indicator are summed up and are entitled as criteria. Benchmarks are transformed to indicators, but values remain values.

Secondly the indicator set of Revitt et al. (2003) was newly classified in three criteria. According to the concept of sustainable development there are three dimensions: social, environmental and economic. That is why the criteria describing the objectives of sustainable stormwater management are classified into social, environmental and economic criteria. Hence, the detailed classification of Revitt et al. (2003) is grouped into social, environmental and economic criteria. How this is done, is described in the next paragraph.

First of all criteria “site characteristics” and “legal and urban planning” are not identified as criteria because they describe the structural measure itself but not the objectives of sustainable stormwater management. The site characteristics “site area” and “soil/ground characteristics” describe the general conditions/ boundary conditions whereas “the legal and urban planning criteria” state external conditions. In addition the stormwater regulations and legal environmental standards in Iran are very low compared to western stormwater regulations. The conformity to building standards and legal status are not of great importance in Iran. Another criteria can be dismissed right away: “Sustainable Development”. This criteria is comprised by the whole system already. However, the sub-criteria “resource use” will be part of the new criteria set as it is an important factor in the concept of sustainable development. Another criteria, “System performance” can be split up and integrated in the criteria water volume impact and water quality impact. The criteria “land cost” can be merged to the general life cycle costs, but the sub-criteria “land take” is transferred and included in “resource use”.

All remaining criteria groups are summed up in an economic, environmental and social group and thereafter all criteria are assigned to each group. In this way the primary and secondary indicators in the report by Revitt et al. (2003) are transformed to criteria split up into three groups. Beforehand it must be noted that criteria cannot only be matched to one but also to more than one group. For example system reliability can be an economic as well as a social criteria. If the system fails it will jeopardize the society through accidental pollution and exceeding storm events. At the same time high failure rates result in high costs. Nevertheless all criteria must be allocated to a single group. In this way system reliability is considered as an economic criteria, such as system durability, maintenance and servicing provision. Thereafter all previous ´operation and maintenance´ criteria are also economic criteria now. The former ´technical and scientific´ criteria are considered as new part of the environmental criteria. The ´social and urban community benefits´ criteria represent the social criteria.

Having classified the criteria newly also the indicators by Revitt et al. (2003) have to be adapted to this study. Indicators must be chosen in accordance to the economic, environmental and social criteria which describe the objectives of sustainable stormwater management. A whole range of potential indicators is provided by Revitt et al. (2003). but only a few are substantial for this study. Therefore the potential indicators are evaluated regarding the following principles. These principles are set by the author regarding the general characteristics of an indicator [c.f. chapter 3.4] and the study area:

- Easy to understand
- About something that can be measured and is believed important
- Communicative
- Relevant for political decision-making and control
- Quantifiable
- Feasible
- General indicators: simple and good

The new classification and the selection of appropriate indicators and criteria are figured in the table of the DayWater report by Revitt et al. (2003) for indicators for sustainable stormwater management [Table 16]. Why an indicator is selected or dismissed is commented in the table.

Table 16: Criteria and indicator selection adapted from DayWater report (Revitt et al., 2003)
Bold: Criteria and indicator selected, ***Bold and Italic Type: New adapted criteria and indicator***, *Italic Type: comments*, Other: dismissed, H/M/L = high/ medium/ low, BMP = best management practice, yr= year

Primary indicator	Secondary indicator	Benchmarks	Threshold values/ units
Criteria		***Indicator***	***Units/ Values***
[Site Characteristic Criteria] *Boundary conditions*			
Site area	(i) Drainage characteristics (ii) Physical site restrictions	(i) - Percentage of impermeable contributing area - Minimum land-take required to accommodate a specific BMP or combination of BMPs - Design storm runoff volumes - Time series runoff volume(s) - Receiving water body type (ii) - Site gradient - Water table level - Potential for excessive site construction sediment loads - Fissure/matrix flow	 - % - m^2 - m^3/ha - m^3/ha*hr - stream/ river/ lake/ coastal - %; ratio - m - mg/l - Fissure/matrix
Soil/ground Characteristics	(i) Infiltration capability/ groundwater protection (ii) Soil/ground stability (iii) Earthquakes	(i) - Soil type - Infiltration rates - Storage volume of unsaturated zones - Vegetation cover type (ii) – Liability to subsidence/land slip (iii) – Seismic risk	 - Hydraulic conductivity (k value) (m/s) - mm/hr - m^3/ha - None/grass/trees etc. - Yes/no - Richter scale

Continuation of Table 16 (page 42)

[Technical & Scientific Criteria] *Technical details, c.f. chapter 4 Structural measures. Technical and Scientific Criteria are not criteria but affect social, environmental and economic criteria, hence are integrated there. Some criteria/ indicators selected.*			
System Performance	(i) Storage and flood control (ii) **Water quality** treatment Shifted to water quality impact criteria	(i) - Design storm return interval (RI; 1,5,10, 25….yrs) storage volume - Length of antecedent dry periods - Response rate for superimposed critical/historic storm durations - Ratio of storage to contributing drainage area - Number of floods per year within catchment - Overflow frequency and duration - Discharge or throttle rate - Uniform flow distribution (ii) - Pollutant concentration probability exceedance for given target levels - First-flush capture potential (10/15mm effective runoff treatment for all storms) - %age **pollution capture/** *NEW:* QUALITY OF WATER OUTFLOW for given RI storms and retention times	- m^3/ha - Days - m^3/ha*hr - Ratio - 1….n - 1….n - m^3/s - H/M/L - % exceedance for given target level - mm runoff/av storm event - % capture for given RI or retention time
System flexibility, adaptability and potential for reuse	Capability for change over time	- Design freeboard for storage and water quality change - **Ease of retrofitting** and Modification, *for economic criteria* - Costs of retrofitting and add-on structures/features - Potential to recycle system components/waste, *included in ease of retrofitting*	- %; m^3/lifetime - H/M/L - € (av.cost) - H/M/L
Impact on drainage system	Integration with existing system	- Flow reduction to STP and CSOs, *not feasible and quantifiable* - Reduction in stormwater flows**,** *included in environmental criteria*	- %; m^3 - %; m^3/ha
Operation and Maintenance Criteria – ***Economic criteria***			
System Reliability	(i) Performance reliability, health & safety (ii) Risk management	(i) - Hydraulic retention time, *not communicative* - **In-basin quality condition** and health hazards – *social indicator* - Alarm/intervention procedures - Safety level/provision for accidental pollution etc *not quantifiable* - Number of in-basin/receiving water pollution complaints – *for operational indicator proposed* (ii) - **Probability of system failure** – *if well maintained, see description in text* - Consequences of storm event exceeding design storm RI, *cf above*	- Hours - Trophic state; smell; stagnant water; bacteriology etc. - Yes/no - H/M/L - Number/yr - % probability - Flooding depth (m)
System Durability – ***System***	Design life	- Operational lifetime, *included in O&M costs* - Sedimentation rates and storage	- Years - m^3/yr; % reduction in

Continuation of Table 16 (page 42)

Robustness		volume, *not relevant here* - **System robustness***, if O&M missing*	storage volume/yr - H/M/L
Maintenance and Servicing Provision	**O & M requirements**	- Need and **frequency for O & M** servicing to maintain: technical/ environmental/ amenity/ habitat objectives – *also in O&M costs included* - Risk to maintenance operative's safety, n*ot feasible* - On-site herbicide/pesticide applications, *too detailed* - De-icing chemicals *too detailed* - Sediment disposal – *in O&M costs included* - Plant replacement in constructed wetlands – *no plants essential* - Risk of littering - Risk that public lose interest leading to O&M problems *Both included in system robustness*	- H/M/L; frequency/yr - H/M/L - Number/yr; litres/yr - Number/yr; tonnes/yr - m^3/yr - Frequency/yr - H/M/L - H/M/L
Environmental Criteria			
Water Volume Impact	Flooding	- Draw-down times, *not easy to understand* - Downstream erosion, *not important* - **Groundwater recharge** - Downstream flow protection value, *not feasible transformed into → next indicator = NEW: FLOODING EFFECT OF RECEIVING WATERS* - **NEW: Flooding effect of receiving waters** - compatible RI interval, *see new indicator above*	- Hours - H/M/L - m^3/yr - H/M/L - % decrease of certain RI interval - years
Water Quality Impact	Pollution control	- Treatment retention times - Dilution ratios *Both not relevant and easy to understand* - Litter/gross solids; floating matter; surface oils – Receiving water quality – *see new indicator below* - Receiving water classification, *no classification in Iran* - Groundwater quality, *see new indicator below* - Thermal effects, *not important* - %age compliance with consent/receiving water WQOs and standards – *see receiving water quality* - **NEW: Quality of water outflow**	- Hours/average storm event - Ratio - H/M/L, *1…n* - 1…n - 1…n - H/M/L - %/yr - % average removal rate
Ecological Impact	**Habitat and ecological Diversity**	- **Number of key species introduced**/attracted, *most important indicators among the following* - Receiving water hydrobiological scores - Pests/vermin introduced - Invasive/unwanted species - Conservation status	- 1….n - 1….n - Yes/no - Yes/no - H/M/L

Continuation of Table 16 (page 42)

		(plant/insect/invertebrate/mammal) *All too detailed*	
Social and Urban Community Benefits Criteria – ***Social Criteria***			
Amenity; Aesthetics; Access and Community Benefits	**Social inclusion and multifunctional use**	- **Level of amenity provision** (fishing,boating, recreation etc)**,** *multifunctional use value* - Increased access provision *Incorporated in indicator above* - Community participation (ranger service, liaison groups, volunteer nature groups etc) and formal community recognition through nature trails, birdwatching; environmental days etc., *operational and educational indicator* - Numbers of visitors etc., *integrated above* - Vandalism, *integrated in system robustness* - Residents' perception of increased environmental benefits, *integrated in Stakeholder Acceptability*	- H/M/L - H/M/L - H/M/L - H/M/L - Yes/no - % user survey
Public Information and Awareness **Educational aspects**	Public awareness and understanding	- Interpretation boards, signage, brochures/literature, visitors centre etc., *see below* - Awareness in local/regional Community, *integrated in acceptance of onsite treatment* - **Use as** educational and/or technical **demonstration site** - Public meetings/hearings, *not relevant*	- H/M/L - % awareness survey - Number of site visits; - Number/yr; yes/no
Stakeholder Acceptability	Perceived Acceptability and Impacts	- Local community willingness-to-pay, *municipality = payer* - **Acceptance of on-site treatment** as opposed to conventional drainage systems**,** *but hard to quantify* - Level of inhabitant willingness to participate in on-going site improvement, *see above*	- H/M/L - H/M/L - H/M/L,
Health and Safety Risks, *can be disregarded*	Risk Audits	- Local community concerns (injury, infection, drowning etc) - Formal technical risk exposure audit (flood risk, health risk, safety risk)	- % user survey - H/M/L
Sustainable Development	(i) Sustainable urban living, *this indicator set evaluates the sustainability of selected measures, therefore this criteria is an overall criteria anyway* (ii) **Resource use**	(i) - Contribution to urban sustainable development policies - Role in Agenda 21 - Role in Biological Action Plans (BAPs) - Additional benefits offered by different BMPs (ii) - **Material use**: aggregate/concrete/top-soil use and costs, *for construction*	- H/M/L - H/M/L - H/M/L - Yes/no - H/M/L;

Continuation of Table 16 (page 42)

		only - **Energy use**: construction, operation and maintenance energy consumption, *for construction only*	- kW; kW/m³ storage
Economic Criteria			
Life Cycle Costs	(i) Investment and operational costs (ii) Community costs	(i) - Design (including site survey costs), *included in capital costs* - **Capital costs** - **Operational** & maintenance **costs** - Sediment disposal costs - Site decommissioning costs *Both included in operational costs* (ii) - Stormwater fees - O&M fees *No fees at all*	 - € - € - €/yr - €/yr (or lifetime) - € - Increase/decrease - Yes/no; €/yr
Financial Risks, *can be disregarded*	Risk exposure	- Cost-Benefit analysis - Investment loss risk - Site reclaim value - Existence of system failure insurance	- C:B ratio - H/M/L; € - H/M/L; € - Yes/no
Affordability- *can be disregarded*	Long term affordability	- Adoption and liability coverage - Economic add-on value (enhanced land/property values) - Amenity income streams - Long term management provision	- H/M/L; € - €/ha - €/yr - H/M/L
Land cost, *included in capital costs*	**Land take**, *include in resource use [m²/design rain]*	- Land costs/m²	- €/m²
[Legal and Urban Planning Criteria] *External condition, in the case of Iran regulations and laws have a very low standard compared to European standards*			
Urban Stormwater Management Issues	(i) Stormwater regulations (ii) Non-stormwater regulations	(i) - Fulfilment of European regulations - Fulfilment of national regulations - Fulfilment of local regulations (ii) - Fulfilment of legislation relating to construction, nature conservancy and preservation, groundwater, housing density and type, urban planning, building regulations, health and safety and sanitary codes	 - Yes/no - Yes/no - Yes/no - Yes/no
Planning and Development Issues	Conformity to building standards	- Number of units - Design flexibility - Treatment train benefits	- 1….n - H/M/L - H/M/L
Adoption	Legal status	- Legally binding contract - Health and safety - Operation and maintenance - Legislation to enforce use of BMPs on private property	- Yes/no - Yes/no - Yes/no - Yes/no

6.2.4 Assessment of measures

The final result of this study encompasses the assessment of the selected measures for their contribution to sustainable development in Tehran´s stormwater management through appropriate indicators. The result should point out how far the measures meet the objectives of sustainable development in stormwater management. This assessment is conducted by applying a multi criteria decision method, namely scoring. The scoring method is an easy way to structure and analyze the decision problem (Mollaghasemi & Pet-Edwards, 1997).

For the assessment each indicator must be quantified through values for each measure. As the indicators are either economic, environmental or social indicators they cannot always be calculated. Therefore the indicators are described through subindicators that help to quantify the values through qualitative accuracies. The subindicators describe characteristics of the measure and it is stated through yes if the measure has this characteristic or not. The indicator values have been roughly estimated from the available data, withdrawn from international manuals about structural stormwater measures, taken from the design description or interpreted for the situation in Tehran. This means that all values are rather approximate. This means that they should represent benchmarks in the system. In order to make the quantification of the indicator values more transparent chapter 7.2.1 contains a detailed description how each single indicator value was found for a specific measure.

After yielding the values for the indicators the relative importance of each indicator has to be determined. On a scale of 1 to 100 the weights w_i are given for each indicator. The relative importance of all indicators need not exceed the sum of 100 (range 1 to 100). The weighting is conducted by the decision maker for this study. Here the decision maker for this study is represented by the consultant of the stormwater management master plan for Tehran that is currently elaborated.

In the scoring method scores are assigned to each indicator. In this study the scores are 0, 1, 5, and 10. These scores represent the specific indicator value of the measure. In other words the scores can be associated with the theoretical performance of the measure. Moreover the scores state the contribution to sustainable development in stormwater management in a certain indicator. 10 is a very high and 1 a very low contribution. 0 means that the measure does not have any aspect of sustainable development at all. To transform the indicator values of each measure into scores the theoretical performance relative to the other measures must be known. Therefore the range of the indicator values of all measures is needed. This range is divided into four classes in respect to the four scores. For example, measure X has 10, measure Y 90 and measure Z 35 capital costs. The range is from 10 to 70 that are divided equally into the classes [10-30], [30-50], [50-70], [70-90]. Hence score for measure X is 10, for measure Y 5 and for measure Z 0, because the lower the costs the higher the theoretical performance. It depends on the indicator whether the highest value is assigned to the highest or to the lowest score. The final indicator [c.f. Appendix D] displays the direction of preference.

In order to achieve the worth of the alternatives, the sum of weights times scores is computed. To get real weight influence the weights are divided by 100. The sum of the products for each dimension of sustainable development represents scores which state the grade of sustainable development for each measure. This means the measure contributes the most to sustainable development if all three dimensions, thus objectives, are fulfilled to their maximum. Comparing all scores, suggestions should be made for the sustainable structural measures for Tehran. This will be the final result of this study (Mollaghasemi & Pet-Edwards, 1997).

7 Results

7.1 Structural measures for Tehran

The sustainable structural stormwater measures for the 22nd district of Tehran must be adapted for the arid climate. The major requirements for these measures for Tehran´s stormwater management were objectives in water quality & water quantity and groundwater recharge. The measures should lower stormwater flows, increase stormwater runoff quality and at the same time recharge the groundwater aquifer. The selection due to these objectives is shown in Table 17.

Table 17: Structural control selection matrix (AMEC Earth and Environmental et al., 2001)

General application	**Water quality& quantity**	**Groundwater recharge**	**Arid climate**	**Notes**
Structural control alternative				
Detention basin (Extended detention basin)	●	○	●	Infiltration into groundwater provided through modification in design
Retention pond	●	○		
Constructed wetland	●	○		
Sedimentation tank	●		●	
Infiltration basin	●	●	●	Not recommended by AMEC Earth and Environmental et al. (2001)
Infiltration trench	●	●	●	
Soakaway	●	●	●	Similar to infiltration trench
Sand filter	●	●	●	
Swale	○	○		
Filter strip		○		
Pervious pavement	●	●	●	

● Provided ○ Slightly provided

It can be seen that only a few measures fulfill Tehran´s stormwater management objectives and fit Tehran´s arid climate. The next step is to analyse if any of those measures is restricted by the site conditions of the 22nd district. The measures require low slope gradient (max 5 %), deep permeable soils (infiltration rate > $7*10^{\wedge-6}$) and enough space. These requirements are not restricted by the 22nd district. Therefore the following measures are suggested to be suitable for the locality of the 22nd district:

- Extended detention basin: the extended detention basin has the best removal rates in comparison to an ordinary detention basin
- Infiltration trench: actually the infiltration basins perform better regarding water quality and water quantity, however they are not recommended by AMEC Earth and Environmental et al. (2001) but infiltration trenches are recommended structural stormwater measures. A soakaway is very similar; the only difference is that soakaways are underground structures. Infiltration trenches are preferred because they figure a less complex construction. Summing up, infiltration trenches, infiltration basins and soakaways are very similar though infiltration trenches are most advantageous (recommended, easy construction).
- Sand filter

- Pervious pavement

However, infiltration trench, sand filter and pervious pavement perform best with low sediment input. This is not the case in the 22nd district of Tehran, because it is a residential area and has high total suspended solid loads in stormwater. Nevertheless they are included in the final assessment because this matter can be overcome through operation and maintenance. If these measures are left out the assessment will only contain one sustainable structural measure (extended detention basin). Hence the assessment would not be very significant.

Having elaborated the right strategies, detailed information will be provided in the next chapters for each measure in addition to the description in chapter 4.

Regarding the removal rates they have been calculated with the help of Table 12 in chapter 4.7. All removal rates are summed up and divided to get an average amount. This average removal rate should only provide an approximate figure for the general pollutant capability of the measure.

Generally it must be stated that the design and description of the measures are based on literature deriving from Europe, the US, Australia and New Zealand and are approximations to get an idea for the indicator value. This means that all values are representing estimations from westernized countries but are not adjusted to the local conditions in Tehran. Especially the work material, the construction and the operational costs have been roughly calculated. This was done to achieve approximate values and relative value ranges because data availability from Iran was very poor.

7.1.1 Extended detention basin

Basins should be designed as large, shallow basins [Figure 14 and 15] in order to maximize the degree of pollutant removal. The stormwater runoff enters through an inflow pipe over a riprap as protection for the embankment and exits after a detention time of 24 hours through an efficient orifice. Normally the embankments are constructed out of the excavated soil.

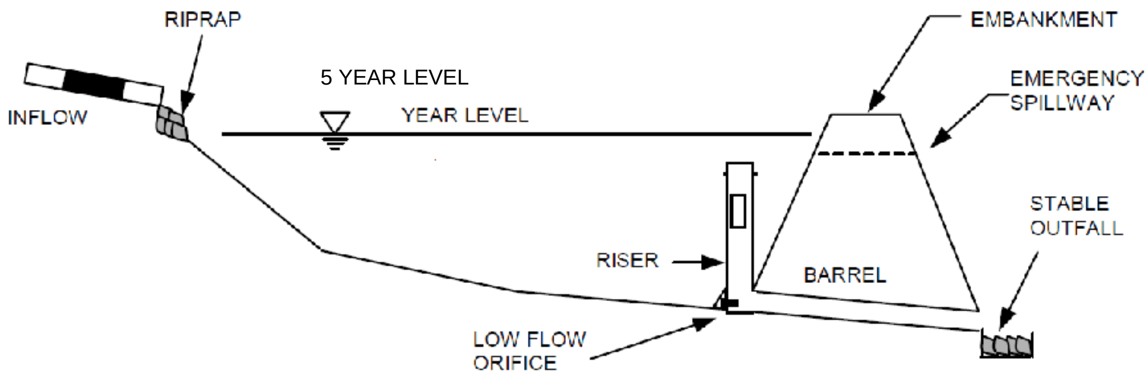

Figure 14: Schematic of a dry extended detention basin (AMEC Earth and Environmental et al., 2001)

Due to the minimum catchment area of 4 ha it can be assumed that extended detention basins are rather large decentralized measures and therefore require not only inflow but also drainage pipes towards the measure. Average removal rate of total suspended solids, nitrogen, bacteria, hydrocarbons and dissolved metals is 50% (Middlesex University, 2003).

Figure 15: Detention basin with infiltration strip (Missa et al., 2005)

7.1.1.1 Calculation and cost

The extended detention basin is designed according to the reports by Missa et al. (2005) & Middlesex University (2003). The basin is calculated in order to detain rainfall over 24 hours.

The designer obtains a treatment volume of 727 m³ and therefore a basin volume of 727 m³ by a 24 hours design rainfall over a 4.5 ha catchment area. This means 1 m³ basin are necessary for 1 m³ of treatment volume and 161.6 m³ basin for a catchment area of 1 ha.

The work and the quantities for the material are calculated at a cost of about 50 €/m³ for a detention basin though the material comprehends only a layer of geotextile and inflow and outflow pipes [Table 18]. The construction of a 727 m³ volume pond would cost 36 353 € in total. However, the total costs would account over 470 000 € if the costs of a supply system for the area of 4.5 ha are considered too. This specific information will be included in the indicator set. The final score will be calculated for the extended detention basin and for the extended detention basin with a drainage system. The operational costs of the same basin account in average 1 €/m³.

Table 18: Work materials for extended detention basin (Missa et al., 2005)

	Work materials	**Unit**	**Quantity/ m³ ext.det.basin**	**Quantity/ m³ treatment volume**	**Quantity/ ha catchment area**
1	Inflow pipe	m	1.0	1.0	161.6
2	Geotextile	kg	0.5	0.5	80.8

7.1.2 Infiltration trench

The long-narrow rock filled trenches [Figure 16 and 17] are structural measures for small catchments and are located close to the impervious areas. A pretreatment step is recommended, for example a grass buffer strip [Figure 17]. Overall the average removal rate of total suspended solids, nitrogen, bacteria, hydrocarbons and dissolved metals is 59%. (Middlesex University, 2003).

Figure 16: Infiltration trench (Auckland Regional Council, 2007)

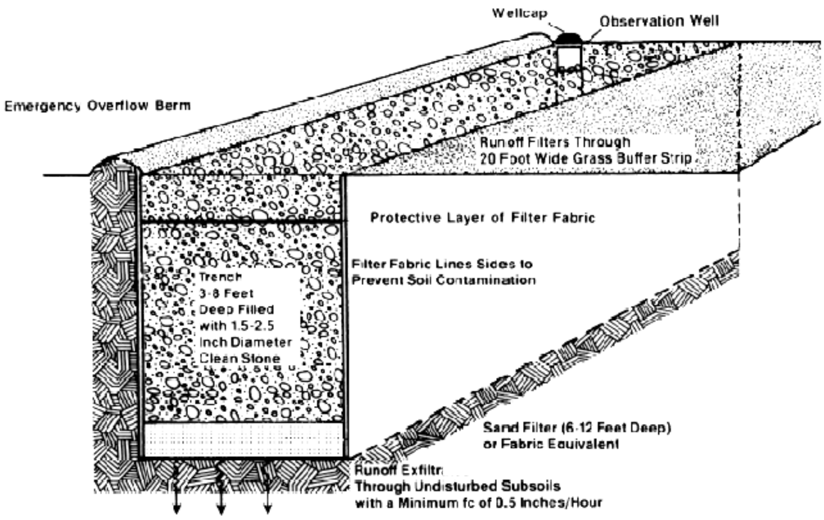

Figure 17: Typical infiltration trench design (Missa et al., 2005)

7.1.2.1 Calculation and cost

The infiltration trench is designed and calculated according to reports by Missa et al. (2005) & Middlesex University (2003).

In the case of the infiltration trench the rainfall duration that yields the greatest dimension of the trench is accounted to 1.50 hours. The calculation sets the dimensions for the infiltration trench for a catchment area of 1 ha: 200 m² trench base and 1.6 m trench depth. This yields a total volume of the infiltration trench of 312 m³ for 151 m³ treatment volume for a catchment area of 1 ha. Concluding, about 2.1 m³ of trench are necessary for the treatment of 1 m³ of stormwater.

The construction of 1 m³ infiltration trench costs approximately 115 €/m³. The operational costs amount approximately 12.5% of the construction costs annually. The work materials of an infiltration trench [Table 19] include stone aggregate, filter fabric, sand layer and observation well that can be viewed as one third of a normal pipe due to its narrow diameter. In total the costs account 35 837 € for the construction of an infiltration trench with a dimension of 312 m³.

Table 19: Work materials for an infiltration trench

	Work materials	Unit	Quantity/ m³ of infiltration trench	Quantity/ m³ treatment volume	Quantity/ ha catchment area
1	Gravel	m³	0.9	1.8	280.4
2	Sand	m³	0.1	0.2	31.2
3	Filter fabric	kg	0.5	1.0	155.8
4	Pipe (1/3 observation well)	m	0.3	0.7	93.5

7.1.3 Sand filter

The original sand filters are designed as two chamber structures [Figure 18 and 19] and are called surface sand filters. The structures of the surface sand filter are constructed out of impermeable media (e.g. concrete) or the use of excavations for the embankments. The sedimentation basin is similar to a detention basin and is connected via pipes to the sand filter bed areas. The sand filter consists of typically 0.5 m layer of clean washed medium sand and the depth of the filter media (d_f) should be half the height (h_f) of the water above the filter media [Figure 19]. The average removal rate of total suspended solids, nitrogen, bacteria, hydrocarbons and dissolved metals is 49% (AMEC Earth and Environmental et al., 2001).

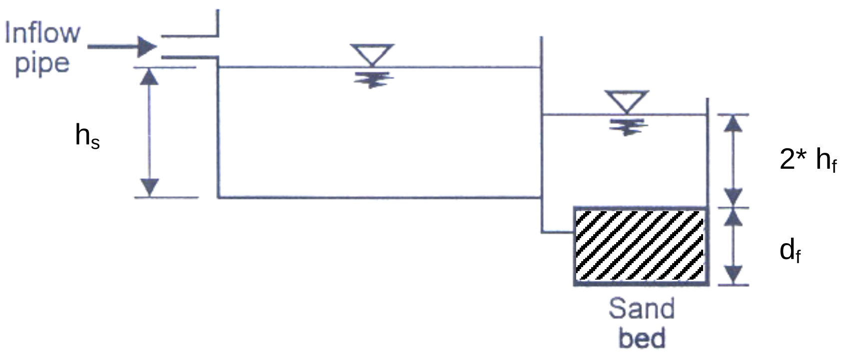

Figure 18: Schematic of a surface sand filter (AMEC Earth and Environmental et al., 2001)

Figure 19: Surface sand filter (AMEC Earth and Environmental et al., 2001)

7.1.3.1 Calculation and cost

The sand filter is designed and calculated according to the findings by AMEC Earth and Environmental et al. (2001).

The most affecting rainfall for the sand filter is the 24 hours design rainfall. The catchment area is set to 1 ha. A water quality volume of 162 m³ is treated in a sedimentation chamber of 35 m² and a sand filter bed of 30 m². Summing up rain from a catchment area of 1 ha needs a total sand filter volume of 129.5 m³. In other words 1 m³ of stormwater can be treated by providing 0.8 m³ of sand filter (including sedimentation chamber and filter storage above filter bed).

AMEC Earth and Environmental et. al (2001) do not provide exact numbers for costs, though United States Environmental Protection Agency (2004) states the approximate installation costs for sand filters with 247€/ m³ of water quality volume. This means a total construction cost quantity of 42 951 € for a sand filter of 65 m² total size. The operational costs are estimated at 5% of the construction costs annually. Work materials include materials for the sedimentation basin and the sand filter [Table 20].

Table 20: Work materials for sand filter

	Work materials	**Unit**	**Quantity/ m³ of sand filter**	**Quantity/ m³ treatment volume**	**Quantity/ ha catchment area**
1	Sand (11% of total volume)	m³	0.11	0.1	14.2
2	Filter fabric	kg	0.5	0.3	64.8
3	Inflow pipe	m	1.0	0.8	129.5

7.1.4 Pervious pavement

A pervious pavement consist of layers of porous pavement [Figure 20], a sand layer or a granular filter, the sub-base layer and the filter fabric (or geotextile) protecting the soil [Figure 21]. All layers must be constructed properly, protecting the sub-surface from entering of fine particles during the construction phase. The upper filter fabric can be dismissed. Overall the average removal rate of total suspended solids, nitrogen, bacteria, hydrocarbons and dissolved metals is 65%.

Figure 20: Pervious pavement (Cahill, 2007)

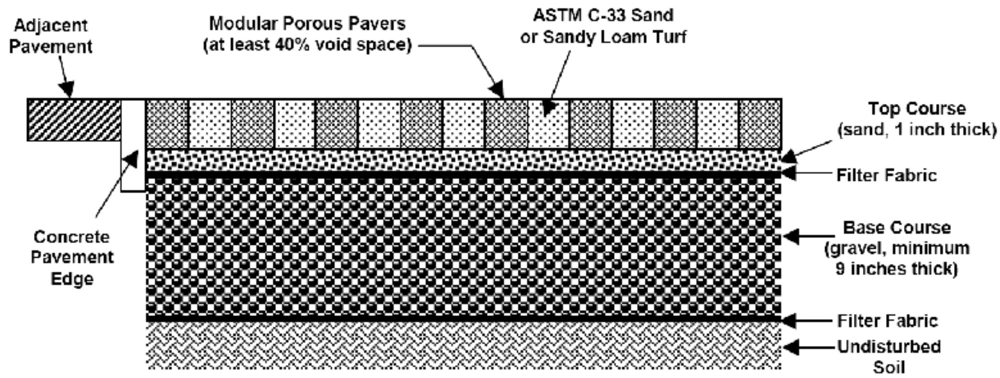

Figure 21: Schematic of a pervious pavement (AMEC Earth and Environmental et al., 2001)

Note: According to Missa et al. (2005) the Base Course has no thickness restrictions and only one filter fabric between base and soil is applied.

7.1.4.1 Calculation and cost

The pervious pavement is designed and calculated according to reports by Missa et al. (2005) & Middlesex University (2003) for pavements with a storing structure.

The catchment area accounts 0.5 ha. The duration of 25 min of a 5 year rainfall yields the biggest dimension. Thereafter the necessary depth of the sub-base under the porous surfaces accounts 7.8 cm. This yields a total volume of 98 m³ of pervious pavement. Moreover 98 m³ of pervious pavement treat a water volume of 48 m³. Therefore 2 m³ of pervious pavement must be designed for the treatment of 1 m³ stormwater. For the treatment of stormwater runoff of a catchment area of 1 ha a total of 195.5 m³ pervious pavement must be calculated.

The construction costs amount 190 €/m³ in average. Therefore the construction of pervious pavement for 0.5 ha catchment area would cost 18 576 €. Costs include working material [Table 21]. Operational costs amount approximately 5% of the construction costs annually. The operational costs derive from Peluso and Marshall (2002) as the report of Middlesex University (2003) does not state reliable numbers.

Table 21: Work materials for pervious pavement

	Work materials	**Unit**	**Quantity/ m³ of perv. pavement**	**Quantity/ m³ treatment volume**	**Quantity/ ha catchment area**
1	Pervious pavement	m³	0.05	0.1	9.8
2	Sand	m³	0.02	0.04	3.9
3	Gravel	m³	0.1	0.2	19.6
4	Filter fabric	kg	0.5	1.0	97.8

7.1.5 Storm sewer

Although a storm sewer is not the desired measure for the new stormwater management in Tehran, it is included in the description of structural measures in order to reveal its contribution to sustainable development too.

Storm sewers are designed as underground pipes and the total runoff impedes their diameter. After the excavation of the soil the trenches are filled with embedding material and the pipes are placed with joints into the trench [Figure 22] (Butler & Davies, 2000). The trench dimensions is assumed two times the diameter (=d) times two times the diameter [Figure 23]. In addition the trench is placed 0.8 m below surface.

Figure 22: Construction of storm sewer (Trauner, 2009)

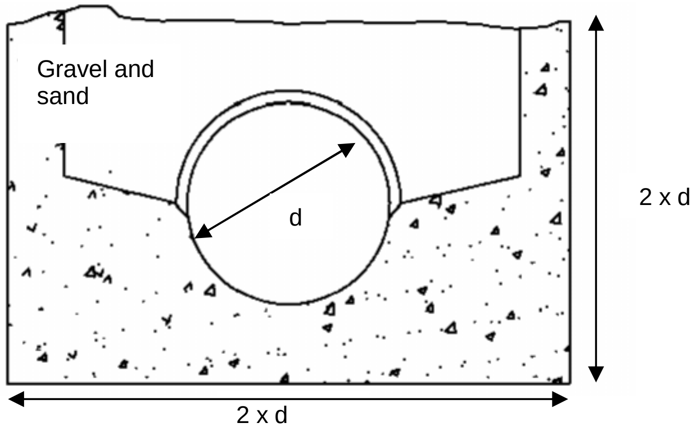

Figure 23: Storm sewer design (Moberg, 2009)

7.1.5.1 Calculation and cost

The Prandtl-Colebrook formula provides the basis for a rough calculation of a storm sewer system (Butler & Davies, 2000). In this case storm sewers are designed for a catchment area of 4.5 ha. This implies an impervious area of 1.8 ha. Hence a 10 m wide road with the length of 1800 m can be assumed as characteristic impervious area which has to be provided with storm sewers.

The total runoff used in the calculation is the runoff with a duration that equals the concentration time. In total a diameter of 350 mm for the storm sewers conveying 322.8 l/s is yielded as result. Summing up, storm sewers with a diameter of 350 mm and a length of 1800 m are necessary for the collection of stormwater of a catchment area of 4.5 ha. This equals to 400 m of storm sewers for a catchment area of 1 ha.

The cost estimation has been taken from a recent Austrian analysis. The construction costs of a sewer with 1 m length and 350 mm diameter pipe are calculated at 241 € (Amt der niederösterreichischen Landesregierung , 2009). A 1800 m long sewer would cost 433 800 € to build. The operational costs are estimated at 1€/ m. The work materials include the pipe, sand and gravel [Table 22]. It must be noted that the work materials of the manholes are not included but are included in the costs.

Table 22: Estimated work materials for storm sewer

	Work materials	**Unit**	**Quantity/ m storm sewer, d=0.35 m**	**Quantity/ ha catchment area (≙400 m storm sewer)**
1	Concrete pipe	m	1.0	400
2	Sand	m³	0.2	80
3	Gravel	m³	0.3	120

7.1.6 Comparison among alternatives

A short summary of all the selected measures for the 22nd district of Tehran and the conventional option is provided [Table 23].

Analysing the numbers provided in the table it can be said that the extended detention basin is a sustainable structural measure designed for rather big catchment areas and large treatment volumes. Moreover the extended detention basin accounts relatively low costs compared to the other measures and their treatment volumes. For example infiltration trench and sand filter cost the same though they treat only 20% of the stormwater collected in extended detention basins. The measure pervious pavement is very specific, because it is designed for small catchment areas, consuming little or no land because it substitutes normal pavement or asphalt. Apart from all it can be seen that the sewer system is the most expensive measure and has a totally different cost range (100 thousands, instead of 10 thousands).

Table 23: Comparison of measures designed for a 5 year return interval

Measure	Catchment area [ha]	Size of measure [m²]/ Depth [m]	Treatment Volume [m³]	Construction Cost [€]
Extended detention basin	4,5	450/ 2.1	727	36 353
Infiltration trench	1	200/ 1.6	150*	35 836
Sand filter	1	65/ 1.8	162	42 951
Pervious pavement	0,5	1250/ 0.08	48*	18 576
Sewer system	4,5	1800 m Length/ Ø 350 mm	97	433 800

* In the calculation by Missa et al. (2005) the impermeability index is not taken into consideration and therefore the total runoff excluding impermeability index figures the input for the calculation of the treatment volume.

However, when comparing the measures over the long range it must be noted that the life expectancies of the different measures is varying. Sustainable structural measures have a shorter design life as the conventional storm sewer system. For example extended detention basins are said to last more than 10 years. Infiltration trenches are lasting 10 to 30 years before rehabilitation is needed. Pervious pavements have a design life of at least 15 to 20 years. Sand filters are said to last 25 to 50 years with change of the sand filter every 5 years (United States Department of Transportation, 2009), (AMEC Earth and Environmental et al., 2001), (Missa et al., 2005). Overall it must be stated that the available data upon life expectancy is not very specific but it is clear that the storm sewers have a longer lifetime. In fact storm sewers have a life time up to 50 years. Because data is unspecific the calculations take into account two different life times for the sustainable structural measures. It is assumed that the life time of the sustainable structural measures is either a third or half the lifetime of a storm sewer. This means that the lifetimes are set to 15 or 25 years in comparison to the life time of storm sewers of 45 and 50 years (Butler & Davies, 2000). This specific information is considered when calculating the capital costs, the material and the energy use for the construction in the indicator set.

7.2 Indicator set

The methodology of the selection of the indicator set is explained in the chapter 6.2.3; the indicator set [Table 24] is primarily based on the indicator set for sustainable stormwater management by Revitt et al. (2003) and adapted to the conditions in Tehran. If Revitt et al. (2003) listed an indefinite unit, the author has set subindicators instead. The subindicators describe characteristics of the measure. By “yes” it is stated that the measure has this characteristic. How the indicator values are achieved is explained in the next chapter. In addition to the new criteria and indicators the weights derived from the decision maker are assigned to the indicators. The decision maker for this study is represented by the consultant of the stormwater management master plan for Tehran that is currently elaborated.

Table 24: New criteria and indicator set including units and weights for assessment

Economic criteria	Indicator	Units	Weights
System reliability	- Probability of system failure	- % probability	- 5
System flexibility, adaptability and potential for reuse	- Ease of retrofitting *Subindicators:* *Ease of modification* *Potential for recycling major system components* *Use for another function than stormwater management*	- Number of yes	- 2
System robustness	- System robustness *Subindicators* *If no maintenance* *If no maintenance and additional litter input* *If no maintenance and dry periods (arid climate)*	- Number of yes	- 8
Operation and maintenance requirements	- Frequency for operation and maintenance	- Frequency/year	- 6
Life cycle costs	- Capital costs - Operational costs	- €/ ha - €/ ha and year	- 8 - 7
Environmental criteria	**Indicator**	**Units**	**Weights**
Water volume impact	- Groundwater recharge - Flooding attenuation in receiving waters	- % of attenuated stormwater - % of storage volume/ treatment volume	- 10 - 5
Water quality impact	- Quality of water outflow	- Average % removal rate	- 10
Habitat and ecological diversity	- Number of key species introduced	- 0, 1, … n	- 3
Social Criteria	**Indicator**	**Units**	**Weights**
Social inclusion and multifunctional use	- Level of amenity provision *Subindicators:* *Landscape enhancement/ structure* *Sports* *Part of urban design*	- Number of amenities/yes	- 6
Educational aspects	- Use as demonstration site *Subindicators:* *For schools* *For universities* *For public*	- Number of yes	- 4
Stakeholder Acceptability	- Acceptance of onsite treatment *Subindicators:* *Public* *Ministry of energy (water)* *Operator (municipality)* *Ministry of Tehran (urban planning)* - In-basin quality condition *Subindicators:*	- Number of yes - Number of yes	- 6 - 8

Continuation of Table 24 (page 57)

	Trophic state *Smell* *Stagnat water/ mosquitos*		
Resource use	- Material use for construction - Energy use for construction - Land take	- Total quantity for design/ catchment area* year - Energy units for design / catchment area* year - % of impervious catchment area	- 3 - 3 - 6

7.2.1 Quantification of indicators

In order to make the quantification of indicators traceable for all readers this chapter aims to describe how the values for each indicator were accomplished. Therefore all indicators are listed and a specific description is given below. The measures are abbreviated with B/ extended detention basin, I/infiltration trench, F/sand filter, P/pervious pavement and S/storm sewer.

- Probability of system failure

This value should indicate the system instability when the system is operated and maintained as advised. The information of recorded failures is withdrawn from the design description. Furthermore the probability of system failure is assessed high if the system is prune to clogging. This is the case for I, F and P. Instead, B and S have a very low probability of system failure. The probability ranges from 0% (very low/ S+ B) to 50% (high/ I+F+P).

- Ease of retrofitting

The ease of retrofitting is hard to quantify. Therefore subindicators are introduced to define the indicator more clearly. The subindicators were then estimated. If all subindicators (ease of modification, potential for recycling system components, use for another function than stormwater management*)* are fulfilled the measure achieves the highest score (3x yes). The fulfillment is stated by "yes". The range is from 0 to 3x yes. B achieves 3x yes because it can be modified to a normal pond, major system components can be recycled (there are no major components) and it can be used for a playground area in dry times. I and F achieve 1x yes for recycling of major system components; P achieves 2x yes for ease of modification to a normal pavement, and use as pavement (no recycling due to concrete pavement). S achieves 0x yes.

- System robustness

The system robustness can only be estimated. This is done with the help of subindicators: Is the system robust if there is no maintenance, no maintenance and additional litter input and no maintenance and long dry periods. The fulfillment is stated by "yes". The range is from 0 to 3 x yes. B is very robust (3x yes), clogging of the bottom may occur but this leads not to a failure of the system. I, F and P are not robust (0x yes) due to clogging. They require regular maintenance. S is robust (2x yes), if there is additional litter it might fail.

- Frequency for operation and maintenance

The frequency for operation and maintenance is easy to assess as it is a value presented in the design descriptions. The range is from every 5 years (S) to monthly (F). Therefore the range is set to 0 to 12 times/ year. S achieves 0, I and P 6, B 2 and F 12 times/year.

- Capital costs

The capital costs are calculated with the prices given in the design description and for a reference period of 45 years or 50 years. Therefore the prices are based on westernized standards because data availability of Iranian standards was poor. In respect to this the construction costs of the structural measures have to be calculated three or two times. The discount rate has to be taken into account. A lifetime of 15 or 25 years is assumed for the sustainable structural measures and a lifetime of 45 or 50 years for the conventional storm sewer measure. The range is from 15 055/ 11 109 (E) to 96 400/ 96 400 (S) €/ ha catchment area. I costs 66 785/ 49 280 €, F costs 80 045/ 59 064 € and P costs 69 236/ 51 088 €/ ha catchment area. The first value states the value for a reference period of 45 years and 15 years lifetime for B, I, F and P, and 45 years for S. The second value states the value for a reference period of 50 years and 25 years lifetime for B, I, F and P, and 50 years for S.

- Operational costs

The operational costs are calculated with the prices given in the design description and therefore not based on Iranian prizes because data availability was poor. The range is from 160 (E) to 4500 (I) €/ ha catchment area and year. S have costs of 1000€, F have costs of 2150€ and P have costs of 1900€/ ha catchment area and year.

- Groundwater recharge

The indicator groundwater recharge should state how much of the attenuated stormwater is actually infiltrating into the ground. The range is from 0% (S) to 100% (I, F and P). The infiltration rate of B is assumed with 30%. The values are assessed in respect to the design descriptions.

- Flooding attenuation in receiving waters

The indicator states how much water each of the measures is attenuating. All measures are designed for the same 5 year annual rainfall. Hence the storage volume is the total volume of a rain event that occurs every 5 years. Furthermore all sustainable structural measures are dimensioned to store the water quantity that is generated. Therefore B, I, F and P have a 100% attenuation, but S has a 0% attenuation. The range is from 0 to 100%. The values derive from the calculation and design description.

- Quality of water outflow

The quality of water outflow is assessed through the average removal rate of each measure. The removal rates derive from the literature stated. This average value is calculated from Table 12 [c.f. chapter 4.7]. All removal rates are summed up and divided to get an average amount. This figures should only provide an approximation for the general pollution capability of the measure but not state a real value. Hence B has 50%, I 58.5%, F 48.8%, P 65% and obviously S 0%. Therefore the range is from 0 to 65%.

- Number of key species introduced

This indicator should display how many key species are introduced in receiving waters through the effect of the measure on the quality of receiving waters. This is difficult to assess because no data upon key species is recorded in literature. Therefore the number is estimated due to the change in the water quality of the receiving waters. The range is from 0 (S) to 3 (B) key species. B achieves the highest number (3) because it is not only reducing pollutant concentration but also improving water quality in receiving waters. B is not holding back pollutants but also discharges cleaner water downwards. I, F and P introduce 1 species because these measures reduce pollutant concentration in receiving waters. Obviously S achieves 0.

- Level of amenity provision

The level of amenity provision is hard to quantify but subindicators are introduced to define the level more clearly. The subindicators are the amenities landscape enhancement/ structure, sports and part of urban design. It is stated by the number of yes how much amenities are provided by the measures. The range is from 0x to 3x yes. B has 3x yes because it enhances the landscape and provides sport opportunitites and can be also part of urban design as playground (e.g). I and F are accounted 1x yes because the measures can provide landscape enhancement or structure. P has 2x yes because it provides sport opportunities and is part of urban design. S provides no amenities (0). The amenities are assessed with the help of the subindicators.

- Use as demonstration site

All sustainable structural measures can be used as demonstration site, because they are all constructed above ground and their functions can be explained clearly to pupils of all educational levels. The educational levels are schools, universities and public as subindicators. Therefore B, I, F and P achieve 3x yes and S 0x Yes. The range is from 0 to 3x yes. The values are assessed with the help of the subindicators.

- Acceptance of onsite treatment

How well each measure is accepted can only be estimated. Therefore stakeholder groups are introduced as subindicators: public, ministry of energy for water issues, municipality as operator and ministry of Tehran for urban planning. If the single stakeholder groups accept the treatment measure the value will be 1x yes. The range is from 1 to 4x yes. B has 4x yes because it is accepted by the public due to the many amenities, accepted by the municipality for low operation and maintenance works, accepted by the ministry of energy for its good water quality and quantity objectives, and accepted by the ministry of Tehran for urban planning due to the small land take. I achieves 1x yes because it is accepted only by the ministry of energy for its good water quality and quantity objectives. It is not accepted by the other stakeholders because of few amenities (public), high operation and maintenance works (operator) and high percentage of land take (ministry of Tehran). F instead is accepted by the ministry of energy for its good water quality and quantity objectives and by the ministry of Tehran for minimal land take (2x yes). However operation and maintenance works are high and few amenities are provided for the public. P has a high acceptance (3x yes) because it is part of the urban structure (ministry of Tehran), has reasonable water quality and quantity objectives (ministry of energy), many amenities (public) but high operation and maintenance works (operator). Apart from the sustainable structural measures storm sewer has a medium acceptance because it is easy in operation and maintenance, has no land take, but provides no amenities and water quality and quantity objectives (2x yes).

- In basin quality condition

The in basin quality condition indicator includes the subindicators trophic state, smell and stagnat water/ mosquitos. The range is from 0 to 3x yes. All values are assessed values. B gets 3x yes due to the 24 hour detention of water and the sludge at the bottom during dry times. This may result in trophic state, smell and stagnant water. I gets 0x yes because the water is percolating through the measure and no sludge layer can build up. F gets 3x yes because it has stagnant water in the sedimentation basin and above the sand filter and can build up sludge in the sedimentation basin that can lead to smell and trophic state. P has 0x yes for the same reasons as I. Finally S gets 0 x yes for the same reasons.

- Material use for construction

The values for the material use are withdrawn from the design description. It can be seen that all measures need similar materials. Therefore the total quantity as sum of all quantities can be calculated. The result provides only a theoretical figure of the total quantity of materials without a unit. However it figures the approximate dimension how much material the single measure needs. In order to compare the single quantities, the number is calculated for the construction of the measure dimensioned for a catchment area of 1 ha and year. The values are given for a life time of 15 and 25 years for B,I, F and P, and respectively for 45 and 50 years for S. This means that the numbers of B, I, F and P are divided by 15 or 25, and S by 45 or 50. The range is from 8.7 to 37.4 or from 5.2 to 22.4 [Table 25].

Table 25: Estimated material use for reference period

	Pipe [m] or pavement [m³]	Filter fabric [kg]	Gravel/ sand [m³]	TOTAL/ ha catchment area	TOTAL/ year *ha catchment area [15/45 yrs]	TOTAL/ year *ha catchment area [25/ 50 yrs]
B	161.6	80.8	/	242	16.2	9.68
I	93.5	155.8	311.6	561	37.4	22.4
F	129.5	65.8	14.2	209	13.9	8.4
P	9.8	97.8	23.5	131	8.7	5.2
S	400	/	200	600	13.3	12.0

- Energy use for construction

The most difficult indicator to assess is the energy use. No data is found in the literature and therefore the author acts on the following assumptions: the construction of the measure needs energy. It is needed energy in respect to all material actions. All material actions are conducted with machines that need fossil energy. Furthermore all measures need the same type of energy and same types of material. Depending on the measure the following actions are considered: excavation of soil, transport and placement of new material, transport of excavated soil and placement of excavated soil for embankments. The numbers for each single action are based on the material use and assessed with the help of the design description. The following results are yielded for the energy use for the construction. In order to compare the single quantities, the number is calculated for the construction of the measure dimensioned for 1 ha catchment area and year. The values are given for a life time of 15 and 25 years for B, F, I and P or 45 and 50 years for S. The range is from 32.0 to 79.4 or from 21.2 to 47.6 energy quantity (no unit!) [Table 26].

Table 26: Estimated energy use

	Excavation of soil	Transport and placement of new material	Transport of excavated soil	Placement of excavated soil/ embankments	TOTAL/ ha catchment area	TOTAL/ year* ha catchment area [15/ 45 yrs]	TOTAL/ year*ha catchment area [25/ 50 yrs]
B	162	242	/	162	568	37.9	22.72
I	312	561	312	/	1191	79.4	47.6
F	130	209	/	130	545	36.3	21.8
P	196	131	196	/	529	35.2	21.2
S	420	600	196	224	1440	32.0	28.8

- Land take

The land take is calculated by the dimension of the measure and size of the impervious catchment area. An impermeability index of 0.4 is assumed (Indiana Geological Survey, 2004). B takes up 2.5%, I 5%, F 1.6%, P and S 0% land of the impverious catchment area. P and S use no land because P is substituting ordinary pavement and S is constructed underground. Therefore the range is from 0 to 5%. The values derive from the calculations.

7.3 Assessment and ranking

By assessing each indicator for each measure in respect to the concept of sustainable development a score for each dimension of sustainable development is achieved. This score states the contribution to sustainable development in stormwater management. The following scores are gained [Figure 24 and 25]. In respect of the inaccuracy of the lifetimes of sustainable structural stormwater measures in literature two different lifetimes are chosen. Therefore two scores for each measure and dimension are gained. In addition the score for the extended detention basin including a sewer supply system is also set in the figure. How these scores are calculated is provided in the individual indicator set in the appendix.

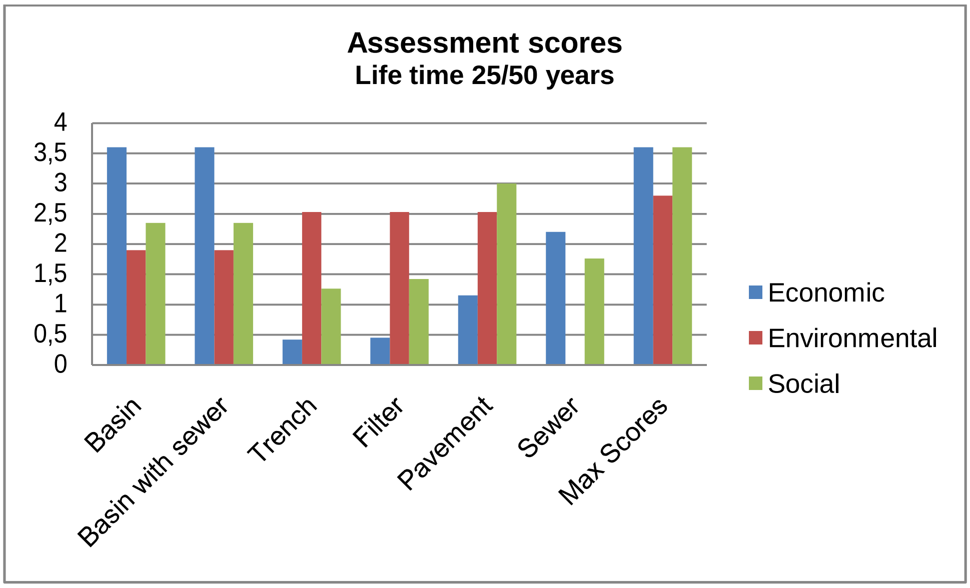

Figure 24: Assessment scores for a life time of 25/50 years

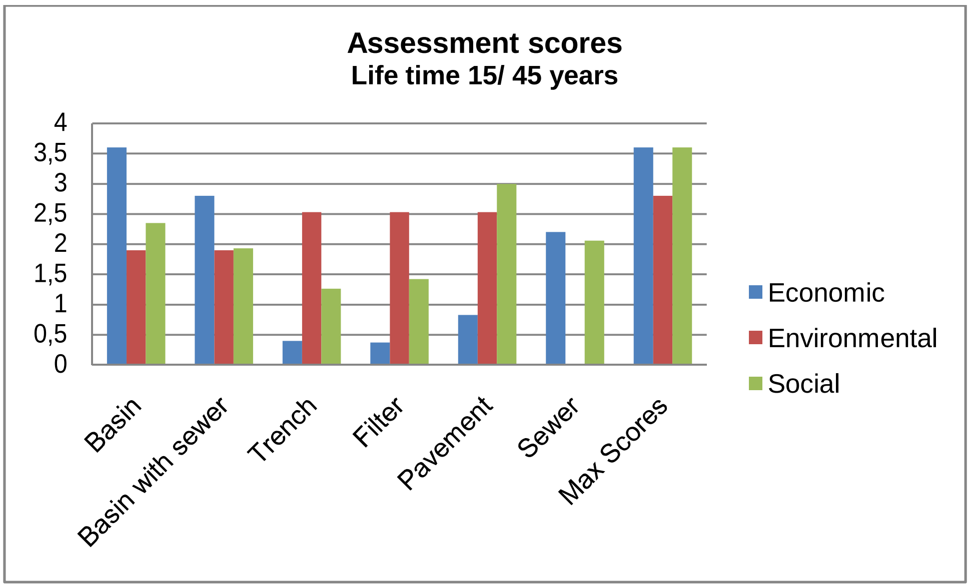

Figure 25: Assessment scores for a life time of 15/ 45 years

As stated in the methodology the measure that fulfills the objective to their maximum is said to be best contributing to sustainable development of stormwater management in Tehran.

The maximum that can be achieved is figured by the serie “Max. Scores”. These scores are calculated by adding the highest score (10) and multiplying it with the preference, thus weight, of the decision maker.

It can be seen that the extended detention basin is the measure that achieves in each dimension the highest scores. Thus is aiming for the maximum in each dimension of sustainable development. Analysing the scores displaying the different lifetimes it can be seen that the life time has not a crucial influence. Also taking into account the sewer system as supply system for the basin does not change the output seriously.

Second measure that fulfills the objectives as well is the pervious pavement. However there is a lack in maximizing the economic dimension. The filter and the trench have a similar output of their scores and thus, are majorly only maximizing the environmental objectives. Apart from that it can be seen, that the storm sewer is efficient in the economic and social goals but does not achieve any environmental goal.

A ranking among the measures which is the one fulfilling best the requirements for sustainable development can be presented:

1.) Extended detention basin
2.) Pervious pavement
3.) Sand filter + infiltration trench
4.) Storm sewer

Remarks, statement and arguments to and beyond this ranking are given in chapter 8.

8 Discussion

The assessment of the selected measures for Tehran gained crucial results. Four sustainable structural and one conventional stormwater measures were compared among each other and assessed for their contribution to sustainable development. The assessment leads to the following result and ranking: The extended detention basin contributes the most to sustainable development in stormwater management relative to the others. It maximizes the most all three objectives. Second best is the measure pervious pavement that fails to maximize the economic objectives compared to the extended detention basin. The other two sustainable structural measures, infiltration trench and sand filter, score for their maximum only in the environmental part. Remarkably is that the the storm sewer is maximizing social and economic dimension of sustainable development but not the environmental dimension and therefore fails in the concept of sustainable development. Analysing the scores it must be stated that the change in lifetimes and additional supply system did not have an effect on the ranking.

Regarding the assessment, also the weights assigned by the decision maker did not influence the output very much. Looking at the weight share the decision maker has distributed the weights evenly among the indicators. The indicator groundwater recharge and quality of water outflow are rated the highest weights, hence 10% each. All other indicators are weighted between 2 and 8%. This means that none of the 17 indicators has a great influence on the final result compared to the other indicators. The author would doubt if the real decision maker, hence the municipality of Tehran, decided like this. Probably the cost indicators would be assigned much higher and therefore would be major weights. Summing up it can be stated that the assigned distribution of the weights do not influence the final scores. In fact not the weights of the decision maker but the indicator values and the assigned score figure the crucial arguments for this ranking.

In fact the reason for this output deals with many advantages of the extended detention basin in comparison to the others. The extended detention basin is a simple, easy in operation and maintenance structural stormwater measure at low costs. It has a high level of amenity provision and good retrofit options. The basin meets the water quality as well as the water quantity targets though the groundwater is not recharged at the maximum value. In fact the extended detention basin achieves as high removal rates as the other structural measures though other literature than Middlesex University (2003) state that dry extended detention ponds have little removal capacity AMEC Earth and Environmental et al. (2001). Extended detention basins are best applied in residential areas as for example in the 22nd district of Tehran. The basins are designed to treat runoff from large catchment areas and hence are relative land consuming measures. If the extended detention basin is dimensioned for a large catchment area the stormwater supply system has to be considered too. This is why the scores are also calculated for the case when the construction of an extended detention basin includes the construction of a supply sewer network. And still this does not change the output of the assessment but actually maximizes the single dimensions even more equally.

Then the pervious pavement can be compared to the extended detention basin regarding their contribution to sustainable development in stormwater management. Overall the measure pervious pavement achieves good scores respectively. Pervious pavement is an efficient structural stormwater measure with low material and energy use as well as a second function as urban structure in the city. In comparison to the extended detention basin it is a measure placed directly at source and designed for small catchment areas. Therefore no supply system is needed. However regular maintenance is required to avoid system failure as the system robustness is comparably low. Furthermore the pervious pavement is not recommended for the removal of suspended solids by AMEC Earth and Environmental et al. (2001) though the stormwater runoff in the 22nd district of Tehran holds great concentrations of suspended solids. Therefore the measure might not be appropriate but the problem could be overcome with careful design and very regular maintenance.

At this point it must be noted that the capability for polluted stormwater was not taken as selection restriction on purpose. The stormwater pollutant concentrations in the 22nd district are very high because it is a residential area. But only one of the selected measures is said to cope with such high loadings. That is the extended detention basin. However the other three were also considered for the 22nd district because the capability with high pollutant concentrations is an issue highly dependent from the operation and maintenance. Operation and maintenance are therefore especially important for the measures infiltration trench, sand filter and pervious pavement because there are not necessarily designed for stormwater with high loads of suspended solids. The fact that operation and maintenance are that important for these three measures is issued in the indicator set. Apart from that, the capability for polluted stormwater was not a selection restriction because it would have limited the outcome of the study which does not seem trustable. Furthermore the decision maker are shown a range of measures which different characteristics in stormwater management for Tehran.

Coming back to the measures, another measure that is also not necessarily recommended for stormwater runoff with high pollutant concentrations is the infiltration trench. In the assessment the infiltration trench achieved low scores in economic sector. Compared to the extended detention basin it does not maximize the objectives equally for sustainable development. This may be because it is a measure that consumes a lot of land, thus uses a lot of energy and material and has high operational costs in comparison to the other four measures. It may also because it is a structural measure that fulfills the objectives of the stormwater management in Tehran but is prune for system failure and has relatively very low acceptance among stakeholders and decision makers.

The measure that gained similar assessment scores is the sand filter. The sand filter does not need a supply system and is recommended for hotspot runoff though the sand filter has relatively very high capital costs and the highest maintenance frequency. In addition the sand filter has low in basin conditions, high system failure rates and is not robust compared to the other measures.

The relatively bad result of the infiltration trench and the sand filter was not expected but the assessment of the storm sewer regarding sustainable development was expected. In comparison to the other measures the storm sewer gains high economic and social values but no environmental values. It can be argued now, that the storm sewer is somehow sustainable. Especially in comparison to the infiltration trench and sand filter this can be stated because their contribution to the economic value is very low, thus nearly zero. But in principal does not fulfill the objectives of sustainable development because all three dimensions must be represented by the measure. The storm sewer does not score in the environmental indicators but in the others instead. In fact storm sewers need little operation and maintenance, are not prune to failure and do not consume land for their construction in comparison to the other measures. Summing up it can be said that those measures should be suggested that fulfill the most the objectives at the same amount and time. This would be singularily the extended detention basin. However, a combination of two measures seems meaningful to suggest and implement. Therefore extended detention basin and pervious pavement would be suitable for effective sustainable stormwater management in the 22nd district of Tehran. Furthermore these two measures support each other or would work quite well together as the extended detention basin is designed for large and the pervious pavement for small catchment areas. Such combination of measures are also described as stormwater treatment trains and provide effective stormwater management (Auckland Regional Council, 2003).

8.1 Remarks

Besides the final result this study has actually two interim results: the sustainable structural stormwater measures appropriate for the site conditions in the 22^{nd} district of Tehran and the appropriate indicator set to describe those measures.

The sustainable structural measures are selected primarily regarding the climate. The findings are comparable to the findings of Caraco (2000) who prefers dry extended detention basins, sand filters and rooftop infiltration as stormwater management solutions for semi-arid and arid watersheds. Obviously, once implemented, the measures do not depend on their general ability to work but on the regular maintenance and operation. In addition also information campaigns, workshops and leaflets upon how to keep stormwater clean and at low quantity would help the general situation. Such measures are called non structural measures and are profound part of efficient sustainable stormwater management. These measures are most important as far as preventive measures are concerned. For instance educational aspects are already covered in the indicator set. Here the indicator describes if the measure can be possibly used as an educational demonstration site. This indicator belongs to the group of social indicators. The social, as well as the environmental and economic indicators shall describe the measures in the best possible way. Whether this has been fulfilled or not can only be stated upon implementation.

The selection of the indicators was a subjective process. Including all groups of stakeholders and decision makers in this selection would make the assessment more valid. Another important step would include the real assessment (e.g. by interviews of the public) and calculation with the real costs for Iran of all indicators on site in Tehran. This would make the outcome of this study more specific. In other words the indicators should fulfill the following criteria:

- Readily available
- High quality data
- Internationally comparable

This would make the assessment process much easier. Nevertheless the author tried to make the process as transparent as possible. This was done by setting subindicators and quantitative variables wherever possible. In the case of energy use the quantification of the indicator was the most difficult. But the author tried to assess the energy use in a logic way. Generally speaking the quantification of the indicator values was a rough estimation. This is because there is not enough information available upon the different indicators in literature, especially relevant to the Iranian situation. Assessing indicators was not very easy but through detailed description of the method the problem was tackled. Furthermore it is common knowledge that robust quantifiable sustainability criteria and indicators are missing because of the lack in evaluation of long-term performance, life-time costing and receiving water impacts (Middlesex University, 2003).

Overall it can be said that the outcome that is valid for the real decision makers is the methodology. The study showed which steps are needed for the selection of sustainable structural stormwater measures that contribute to sustainable development and how to prove and assess their contribution. In addition the indicator set provides all the information for the decision maker and the assessment gives an idea about the contribution to sustainable development of the stormwater measures.

8.2 Conclusion

Looking back to the initial point of the study it becomes clear that solving the stormwater problems is only possible through direct implementation of measures. However this study encompasses a methodology for decision makers which measures could prevent the negative impacts of stormwater and involve the concept of sustainable development. This result should represent the idea for future implementations.

The following concluding general remarks are given by the author:

- Indicator sets give a clear description of stormwater measures, especially in comparison to each other and in respect to the concept of sustainable development.
- The selection of objectives, criteria and indicators proves to be a well elaborated methodology in order to assess the success of measures.

The following concluding site specific remarks are given by the author:

- The assessment of the measures reveals the following sustainable structural stormwater measures for Tehran: extended detention pond and pervious pavement.
- A combination of measures designed for small and large catchment areas is suggested for the implementation in the 22nd district of Tehran.
- Before implementation all indicator values should be quantified with real calculated values and original data to specify the final scores of the assessment.
- Besides this the conventional storm sewer system cannot be dismissed totally of the stormwater management as it is needed for the supply of sustainable structural measures.

Finally it can be said that sustainable stormwater management is a new concept that tackles the negative impacts of stormwater caused by urbanization. The idea of sustainable development must be taken into account in all water related issues to preserve the quality as well as the quantity of fresh water resources for the next generation.

9 Summary

Tehran established itself as a megacity within the last two decades. However, infrastructure and especially the stormwater system has not kept pace with this continuing enormous development. Therefore it deems necessary to develop new stormwater measures. The aim of this study is to select structural stormwater measures relevant to the concept of sustainable development which suit the site conditions of the 22nd district of Tehran. The 22nd district of Tehran was chosen as study area because it is a semi urban district that should have a high population growth in future. Hence implementation of new structural measures is meaningful. Furthermore the selected measures are compared in respect to their contribution to sustainable development. This is done through assessment by indicators and assigned weights by the decision maker.

The first part of the thesis briefly introduces the terms stormwater, stormwater management, sustainable development and indicator. Furthermore sustainable stormwater management, its objectives and measures are described. An array of sustainable structural stormwater measures is presented that were found in the most common literature regarding sustainable stormwater management. These measures are compared with each other concerning their objectives in terms of water quality, water quantity and groundwater recharged. Apart from sustainable structural stormwater measures conventional measures are also taken into account. Therefore a storm sewer system is presented. In addition to these measures, tools are needed to assess the effectiveness of the measures. These tools are indicators which should describe the measures in detail and quantify their disadvantages and advantages concerning sustainable development.

One important part of the master thesis concerns the origin of the materials and a description of the methodology. The characteristics of the study area the 22nd district of Tehran are presented. The methodology comprises a process from the literature review to the assessment of the sustainable structural stormwater measures through appropriate indicators and valid for the 22nd district of Tehran. Therefore the intial results of the study includes sustainable structural stormwater measures that are appropriate for the 22nd district of Tehran. Extended detention basins, infiltration trenches, sand filters and pervious pavement are selected to be preferred stormwater measures for these climates. The selection is followed by a detailed description and a calculation of the dimensions and the costs for each measure. This was done in order to provide enough information for the indicators. The indicators were derived from a valid indicator set for sustainable stormwater management and are split into groups of economic, environmental and social criteria. In this study the measures are evaluated for their contribution to sustainable development through indicators. Thereafter all indicators assess the contribution to sustainable development for each measure with each indicator quantifing a single aspect of sustainable development. By applying the scoring method each indicator value is transformed into a score that states their contribution to sustainable development on a scale from 0 to 10. In addition, weights are assigned to each indicator by the decision maker. In this assessment, extended detention basins fulfills the most the concept of sustainable development as it maximizes the most equally the different dimensions. However, it is also suggested to implement the pervious pavement, as it scoring quite well compared to the extended detention basin and would work together quite well. The other two sustainable structural measures, infiltration trench and sand filter, have lacks in the economic and social objectives. Furthermore the storm sewer is lacking the environmental objectives totally. It can be argued to which extent a measure is still seen as sustainable or fails totally the concept.

The final part of this master thesis involves the discussion of the results. Sustainable structural measures for arid climates are well known. Appropriate indicator sets for sustainable stormwater management are, however not yet entirely agreed upon. The assessment of the selected measures revealed that the extended detention basin performs very well in theory with respect the concept of sustainable development and for the study area. An alternative is presented by pervious pavement that is primarily designed for small catchment areas. Thereafter a combination of measures might have a valuable effect on the current stormwater problems in Tehran. Furthermore the conventional system cannot be neglected totally as it provides stormwater supply for these measures. Overall it can be said that the process of selecting measures and indicators as well as their assessment provides a representative methodology for sustainable planning for stormwater management. In addition all important information is provided in the assessment and indicator sets for the decision makers as well as stakeholders. In respect to the detailed information needed for the indicators it is suggested to requantify the indicators on site before implementation. But nonetheless the results of this study can still be seen as generally valid data output.

10 Figures

11 Tables

12 References

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Appendix

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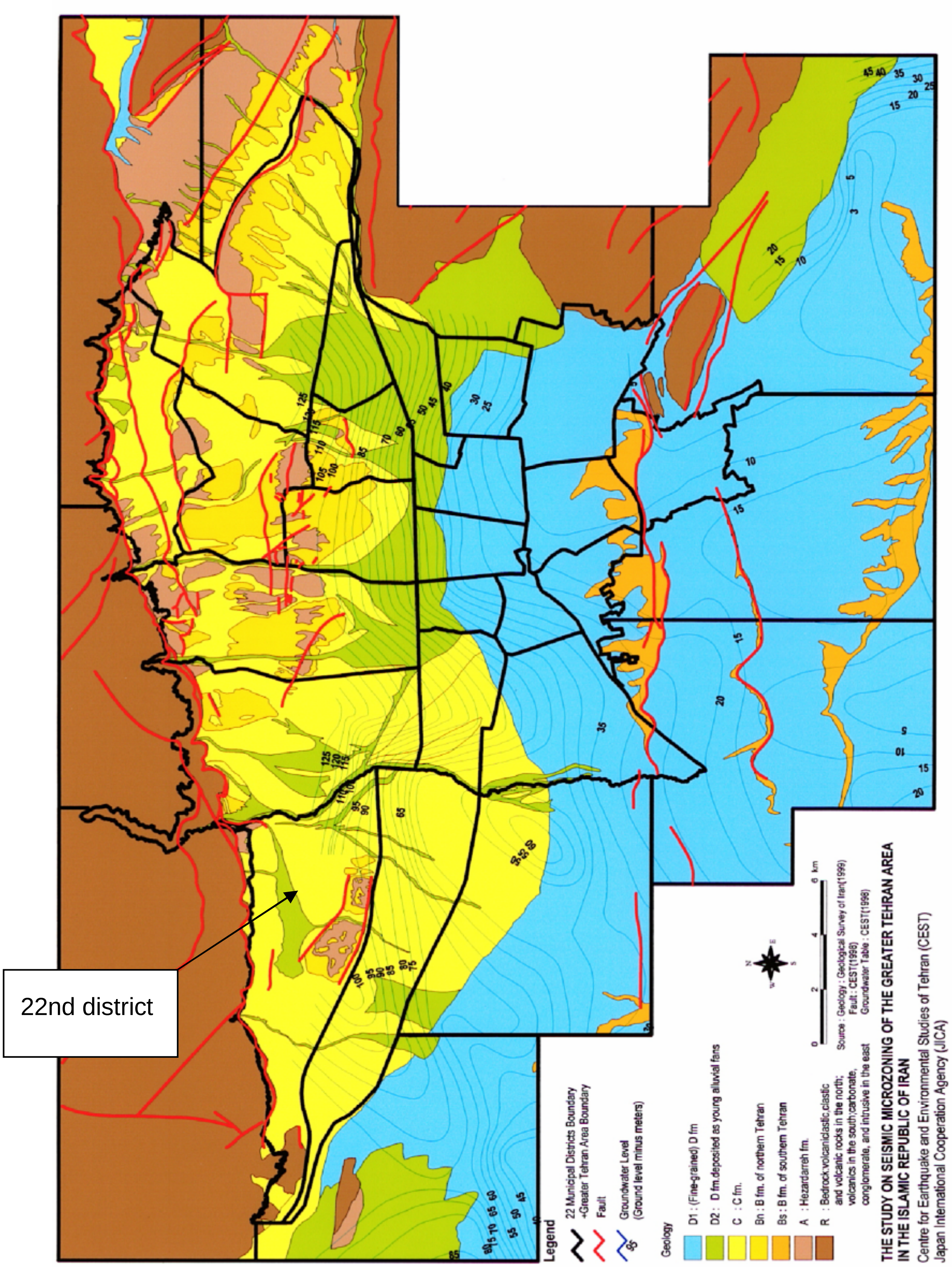
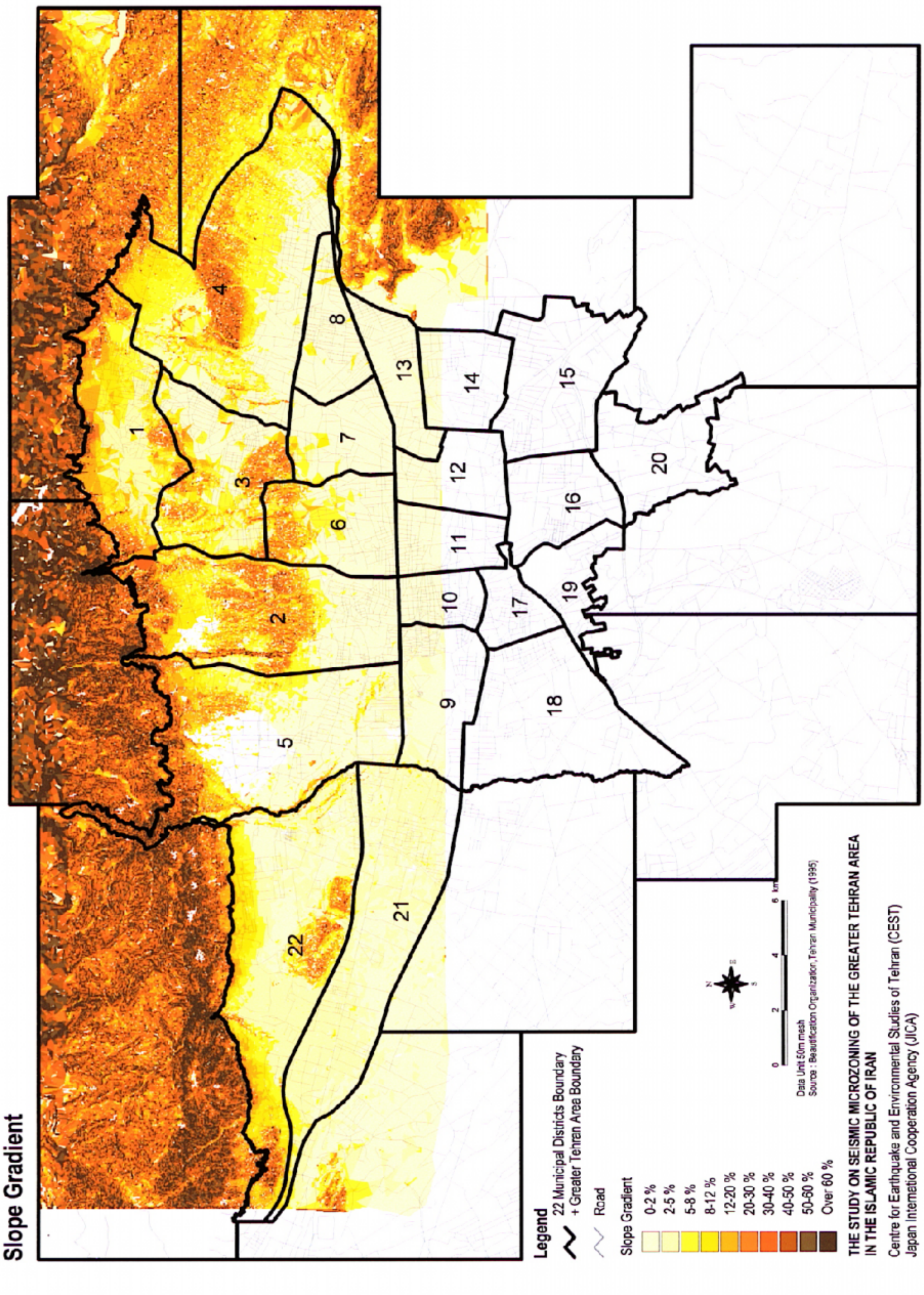
Appendix A: Maps

Geology and groundwater map (JICA et al., 2000)



Slope gradient map (JICA et al., 2000)



Appendix B: Design rain

I= $C_{ALT.RP}$ * D (-0,644)
I… Intensity [mm/hour]
D… Duraton of Rainfall [minutes]
C_{ALT*RP}…. Combined Altitude & Return Period Coefficient

Duration [minutes]	Intensity [mm/hour]	Intensity [m/h]
5	64,55571643	0,064555716
10	41,3115403	0,04131154
15	31,81768787	0,031817688
25	22,89802485	0,022898025
30	20,36129049	0,02036129
60	13,029927	0,013029927
88,8	10,12263175	0,010122632
90	10,03550454	0,010035505
97	9,562917104	0,009562917
120	8,338322064	0,008338322
150	7,222185137	0,007222185
180	6,422082712	0,006422083
240	5,335994194	0,005335994
300	4,621737762	0,004621738
420	3,721335663	0,003721336
540	3,16526304	0,003165263
660	2,781538615	0,002781539
1080	2,025566424	0,002025566
1440	1,68300708	0,001683007

Coefficients of generalized IDF for Return Period of 5 years

Altitude	Coefficients
900	123
1000	135
1100	147
1200	158
1300	170
1400	**182**
1500	194
1600	205
1700	217
1800	229
1900	240
2000	252
2100	264
2200	276
2300	287
2400	299
2500	311

Source: (Mahab Ghodds, 2009)

Appendix C: Calculation of measures

Extended detention basin

Calculation assessed due to design rule 24 hours detention, general layout adapted from Missa et al. (2005)

Catchment area	Ac [m²]		45000	Notes
Intensity of rainfall event	i [mm/hr]		1,7	
Duration of rainfall event	td [hr]	$TV = \frac{R * I * Ac}{1000}$	24	
Treatment volume	TV [m³]		727,1	
Storage volume	[m³]		727,1	
Impermeability Index	I [/]	$R = i * t_D$	0,4	
Design rainfall	R [mm]		1223,6	
Space required of catchment area eff.	[%]		2,5	
Area of the basin surface	Ab [m²]		450	
Ratio: Length/ Width	/		3,4	
Length of the basin surface	l [m]		34	L/ W = 3:1 recom.
Width of the basin surface	w [m]		10	
Depth of basin	d [m]		2,1	Max. 2.5m recom.
Land use of impervious catchment area	[%]		2,5	
Volume of ext.det.pond	[m³]		727,1	
Volume/ m³ treatment volume	[m³]		1,0	
Volume/ ha catchment area	[m³]		161,6	
Approx. design life	[yrs]		15	
Discount rate	rt[%]		4	
Reference period	t[yrs]		45	

Discount formula $$PV(C_t) = \frac{C_t}{(1 + r_t)^t}$$

	Construction cost [€]	Operation cost/ year [€]
m³ Extended Detention basin	727,1	727,1
€/ m³	50,0	1,0
Total construction costs	36353,0	727,1
€ Total construction costs/ ha catchment area	8078,4	161,6
Reference period/ Life time	45/15 years	
Reinvestment cost for 2. period (t=15)	4485,7	
Reinvestment cost for 3. period (t=30)	2490,7	
Total capital costs/ ha catchment area	15054,8	

€ Total construction costs/ ha catchment area	8078,4
Reference period/ Life time	50/ 25 years
Reinvestment cost for 2. period (t=25)	3030,4
Total capital costs/ ha catchment area	11108,8

Infiltration trench

Calculation adapted from Missa et al. (2005)

Catchment area	Ac [m²]		10000	Notes
Intensity of rainfall event	i [mm/hr]		10,0	
Duration of rainfall event	td [hr]	$TV = \frac{R * I * Ac}{1000}$	1,5	
Treatment Volume	TV [m³]		150,5	
Storage volume	[m³]		93,5	
Impermeability Index	I [/]	$R = i * t_D$	0,4	
Design Rainfall	R [mm]		15,1	
Area of the trench base surface	Ab [m²]		200	Approx. 2% of Ac
Ratio: Length/ Width	/		2	
Length of the trench base surface	l [m]		25	
Width of the trench base surface	w [m]		8	
Perimeter of trench	P [m]		66	
Infiltration coefficient of trench	K [m/h]		0,15	
Porosity of fill material	n [%]		0,3	30%
Duration of rainfall event	td [h]		1,5	
Land use of impervious catchment area	[%]		5,0	
Volume of infiltration trench	[m³]		311,6	
Volume/ m³ treatment volume			2,1	
Volume/ ha catchment area	[m³]		311,6	
Approx. Design life	[yrs]		15	
Discount rate	rt[%]		4	
Reference period	t[yrs]	$a = \frac{A_b}{P} - \frac{A_d.i}{P.K}$	45	
	a [m]	$b = \frac{P.K}{n.A_b}$	-7,1	
	b [/]		0,2	
	e [/]	$h_{max} = a.(e^{(-b.t_d)} - 1)$	0,8	
	h [m]		1,6	0.9-3.7m

Discount formula $PV(C_t) = \frac{C_t}{(1 + r_t)^t}$

	Construction cost [€]	Operation cost/ year [€]	
m³ Infiltration trench	311,6	311,6	
Cost/ m³	115,0	0,1	12.5%
Total construction costs	35836,6	4479,6	
Total construction costs/ ha catchment area	35836,6	4479,6	
Reference period/ Life time	45/15 years		
Reinvestment cost for 2. period (t=15)	19898,8		
Reinvestment cost for 3. period (t=30)	11049,1		
Total capital costs/ ha catchment area	66784,5		

Total construction costs/ ha catchment area	35836,6
Reference period/ Life time	50/ 25 years
Reinvestment cost for 2. period (t=25)	13442,9
Total capital costs/ ha catchment area	49279,5

Duration [hours]	Intensity [m/h]	a [m]	b [/]	e [/]	h[m]
0,08	0,06	-62,18	0,17	0,99	0,85
0,17	0,04	-38,70	0,17	0,97	1,05
0,25	0,03	-29,11	0,17	0,96	1,18
0,42	0,02	-20,10	0,17	0,93	1,34
0,50	0,02	-17,54	0,17	0,92	1,39
1,00	0,01	-10,13	0,17	0,85	1,54
1,50	**0,01**	**-7,11**	**0,17**	**0,78**	**1,56=MAX**
2,00	0,01	-5,39	0,17	0,72	1,52
2,50	0,01	-4,26	0,17	0,66	1,44
3,00	0,01	-3,46	0,17	0,61	1,35
18,00	0,00	0,98	0,17	0,05	-0,93
24,00	0,00	1,33	0,17	0,02	-1,30

Sand filter

Calculation adapted from AMEC Earth and Environmental et al. (2001)

Catchment area	Ac [m²]		10000	Notes
Intensity of rainfall event	i [mm/hr]		1,7	
	i [m/hr]		0,0017	
Duration of rainfall event	td [hr]	$TV = \frac{R * I * Ac}{1000}$	24	
Treatment volume = water quality volume (WQV)	TV [m³]		161,6	
	WQV [cu ft]		5703,4	
Storage volume	StV[m³]	$TV = WQ_V$ $St_V = 0{,}75 * WQ_V$	121,2	
Impermeability index	I [/]		0,4	
Design rainfall	R [mm]	$R = i * t_D$	40,4	
Area of the filter media surface	Af [sq ft]	$A_f = (WQ_V * d_f)/(k * (h_f + d_f) * t_f$	324,4	
	Af [m²]		30,2	
Average height of water above filter media	hf [feet]		3	
Design filter bed drain time	tf [day]		1,7	1.67
Depth of filter media	df [feet]		1,5	
Permeability of sand	K [foot/day]		3,5	3.5 ft/day
Porosity of fill material	n [%]		0,4	30-40%
Volume filter storage	Vf [cu ft]	$V_f = A_f * d_f * n$	193,9	
Volume above filter	Vf temp [cu ft]	$V_{f-temp} = 2 * h_f * A_f$	1946,3	
Volume sediment basin	Vs[cu ft]		2137,3	
Area of the sediment basin surface	As [sq ft]	$A_s = 0.066 * WQ_V$	376,4	

	As [m²]	35,0
Height of sediment basin	hfs [feet]	5,7
Land use of impervious catchment area	[%]	1,6
Volume of sand filter (including Vs and Vf temp)	[m³]	129,5
Volume/ m³ treatment volume	[m³]	0,8
Volume/ ha catchment area	[m³]	129,5
Approx. Design life	[yrs]	15
Discount rate	rt[%]	4
Reference period	t[yrs]	45

Discount formula $$PV(C_t) = \frac{C_t}{(1+r_t)^t}$$

	Construction cost [€]	Operation cost/ year [€]
m³ sand filter	13,7	
m³ above sand filter	55,2	
m³ stormwater treated	161,6	
Cost/ m³ stormwater treated	247,1	5%
m³ sediment basin	60,6	
Cost/ m³ sediment basin	50	
Total construction costs	42952,1	2147,6
Total construction costs/ ha catchment area	42952,1	2147,6
Reference period/ Life time	45/15 years	
Reinvestment cost for 2. period (t=15)	23849,8	
Reinvestment cost for 3. period (t=30)	13242,9	
Total capital costs/ ha catchment area	80044,8	

Total construction costs/ ha catchment area	42952,1
Reference period/ Life time	50/ 25 years
Reinvestment cost for 2. period (t=25)	16112,1
Total capital costs/ ha catchment area	59064,1

Duration [hours]	Intensity [m/h]	Treatment volume [cu ft]	Area of filter media surface [sq ft]
0,08	0,06	759,61	43,20
0,17	0,04	972,20	55,30
0,25	0,03	1123,16	63,88
0,42	0,02	1347,17	76,62
0,50	0,02	1437,51	81,76
1,00	0,01	1839,83	104,64
1,50	0,01	2125,52	120,89
2,00	0,01	2354,74	133,93
2,50	0,01	2549,43	145,00
3,00	0,01	2720,39	154,73
18,00	0,00	5148,18	292,81
24,00	**0,00**	**5703,37**	**324,39**

Pervious pavement

Calculation adapted from (Missa et al., 2005)

Catchment area	Ac [m²]		5000	Notes
Intensity of rainfall event	i [mm/hr]		22,9	
Duration of rainfall event	td [hr]	$TV = \frac{R * I * Ac}{1000}$	0,42	
Treatment Volume	TV [m³]		48,1	
Storage volume	[m³]		39,1	
Impermeability Index	I [/]	$R = i * t_D$	0,4	
Design Rainfall	R [mm]		9,6	
Area of porous surface	Ap [m²]		1250	
Infiltration coefficient of subbase material	K [mm/h]		40	
Total Area	At [m²]		6250	At/Ap=4/1 recom.
Porosity of fill material	e [/]	$d_p = \frac{t_d}{e}.(\frac{A_t}{A_p}.i - K)$	0,4	
Sub base depth (gravel layer)	dp [mm]		78,2	
	dp [cm]		7,8	
Land use of impervious catchment area	[%]		62,5	
Volume of pervious pavement	[m³]		97,8	
Volume/ m³ treatment volume	[m³]		2,0	
Volume/ ha catchment area	[m³]		195,5	
Approx. Design life	[yrs]		15	
Discount rate	rt[%]		4	
Reference period	t[yrs]		45	

Discount formula $$PV(C_t) = \frac{C_t}{(1 + r_t)^t}$$

	Construction cost [€]	Operation cost/ year [€]
m³ pervious pavement	97,8	97,8
Cost / m³	190	5%
Total construction costs	18576,0	928,8
Total construction costs/ ha catchment area	37151,9	1857,6
Reference period/ Life time	45/15 years	
Reinvestment cost for 2. period (t=15)	20629,2	
Reinvestment cost for 3. period (t=30)	11454,6	
Total capital costs/ ha catchment area	69235,7	
Total construction costs/ ha catchment area	37151,9	
Reference period/ Life time	50/ 25 years	
Reinvestment cost for 2. period (t=25)	13936,3	
Total capital costs/ ha catchment area	51088,3	

Duration [hours]	Intensity [mm/hour]	dp [cm]
0,08	64,56	5,89
0,17	41,31	6,94
0,25	31,82	7,44
0,42	**22,90**	**7,76=MAX**
0,50	20,36	7,73

1,00	13,03	6,29
1,50	10,04	3,82
2,00	8,34	0,85
2,50	7,22	-2,43
3,00	6,42	-5,92
18,00	2,03	-134,42
24,00	1,68	-189,51

Storm sewer

Calculation by Prandtl Colebrook and Kirpich Formula

Catchment area	Ac [m²]		45000	Notes
Intensity of rainfall event	i [mm/hr]		64,6	
Duration of rainfall event = Time of concentration	td [hr]	$TV = \frac{R * I * Ac}{1000}$	0,08	
Treatment Volume	TV [m³]		96,7	
Storage volume	[m³]		/	
Impermeability Index	I [/]	$R = i * t_D$	0,4	
Design Rainfall	R [mm]		5,4	
Drainage length	ld[m]	$lf = \sqrt{\Delta h^2 + l_D^2}$	300	Assessed google maps
Actual Flow length	lf[km]		0,3	
Slope gradient	G [%]		5	
Height difference	Δh[m]	$T_c = (0{,}868 * \left(\frac{l^3}{\Delta h}\right))^{0.385}$	15	
Tc	Tc[hr]		0,08	
Impervious area [e.g. 10 m wide road]	Ai [m²]		18000,00	
Length of sewers	l [m]		1800	
Profile of Sewers	[mm]		350	
Total runoff	[l/s]	322,8		
Land use of impervious catchment area			/	
Storm Sewer Length/ m³ treatment volume	[m]	18,6		
Storm Sewer Length/ ha catchment area	[m]	400,0		
Approx. Design life	[yrs]		45	
Discount rate	rt[%]		4	
Reference period	t[yrs]		45	

	Construction cost [€]	Operation cost/ year [€]
m sewer system	1800,0	1800,0
Cost/ m	241,0	1,0
Total construction costs	433800,0	1800,0
Reference period/ Life time	45/45 years	
Total construction costs/ ha catchment area	96400,0	400,0

Total capital costs/ ha catchment area	96400,0

Total construction costs/ ha catchment area	96400,0
Reference period/ Life time	50/ 50years
Total capital costs/ ha catchment area	96400,0

Appendix D: Indicator sets

Extended detention basin

INDICATOR	UNITS	RANGE/ CLASSES	VALUES	WEIGHTS	SCORES	PRODUCT
Probability of system failure	%	0-12.5, -25, -37.5, -50	0	0,05	10	0,5
Ease of retrofitting	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3x Yes	0,02	10	0,2
System robustness	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3x Yes	0,08	10	0,8
Frequency for operation and maintenance	Frequency/year	0-3, -6, -9, -12	2	0,06	10	0,6
Capital costs*	€/ ha catchment area	15055-35391, -55727, -76063, -96400 *(11109-32 432, -53755, -75078 -96400)*	15055 *(11109)*	0,08	10 *(10)*	0,8 *(0,8)*
Operational costs	€/ ha catchment area*year	160-1245, -2330, -3415, -4500	160	0,07	10	0,7
					SCORE for ECONOMICAL INDICATORS	**3,6 *(3,6)***
Groundwater recharge	% of attenuated stormwater	100-75, -50, -25, -0	30	0,1	1	0,1
Flooding attenuation in receiving waters	%	100-75, -50, -25, -0	100	0,05	10	0,5
Quality of water outflow	Average % removal rate	65-48, -32, -16, -0	50	0,1	10	1
Number of key species introduced	0,1….n	3, 2, 1, 0	3	0,03	10	0,3
					SCORE for ENVIRONMENTAL INDICATORS	**1,9 *(1,9)***
Level of amenity provision	Number	3x Yes, 2x Yes, 1x Yes, 0x Yes	3xYes	0,06	10	0,6
Use as demonstration site	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3xYes	0,04	10	0,4
Acceptance of onsite treatment	Subindicators	4x Yes, 3x Yes, 2x Yes, 1x Yes	4x Yes	0,06	10	0,6
In basin quality condition	Subindicators	0xYes, 1x Yes, 2x yes, 3x Yes	3x Yes	0,08	0	0
Material use for construction*	Total quantity/ ha catchment *year	8.7-15.9, -23.1, -30.3, -37.4 *(5.2-9.5, -13.8, -18.1, 22.4)*	16,2 *(9,7)*	0,03	5 *(5)*	0,15 (0,15)
Energy use for construction*	Energy quantity/ ha catchment*year	32-44, -56, -68, -80 *(21.2-27.8, -34.4, -41, -47.6)*	37,9 *(22,7)*	0,03	10 *(10)*	0,3 *(0,3)*
Land take	% of impervious catchment area	0-1.25, -2.5, -3.75, -5	2,50	0,06	5	0,3
					SCORE for SOCIAL INDICATORS	**2,35 *(2,35)***

*… influenced by life time 15 yrs *(25)* and reference period 45 *(50)*

Extended detention basin with storm sewer as drainage pipe

INDICATOR	UNITS	RANGE/ CLASSES	VALUES	WEIGHTS	SCORES	PRODUCT
Probability of system failure	%	0-12.5, -25, -37.5, -50	0	0,05	10	0,5
Ease of retrofitting	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3x Yes	0,02	10	0,2
System robustness	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3x Yes	0,08	10	0,8
Frequency for operation and maintenance	Frequency/year	0-3, -6, -9, -12	0	0,06	10	0,6
Capital costs*	€/ ha catchment area	15055-35391, -55727, -76063, -96400	15055+96400	0,08	0	0
Operational costs	€/ ha catchment area*year	160-1245, -2330, -3415, -4500	160	0,07	10	0,7
SCORE for ECONOMICAL INDICATORS						**2,8 *(2,8)***
Groundwater recharge	% of attenuated stormwater	100-75, -50, -25, -0	30	0,1	1	0,1
Flooding attenuation in receiving waters	%	100-75, -50, -25, -0	100	0,05	10	0,5
Quality of water outflow	Average % removal rate	65-48, -32, -16, -0	50	0,1	10	1
Number of key species introduced	0,1….n	3, 2, 1, 0	3	0,03	10	0,3
SCORE of ENVIRONMENTAL INDICATOR						**1,9 *(1,9)***
Level of amenity provision	Number	3x Yes, 2x Yes, 1x Yes, 0x Yes	3xYes	0,06	10	0,6
Use as demonstration site	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3xYes	0,04	10	0,4
Acceptance of onsite treatment	Subindicators	4x Yes, 3x Yes, 2x Yes, 1x Yes	4x Yes	0,06	10	0,6
In basin quality condition	Subindicators	0xYes, 1x Yes, 2x yes, 3x Yes	3x Yes possible	0,08	0	0
Material use for construction*	Total quantity/ ha catchment *year	8.7-15.9, -23.1, -30.3, -37.4 *(5.2-9.5, -13.8, -18.1, 22.4)*	16,2+8.7	0,03	1	0,03
Energy use for construction*	Energy quantity/ ha catchment*year	32-44, -56, -68, -80 *(21.2-27.8, -34.4, -41, -47.6)*	37,9+32	0,03	0	0
Land take	% of impervious catchment area	0-1.25, -2.5, -3.75, -5	2,50	0,06	5	0,3
SCORE for SOCIAL INDICATORS						**1,93 *(1,93)***
*… influenced by life time 15 *(25)* yrs and reference period 45 *(50)*						

Infiltration trench

INDICATOR	UNITS	RANGE/ CLASSES	VALUES	WEIGHTS	SCORES	PRODUCT
Probability of system failure	%	0-12.5, -25, -37.5, -50	50	0,05	0	0
Ease of retrofitting	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	1x Yes	0,02	1	0,02
System robustness	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	0x Yes	0,08	0	0
Frequency for operation and maintenance	Frequency/year	0-3, -6, -9, -12	6	0,06	5	0,3
Capital costs*	€/ ha catchment area	15055-35391, -55727, -76063, -96400 *(11109-32 432, -53755, -75078 -96400)*	66785 *(49280)*	0,08	1 *(5)*	0,08 *(0,1)*
Operational costs	€/ ha catchment area*year	160-1245, -2330, -3415, -4500	4 500	0,07	0	0
					SCORE for ECONOMICAL INDICATORS	**0,4 *(0,42)***
Groundwater recharge	% of attenuated stormwater	100-75, -50, -25, -0	100	0,1	10	1
Flooding attenuation in receiving waters	%	100-75, -50, -25, -0	100	0,05	10	0,5
Quality of water outflow	Average % removal rate	65-48, -32, -16, -0	58,5	0,1	10	1
Number of key species introduced	0,1….n	3, 2, 1, 0	1	0,03	1	0,03
					SCORE for ENVIRONMENTAL INDICATORS	**2,53 *(2,53)***
Level of amenity provision	Number	3x Yes, 2x Yes, 1x Yes, 0x Yes	1x Yes	0,06	1	0,06
Use as demonstration site	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3x Yes	0,04	10	0,4
Acceptance of onsite treatment	Subindicators	4x Yes, 3x Yes, 2x Yes, 1x Yes	1x Yes	0,06	0	0
In basin quality condition	Subindicators	0xYes, 1x Yes, 2x yes, 3x Yes	0x Yes	0,08	10	0,8
Material use for construction*	Total quantity/ ha catchment *year	8.7-15.9, -23.1, -30.3, -37.4 *(5.2-9.5, -13.8, -18.1, 22.4)*	37,4 *(22,4)*	0,03	0 *(0)*	0 *(0)*
Energy use for construction*	Energy quantity/ ha catchment*year	32-44, -56, -68, -80 *(21.2-27.8, -34.4, -41, -47.6)*	79,4 *(47,6)*	0,03	0 *(0)*	0 *(0)*
Land take	% of impervious catchment area	0-1.25, -2.5, -3.75, -5	5	0,06	0	0
					SCORE for SOCIAL INDICATORS	**1,26 *(1,26)***
*… influenced by life time 15 yrs *(25)* and reference period 45 *(50)*						

Sand filter

INDICATOR	UNITS	RANGE/ CLASSES	VALUES	WEIGHTS	SCORES	PRODUCT
Probability of system failure	%	0-12.5, -25, -37.5, -50	50	0,05	0	0
Ease of retrofitting	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	1xYes	0,02	1	0,02
System robustness	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	0x Yes	0,08	0	0
Frequency for operation and maintenance	Frequency/year	0-3, -6, -9, -12	12	0,06	0	0
Capital costs*	€/ ha catchment area	15055-35391, -55727, -76063, -96400 *(11109-32 432, -53755, -75078 -96400)*	80045 *(59064)*	0,08	0 *(1)*	0 *(0,08)*
Operational costs	€/ ha catchment area*year	160-1245, -2330, -3415, -4500	2150	0,07	5	0,35
					SCORE for SOCIAL INDICATORS	**0,37 (0,45)**
Groundwater recharge	% of attenuated stormwater	100-75, -50, -25, -0	100	0,1	10	1
Flooding attenuation in receiving waters	%	100-75, -50, -25, -0	100	0,05	10	0,5
Quality of water outflow	Average % removal rate	65-48, -32, -16, -0	48,75	0,1	10	1
Number of key species introduced	0,1….n	3, 2, 1, 0	1	0,03	1	0,03
					SCORE for ENVIRONMENTAL INDICATORS	**2,53 *(2,53)***
Level of amenity provision	Number	3x Yes, 2x Yes, 1x Yes, 0x Yes	1x Yes	0,06	1	0,06
Use as demonstration site	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3x Yes	0,04	10	0,4
Acceptance of onsite treatment	Subindicators	4x Yes, 3x Yes, 2x Yes, 1x Yes	2x Yes	0,06	1	0,06
In basin quality condition	Subindicators	0xYes, 1x Yes, 2x yes, 3x Yes	3xYes	0,08	0	0
Material use for construction*	Total quantity/ ha catchment *year	8.7-15.9, -23.1, -30.3, -37.4 *(5.2-9.5, -13.8, -18.1, 22.4)*	13,9 *(8,4)*	0,03	10 *(10)*	0,3 *(0,3)*
Energy use for construction*	Energy quantity/ ha catchment*year	32-44, -56, -68, -80 *(21.2-27.8, -34.4, -41, -47.6)*	36,3 *(21,8)*	0,03	10 *(10)*	0,3 *(0,3)*
Land take	% of impervious catchment area	0-1.25, -2.5, -3.75, -5	1,6	0,06	5	0,3
					SCORE for SOCIAL INDICATORS	**1,42 *(1,42)***
*… influenced by life time 15 yrs *(25)* and reference period 45 *(50)*						

Pervious pavement

INDICATOR	UNITS	RANGE/ CLASSES	VALUES	WEIGHTS	SCORES	PRODUCT
Probability of system failure	%	0-12.5, -25, -37.5, -50	50	0,05	0	0
Ease of retrofitting	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	2x Yes	0,02	5	0,1
System robustness	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	0x Yes	0,08	0	0
Frequency for operation and maintenance	Frequency/year	0-3, -6, -9, -12	6	0,06	5	0,3
Capital costs*	€/ ha catchment area	15055-35391, -55727, -76063, -96400 *(11109-32 432, -53755, -75078 -96400)*	69236 *(51088)*	0,08	1 *(5)*	0,08 *(0,4)*
Operational costs	€/ ha catchment area*year	160-1245, -2330, -3415, -4500	1900	0,07	5	0,35
SCORE for ECONOMICAL INDICATORS						**0,83 *(1,15)***
Groundwater recharge	% of attenuated stormwater	100-75, -50, -25, -0	100	0,1	10	1
Flooding attenuation in receiving waters	%	100-75, -50, -25, -0	100	0,05	10	0,5
Quality of water outflow	Average % removal rate	65-48, -32, -16, -0	65	0,1	10	1
Number of key species introduced	0,1….n	3, 2, 1, 0	1	0,03	1	0,03
SCORE for ENVIRONMENTAL INDICATORS						**2,53 *(2,53)***
Level of amenity provision	Number	3x Yes, 2x Yes, 1x Yes, 0x Yes	2x Yes	0,06	5	0,3
Use as demonstration site	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	3x Yes	0,04	10	0,4
Acceptance of onsite treatment	Subindicators	4x Yes, 3x Yes, 2x Yes, 1x Yes	3x Yes	0,06	5	0,3
In basin quality condition	Subindicators	0xYes, 1x Yes, 2x yes, 3x Yes	0x Yes	0,08	10	0,8
Material use for construction*	Total quantity/ ha catchment *year	8.7-15.9, -23.1, -30.3, -37.4 *(5.2-9.5, -13.8, -18.1, 22.4)*	13,3 *(5,2)*	0,03	10 *(10)*	0,3 *(0,3)*
Energy use for construction*	Energy quantity/ ha catchment*year	32-44, -56, -68, -80 *(21.2-27.8, -34.4, -41, -47.6)*	35,2 *(21,2)*	0,03	10 *(10)*	0,3 *(0,3)*
Land take	% of impervious catchment area	0-1.25, -2.5, -3.75, -5	0	0,06	10	0,6
SCORE for SOCIAL INDICATORS						**3,0 *(3,0)***
*… influenced by life time 15 yrs *(25)* and reference period 45 *(50)*						

Storm sewer

INDICATOR	UNITS	RANGE/ CLASSES	VALUES	WEIGHTS	SCORES	PRODUCT
Probability of system failure	%	0-12.5, -25, -37.5, -50	0	0,05	10	0,5
Ease of retrofitting	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	0x Yes	0,02	0	0
System robustness	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	2x Yes	0,08	5	0,4
Frequency for operation and maintenance	Frequency/year	0-3, -6, -9, -12	0	0,06	10	0,6
Capital costs*	€/ ha catchment area	15055-35391, -55727, -76063, -96400 *(11109-32 432, -53755, -75078 -96400)*	96400 *(96400)*	0,08	0 *(0)*	0 *(0)*
Operational costs	€/ ha catchment area*year	160-1245, -2330, -3415, -4500	1 000	0,07	10	0,7
					SCORE for ECONOMICAL INDICATORS	**2,2 (0)**
Groundwater recharge	% of attenuated stormwater	100-75, -50, -25, -0	0	0,1	0	0
Flooding attenuation in receiving waters	%	100-75, -50, -25, -0	0	0,05	0	0
Quality of water outflow	Average % removal rate	65-48, -32, -16, -0	0	0,1	0	0
Number of key species introduced	0,1….n	3, 2, 1, 0	0	0,03	0	0
					SCORE for ECONOMICAL INDICATORS	**0 *(0)***
Level of amenity provision	Number	3x Yes, 2x Yes, 1x Yes, 0x Yes	0x Yes	0,06	0	0
Use as demonstration site	Subindicators	3x Yes, 2x Yes, 1x Yes, 0x Yes	0x Yes	0,04	0	0
Acceptance of onsite treatment	Subindicators	4x Yes, 3x Yes, 2x Yes, 1x Yes	2x Yes	0,06	1	0,06
In basin quality condition	Subindicators	0xYes, 1x Yes, 2x yes, 3x Yes	0x Yes	0,08	10	0,8
Material use for construction*	Total quantity/ ha catchment *year	8.7-15.9, -23.1, -30.3, -37.4 *(5.2-9.5, -13.8, -18.1, 22.4)*	8,7 *(12)*	0,03	10 *(5)*	0,3 *(0,15)*
Energy use for construction*	Energy quantity/ ha catchment*year	32-44, -56, -68, -80 *(21.2-27.8, -34.4, -41, -47.6)*	32 *(28,8)*	0,03	10 *(5)*	0,3 *(0,15)*
Land take	% of impervious catchment area	0-1.25, -2.5, -3.75, -5	0	0,06	10	0,6
					SCORE for SOCIAL INDICATORS	**2,06 (1,76)**
*… influenced by life time 45 yrs *(50)* and reference period 45 *(50)*						