UNESCO-IHE
INSTITUTE FOR WATER EDUCATION

Development of Stormwater Management Strategies in Tel Aviv, by Application of City Water Balance Model to Describe Material Flows

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SWITCH

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Master of Science Thesis
by

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Dedicated to my late beloved brother; Ezekiel
Whose memories I will forever cherish

Abstract

Urban water systems in most cities are currently faced with pressures amongst them being water scarcity where demands from external water sources almost equal supply capacity. There is therefore a need to make more use of the total water resources available to urban areas. The alternative approach to the exploitation of these resources is the consideration of stormwater and wastewater as potential water resources, an idea that is being promoted by the emergent paradigm of integrated urban water management through the consideration of water supply, stormwater and wastewater concurrently as components of the total urban water cycle. This research is a build up on previous research work by Hoang (2008) and aims to develop and measure by the use of sustainability indicators strategies to turn the stormwater into a resource for Tel Aviv city. City Water Balance, an all systems model with a one day time step is used in MFA for the urban catchment of Tel Aviv. Stormwater flow rates and quality are determined from a representative sub catchment of Tel Aviv, at a selected location. These measurements are used to calibrate the model. For a storm event with a rainfall amount of 18mm and storm duration of 3 hrs the average discharge is 4623 m^3/day. Stormwater quality parameters analyzed included; EC, major ions (NH_3-N, NO_3-N, Ca, Na, K, Cl, HCO_3, SO_4 and Mg) and trace elements (Pb, Cu, Al, PO_3-P, Si, Fe and Ba). Pollutant loads were calculated and the order for trace elements was as follows; Si > Fe > Al > P > Pb > Ba > Cu. Further, parameters were assessed for general characteristics as well development of relationships between runoff and concentrations. For the majority of the stormwater samples the order of concentration of the major elements was as follows; HCO_3 > Cl > SO_4 >NO_3-N and Na > Ca > Mg > K (mg/l). From the pollutant and hydrograph, the peak of concentrations of some major ions as well as for some traces elements appeared to precede that of the flow rate. The model predicted stormwater flow rates of 16 MCM/yr. proposed stormwater management systems are then modelled to demonstrate the effectiveness of the systems in pollutant load removal, reduction in stormwater flow from Tel Aviv catchment as well as reductions in mains water demand. Evaluation by sustainability indicators was also done. The management systems consisted of; permeable pavements, mixing of stormwater with sewage while incorporating decentralized tanks, rainwater harvesting tanks, constructed wetlands, aquifer recharge and porous pipe retrofits. Systems were found to significantly reduce mains water demand e.g constructed wetlands; 23%, raintanks; 19% constructed wetlands; 23%, and decentralized tanks; 17%. They were also effective in runoff reduction e.g constructed wetlands; 23%, raintanks; 48%, decentralized tanks; 30% and permeable pavements; 10%. On the other hand pollutants removal efficiencies varied depending on type of pollutant, e.g Constructed wetlands had 100% efficiency for most pollutants, while permeable pavements had 15, 8 & 22% for P, Cu & Pb respectively. In conclusion, strategies were proposed for implementation in order of; constructed wetlands, raintanks, decentralized tanks and permeable pavements. Further assessment of ground recharge was recommended.

Keywords: Stormwater, Strategies, Material Flow Analysis, City Water Balance

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List of Abbreviations

EF	ratio between mean concentration of runoff parameters and in rainfall
CM	cubic meter
CW	constructed wetlands
CWB	City Water Balance
IGUDAN	Dan regional association for environmental infrastructure
Imp ha	Impervious area measured in hectares
km	kilometer
m^3	cubic meter
MCM	million cubic meter
MFA	material flow analysis
NWC	national water company
POS	public open space
PS	pervious space
Sis	sustainability indicators
SWITCH	Sustainable water management improves tomorrow's cities' health
WWTP	wastewater treatment plant
WW	wastewater

1.0 INTRODUCTION

1.1 Background

Global environmental changes have significant implications on global hydrological regimes and water resources. Urban populations dramatically alter materials and energy fluxes within the affected areas with resulting concomitant changes which then impact on urban waters and their aquatic ecosystems, and result in their degradation.

Urban water systems serve to provide water supply to meet demand, proper sanitation and drainage services. For cities all over the world these systems are currently faced with global change pressures, escalating costs and other risks. Amongst the pressures is water scarcity where demands from external water sources almost equal supply capacity. There is therefore a need to make more use of the total water resources available to urban areas. The emergent paradigm of integrated urban water management promotes the consideration of water supply, stormwater and wastewater concurrently as components of the total urban water cycle. One way to achieve this goal is by quantifying the water balance of the whole urban water cycle since it provides a greater understanding of the inputs and outputs of water from the urban catchment. Tel Aviv a city whose major water issue is water scarcity could benefit from this approach.

Previous research work on Tel Aviv has established the city water balance as well as the possible changes that can be expected based on climate change, population growth and further urbanization. The stormwater flow was calculated to be 20 Million Cubic Meter (MCM) per year, which is equal to about 45% of the total water demand in the city (Duong 2008). It is believed that capturing this flow and turning it into a resource could improve the overall sustainability of the urban water system. This research will therefore build up on previous research work by Hoang (2008) and aims to develop and measure by the use of sustainability indicators strategies to turn the stormwater into a resource for the city. This research is being conducted under SWITCH which is a five year action research programme and has its vision based on the sustainable urban concept and aims to bring a change in urban water management away from the existing ad hoc solutions towards more coherent and integrative approaches. It is co-funded by the European Commission and implemented by a cross-disciplinary team of 33 partners and 13 cities in 15 countries around the world. Tel Aviv is one of the 13 cities selected by SWITCH for carrying out its research.

City Water Balance model, a relatively new strategic tool that is currently being developed by Ewan Last a PhD student at the University of Birmingham within the SWITCH urban water research programme, shall be employed. It is developed to allow for a structured system analysis and assessment of the water quantity and quality within the urban water system.

1.2 Case description and problem statement

Tel Aviv city is situated in the coastal plain of Israel and has a Mediterranean climate, with a dry summer and a rainy season from October to April (see Figure 1.1). The annual precipitation is 530 mm. The city has an area of 51.8 km^2.

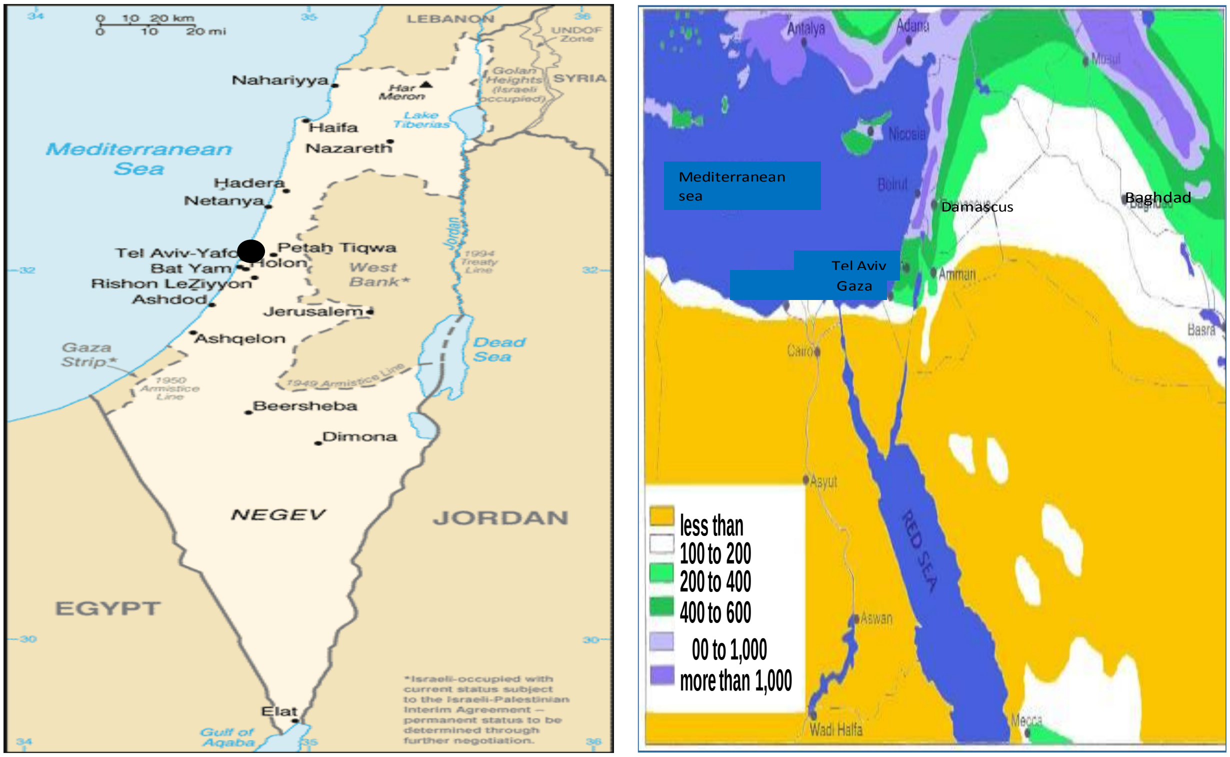


Figure 1.1 The study area, Tel Aviv city and broad picture of rainfall patterns in Israel

[*Source:* http://geography.about.com/od/findmaps/ig/Country-Maps/Israel-Map.htm ; Mekorot NWC]

Tel Aviv is the largest, most populous city in the metropolitan area of Gush Dan and as well the main commercial, industrial, tourist and cultural centre of Israel. It is considered to be a financially stable city, with a population of over one million arriving to the city on each working day. The city is an extension of the old Yafo. It is over 100 years old and is governed by Tel Aviv-Yafo municipality (Tel Aviv Yafo Municipality, 2007).

The annual population growth rate is lately 2.2%. Total population is estimated to 390,400 inhabitants for an area of municipal jurisdiction of 51.76 km^2 with a high population density of 7200 persons/km^2. Total number of household's is 161,500 households (average persons/household is 2.2) (Switch, 2006a; Tel Aviv Yafo Municipality, 2007).

The dominating material used for constructing most buildings is concrete. Roofs consist of concrete slabs, tar and tiles. For recreation there are two parks; one on the eastern part and another on the northern part along the Yarqon river, each having an area of 2 Km^2. The average daily traffic flow is approximately 500,000 vehicles (Tel Aviv Yafo Municipality, 2007; Wikipedia).

Like most cities in developed countries and more so in arid regions population growth and urbanization has been characterized by increased water demand and negative impacts on the renewable water resources. Total Average water demand in Tel Aviv is 48MCM. With demand nearing supply capacity Tel Aviv is faced with looming water shortages (Tel Aviv Yafo Municipality, 2007).

Sources of water for Tel Aviv are mainly surface water, coastal and mountain aquifer and sea water desalination. Surface water is mainly from Lake Galilee which is fed by River Jordan. All this sources supply water through the Mekorot National Water Carrier (NWC). In addition, Tel Aviv municipality has its own operated local wells. 85% of the water demand is met by water supplied by the NWC. Before supply the water undergoes treatment measures to comply with the WHO Drinking Water Standards (Mekorot NWC).

The coastal plain aquifer, considered to be the most important aquifer in Israel is rapidly deteriorating. Its water volume and quality have been depleted and deteriorated, respectively, over the past 50 years. Enhanced urbanization, taking place during the past decade in the coastal plain (Tel Aviv being one of the coastal cities) is likely to enhance these processes (Asaf, 2004). Among the main contaminants that are contributing to the aquifer deterioration in Tel Aviv are; chrome and trichloroethylene from industries, and nitrate mainly from cesspits ((Jackman, 2010). Further, over pumping from the wells causes sea intrusion leading to increased salinity. There has been a gradual shut down of wells with 11 wells being shut down in 2006 due to nitrate increment, hence reducing the amount of water supplied from the local sources (see Figure 1.2). Since the contamination and closure of the wells started sustainability is not a characteristic of water sources within the city (Jackman, 2010).

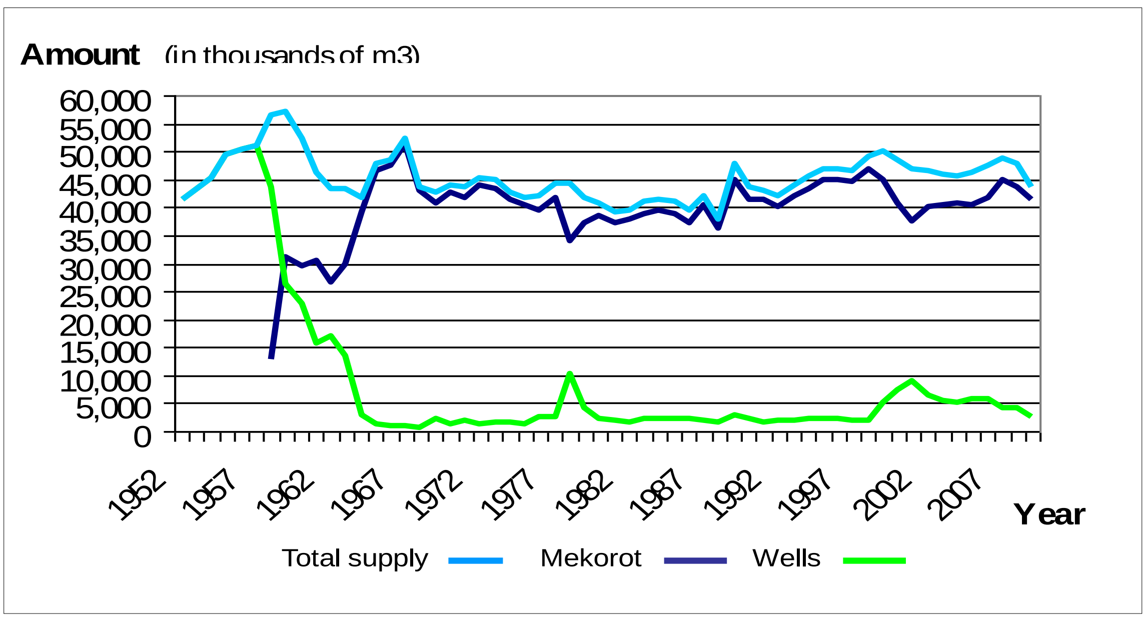


Figure 1.2 Water supply to Tel Aviv Yafo

[*Source:* Jackman, 2010]

The external water sources from which Tel Aviv mainly relies are faced with pressures owing to increased demands and climate change effects. Further, the recycling waste water systems do not contribute to water for re use within the city.

Wastewater from Tel Aviv is handled by Shafdan Wastewater Treatment Plant (WWTP) situated in Reshion Lezion city, south of Tel Aviv city. The plant serves a population of about 2 million people and treats approximately 370,000 m^3/day Tel Aviv contributes an average 80,000 m^3/day. Effluent from the treatment plant undergoes a reclamation process by the application of SAT technology through an extensive system which includes production wells, transmission lines and supporting systems, it is then supplied to the south for agricultural purposes. Reclaimed water is therefore not re used in Tel Aviv city.

Tel Aviv experiences storm events during winter from which considerable amounts of run off develops (see Figure 1.3). The increased volumes of stormwater are currently being channelled to the sea via expensive drainage systems with no prior treatment. Additionally Tel Aviv municipality has no monitoring system or research to evaluate the amount of stormwater as well as the quality generated from the city. Previous studies estimated the amount of stormwater runoff to be 20 MCM per year (Duong 2008).

Figure 1.3 Road and pavement runoff during a storm event

Tel Aviv's severe water shortages require a thorough examination of stormwater quality and an evaluation of its reuse, rather than its drainage.

Some of the ways in which Israel and Tel Aviv in general deals with water shortage crisis are through reduction of the water demand and enlargement of water supply resources through development of new water sources.

In Tel Aviv municipality the responsibility to manage urban water systems is fragmented, making integration of stormwater management strategies challenging. SWITCH creates and forges a stronger link between research institutions, state, government departments and local municipalities which represents a significant paradigm shift in the management of urban water systems in Tel Aviv.

1.3 Research Questions

- Is there a significant amount of runoff generated from the urban catchment of Tel Aviv?
- What are the constituent runoff quality parameters and there characteristics?
- What are the benefits associated with stormwater reuse within the city?

1.4 Research Hypothesis

By use of a model stormwater quantity and quality from an urban catchment can be predicted. The model is an all systems, has a one day time step and its concepts are based on previous integrated urban water system models i.e. Aqua Cycle and UVQ (Urban Volume and Quality).

1.5 Research Objectives

It is from the foregoing case description that the research objectives were formulated with the overall objective of developing stormwater management strategies for Tel Aviv.

The Specific objectives were as listed below;

- To carry out a physical characterization of the urban area
- To calibrate the City Water balance model by measuring stormwater flow rates and pollutant loads at selected sea/river outfalls.
- To assess stormwater quality at the selected locations through identification and characterization of major elements (Temp, pH, EC, NH_3-N, NO_3-N, Ca, Na, K, Cl, HCO_3, SO_4 and Mg) and trace elements (Pb, Cu, Al, PO_3-P, Si, Fe and Ba).
- By use of the model to identify and evaluate potential stormwater management measures the city could take.
- To assess the effect of different stormwater management measures on the sustainability of the system, as measured by sustainability indicators

2.0 LITERATURE REVIEW

2.1 Urban Centers in Perspective

Amongst land use activities in the world, urbanization is the fastest growing. It has been reported that for the first time in centuries, over 50% of the world's population currently live in urban areas of both developed and developing countries (United Nations, 2008). The result of this land use changes are numerous consequences, amongst them being water scarcity pressures, where demands from external water sources almost equal supply capacity (Mitchell, 2006). A good example are the six Australian state capital cities, which in 2006 faced water restrictions, affecting an estimated 70% of the Australian population of 21 million people (Fletcher, et al., 2008). Similar shortages face parts of Africa, China, Singapore, the USA, Israel, and Europe (Niemczynowicz, 1996; Vlachos and Braga, 2001).

In addition to the increased water demand, these expansions also lead to changes in land use and dramatic alteration of material and energy fluxes with resulting concomitant changes which then impact negatively on the environment. Evidences of these environmental impacts include; escalated flood risks due to increase in overland flow, polluted surface and groundwater, modification of the urban climate and increase in water and energy usage (Centgraf, 2005)

On the whole, the increasing sizes, density and heterogeneity call for massive efforts for managing water supply, waste water and stormwater systems. Indeed, it is rather apparent that urgent decisions must be made in regard to such overriding freshwater problems as increasing demands for the water users, changes in physical environment altering the water balance, and the disposal of wastes that might contaminate surface waters and groundwater both at local and regional levels. At a city scale this problems can be addressed within the Local Authorities, since local authorities are believed to be important actors in the transition towards sustainable development. They are among other things responsible for spatial planning, environmental planning, and supervision of various industrial activities, waste management and provision of services (Lindqvist et al., 2004; Maksimovic and Tejada-Guibert, 2001).

2.2 Urban Water Systems and Effects of Urbanization

An important component of any urban area, be it a city or regional centre, is the water system, providing water supply, sanitation and drainage services to its inhabitants (Mitchell, 2006). In industrialized countries these three are an integrated part of the urban planning and services to citizens.

Urban drainage systems are needed in these developed urban areas because of the interaction between human activity and the natural water cycle. The interaction has two main forms; abstraction of water from the natural cycle to provide water supply for human life and the covering of land with impervious surfaces that divert rainwater away from the local natural system of drainage. These interactions give rise to two types of water that require draining;

Wastewater

This is water that has been supplied to support human life, and satisfy the needs of industry. After use it requires to be properly drained in order to avoid pollution and health risks.

Stormwater

This is rainwater or water resulting from any form of precipitation that has fallen on a built up area. The changes in land use in urban areas have been associated with an increase in surface runoff which in most urban centres the surface runoff is drained through separate or combined sewers (Butler and Davis, 2004; Nix, 1994). Basically, these changes to hydrology are well documented and are related to two factors: (i) The proportion of the catchment, which is made up of impervious surfaces and (ii) the hydraulic efficiency of flow paths from these impervious areas to receiving waters. Urbanization is believed to result in a decrease in the lag time between rainfall and runoff and an increase in peak flow, with the greatest proportional increase occurring for the smaller, more frequent events (because in any case, for larger events, pervious areas become saturated and begin to produce runoff) (Wong et al., 2000).

Land changes not only affect the stormwater quantity but also affect the quality. Pollutants in run off are mainly discharged from various sources, which Choe et al. (2002) and Allen et al. (2000) referred to as non point sources. A number of investigators have found various kinds of pollutants as well as significant levels of pollutant loads. The concentration and the load of such pollutants are closely related to the land use type of the catchment and the rainfall condition. Further, sewers are prone to overflowing and leakages especially during the wet seasons. In extreme cases groundwater in urban areas is greatly impaired by the quality and quantity of the recharging water and the stormwater quality precludes its further use (Butler and Davis, 2004: Nix, 1994).

Urban areas are classified into; pavements (including roads, parking lots and airports), roofs, residential areas, commercial areas, industrial areas, parks and lawns, and open undeveloped areas. All of these classes generate stormwater of different quality; as established by Choe et al. (2002) while characterising surface runoff from urban areas in Korea (see Table 2.1 and 2.2). Typical values and ranges of pollutant concentrations and loads have been given by Ellis (1986) and are presented in table 2.3. According to Choe et al. (2002) and (Mikkelsen, 1994) the surface runoff generated in residential, commercial and industrial zones in urban areas is highly likely to contain hazardous materials such as oil components and heavy metals as well as floating materials. For industrial areas, the quality of stormwater is highly dependent on the type of industry and site conditions. In heavy-industrial areas the pollutants are in high concentrations, while for light industries the levels of concentration are lower and compare with those of commercial areas. While continuing with this line of research, Smith et al. (2000) added that, parking areas, roads and gas stations are known to contribute hydrocarbons, oxides of nitrogen, sulphur, lead and at some places salt de-icing (halite), all of which are vehicle related. Further, previous studies by Shinya et al. (2000) have shown that there is a correlation between vehicle density and high levels of pollution on major arterial roads.

On the other hand, stormwater from residential areas is often of high quality. However, sometimes it is characterized by pollutants; including detergents, plant related nutritional

materials and fertilizers, herbicides and insecticides. While some authors consider roofing to produce clean water, occurrences of high concentrations of heavy metals have been recorded depending on roofing material. Wash-offs from old painted structures in both residential and commercial areas is the main contributors of lead in stormwater and as such roof runoff can be an important source of trace pollutants (Asaf et al., 2004; (Davis, 1999); (Gromaire-Mertz, et al., 1999).

Table 2.1 EMC of stormwater runoff from urban areas (Unit: mg/l)

Constituents		BOD	COD	SS	TKN	TP	Cr	Cu	Pb	Fe
Residential	Multi.	76.2	211.2	145.8	4.46	1.21	0.051	0.077	0.426	3.910
	Sing.	125.3	226.0	414.1	6.81	2.85	0.044	0.099	0.189	5.930
	Com.	168.8	501.4	276.1	14.08	1.88	0.028	0.060	0.102	6.020
	Avg.	**123.4**	**312.9**	**278.7**	**8.45**	**1.98**	**0.041**	**0.079**	**0.239**	**5.286**
Industrial	Metal	58.8	118.4	88.3	4.40	2.60	0.067	0.044	0.157	3.473
	Food	34.2	71.7	90.7	3.60	1.30	0.080	0.045	0.085	3.903
	Textile	36.1	50.0	139.8	7.20	1.90	0.054	0.020	0.079	3.900
	Avg.	**43.0**	**80.0**	**106.3**	**5.07**	**1.93**	**0.067**	**0.036**	**0.107**	**3.759**
Entire Avg.		**83.2**	**196.5**	**192.5**	**6.76**	**1.96**	**0.054**	**0.058**	**0.173**	**4.523**

[*Source:* Choe et al., 2010]

Table 2.2 Pollutant loading rates from residential and industrial zones (Unit: kg/ha/yr)

Constituents		BOD	COD	SS	TKN	TP	Cr	Cu	Pb	Fe
Residential	Multi.	582	1,614	1,114	34.1	9.2	0.39	0.59	3.26	29.89
	Sing.	958	1,728	3,165	52.1	21.8	0.34	0.76	1.44	45.33
	Com.	1,290	3,833	2,111	107.6	14.4	0.21	0.46	0.78	46.02
	Avg.	**943**	**2,392**	**2,130**	**64.6**	**15.1**	**0.31**	**0.60**	**1.83**	**40.41**
Industrial	Metal	449	905	675	33.6	19.9	0.51	0.34	1.20	26.55
	Food	261	548	693	27.5	9.9	0.61	0.34	0.65	29.83
	Tex.	276	382	1,069	55.0	14.5	0.41	0.15	0.60	29.81
	Avg.	**329**	**612**	**812**	**38.7**	**14.8**	**0.51**	**0.28**	**0.82**	**28.73**
Entire Avg.		**636**	**1,502**	**1,471**	**51.7**	**15.0**	**0.41**	**0.44**	**1.33**	**34.57**

[*Source:* Choe et al., 2010]

Table 2.3 Pollutant event mean concentrations and unit loads for stormwater

Parameter	***EMC (mg/l)***	***Unit load kg/imp ha.yr***
Total suspended solids (TSS)	21 - 2582 (190)	347 - 2340 (487)
Biological oxygen demand ($BOD_{5)}$)	7 - 22 (11)	35 - 172 (59)
Chemical oxygen demand (COD)	20 -365 (85)	22 - 703 (358)
Ammonia cal nitrogen	0.2 - 4.6 (1.45)	1.2 - 25.1 (1.76)
Total nitrogen	0.4 - 20 (3.2)	0.9 - 24.2 (9.0)
Total phosphorus	0.02 - 4.30 (0.34)	0.5 - 4.9 (1.8)
Total lead	0.01 - 3.1 (0.21)	0.09 - 1.91 (0.83)
Total Zinc	0.01 - 3.68 (0.30)	0.21 - 2.68 (1.15)
Hydrocarbons	0.09 - 2.8 (0.4)	-
Faecal coli forms	400 - 50,000 (6430) (MPN/100ml)	0.9 - 3.8 (2.1) $*10^9$ counts/ha

[*Source:* Ellis, 1986]

Composition and concentration of pollutants in stormwater runoff from a city is usually dependent on the characteristics of various catchment sub-divisions, pollutant wash-off potentials, the features of a storm event and the dry and wet atmospheric depositions (Gobel, 2006). The size of a catchment and percentage of impervious areas determines the timing of the concentrations and flow peaks (Lee et al., 2002). During individual storms the concentrations of pollutants varies temporarily. It is rather obvious that during small rainfall events most runoff and pollutant quantities come from impervious areas that are directly connected. However, as the rainfall deepens then non-paved areas become significant contributors. It is interesting to note that a temporal pattern of pollutant concentrations in stormwater drains that could be identified as flush and dilution effects has been identified (Ben-Othman et al., 1997). Such temporal patterns of pollutant concentrations are well documented. In a study on quality of roof runoff Zobrist et al. (1999) observed that, most constituents in stormwater runoff such as major ions, nutrients, heavy metals and pesticides appear in high concentrations in the first minutes or first tenths mm of runoff depth. With increasing time or runoff depth, concentrations decrease exponentially to a nearly constant level. Asaf et al. (2004) while investigating chemical and isotopic composition of urban water observed that samples collected during the first event in the season or at the beginning of each storm event give higher concentrations than those in the subsequent events or in the following samples within the same event. Further, Lee and Bang (2000) while comparing stormwater runoff flow to pollutant concentrations by analyzing combined pollutant concentrations and runoff graphs established that, depending on catchment land use types, pollutant concentrations peak usually occurs or is immediately followed by the runoff flow peaks (see Figures 2.1 & 2.2).

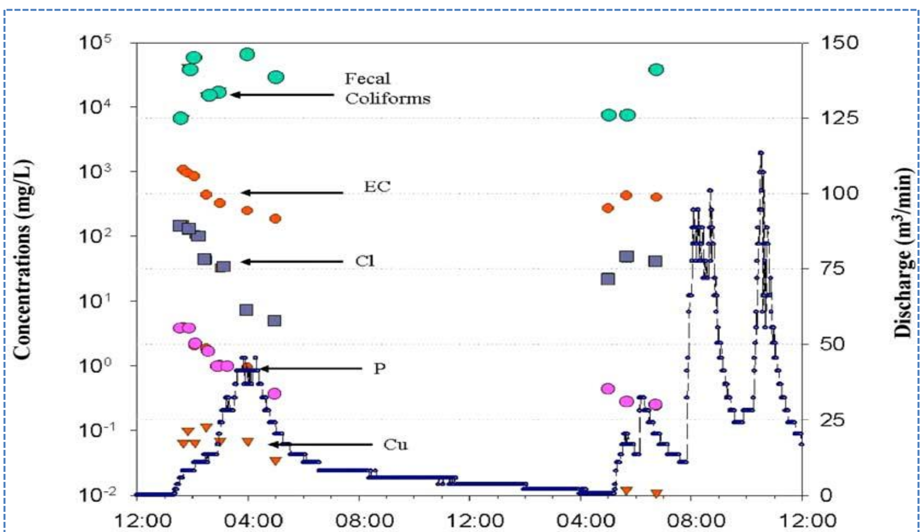


Figure 2.1 Stormwater discharge (line) and temporal variations in fecal coliforms (cfu/100 ml), EC (ms/cm), and Cl, P and Cu (mg/l)

[*Source:* Asaf et al., 2010]

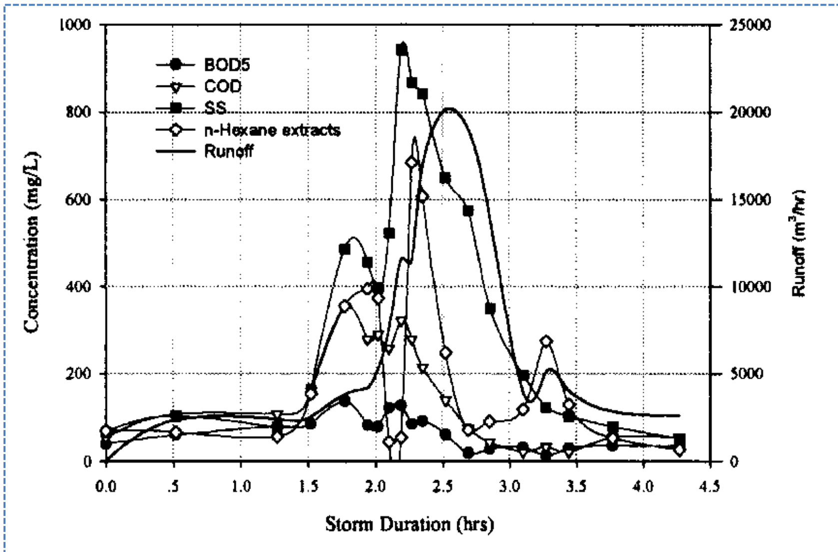


Figure 2.2 Stormwater discharge (line) and temporal variations in BOD, COD,SS and n-hexane (mg/l)

[*Source:* Lee and Bang, 2000]

2.3 Integrated approaches - role of municipalities & tools used

Currently municipal drainage and sanitary systems are increasingly being perceived as resources that need to be exploited rather than unavoidable by-products of urbanization. Planning and operating the systems separately sees a foregone potential for utilization of urban stormwater and wastewater for beneficial purposes, and disregards the fact that these systems are inter-connected and interrelated. The issue of pollution has also become important and has seen treatment facilities being integrated into the system in an effort to preserve the integrity of the receiving aquatic ecosystem (Makropoulos et al., 2008; Rauch et al., 2005).

The challenge today is to move from the individual considerations of a system performance to an integrated management of the urban drainage which consists of the sewer system, the wastewater treatment plant and the receiving water. In order to re-orientate urban areas towards sustainability, it is recognized that the different aspects of urban water systems should be viewed in relation to each other, which requires the adoption of an integrated approach to urban water system planning, provision and management. In this case then integrated approaches to urban stormwater drainage management are being increasingly advocated as necessary for advancing more sustainable and holistic management of urban water environment, and are developed based on the principles of integrated urban water management (Mitchell, 2006; Rauch et al., 2005).
Mitchell (2004) summarizes the principles of integrated urban water management as follows;
- Consider all parts of water cycle, natural and constructed, surface and sub–surface, recognizing them as an integrated system.
- Consider all requirements for water, both anthropogenic and ecological
- Consider the local context, accounting for environmental, social, cultural and economic perspectives.
- Include all stakeholders in the process

- Strive for sustainability, balancing for environmental, social and economic needs in the short, medium and long term.

The proper success of the integrated approach in stormwater drainage requires numerical tools to predict the behaviour of the complete system under historical and future scenarios (Rauch et al., 2005). One such numerical tool suggested by researchers as well as municipal and national policy-makers is substance flow analysis (SFA) or material flow analysis (MFA). From a perspective of municipal environmental management, MFA can provide important quantitative and qualitative knowledge on the regional metabolism of different substances that support management strategies in municipalities. An MFA may help to identify hot spots for action to reduce environmental loads (Lindgvist et al., 2004).

Amongst the approaches adopted in integrated management of the urban drainage system are source control techniques. Mitchell (2006) identifies a broad range of tools that are employed within IUWM to include but not limited to; water conservation and efficiency; water sensitive planning and design, utilization of non–conventional water sources including roof runoff, stormwater, grey water and wastewater; the application of fit–for–purpose principles; stormwater and wastewater source control and pollution prevention; stormwater flow and quality management; the use of mixtures of soft (ecological) and hard (infrastructure) technologies; and non–structural tools such as education, pricing incentives, regulations and restriction regimes.

2.4 Rationale for harvesting stormwater runoff

Brown and Davies, 2007; Coombes and Mitchell, 2006 stated that; while there are several potential alternative water supplies that may help to address water shortages, such as recycling of wastewater or desalination of sea water, the harvesting and treatment of urban runoff has the advantage of higher public acceptance than wastewater recycling. Indeed in some cities the amount of stormwater generated is comparable to a significant percentage of demand. For example, Mitchell et al. (2003) showed that in three major Australian cities - Brisbane, Melbourne, and Sydney the annual stormwater discharged (from separate stormwater sewer systems) was similar to their total water demand (of which 50% is for non potable uses). Duong (2008) stated that Tel Aviv produces runoff of 20 MCM per annum equivalent to 45% of water demand in the city. An increasing recognition of the impacts of unmitigated urban runoff is the other key driver for harvesting of stormwater (Fletcher et al., 2008). The effects of urbanization to a catchment's hydrology are well documented and have been discussed in detail in section 2.2.1 of this study.

Even though the basis for harvesting stormwater runoff for the purposes of supplementing drinking water as well as protecting the receiving environment are quite explicit and strong, re use of stormwater still remains overlooked in many cities. An example of such cities is Tel Aviv, Israel. Among the reasons for this could be; the perceptions that such stormwater harvesting systems are expensive to implement and have limited economic benefits. The other reason may be the lack of technology and facilities already in place, relative to other components of the urban water management systems.

2.5 Source control techniques in stormwater harvesting

Butler and Davis (2004) recognizes that some cities in different parts of the world are moving towards making better use of natural drainage mechanisms. In countries like the US and others, this is better known as 'Best Management Practices' BMPs, while in the UK since mid-1990s the term has been SUDS (Sustainable Urban Drainage Systems or Sustainable Drainage Systems). The techniques developed are rather source oriented and integrative and basically concentrate on stormwater. They can be either structural or non-structural. Structural BMPs are made up of four main components: collection, treatment, storage, and distribution, which may also play a role in flood protection (see Figure 2.3).

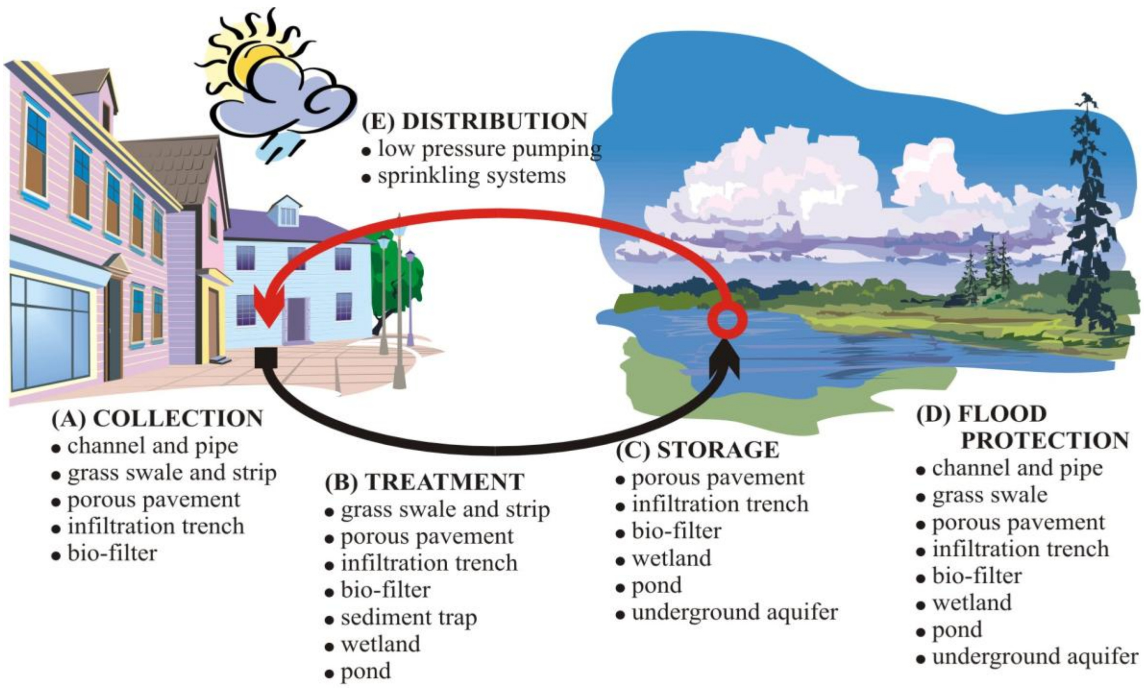


Figure 2.3 Main components of urban stormwater harvesting systems

[Source: Fletcher et al., 2008]

Research into SUDS from the urban water cycle management perspective shows that, significant economic, social and environmental benefits to the community may be derived from more efficient use of water resources and infrastructure. Traditional stormwater treatment systems have been retrofitted, or new systems have been built for harvesting. Australia is a leading example due primarily to its severe long-term drought. In the last few years, the practice has increasingly been supported by the authorities as a valuable alternative water resource (Brown and Clarke, 2007). In other countries; the UK, Sweden, Japan and the USA examples of SUDS technique adopted are porous pavements, with new porous pavements registering infiltration capacities of > 4500 mm/h (Newton et al., 2003; Pratt et al., 1995). On the aspect of water quality, research has shown that where the pavement is used for car parking, any oils dropped on and washed into the structure by the stormwater could be degraded (Pratt, 1999). Treatment efficiencies of around 80, 65 and 60% for total suspended solids, total P, and total N respectively, and around 85 and 75% for hydrocarbons and metal reductions respectively have been recorded (Pagotto et al., 2000; Pratt et al., 1995).

2.6 Substance flow analysis - methodology

Substance Flow Analysis (SFA) or Material Flow Analysis (MFA), originally developed by Baccini and Brunner (1991) is an analytical tool that can be used in regional environmental management. It can provide a holistic picture of physical flows of resource use and loss through a given region in a specific period, and examines all material/substance inflows, outflows, and stocks through each process in the economy (Seelsaen, et al., 2007).

The specific goals of the different SFA studies differ somewhat. However, in general, the goal is to obtain knowledge and understanding of the metabolism of a certain group of substance(s) within a given system. An SFA can focus on stocks and flows of, for instance, trace elements in a region, or focus on stocks and flows of a substance in relation to a certain product. An MFA takes place in three stages; initially there is a phase of defining the system and system components to be studied, secondly, the stocks and flows of the substance(s) studied are identified and quantified, and in the third phase, the quantitative results are interpreted in accordance with the purpose of study, for instance regarding the potential to decrease the magnitude of a certain flow or regarding the environmental impact of the flows studied (Lindqvist et al., 2004).

2.6.1 Categories and Indicators for Interpretation in SFA

The interpretation in SFA is normally dependent upon the specific perspective from which a particular SFA study is performed. However there are documented suggestions for frameworks for the interpretation of results in SFA. Two examples of frameworks can be identified; a set of SFA indicators by van der Voet et al. (2000) called chain management. The indicators are related to flows and stocks on the environment as well as in the economy and flows between environment and economy. Lindqvist-Ostblom (1995) and Lindqvist and Eklund (2001) proposed a tentative framework which supports the interpretation of quantitative data on stocks and flows into more policy oriented or management oriented information; for example by analyzing the function of a substance in society and the capacity to influence the flows and stocks of substances (Table 2.3).

Table 2.4 Framework of Categories and Indicators for SFA analysis

Categories and Indicators	Meaning
Category 1: Quantities	Comparison of magnitude of stocks and flows of the substance. Tells something about the potential of future pollution problems and indicates resource aspects of the substance
Environmental accumulation	The increase of a certain environmental stock over the year/period
Category 2: Exposure to humans and the environment	Related to where in the system and within what time scale a flow occurs
Concentration	The concentration of a substance in an environmental compartment - a translation of the substance stock
Daily Intake	The average daily intake of the substance by humans

[Source: adopted from Lindqvist et al., 2004]

2.6.2 Substance Flow Analysis Application in Urban Water

The Urban Water Cycle provides a good conceptual and unifying basis for Substance Flow Analysis in which an assessment is carried out of how selected substances are moving through the systems and where they remain: in the receiving waters, in the sewage or in the air. Results from these studies can be used for creating inventories for urban water. In such studies the major components of the urban hydrological cycle are assessed for certain time periods. Effects of short term variability's of the system are avoided by ensuring that study time durations exceed time constants of the system under study (Marsalek et al., 2008)

Numerous literature contains examples of SFA tools (models) which by addressing such issues as; verification of pathways in the cycle, quantifying flows and fluxes of sediments and chemicals along the pathways, assessing component variations, and assessing impacts of climatic, population and physiographic changes on the Urban Water Cycle helps establish and quantify changes within the Urban Water Cycle. One such tool is SIMBOX, a computer programme which was used in a case study to evaluate Material Flow Analysis of copper associated with the stormwater runoff pathway in the upper Parramatta River Catchment, Sydney, Australia. The evaluation was carried out with an aim of showing the significance of stormwater pollution, a non point source, in the contamination of the river. The system boundary was defined and processes grouped as per land use categories. Within this catchment the main sources of copper in the stormwater runoff were identified as; fertiliser, rainfall, roots killer, copper trace element, water supply and brake pad wearing from traffic. A baseline scenario for the MFA model was run in order to show the amount of copper load in the stormwater runoff from the catchment. Total flow of copper in stormwater was found to be 61tonnes/yr. Further, a stormwater treatment system was modelled to demonstrate the effectiveness of the system in copper removal. The treatment system consisted of compost which was used as a filtration medium and was found to remove dissolved copper up to 1330 g Cu/kg compost. It was also observed that both compost and sand are able to retain copper bound on particulate matter such that the system achieves a treatment efficiency of 90%, hence removing the majority of the dissolved and particulate copper in stormwater. In conclusion, it can be said that through the MFA of copper, it was possible to view the treatment in the context of the total urban water system (from the anthropogenic to the receiving environment). Also it was shown that treatment systems can remove the majority of copper (heavy metals) thus protecting the receiving environments (Marsalek et al., 2008; Seelsaen et al., 2007).

In this study, CWB a model which provides useful approaches to performing SFA calculations will be applied to identify important sources of contaminants, their flow paths (anthropogenic or natural) of some trace metals, major ions and physical parameters associated with stormwater runoff in the urban catchment of Tel Aviv as well as design management options.

Management options will be proposed and their impacts on water balance and contaminant fluxes evaluated by use of CWB. Some of the categories and indicators for interpretation and assessment of water management strategies results are the sustainability indicators previously suggested by Duong (2008).

2.7 City Water Balance Model

2.7.1 Introduction

City Water Balance model is under development by Ewan Last, a PhD student at the University of Birmingham as part of the SWITCH project under theme 1.2 "Integrated Modelling and Decision Making for Urban Water Management" which is under the urban water paradigm shift theme 1. Its concepts are based on previous integrated urban water system models, Aqua cycle and UVQ (Urban Volume and Quality) it however differs significantly with these models in that it incorporates cost and energy as part of the model.

2.7.2 Complete urban water cycle and associated contaminants

Urban Water Cycle which is as a result of the modification of the Hydrologic Cycle due to influences and interventions of human activities operates mainly on two main systems; rainfall-drainage system and supply-wastewater system. The rainfall – drainage system consists of naturally occurring processes; interception, depression storage, soil infiltration, evaporation, interflow, soil drainage and pervious surface runoff, which occur alongside the introduced process; pipe infiltration and ex-filtration, illegal stormwater inflow, and impervious surface runoff. Additionally the drainage network has been modified to include concrete channels, culverts, and underground pipes. On the other hand the supply-wastewater system is simpler and consists of an artificial water conveyance system constructed to deliver water to the urban centres and remove wastewater produced (Mitchell, 2005).

Historically these two systems were planned and operated separately and as such the current research is dominated by detailed modelling of the subcomponents of the total water system, particularly the inter-connectedness and interaction between the potable water supply- waste water discharge network, and the rainfall-stormwater runoff network which are rarely considered within the same framework of modelling. The quantification of urban water and contaminant balance as well as the detailing of flow paths and contaminant concentrations within the urban water system facilitates the understanding of the impacts of the interaction of water with the urban area (Decker et al., 2000).

City Water Balance serves to analyze and simulate the water flow through existing urban water systems from source to discharge point, including water use by the commercial (including municipal uses) and industrial sectors for a given time interval through the application of the principle of mass conservation. Water balance outputs are also necessary for the analysis of mass flows of contaminants through the urban water system. All stages in the passage of water through the urban water cycle including water supply, wastewater production and stormwater runoff system are all accounted for in the modelling approach.

2.7.3 Water flow processes within the model

The modelling cycle starts with water entering the system as precipitation or (fresh) water that is imported from catchment areas outside the city in order to meet the indoor and outdoor water use requirement. It then goes through the system and exits as wastewater, stormwater or evapotranspiration. Changes in storage within the system are calculated by use of state of the

water stores. As such the mapping of contaminants in the model coincides directly with the mapping of the water flows. Other processes represented in the model are; interceptions, depression storage, soil infiltration, interflow, and soil drainage. Pervious surface runoff (after saturation) occurs alongside other introduced processes of pipe infiltration and exfiltration, unplanned stormwater inflow, and impervious surface runoff. Inputs into the stormwater drainage network are not only from rainfall but also include contributions from the reticulation system through outdoor water use and wrong connections (see Figure 2.4).

Imported water commonly leaks into the ground water, or is applied to parks and gardens as well as being used indoors for residential, commercial, industrial and municipal purposes. The wastewater disposal system receives inputs from unplanned stormwater inflow and infiltration of soil moisture in to the pipe work in addition to waste water from indoor water use (Eiswith et al., 2004). Sewer overflows and pipe leakage (exfiltration) are termed as outflows (Mitchel, 2001).

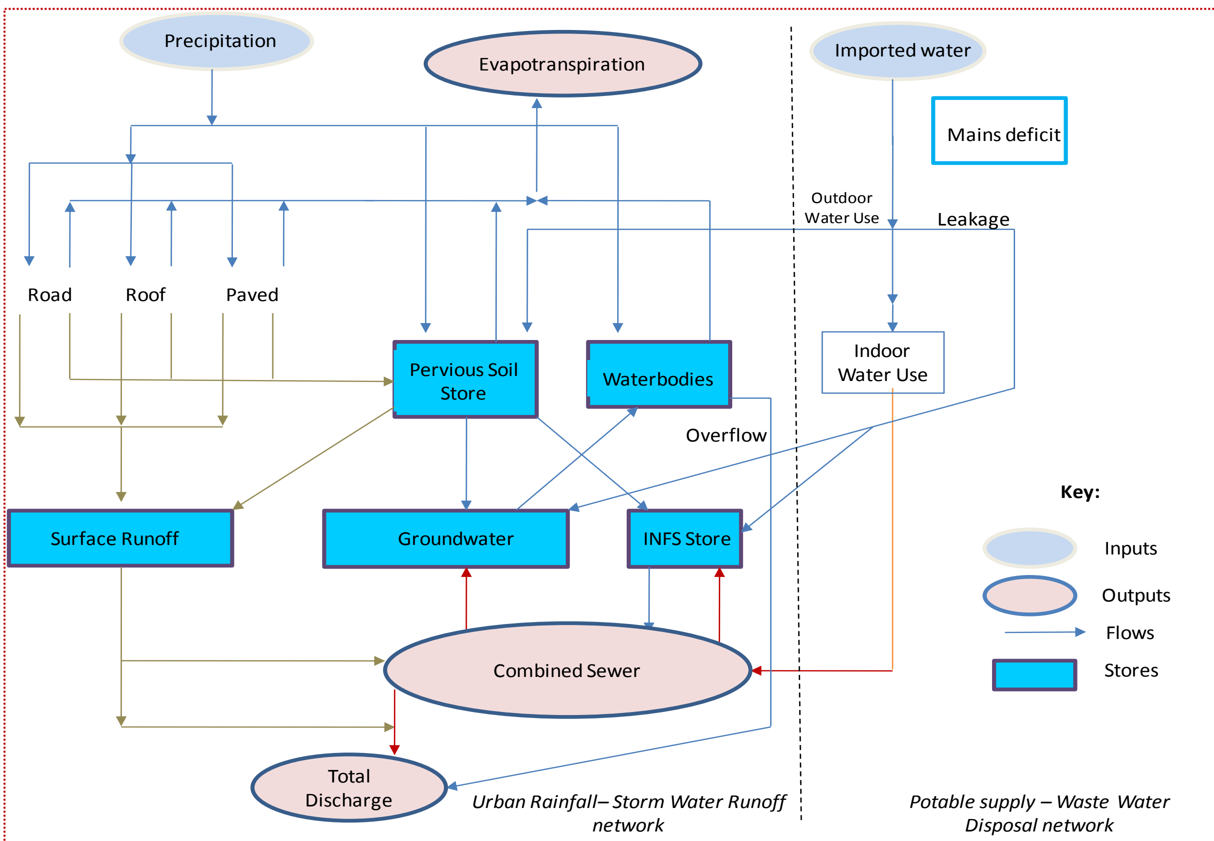


Figure 2.4 Schematic representation of the UWC (Stocks and Flows)

[Source: adopted from CWB Manual, 2010]

2.7.4 Model Application

The model is of use in assessing a range of alternative water management options in response to future scenarios by demonstrating how each option differs in its effect on both water and contaminants within the urban water system, as well as the associated cost and energy, and hence help decision makers choose sustainable water management strategies using sustainability

indicators. It is therefore a requirement for the source of contaminants, their flow paths, and the sinks to be identified as well as quantification of the contaminant load. Contaminant loads are expressed as event mean concentrations. For the calculation of loads the associated flow volumes are required. Linking the water and contaminant balances usually allows for the effects of the changes in water supplies and disposal options to be identified for the water flows and mass loads.

2.7.5 Spatial Scales in CWB

The appropriate spatial resolution for modelling stormwater and wastewater schemes is determined by the scale at which they operate. These scales are the basis for input and output of data for simulation. CWB uses three nested spatial scales namely; unit blocks, miniclusters, and catchment (study area). The choice of the spatial scales is based on the level at which water management options operate.

Unit blocks - These are generic units of land representing the various land use types within the cityscape. Examples are; residential blocks, industrial blocks and hotels. Each unit has certain attributes. Fundamental attributes are; pervious/impervious proportions, water demand profiles and pollutant input loads. It represents the smallest scale at which the water management operations can be managed. Modelling the unit block allows cumulative effect of individuals' action; stormwater and wastewater use at unit block scale to be on the whole catchment (Mitchell, 2005). Figure 2.5 shows a unit block based on UVQ model.

Mini cluster scale - These are large parcels constructed by assigning a number of unit blocks to them, all with identical attributes. Mitchell (2005) also refers to them as local neighbourhoods or suburb and can be used within the model to represent the spatial scale at which community water servicing are managed. Sub-catchments are at a larger scale and contain one or more mini-clusters. The boundaries of the sub-catchments are determined by the sewer stormwater network.

It is important to note that large roads and public open spaces (POS) can be represented by large area unit blocks with appropriate impervious proportions and water demand profile.

Study area - This is the entire catchment.

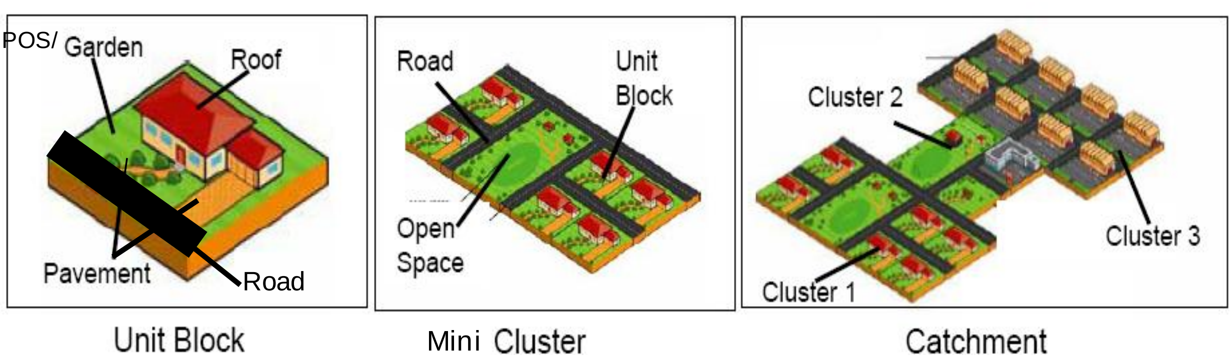


Figure 2.5 Spatial scales in CWB

[*Source:* adopted from Mitchell, 2005]

2.7.6 In put Data

CWB requires input data for each miniclusters and associated unit blocks within the study site, which can be highly specific to the study site or generic depending on the user requirements and data availability. Each unit block scale has certain attributes. Fundamental attributes are pervious/impervious proportions, water demand profiles and pollutant input loads. Physical characteristics are described by both calibrated and measured parameters.

As previously mentioned water demand input is based on land use. It is split in to four distinct generic uses and for each of these the demand per functional unit must be specified. An exception to this split usage is residential land use for which demand profile can be based on choice of water using appliance.

A number of water management options are available in CWB (see Table 2.4). For modelling alternative water management options some knowledge of treatment performance, storage capacity, water sources and uptake rates is required. Natural systems data that is required includes; soils data, climate data, ground water, lakes and rivers within the catchment. The climate input requirements is a representative of daily rainfall and potential evaporation time series for the period of simulation.

Table 2.5 Water Management options (Including SUDS) available in CWB

Spatial scale	*Method*	*Source(s) of water*	*Uses*
Unit Block	Green roofs	Precipitation	Drainage
	Rain tanks	Roof runoff, Covered Surfaces (drainage)	Toilet, kitchen bathroom, laundry unit block irrigation
	Swales	unit block runoff	
	Septic tank	Wastewater flows: Toilet, kitchen, bathroom And laundry	
	Waste water unit	Wastewater flows: Toilet, kitchen, bathroom and laundry and inflow	Hot water systems Toilet, irrigation
	Porous paving	unit block runoff	
	Borehole	Infiltrated water	Kitchen, bathroom, toilet, laundry, unit block irrigation
	Grey irrigate	Grey water flows: Kitchen, bathroom And laundry	Unit block irrigation
Miniclusters	Filter strips	Unit block Runoff	
	Swales	Mini cluster Runoff	
	Soak-aways	Miniclusters Runoff	
	Porous Asphalt	Miniclusters Runoff	
	Wastewater store	Remaining runoff from the above four	Toilet and irrigation
	Stormwater store	Miniclusters Runoff	Toilet and irrigation

Data describing contaminant concentrations for portable water, rainwater, groundwater, evaporation, roof, road and paved area runoff are required. In addition contaminant loads to kitchen, bathroom, laundry and toilet and fertilizer application rates are required. Review and selection of appropriate contaminant loads and concentrations derived from international literature can be used to specify input flows where local data are not available. Any data from case study sites describing output flows or concentrations provide a basis for model calibration.

2.8 Tel Aviv's Urban Water Systems

Urban water systems in Tel Aviv include; water supply and distribution, natural systems and drainage system composed of both sewage and stormwater. As mentioned in section 1.2, the responsibility to manage urban water systems in Tel Aviv municipality is fragmented. Water supply is mainly from an external water source; Mekorot NWC. To a smaller percentage, Tel Aviv has locally operated wells drawing from the coastal aquifer. The water company of Tel Aviv municipality is charged with the responsibility of water distribution, stormwater drainage and municipal waste water collection of the city to the separate drainage systems. Industrial waste water collection is by the IGUDAN. All the waste water is centrally treated at the Shafdan WWTP situated in Reshion Lezion in the south of Tel Aviv city. The integrated water system components to be studied are as shown in the schematic representation below. The municipal boundary served as the systems boundary.

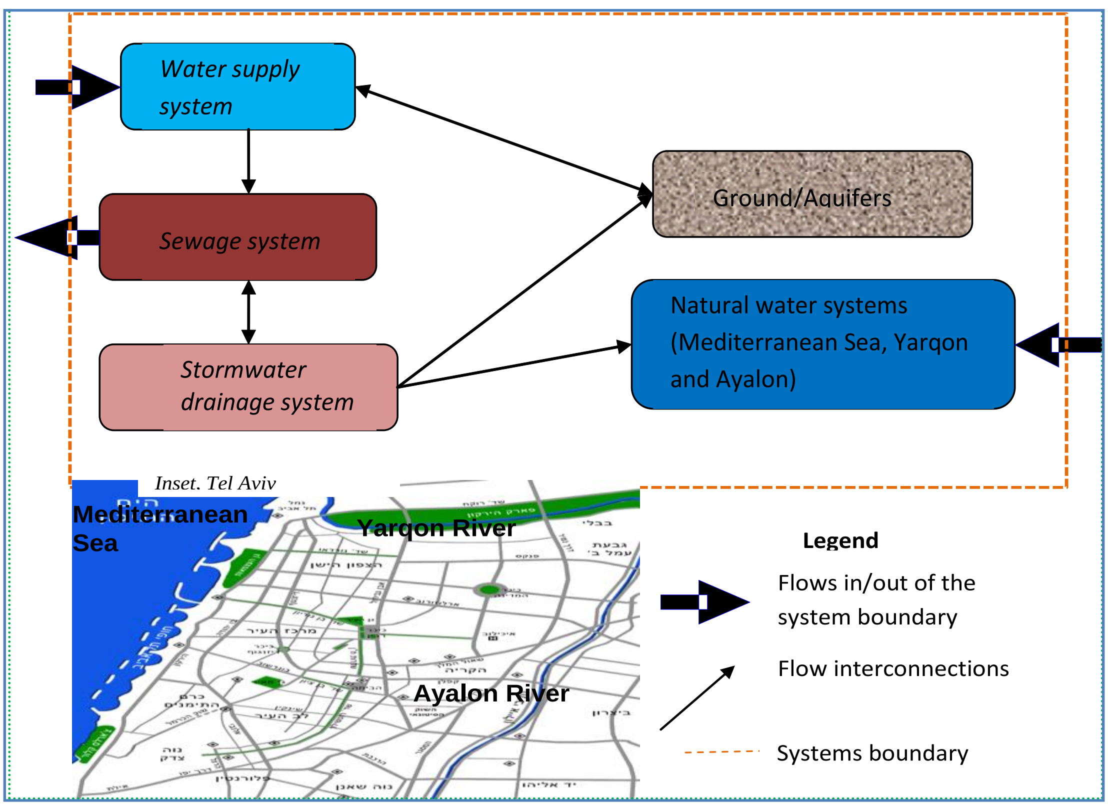


Figure 2.6 Integrated system components and system boundaries

[*Source:* Adopted from Ben-Sasson et al., 2010]

2.8.1 Water supply systems

2.8.1.1 History of water supply to Tel Aviv Yafo

In the year 1909 the city was characterized by; a scarce population, an abundance of good quality groundwater due to adequate conditions: open areas (scarce number of buildings), sands, and rain seeping into ground water. The whole city was therefore supplied by municipal and private wells. However, by the thirties of the last century, salination of the underground water begun due to intensive pumping and the forties saw the beginning of a process of shutting of wells (Jackman, 2010). Between the years 1958-1963 the city was connected to the Yarqon-Negev line hence there was a combination of water supply by the municipality and Mekorot NWC (Jackman, 2010).

2.8.1.2 Current situation

From the year 1964 to date there has been an increase of supply from the NWC and a decline in the amount of water supplied by the municipal wells (see Figure1.2). Sources of water for Tel Aviv Yafo are therefore mainly; surface water, coastal and mountain aquifers and sea water desalination. Surface water and part of the ground water is supplied by the Mekorot NWC. Tel Aviv municipality has in total 34 locally operated wells with 17 currently operational (see Figure 2.7). The reduction in the number of operational wells is due to; salination, pollution (technological progress), changing standards for testing water quality and adding new testing parameters (Jackman, 2010).

Water from the NWC is stored in three reservoirs; one in the east and the other two on the north both having storage capacities of 24,000 and 10,000 CM respectively. The total capacity of the reservoirs is approximately $^{1}/_{3}$ of the daily demand. These reservoirs serve to reduce pressure heads thus prevent pipe network from bursting as well as store water for emergency purposes (Tel Aviv Yafo Municipality, 2009).

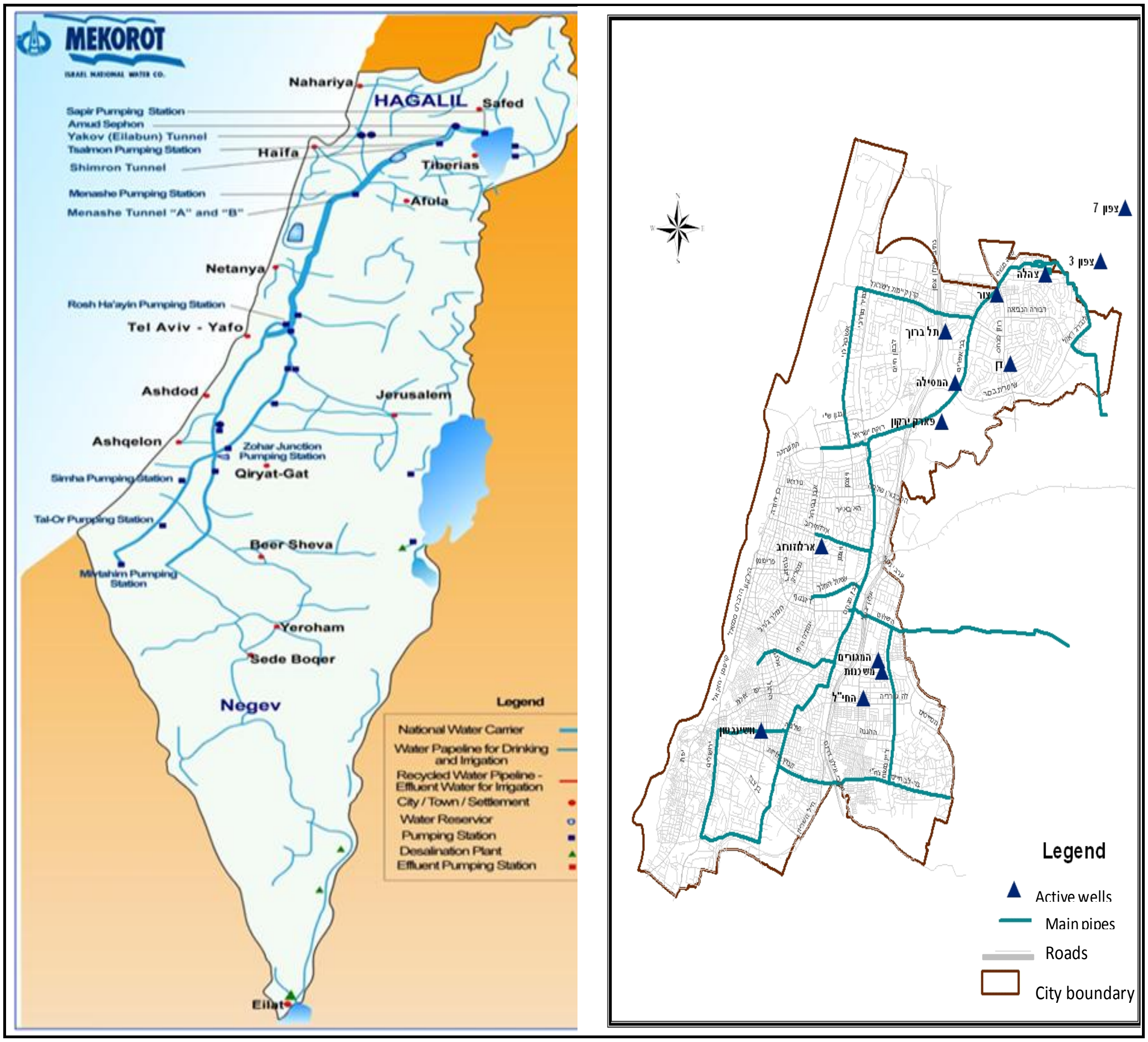


Figure 2.7 Water supply from the NWC, Tel Aviv local wells and main distribution pipes

[*Source:* Mekorot NWC, 2009; Jackman, 2010]

The total yearly water demand in Tel Aviv ranges within 47 - 50 MCM. In 2009 Tel Aviv was supplied with 41,200,800 m^3 and extracted 2,500, 600 m^3 from the local wells. On average, 85% of the demand is met by water supply from the NWC while the other 15% is by the local wells (Tel Aviv Municipality, 2009).

Water supplied to Tel Aviv is distributed to meet the various unit block demands. Figure 2.8 shows the specific unit blocks demands as a percentage of the total supplied, split usage for domestic units. On average, of the annual water supplied, 60% and 9% goes to meet domestic and public open space (POS) irrigation demands respectively.

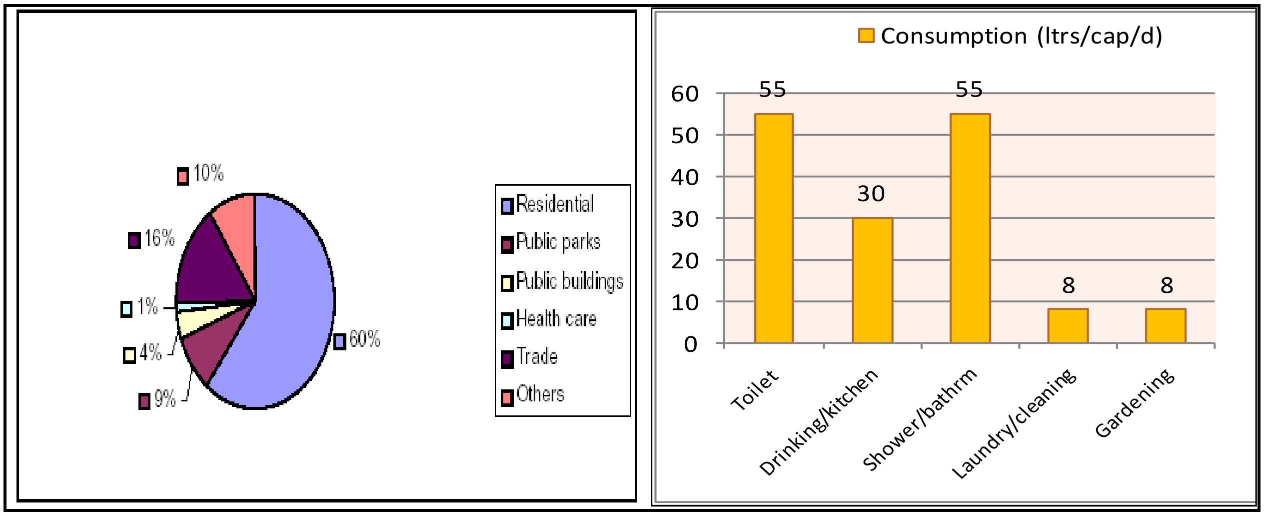


Figure 2.8 Distribution of urban water consumption of Tel Aviv and unit demands (2009)

[*Source:* adopted from Tel Aviv Yafo Municipality, 2009; Ben-Sasson et al., 2010]

20% (10 km^2) of Tel Aviv's' area is gardening within the city (POS) with an exception of private gardens. Of the 10 km^2, 4 km^2 is the total area for Yarqon and Ayalon parks which are not irrigated with fresh water. Of the remaining 6 km^2, 70% i.e. 4.2 km^2 is irrigated, while 30% i.e. 1.8 km^2 are impervious spaces within the POS (roads, buildings and play grounds) (Figure 2.9). Irrigation is mainly carried out in summer (Tel Aviv Yafo Municipality, 2009).

Tel Aviv looses a considerable amount of the water supplied through leakage and theft. The total amount lost is estimated to 5.5% per annum (see Figure 2.9). An estimated amount of 2,200,110 m^3 was lost in the year 2007 (Tel Aviv Yafo municipality, 2009 and Mekorot NWC, 2009).

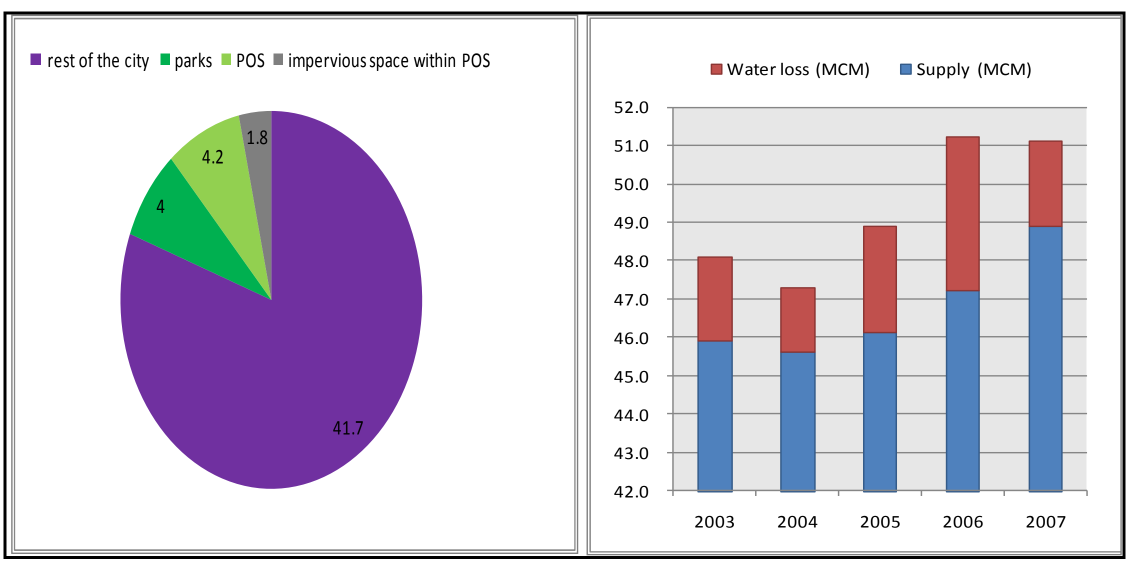


Figure 2.9 Gardening (km^2) and water loss (both physical and administrative losses)

[*Source:* adopted from Tel Aviv Yafo Municipality, 2009; Ben-Sasson et al., 2010]

2.8.1.3 Water Quality

Water supplied complies with the WHO Drinking Water Standards. Before supply the water undergoes treatment measures. Surface water undergoes filtration and disinfection. Turbidity before treatment is up to 3 NTU, after treatment it is <0.3 NTU and fecal coli form is reduced to zero. These are the only water quality parameters that the water is treated for. In addition, water in the distribution system is sampled and tested regularly to ensure that quality water is supplied.

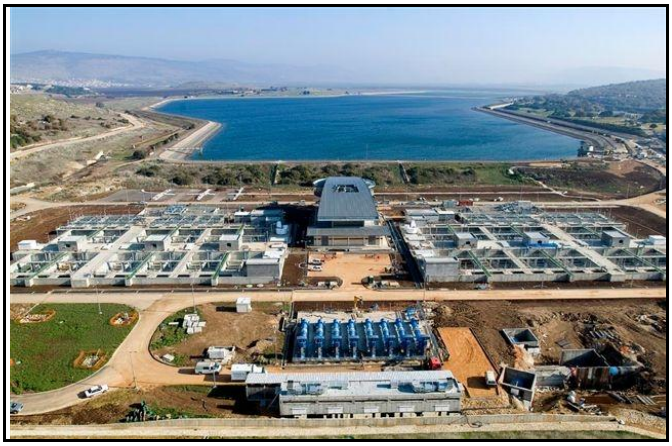


Figure 2.10 A layout of the Filtration Plant

[*Source:* Mekorot NWC, 2009]

For ground water, water quality testing is usually done for the aquifers to determine whether the water fits the drinking water standards. If a particular aquifer source does not meet these standards then it is not exploited. The only treatment is disinfection with chlorine against microbiology. Usually fecal coli form before disinfection is 0-3/100 ml and 0 after disinfection. A set of water quality parameters for water supplied from the Mekorot NWC is as shown in the Table 2.6. Similar values are also obtained for water from local wells. A full list of the water quality parameters is as attached in Appendix 1.

Table 2.6 Chemical parameters in drinking water and WHO standards

Parameters	***Units***	***Std value (WHO)***	***Average Value***
Nitrate as NO_3	mg/l	70	1.5
Lead as Pb	µg/l	10	0
Calcium as Ca	mg/l	No std	60
Chloride as Cl	mg/l	600	228
Copper as Cu	µg/l	1400	0.5
Iron Total as Fe	µg/l	1000	23.4
Hardness as CaCo3	mg/l	No std	287
Detergents as LAS	µg/l	1000	0
Magnesium as Mg	mg/l	150	33
Sulfate as SO_4	mg/l	250	65.6
Dissolved Matter at 180	mg/l	1500	627
Zinc as Zn	µg/l	5000	16.5

[*Source:* Mekorot NWC]

2.8.2 Drainage Systems

The drainage systems in Tel Aviv are separate in 97% of the municipality's area. The other 3% mainly in the far south east and south west of the city has no separate drainage system (due to unplanned development) and stormwater is directed to the sewage drainage system.

2.8.2.1 Sewerage System

The IGUDAN is responsible for the Dan metropolitan region collection of waste water. Local collection for the city of Tel Aviv is by the Municipal council. The collection network for Tel Aviv consists of pumping stations and carrier lines. The carrier lines run parallel to the Ayalon and Yarqon Rivers and along the Mediterranean shore and have a total length of 575 Km (see Figure 2.13). The pump stations are located at various locations within the city. Both serve to collect and direct the waste water to the main pipe which then carries the waste water to Shafdan WWTP owned by the IGUDAN. On average waste water from Tel Aviv is 60% of that supplied, an average of 80,000 CM daily productions and 26.6 MCM yearly averages (Shafdan WWTP).

Within the sewage system cesspits also exist. There are a total of 480 cesspits all over Tel Aviv currently (see Figure 2.11). They contribute to ground water pollution as they are a source of nitrate. Nitrate contamination is a major reason for closure of wells in Tel Aviv (Jackman, 2010).

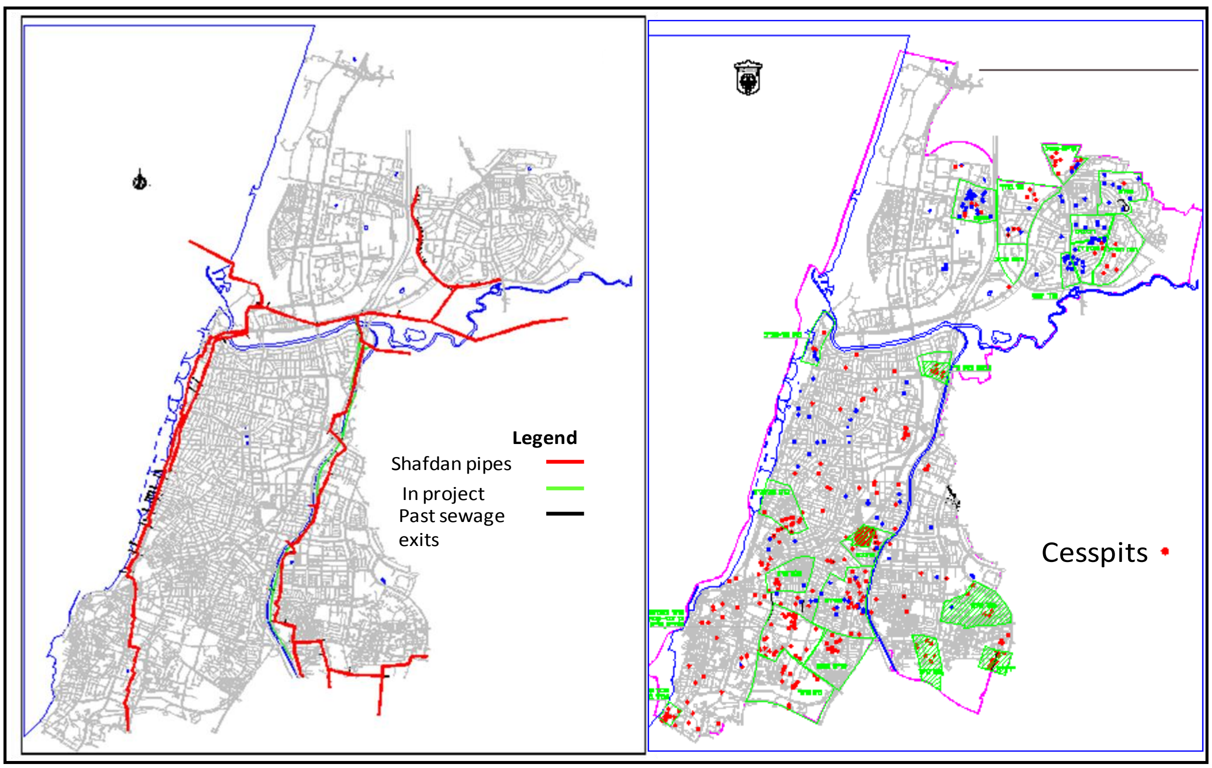


Figure 2.11 Sewage pipes and cesspits
[*Source:* Shafdan WWTP]

Waste water management is through two steps; biological waste water treatment and further reclamation through SAT technology. Biological treatment with removal of phosphorus is carried out at the Shafdan WWTP, a plant which is operated by the Mekorot National Water Company for the IGUDAN. The WWTP is a Mechanical - biological treatment plant, based on activated sludge with nitrification and de-nitrification processes. During reclamation the effluent undergoes further treatment by means of SAT technology. The penetration of the effluent into the aquifer provides additional biological treatment of the organic matter, ion exchange, adsorption, deep sand filtration (a few dozen meters of depth), precipitation of metals and inorganic pollutants, as well as inactivation of microorganisms due to long retention time in the ground water.

Contaminants concentration for water quality parameters are as shown in Table 2.7. The reclaimed water is then supplied to the southern region for unrestricted irrigation. In addition treatment efficiencies are also included in the said table. Contaminant concentrations for basic parameters and trace elements are as shown in Appendix 2.

Table 2.7 MBTP effluent and removal efficiencies for water quality parameters (Yearly averages for 2008)

Parameter	***Units***	***Raw Sewage***	***MBTP Effluent***	***Removal Efficiency %***
Chloride	mg/l	283	287	
Dissolved Solids 105^0	mg/l	1,046	905	13
Electrical Conductivity	µmhos/cm	1,821	1,577	13
Hardness, as $CaCo_3$	mg/l	340	304	11
Calcium	mg/l	82	75	9
Magnesium	mg/l	32	27	16
Sodium	mg/l	228	203	11
Potassium	mg/l	24	21.7	9
Sulfate	mg/l	82	99	
Fluoride	mg/l	0.7	0.7	6
Silicon	mg/l	6.8	7.8	
Nitrate, as N	mg/l		0.7	
Nitrite, as N	mg/l		0.9	

[*Source:* Shafdan WWTP]

2.8.2.2 Stormwater Management

Tel Aviv receives an average annual precipitation of 530mm. For a surface area of 51.7 km^2, the annual rainfall amount is calculated as 27.4 MCM.

The drainage system is naturally flowing and the main outfalls for the various sub catchments within the city are either to the Ayalon and Yarqon Rivers or to the sea. The Ayalon connects to the Yarqon which then drains in to the sea. Previous studies estimated the annual runoff to 20 MCM (Hoang, 2008; Tel Aviv Yafo Municipality, 2009).

There are a total of 9 summer pump stations along the Ayalon tributary, Yarqon River and the beach line. During summer, they pump out waste water contributed by the reticulation system through outdoor water use and illegal connections in order to avoid polluting the sea. During winter excess stormwater runoff is pumped out through these stations hence serving to prevent flooding that may be caused by overflows of the naturally flowing drainage system (Tel Aviv

Yafo Municipality, 2009). Tel Aviv has no established stormwater monitoring system and hence the levels of pollutant fluxes as well as quantities of stormwater in to the sea are undetermined.

2.8.3 Natural Water Systems

Natural water bodies within Tel Aviv are; Mediterranean Sea, Yarqon River and its tributary; the Ayalon River. These systems serve as both water sources and effluent disposal systems. As mentioned in section 2.6.1.2 sea water is desalinated and supplied to Tel Aviv by the Mekorot NWC.

The Yarqon River runs through the most densely populated area in Israel - The Dan region. Over the years the rivers have undergone massive degradation and over exploitation, with the Ayalon tributary completely taken over by human interventions. In most cases this river carries effluents and stormwater during the rain season (see Figure 2.12). The Yarqon River is 27.5 Km long. In the past, the spring segment of the River (the upper 7 Km) produced 25,000 m^3 of fresh water per year. Today only 400m^3 are produced. This upper section still carries fresh water discharged by the Mekorot Water Company in order to fulfil farmers' water rights. The water, used for irrigation, has maintained minimum reasonable conditions for some of the animal and plants that were present in this section of the Yarqon. The effluents discharged by the municipalities pollute the remaining 21 km down stream. Of these, the last 4 km contain mostly seawater thus, creating an estuary. This section is in a better condition compared to the 17 polluted km upstream. Tel Aviv lies within the last 7 km on the north and 4 Km on the south of the river respectively as it joins the sea (see Figure 2.12).

A rehabilitation plan is underway for the Yarqon River and incorporates efficient use of limited water resources in the two critical stretches of river, the upper 7 km and middle 17 km stretches. Once rehabilitated, the river will function as a conduit, so that recycled water can be used for vital irrigation of parks, agriculture and other purposes.

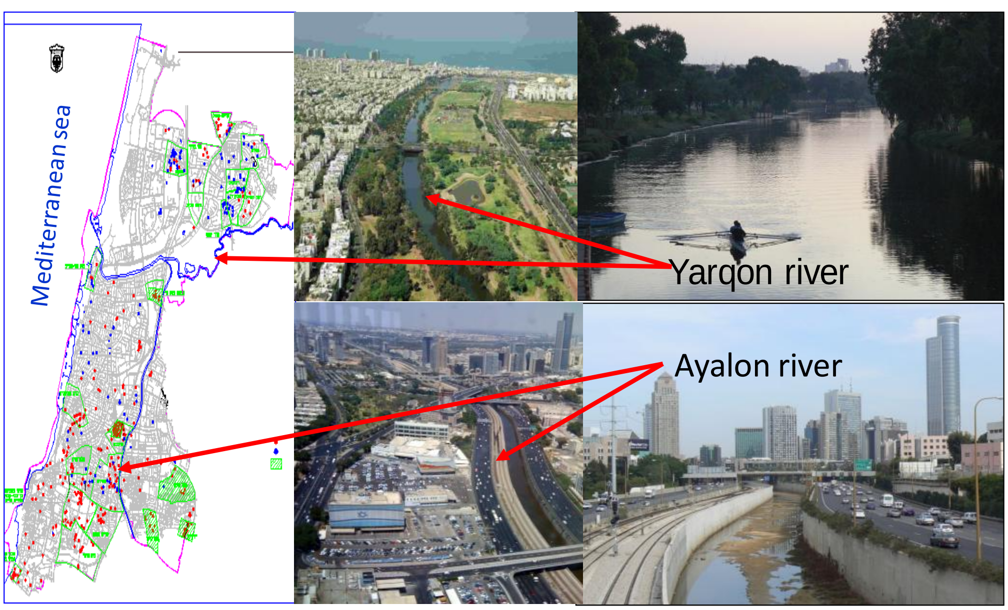


Figure 2.12 Tel Aviv's natural water systems

[*Source:* Adopted from Ben-Sasson et al., 2010]

3.0 METHODOLOGY

3.1 Study Approach

The research methodology comprised of a visit to Tel Aviv Yafo city, familiarization and contacting of key individuals within partner institutions in this research for the set up of logistics prior to the commencement of actual data collection. The visit to Tel Aviv was from the 17th 0f Nov. '09 to 20th of Jan. '10 which was during the rain season.

Upon establishing contact with the partner institutions and the relevant key individuals (Appendix 3), data collection exercise began with first obtaining stormwater drainage and population land use maps that were required for the physical characterization of the city as well as identification of a suitable location for carrying out stormwater flow measurements and sample collection. Sample collection was for the purposes of characterizing the stormwater. Both the stormwater flow measurements and the characterization exercises were with the aim of obtaining data for CWB model calibration. Tel Aviv Yafo Water Company and Yarqon River Authority assisted with relevant information, equipment as well as technical expertise.

It was necessary to understand the general precipitation patterns as well as daily weather predictions in order to arrange logistics for flow measurements and sampling prior to storm events. Institutional websites for the Tel Aviv Yafo Water Company and Yarqon River Authority gave daily weather predictions.

During this period besides stormwater flow measurements, sampling and analysis, site simulation data for setting up CWB for the Tel Aviv Yafo study area was acquired mainly from the city itself through visiting several institutes, scientific literature, observations, and local experience as well as interviewing local people.

Further more, an insight in to the urban water systems of Tel Aviv municipality was gained with an aim of establishing the stocks and flows of the water and contaminants, as well as to gain a general understanding useful when formulating strategies.

The research was carried out in three phases. A summary of the research approach is presented in Figure 3.1 below.

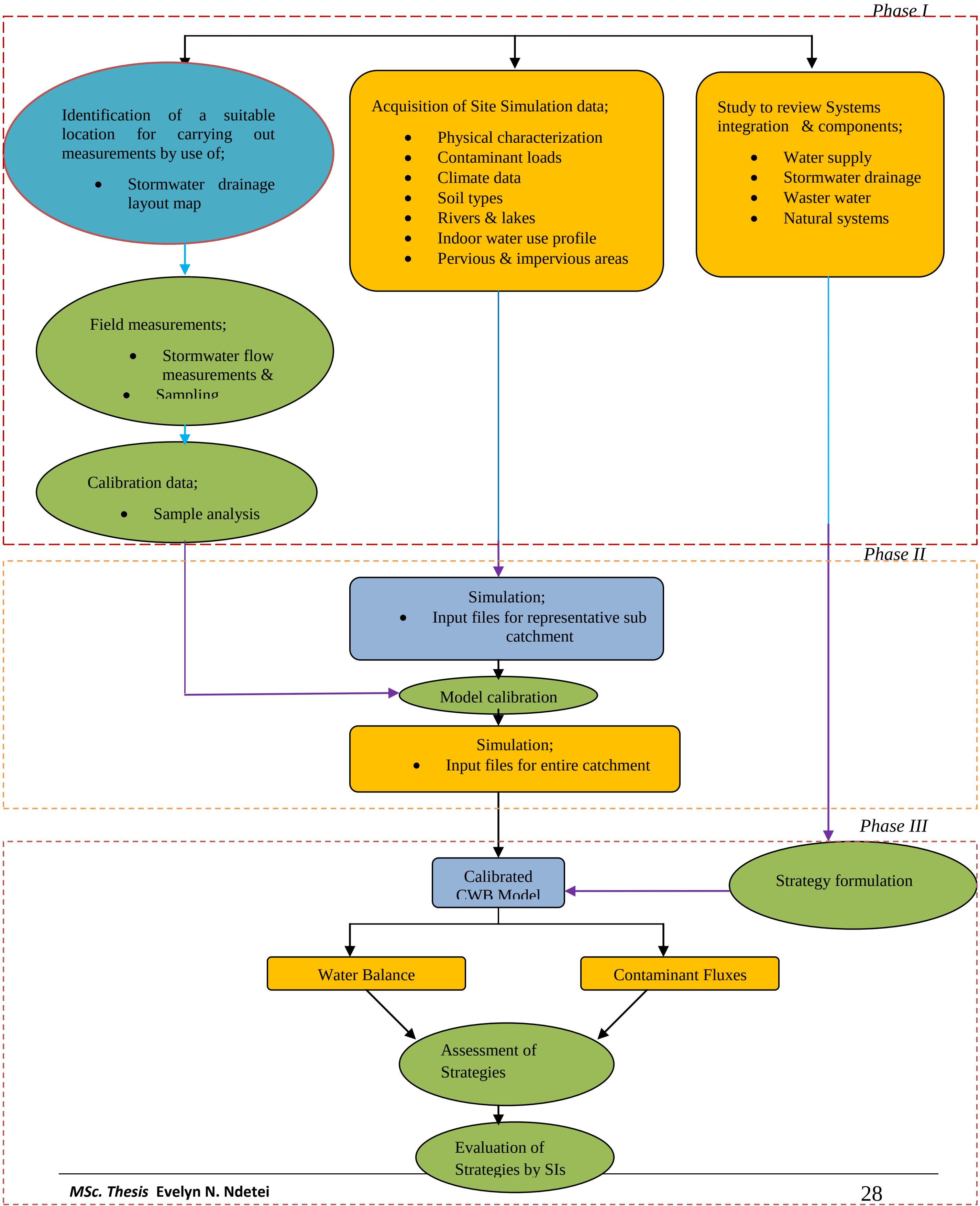


Figure 3.1 Flow chart of study approach

3.2 Site Simulation Data

CWB model simulates integrated urban water systems within a catchment and then predicts the water and contaminant balance. However, to meet the model requirements, an enormous amount of data needed to be acquired and processed. Some of the input parameters were very case specific and were not available locally. A review and selection of appropriate data derived from international literature was used to specify such data inputs.

3.2.1 Physical Characterization

The municipal boundary served as the systems boundary. By use of maps in the GIS software Arcmap, Tel Aviv urban catchment was sub divided into 28 sub catchments based on the stormwater drainage network (see Figure 3.2). The flow network within the sub catchments is as shown in Figure 3.2. Most sub catchments drained into the natural systems i.e. either into the Mediterranean Sea or to the Yarqon River and Ayalon tributary. The main drainage outfalls can be identified from the said figure. There were however some sub catchments that drained into others; sub catchment 4 drained into 6, 27 into 28, and 25 in to 26 and 28. Others drained into both natural systems and to an adjacent sub catchment; 1 drained into 4 and into the sea while 24 drained into 26 and to the Ayalon. For these sub catchments it was assumed that all stormwater was drained in the natural systems. This was for the purpose of making the data suitable for simulation in CWB model.

In order to characterize the catchment, generic pieces of land representing the various land use types within the cityscape were generated. They were referred to as unit blocks, and were generated from existing PDF maps as well as tourist map (see Table 3.1). Similar unit blocks were grouped together to form larger pieces of land referred to as miniclusters, hence, for each sub catchment there was a corresponding set of miniclusters and unit blocks (see Table 3.2). For a full list of the 28 sub catchments and their corresponding miniclusters refer to Appendix 4.

Maps in the GIS software Arcmap, tourist maps and statistical data contained in the statistical year book of the Tel Aviv Yafo municipality were used to delineate physical attributes of the unit blocks. This attributes included; pervious and impervious spaces, roads, pavements and roof areas. Parameter values obtained were used to simulate the catchment and were input in specific input files. Further, the total sub catchment areas were determined by use of the Maps in the GIS software Arcmap. Soil maps and ground water table contour maps were used to determine soil types and underlying aquifer coverage as well ground water heights respectively.

3.2.2 Description of Unit blocks

As explained in section 2.5.4 of this report fundamental attributes of unit blocks are; pervious/impervious proportions, water demand profiles and pollutant input loads. The pervious and impervious attributes are part of the physical characterisation and were determined as explained in section 3.2.1 above, while the remaining attributes together with other relevant data related to unit blocks are as discussed below;

Water demand profiles for the unit blocks required to be split into four generic uses for each land use type and for each of these four uses the demand was specified per functional unit. CWB specified the demand categories for an office as urinals, water closet, kitchen and drinking water.

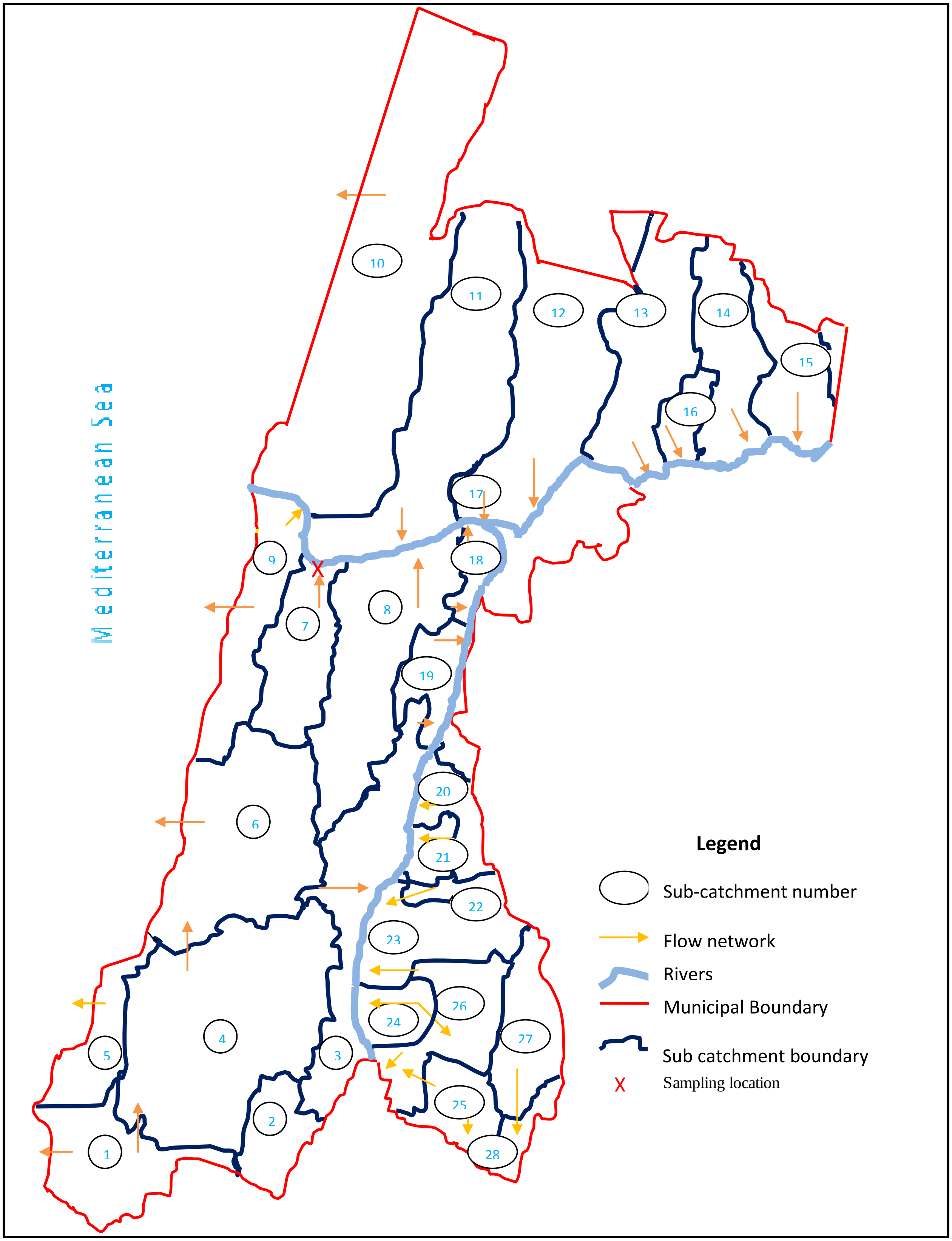


Figure 3.2 Sub-catchments and flow networks within them

Table 3.1 Unit Block types used in CWB

Unit Block	*Unit Block Type*
1	Public open space (POS); parks
2	Industry
3	Terraced residential with a small garden
4	Terraced residential with a large garden
5	Detached residential with small garden
6	Detached residential with large garden
7	Semi-detached with a large garden
8	Semi-detached with a small garden
9	Housing complexes (4 floors) with a small garden
10	Markets, open retail areas
11	Offices (banks, embassies, post offices amongst others)
12	Community centre/public buildings
13	Fire station
14	Hospital/nursing homes
15	Police station
16	Cultural centers/museums/Theaters /art galleries
17	Institutions & libraries
18	Prison
19	Supermarkets & Retail shops
20	Hotels (high water consumption)
21	New neighborhood under construction
22	Airport
23	Parking areas
24	Petrol station
25	Religious places, Monuments
26	Transportation (stations)& storage
27	Others (cemeteries, sports grounds)
28	Open beach area (Givat Aliya beach)

[*Source:* adopted from Tel Aviv Yafo Municipality, 2010]

Table 3.2 Sample of sub catchments and corresponding mini clusters and unit blocks

Sub Catchment	*Mini cluster*	*Unit Block type*	*Sub Catchment*	*Mini cluster*	*Unit Block type*
7	1	1	1	16	1
	2	2		17	9
	3	8		18	11
	4	9		19	19
	5	11		20	21
	6	12		21	23
	7	13		22	24
	8	14		23	27
	9	15		24	28
	10	19			
	11	20			
	12	23			
	13	24			
	14	25			
	15	3			

While that for residential was specified as; toilet, kitchen, bathroom and laundry. The functional unit for offices was specified as m^2 while that for residential was persons, and so values for each demand category required to be entered as litres/m^2 or litres/person. A multiplying factor was then specified that was multiplied by the unit demands to give total demands for the unit blocks in liters/day. For offices the multiplying factor used was area (which is the internal area of the office) while that for residential land use was occupancy. Values used for residential unit demand split into the four categories were as shown in Table.3.3.

Table 3.3 Residential Unit block demands

Use	*Consumption (liters)*	*%*
1 Toilet	55-60	35
2 Drinking, cooking/kitchen	30	20
3 Shower/bathroom	55-60	35
4 Laundry & cleaning	8	5

[Source: Tel Aviv Yafo Municipality, 2009]

Data for the office split usage was not available. For this unit block types together with the other unit block types that CWB manual did not have a description of the demand categories and neither were functional units specified, data on average yearly unit demands was used to estimate the daily unit demands for the split usage. The details of these yearly unit demand averages are as shown in Appendix 5.

The housing units in Tel Aviv include dwelling and non dwelling units. The dwelling (residential) unit block types that are common in Tel Aviv are complexes of 4-10 flours that contain approximately 8 units per floor (Centre for economic and social research, 2004). The other types of residential housing include; terraced, detached and semi-detached. The non dwelling units include; commercial, manufacturing, services and institutions. Occupancy for the residential unit blocks was estimated from the municipality statistical data for the areas of Jurisdiction referred to as Quarters. Occupancy for each quarter was obtained by dividing the population per quarter by its respective number of households. Based on their location the residential unit blocks were then matched to the respective quarters (see Table 3.4). For all the other unit block types occupancy was assumed to be 1.

Table 3.4 Unit block occupancy

Unit block type	*Quarters used*	*Average occupancy*
Terraced residential with a small garden	5, 6 & 8	1.8
Terraced residential with a large garden	7	2.5
Detached residential with small garden	3 & 4	1.6
Detached residential with large garden	3 & 4	1.6
Semi-detached with a large garden	1	2.4
Semi-detached with a small garden	9	2.6
Housing complexes (4 floors) with a small garden	2	2.7

[Source: adopted from Tel Aviv Yafo Municipality, 2007]

Hotels were defined as unique with water demand varying depending on tourist seasons. Occupancy factor for the hotels was assumed to be 2.5 per room which was increased by a factor of 1.5 % in the months of April, July and August.

Gardening is a common practice in Tel Aviv and refers to open spaces both for the public and residential areas. For most unitblock types it was not possible to calculate the exact areas of open spaces since the land use map obtained did not include open spaces. The distribution for these open spaces was then estimated as a % of the roof areas since roof areas could be easily calculated. Large pieces of land referred to as Public Open Spaces (POS) where defined as independent unit blocks. Examples of this POS are the famous Ayalon and Yarqon recreation parks, smaller urban and unit block parks, open areas along the seafront, public squares and boulevards. The distribution of the public open spaces was estimated by use of maps in the GIS software Archmap and statistical data from the municipalities' statistical year book (Tel Aviv Yafo Municipality, 2004 & 2007).

The Tel Aviv Yafo municipality is responsible for the collection of municipal waste water, while that from industries is by the IGUDAN. The municipal waste water is mainly from residential unit blocks. Details of the industrial waste composition and concentration of contaminants is as shown in appendix 9. There was no data available on Tel Aviv Yafo municipal waste composition and concentrations. For this case, the composition was assumed to be similar to the commonly treated parameters in municipal water (Henze and Comeau, 2008). It was assumed that the contribution of some of the parameters from the split water usage per person in Tel Aviv is comparable to that from other cities (Keldaman, 2010).

3.2.3 Data input files

Parameters were input in specific input files within CWB model whose interface is as shown in figures 3.3 below.

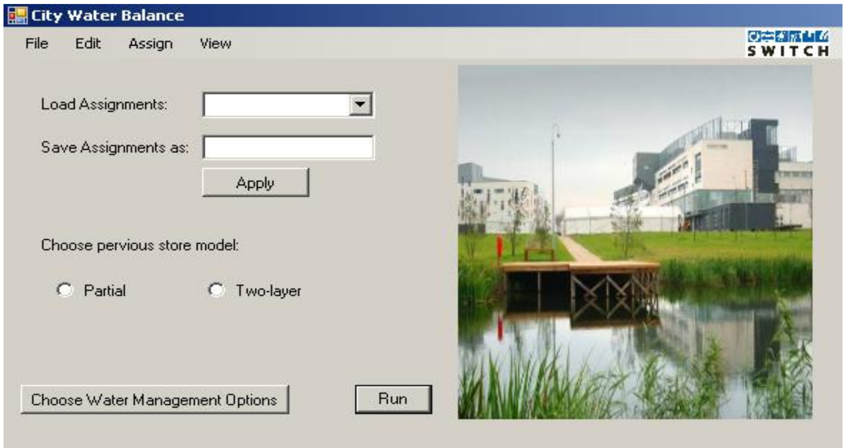


Figure 3.3 CWB user interface

A summary of all the data/parameter types used for the set up of CWB model, their formats as well as the respective sources are as listed in Appendix 6. In total, 200 fields covered all input possibilities. Figure 3.4 shows a view of some of the assigned files.

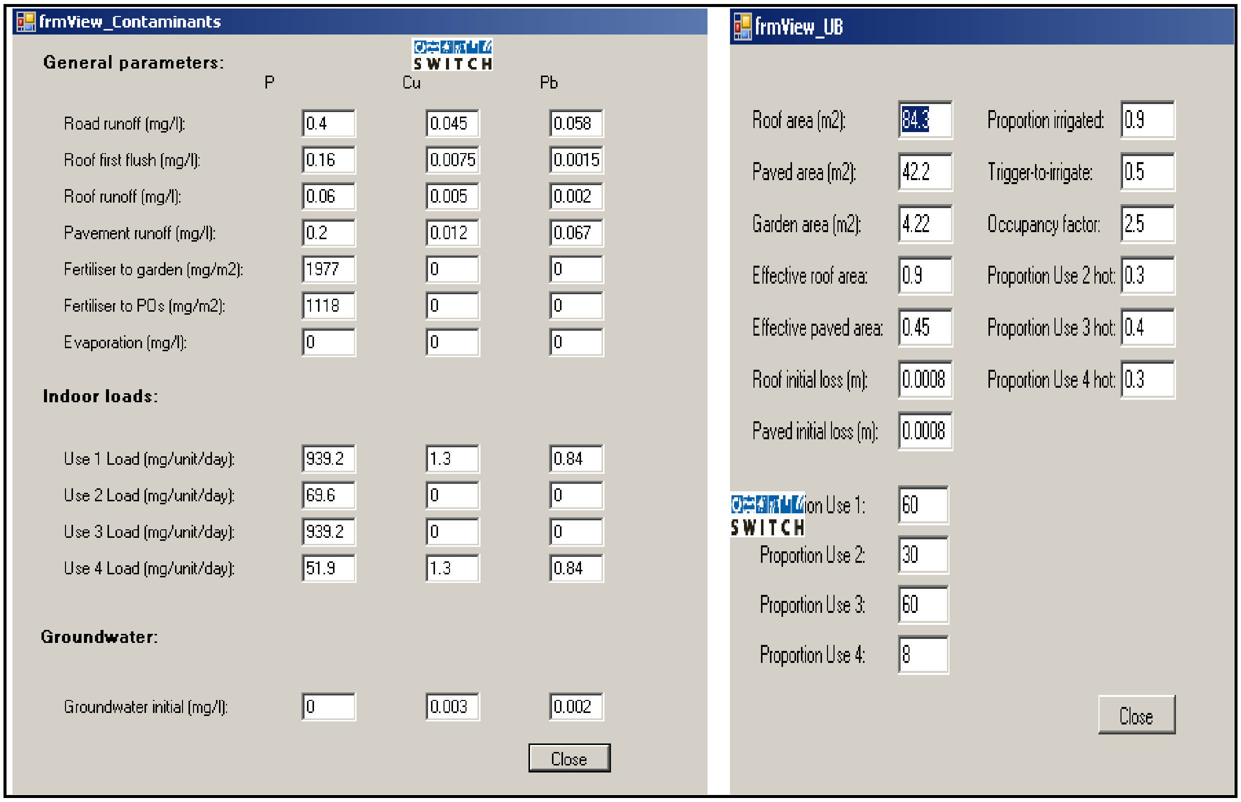


Figure 3.4 Assigned contaminants and unit block attributes files

The climate data comprised of daily series of precipitation and potential evaporation data. The available data was from year 1994 to year 2010. Precipitation data of Tel Aviv was obtained from European Climate Assessment & Data set project (*ECA&D*). Potential Evaporation data was estimated by using the formula from *(Global Program, 2005)*, *i*n which, the monthly heat indexes; the unadjusted potential evaporation values are required. These values were calculated by using the daily temperature data which was also collected from ECA&D.

Other calculated parameter sets included; leakage estimates, woods intercept and proportion of surface runoff as inflow. Leakage proportion was estimated as shown in table 3.5 below.

Table 3.5 Leakage estimation

Year	*Supply (MCM)*	*Water loss (MCM)*	*Leakage Proportion*
2003	45.9	2.2	0.048
2004	45.6	1.7	0.037
2005	46.1	2.8	0.061
2006	47.2	4.0	0.085
2007	48.9	2.2	0.045
		Average	**0.055**

[*Source:* adopted from Tel Aviv Yafo Municipality, 2010]

In estimation of proportion of surface runoff as inflow, wastewater average daily pumping rates from Tel Aviv reading station for 6 months during the rain season were used (Table 3.6)

Table 3.6 Average daily Wastewater pumping rates, estimated inflow and proportions

Month	*Average daily Pumping rates in CM (Q)*	*Estimated inflow in CM (Qi)*	*Proportion (P)*
Oct-08	70,230	11,251	0.16
Nov-08	71,063	12,084	0.17
Dec-08	73,491	14,512	0.20
Jan-09	58,979	0	-
Feb-09	65,479	6,500	0.10
Mar-09	61,885	2,906	0.05
		Average (P*i*)	**0.11**

[*Source:* adopted from Tel Aviv Yafo Municipality, 2010]

Jan - 09 had the least pumping rate and was assumed to be the month with zero inflow. Therefore; estimated inflow in CM (Q*i*) within the other months is calculated as the difference in pumping rates (Q) with that for Jan- 09. P is calculated as Q*i* divided by Q. To obtain the overall inflow proportion (P*i*) the average of p values for the 5 months is calculated

Woods intercept values were estimated from the average of daily rainfall amount in the year 2009, and a constant value representing the % of rainfall that woods are expected to intercept in arid and semi arid areas (Appendix 7).

Woods intercept (m) = (total yearly rainfall (mm) x 0.14/rainy days)/1000............Equation i

3.2.4 Model calibration procedure

In order to calibrate the model, field measurements of stormwater flow rates and quality through identification and characterization of physico-chemical parameters was carried out. The flow measurements and sample collection for characterization was at a sub catchment scale. The sub catchments differed structurally from each other in aspects such as land use activities. Measurements were carried out on one representative sub catchment since only one party was carrying the measurements. The representative sub catchment was mainly composed of residential, commercial and service activities, with little industrial activity.

The sub catchment is located in the North West side of Tel Aviv and covers an area of 1.87 Km^2. It therefore gauges 1.3% of the urban area. It drains into the Yarqon River through a recreational park, by a box culvert of size 2.5 x 1.5 m, barely 10 m from the Yarqon River Authority offices. It is at the drainage outfall that flow measurement and sample collection where done (see Figure 3.5).

3.2.5 Choice of elements for characterization

Parameters where identified based on universal occurrence of the specific parameter in the environment and expected levels of concentration based on Ashdod city case study results (Asaf, et al., 2004). The table 3.7 below summarizes the expected sources of contaminants in stormwater and their significance of occurrence.

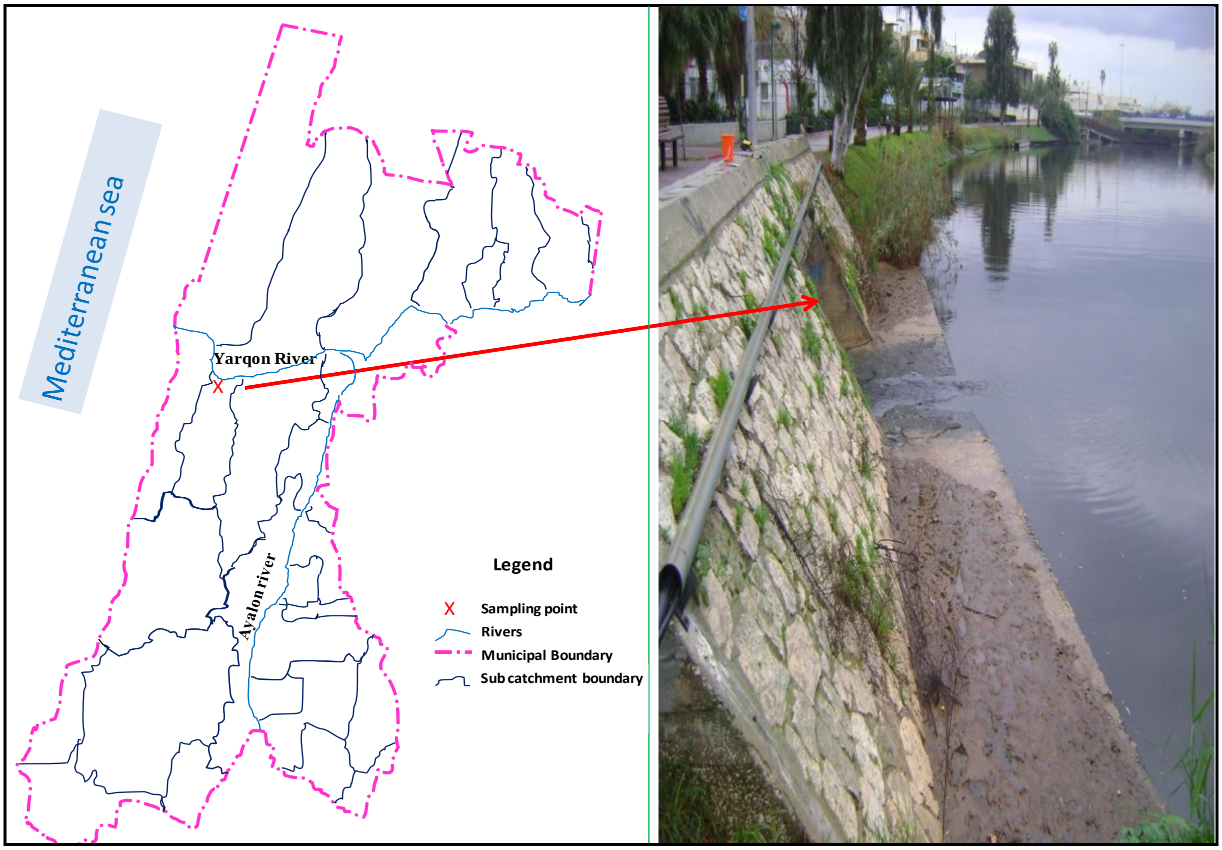


Figure 3.5 Sampling location

Table 3.7 Parameter values, sources and significance

Element	*Source*	*Significance*
Major ions		High levels of concentration are indicators of anthropogenic contamination
SO_4	Vehicles, deicing salt, Industries, marine biogenic sources, sea spray	
NH_4-N, NO_3-N	Fertilizers, vetinery faeces, wastewater inflow	
Na	Soils, industries, sea spray	
P	fertilizers	
Ca, HCO_3	Soils and rocks	
Cl	Industries, sea spray, deicing salts	
Mg	Soils, rocks, sea spray	
Trace elements		High levels of concentration are indicators of anthropogenic contamination
Pb	Mainly from roofing materials, paints, industries, vehicle emissions, oil spillage, atmospheric deposition	
Cu	Vehicle tyre wear, break linings, asphalt road surfaces, industries, atmospheric depositions	
Fe	Fertilizers, wastewater inflows	
K	Brake linings and industries	
Ba, Al	Industries	

[Source: Zobrist et al. 1999]

3.2.6 Flow measurements and sampling

Flow measurements were done by the use of a portable flow meter (Marsh-McBirney Flow-mate, model 2000) at a depth of 80cm and 60cm from the stormwater surface. Stormwater samples were collected manually and stored in 500 ml plastic bottles. Both flow and sample collections were done at 15 minute intervals. On the whole, 4 storm events on 4 different days were sampled. Flow measurements were obtained for 1 storm event. It was not possible to measure flow velocities from the start of the storm event and neither was it possible to sample the first flush of the rain season or for individual storm events. This was because both measurements and sampling exercise begun much after the onset of the rain season and also, most rain storms begun either late in the evening or early morning hours. For this particular storm event measurements were carried out on the second half. The flow meter provided information on the runoff velocity in m/s. Three readings were taken per measurement and the average calculated. The flow rates (m^3/min) were calculated by multiplying channel crossectional area (m^2) and the measured flow velocity (m/s). Average discharge in (m^3/day) was estimated from flow rates and rainfall duration, as follows;

$$Q = \frac{\sum Q_i \times T}{Ts} \qquad \text{.......... Equation ii}$$

Where;
- Q = volume of flow of the storm event (m^3/day)
- T = duration of storm event (min)
- Q_i = time variable flows (m^3/min)
- Ts = number of time variable flows

For analysis of the stormwater discharge, a hydrograph was plotted, with values for the first half of the storm event assumed to be similar to those measured in the second half.

Information on rainfall figures was obtained from online databases. Rainfall intensities could not be obtained since the weather recording stations gave rainfall amounts on daily averages. In total 60 stormwater samples with 3 replicates were collected and analyzed as well as 1 precipitation sample.

3.2.7 Sample analysis

The analyses were carried out using techniques according to Standard Methods (APHA, 1995). Determination of some major ions was done at the Water Treatment Technology Laboratory, the Robert H. Smith Faculty of Agricultural Food and Environment of the Hebrew University of Jerusalem within two hours after sample collection, by use of PRAXIS field chemistry set 3 kit which is in accordance with the Standard Methods. Before the determination of SO_4, NH_4-N and NO_3-N, all samples were filtered through a 0.45 µm. Electrical Conductivity (EC), pH and Temperature were measured in the field in all samples using EC and pH meters (+ 0.1 µs/cm, + 0.1 pH units and+ 0.1 ^{o}C, respectively. Stormwater temperature was determined by use of the EC meter and the pH meter adjusted to this temperature value. Samples for trace elements and the remaining major ions analysis were filtered through a 0.45 µm filter into pre acidified 50ml plastic sample bottles with 3 drops of HNO_3^-. They were then stored in a refrigerator at temperature of 3^{o}C awaiting transportation to Delft, Netherlands for analysis at the UNESCO-IHE laboratories.

Ca, Mg, Na, K as well as the trace elements were measured using ICP (Perkin Elmer, OPTIMA 3000). The detection limit varied from 50 to 500µg/l, depending on the element. PO_4-P analysis was by filtration and the ascorbic acid method at a detection limit of 0.02 mg/l. The results of the analysis in mg/l were presented as the averages of 4 - 5 replicates of each sample. When the minimum value of a specific element was below its detection limit the detection limit value itself was assigned to that element in that analysis for the calculation of load and mean values.

Further, unit pollutant loadings in the runoff for this particular storm event were obtained by multiplying mean parameter concentration by the calculated volume of flow of the storm event.

$$Ls = \frac{Q \times Ca}{A} \qquad \text{Equation iii}$$

Where; Ls = measured pollutant load (kg/km^2/day)
Q = volume of flow of the storm event (m^3/day)
Ca = mean parameter concentration (kg/ m^3)
A = representative catchment area (km^2)

Considering an average total precipitation depth of 605 mm, annual loads were calculated as follows;

$$L = P \times \frac{Ls}{Pm} \times \frac{1}{Cv} \qquad \text{Equation iv}$$

Where; L = annual pollutant load (kg/ha/yr)
P = annual precipitation (605mm)
Ls = measured pollutant load (kg/km^2/day)
Pm = total precipitation depth during the sampling period (18mm)
Cv = conversion factor for km^2 to ha (100)

In order to compare pollutant loads in runoff with those in wastewater, unit loads in wastewater were calculated based on the following equation;

$$L = PL \times P \times 365 \qquad \text{Equation v}$$

Where; L = pollutant load (kg/ha/yr)
PL = amount of load per person (kg/cap/day); (Nitrates- 0.012kg & P- 0.003kg)
P = population/ha (72)

Treatment efficiencies adopted from the Shafdan WWTP were used to determine pollutant loads in WWTP effluent.

4.0 RESULTS AND DISCUSSION

4.1 Stormwater flow measurements

Figure 4.1 illustrates flow rates of the particular storm event for an average rainfall amount of 18mm and duration of 3 hours. Flow values were calculated as explained in the methodology. Average discharge was calculated as 4623 m^3/day.

The relation between runoff and rainfall intensities could not be established due to lack of data on the latter. However, previous measurements and analysis on rainfall and runoff documented in literature show that for most catchments, in a typical rain event the evolution of rainfall and runoff usually follow the same pattern (Zobrist et al., 1999). It can therefore be assumed that this was the case for this particular rain event, and that rainfall was receding when measurements started.

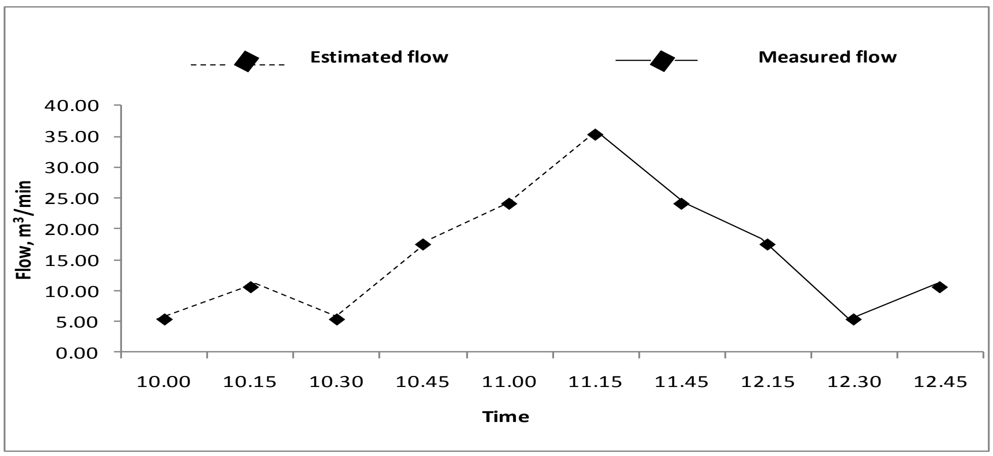


Figure 4.1 Stormwater flow during the storm event of 30th Dec. 2009

4.2 Characteristics of runoff water quality

4.2.1 General characteristics

Table 4.1 presents a statistical summary of the runoff and rainfall quality data. A complete data set of parameter values per storm event is as attached in Appendix 8. The pH value of the stormwater samples ranged from 7.3 to 8.7 and averaged 7.9, implying alkaline conditions. pH values where comparable to the rainfall value of 7.9. The EC ranged from 0.03 to 0.8 ms/cm and averaged 0.21 ms/cm. The rainwater value was within the range of that in stormwater samples.

Table 4.1 Ranges mean values and EF factors of pH, EC (ms/cm), major ion concentration and trace elements (mg/l) in 30 stormwater samples and 1 rainfall sample

a) Stormwater

	Max	Min	Mean	SD	EF
pH	8.7	7.3	7.9	0.4	1.005
EC	0.8	0.03	0.21	0.15	2.4
HCO_3	73.2	25.6	53.5	9.9	1.7
CL	153	15.6	44.8	30.6	2.5
NO_3-N	2.2	0.2	1.01	0.5	5
NH_4-N	1.8	0.3	0.7	0.26	0.8
SO_4	80	4	25.9	23.4	13
Ca	48.5	11	25.9	9.9	2.5
K	19.4	3	7.7	3.9	2.2
Na	403.4	9.4	64.9	96	6.3
Mg	31.8	2.9	8.3	6.9	6.5
Cu	0.1	0.01	0.03	0.021	3.3
Pb	0.2	0.01	0.06	0.03	2.04
Si	5.8	0.9	2.6	1.35	4.2
Al	3	0.15	0.9	0.8	13.2
Ba	0.2	0.04	0.07	0.026	1.5
Fe	3.4	0.21	1.04	0.9	20.7
PO_4-P	0.2	0.001	0.1	0.04	3.3

b) Rainfall

	Average
pH	7.9
EC	0.9
HCO_3	31.7
CL	17.8
NO_3-N	0.2
NH_4-N	0.9
SO_4	2
Ca	10.4
K	3.5
Na	10.3
Mg	1. 3
Cu	0.011
Pb	0.03
Si	0.6
Al	0.07
Ba	0.05
Fe	0.05
PO_4-P	0.03

The order of concentration of the major elements was as follows; HCO_3 > Cl > SO_4 >NO_3-N and Na > Ca > Mg > K, revealing the input of HCO_3 from terrestrial dust (Nativ and Mazor, 1987; Singer, 1994). The SD in the Na samples was 96 while for Ca was 9.9. This big difference in the variance values of the two elements could be attributed to out layers for Na samples. It can be assumed that without the influence of these out of range values, the mean concentration value for Ca could have been greater than that of Na, hence reflecting the input of Ca from terrestrial dust (Singer, 1994). Cloud-borne sea spray, providing mainly Na, Mg, Cl and SO_4 could be the course of high concentrations of Na and Cl both in the stormwater samples and in rainfall (Jaradat et al., 1998; Nativ and Mazor, 2003).

The EF factor i.e the ratio between mean concentrations of an individual constituent in the stormwater and in rainfall was high for SO_4, this could be attributed to vehicle emissions since parking lots, roads and gas stations are known to contribute a large variety of contaminants, SO_4 being one of them (Asaf et al., 2004; Thomson et al., 1996). The ratios of Ca, Mg and HCO_3 support the contribution of limestone and dolomite-related dust while that of Si suggests the contribution of clay-related dust both of which have been recorded in Israel (Ganor et al., 1991). The EF for NO_3-N was quite high as compared to that of NH_4 which was <1, an occurrence which could be due to conversion of NH_4 to NO_3. Presence of NH_4 in significant levels is related to sewer overflows or exfiltration during storm events and fertilizers. K and P enrichment factors also suggest the contribution of fertilizers that are used in private gardens or public open spaces leaching of leaves, atmospheric depositions and to some extend automobile exhaust (Asaf et al., 2004; Thomson et al., 1996). It was observed that most trace elements had high enrichment factors, with the concentrations of some being within the expected range. According to Davis et

al. (2000) universally, levels follow the order; Zn (20-5000 μg/l) > Cu ≈ Pb (5-200 μg/l) > Cd (< 12 μg/l). Cu and Pb concentrations; 0.033 and 0.057 mg/l respectively lie within this range.

Cl, SO_4 and Na had high SD values as compared to those of the other elements; implying a wide data range (see Table 4.1). This variability could be explained by the fact that sources of water quality constituents found in stormwater runoff are diverse and may be attributed to; traffic deposition, dust fall from surrounding environs, pavement wear, maintenance operations, accidental spills, and littering amongst others. Given the attributes of these non point sources, it is not surprising to observe the high variability in terms of numbers and concentrations, of constituents found in stormwater runoff. This variability is sometimes a hindrance to the ability to accurately predict these constituents from site to site and between or within a storm event at a single site (Thomson et al., 1996).

On the overall the concentrations of all pollutants in stormwater (except NO_3-N) were found to be either close to or slightly higher than those measured in other similar studies in Israel under similar physical characterizations (Asaf et al., 2004), this is thought to result from the condition that the traffic is heavier and residential units denser in the selected catchment. In the rainfall sample, concentrations were within the range of those measured in the said studies except for NO_3-N whose values were quite low (Asaf et al., 2004).

4.2.2 Temporal Variations

Within storm events

Stormwater runoff quantity and quality were combined for a storm event to produce hydrographs and pollutant graphs, illustrated in figures 4.2 to 4.4. For this storm event, the concentration of Pb ranged from 0.07 to 0.04 mg/l. Some successive samples were observed to have constant concentrations for example those taken at 11.45am and 12.45pm. The SD value was 0.011, implying that the data were not spread out over a large range. The concentrations were assumed to have decreased exponentially to nearly constant values. Therefore, Pb concentrations depicted a first flush effect since these were samples collected during the second half of the storm event and it could be assumed that the peak of the concentration occurred during the first half (see Figure 4.2). Also, the range of Cu concentrations was 0.03 to 0.01 mg/l with variability similar to that of Pb; 0.01, implying that the data was not spread out over a wide range. The slight build-ups in Cu concentrations observed within the storm event were considered negligible, and values assumed to be relatively constant (see Figure 4.3). Such behavior is as expected given that these were samples collected within the second half of the storm event. The findings of both Pb and Cu are in line with results of previous studies for example, Davis et al. (2001), Lee et al. (2000) and Zobrist et al. (1999) while investigating runoff characteristics at different instances observed that, most constituents in stormwater runoff such as major ions, nutrients, trace elements and pesticides appear in high concentrations in the first minutes or first tenths mm of runoff depth. With increasing time or runoff depth, concentrations decrease exponentially to relatively constant levels (first flush effects). Asaf et al. (2004) while investigating chemical and isotopic composition of urban water observed that samples collected during the first event in the season or at the beginning of each storm event give higher concentrations than those in the subsequent events or in the following samples within the same event. Further, Lee et al. (2000) while comparing stormwater runoff flow to pollutant concentrations by analyzing combined pollutant

concentrations and runoff graphs established that, depending on catchment land use types, pollutant concentrations peak usually occurs at or is immediately followed by the runoff flow peaks.

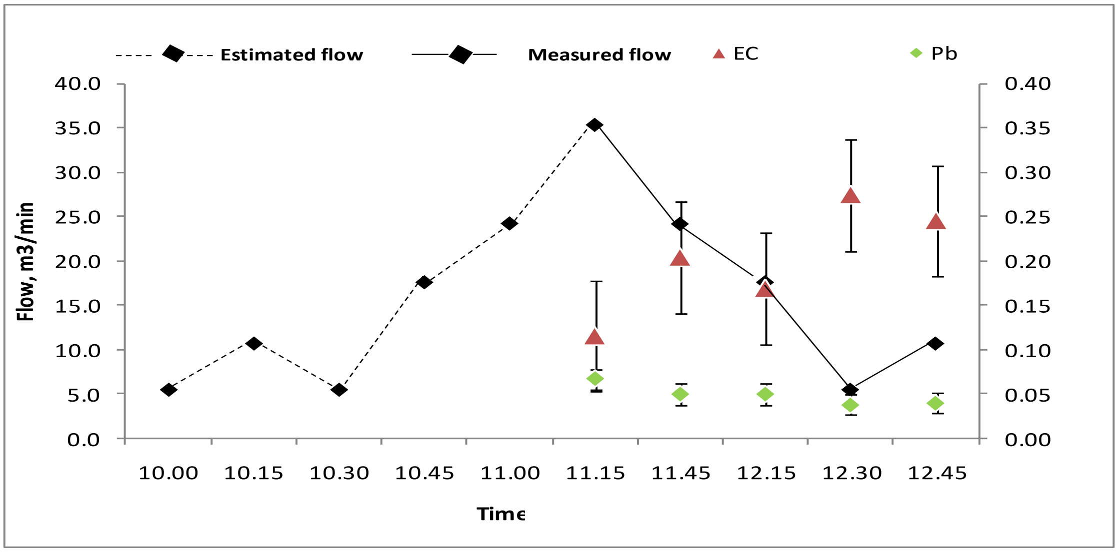


Figure 4.2 Stormwater flow and temporal variations in Pb (mg/l) and EC (ms/cm)

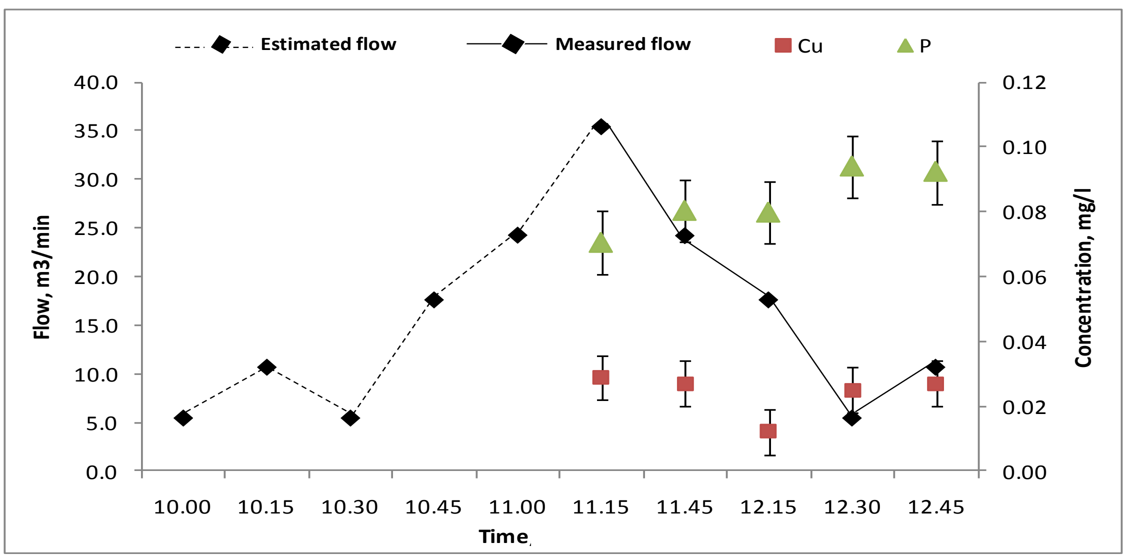


Figure 4.3 Stormwater flow and temporal variations in Cu and P (mg/l)

P range of concentration was 0.07 to 0.09 mg/l. The SD was 0.011 signifying a minor variability within the values, and similarly like for Pb and Cu, P values were assumed to be nearly constant, with the peak having occurred during the first half (see Figure 4.3). P behavior was comparable to previous investigations on stormwater runoff characterization. Asaf et al. (2004) observed a first flush effect on p analysis for an individual storm event, which was assumed to be the case for this particular storm event. Sources of P are mainly; garden, lawn and public open space fertilizers, atmospheric deposition, leaching from leaves and contributions from sewers which

are know for their overflows of untreated wastewater during storm events (Lee and Bang, 2000; Tsoler, 2009). Contributions of P from sewer overflows are likely to be significant in Tel Aviv since the use of phosphate-based detergents is allowed in Israel, amongst other P contributors in wastewater.

Na and Mg ions are all EC related. EC values varied between 0.1 to 0.3 mg/l, with some successive samples having constant values. The build up observed within the storm event was assumed to be negligible. SD value of 0.06 implied that the values were not spread out over a wide range. Given that the storm event was not among the first events in the rain season and that samples were collected in the second half of the event, it could be assumed that the values decreased to nearly constant values and that the steady state concentration was reached before sampling started an evolution which is quite expected. This finding is inline with previous research work by Zobrist et al. (1999). However Asaf et al., (2004) explained that, the relationship between EC and flow discharge is expected to display a dilution effect of the dissolved ions, an explanation which contradicts research findings in this study.

Concentration of NO_3-N ranged within 0.5 to 1.8 mg/l. The SD value was 0.5, implying that the data was spread out over a large range. The decrease in concentration was quite exponential with the last two values being almost constant (see Figure 4.4). This is quite an expected trend based on findings of studies on characterization of runoff. The concentrations are expected to appear in high concentrations and then decrease exponentially with increasing time and runoff. A trend that is attributed to the first flush and dilution effects as explained by Zobrist et al. (1999).

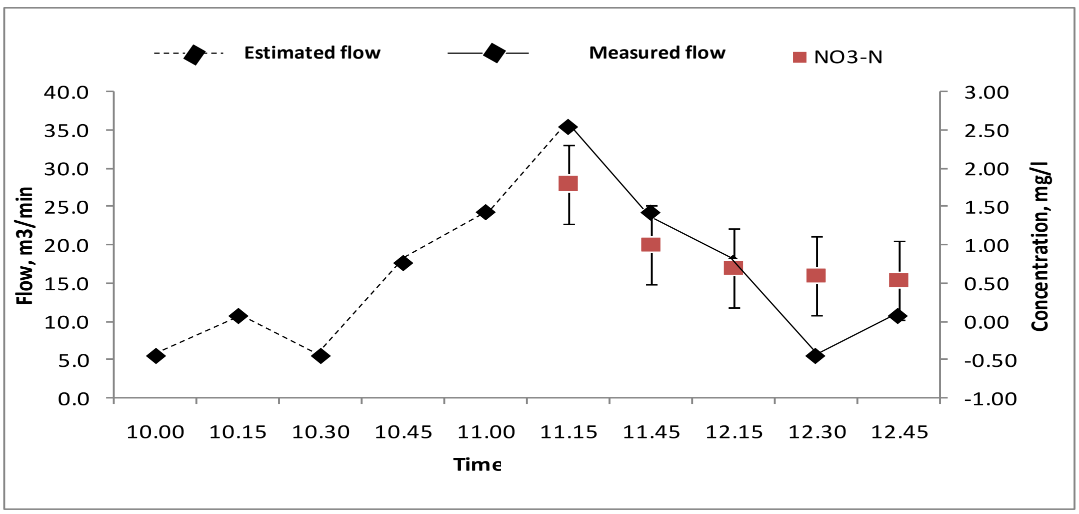


Figure 4.4 Stormwater flow and temporal variations in NO_3-N

Between storm events

Table 4.2 presents mean parameter values for the four storm events. In the 1st storm event most parameters values were relatively low. This is attributed to the relatively low rainfall depth (1mm). Most Parameter values are high e.g Cl, SO4, Ca, K, Na and Cu in the 2nd storm event and gradually decrease in the subsequent events. This observation is inline with research findings by Asaf et al. (2004) who established that higher concentrations are obtained in samples collected during first events in the season and decrease with subsequent events.

Table 4.2 Mean values for pH, EC (ms/cm), major ion concentration and trace elements (mg/l) in 30 stormwater samples for four individual storm events.

	14th Dec 09	18th Dec 09	30th Dec 09	18th Jan 09
pH	7.7	8.2	7.9	7.6
EC	0.2	0.2	0.2	0.2
HCO_3	51.9	52.8	55.5	53.1
CL	16.2	59.6	53.6	31.6
NO_3-N	1.1	0.7	1.0	1.3
NH_3-N	0.7	0.6	0.6	0.7
SO_4	22.7	37.4	25.0	16.5
Ca	22.7	31.0	17.2	26.6
K	8.3	8.2	7.3	7.4
Na	26.7	102.5	83.9	27.4
Mg	5.5	10.2	8.7	6.8
Cu	0.03	0.03	0.02	0.04
Pb	0.1	0.1	0.1	0.1
Si	1.8	3.7	1.3	2.5
Al	0.4	1.6	0.3	0.7
Ba	0.1	0.1	0.0	0.1
Fe	0.6	1.8	0.4	0.8
PO_4-P	0.1	0.1	0.1	0.1

4.2.3 Mass balance assessment

Calculated pollutant loads (equation iv) for the storm event of 30th Dec. 2009 are as presented in Table 4.3 below.

Table 4.3 Pollutant mean concentrations (mg/l) and loads (kg/ha/yr)

	Mean Concentration (mg/l)	*Load (kg/ha/yr)*
Cl	53.6	53.1
NO_3-N	1.01	1
NH_4-N	0.6	0.6
SO_4	25	24.5
Ca	17.2	17
K	7.3	7.2
Na	83.9	83
Mg	8.7	8.6
Cu	0.02	0.02
Pb	0.05	0.09
Si	1.3	1.3
Al	0.33	0.3
Ba	0.05	0.05
Fe	0.43	0.4
PO_4-P	0.09	0.09

The loads for specific parameters were compared to expected typical values and ranges as published in literature. The findings are discussed below.

The loadings for trace elements were in the order; Si > Fe > Al > P > Pb > Ba > Cu. The annual load value for Pb; 0.09 kg/ha/yr represented 12% of the 0.83 kg/ha/yr average typical value expected, as published by Butler and Maksimovic, (2001). The value is also less than the 1.83 kg/ha/yr found by Choe et al., (2002) from a Korean residential area. Pb load was however, within the expected range of pollutant loads; 0.09 - 1.91 kg/ha/yr as given by Butler and Maksimovic, (2001). Similarly for Cu, the load is much less than that found by Athanasiadis et al., (2007) of 4 kg/ha/yr for an urban area and Choe et al., (2002) of 0.6 kg/ha/yr for a residential area. Fe loading was 0.42 kg/ha/yr, much less than that measured by Choe et al., 2002, of 40.41 kg/ha/yr.

The loadings for NH_4-N and NO_3-N were 0.6 and 1 kg/ha/yr. Both values were 34 and 11% of typical excepted values. NH_4-N values were outside the range; 1.2 - 25.1 kg/ha/yr and NO_3-N value within the 0.9 - 24.2 kg/ha/yr range as given by Butler and Maksimovic, (2001). The low values could be attributed to the fact that measurements were only done for the ions in the dissolved phase. Analysis for total nitrogen would possibly have yielded higher loading rates. Similarly for phosphorus, a loading of 0.09 kg/ha/yr was 6% of the typical expected value and outside the range of 0.5 - 4.9 kg/ha/yr as given by Butler and Maksimovic, (2001). The value also compares to that obtained by Taebi and Droste et al., (2003) of 1 kg/ha/yr TP.

On the overall, most pollutant loadings for this storm event were less than expected published mean values even though within the range. This could be attributed to the fact that load values were for an individual event while those published in literature were averages of several storm events within a rain season.

Comparison between pollutant unit loads in runoff and wastewater

Unit load for specific pollutants in raw wastewater, and treated effluent were determined using equation v presented in section 3.3.3 and compared with those in the runoff effluent (see Table 4.4).

Table 4.4 Unit loads (kg/ha/yr) for contaminants in raw wastewater, treated effluent and surface runoff

	Raw Sewage	*MBTP Effluent*	*Runoff*
Pb	0.0576	0.0072	0.05
Cu	0.5256	0.09	0.02
Cl	1018.8	1033.2	52.09
PO_4-P	78.84	8.67	0.08
N (NO_3-N & NH_4-N)	315.36	25.23	1.56

Pb load contributed to the receiving water environment by runoff was almost comparable to that in the raw sewage, but 14% higher than that in the MBTP effluent. Cu load was moderate while CL loads much low in the runoff than in the MBTP effluent. They were 22 and 4% respectively of that in MBTP effluent. Similarly, N and P loads are far less than those in raw and treated wastewater. They are 6 and 1% respectively of that in the wastewater after treatment.

Currently in Israel there are no specific regulations for urban runoff quality discharged to local surface waters. In Figure 4.5 specific runoff parameter concentrations are compared with those in the standard level of permit discharge as defined by environmental regulations and recommended

water quality criteria for freshwater (USEPA, 1999). Comparison between the two should be done with caution since stormwater is usually much polluted but the receiving body in most cases plays a role in dilution. In this study data on first flush shows that Yarqon River is more polluted (figure 4.5).

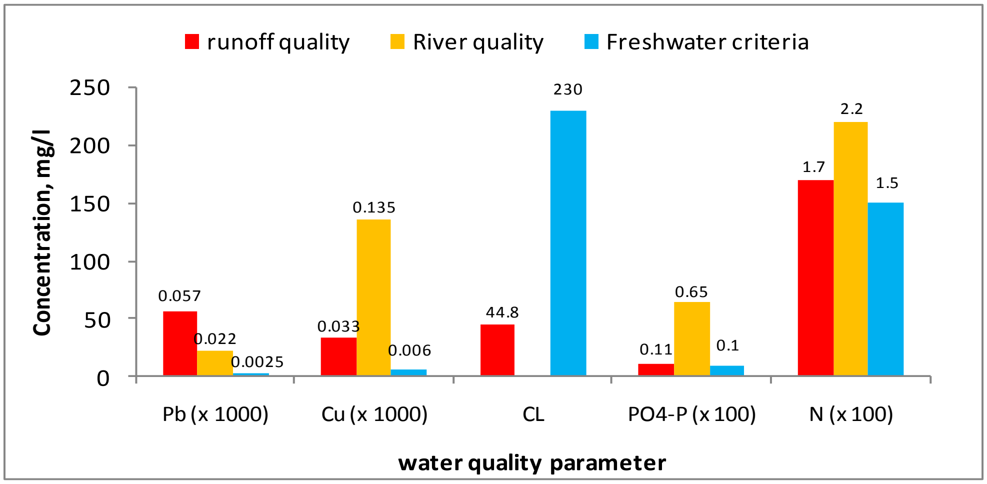


Figure 4.5 Comparison of water quality characteristics between Tel Aviv runoff, Yarqon River (first flush) and recommended freshwater criteria

From figure 4.5 concentrations of heavy metals (Pb and Cu) in the urban runoff is higher than recommended in the water quality criteria. In terms of nutrients i.e. N and P concentrations in the runoff are comparable to those in the criteria. Cl in the runoff is far less than in the recommended criteria.

Based on the comparison of unit loads in runoff with those in water quality criteria and in treated wastewater, stormwater runoff in Tel Aviv can therefore be said to contribute significantly to the decline in the receiving water quality for some pollutants e.g. heavy metals but for others; major ions e.g Cl and nutrients its contribution is rather insignificant. However, various investigators of urban water quality have observed that occasional large storm events discharges in most cases contribute pollutants in greater amounts (nutrients included) and hence shock the receiving water body many times greater than ordinary sanitary effluents (Taebi and Droste et al., 2003). It is therefore important to establish stormwater management systems in order control both the quality and quantity of urban runoff.

4.3 Model Calibration

In order to carry out calibration CWB model was set up to simulate the representative sub catchment. The calibration was based on measured stormwater flows and contaminant loads.

Within the data input files the climate file contained precipitation and evaporation data for the year 2009 and January 2010, while the contaminant files contained parameter sets obtained mainly from literature and the measured values for those very case specific parameters that could not be easily found in literature. Other input files contained data attributes that characterize the representative sub catchment.

Predicted daily stormwater flow values for 14th December 2009 to 19th January 2010 were plotted against the flow value measured. Similarly daily contaminant predictions as loads (kg/ha) for the same period of time where plotted alongside the measured daily contaminant loads. Specific input parameter values that the model responded with high sensitivity (Table 4.5) were then adjusted until the predicted values fell in line with the measured values.

Table 4.5 Parameter values used in model calibration

Output	***Parameter***	***Value***			***Units***
Runoff	Effective impervious areas-roof	0.85			%
	Effective impervious areas-paved	0.5			%
	Paved initial loss	0.001			m
	Roof initial loss	0.001			m
	Road initial loss	0.004			m
	Effective road area	0.8			m2
	Pervious store 1 area proportion	0.5			%
Wastewater	Proportion of surface runoff as inflow	0.33			%
	Sewer exfiltration proportion	0.05			%
	Infiltration store recession constant	0.12			ratio
Mains Water	Proportions POS irrigated	0.7			%
	Proportion irrigated	0.9			%
	trigger to irrigate	0.5			ratio
Pollutants		**P**	**Cu**	**Pb**	
	contaminants in rainfall	0.042	0.002	0.004	mg/l
	contaminants in imported water	0	0.001	0	mg/l
	Road runoff	0.4	0.05	0.06	mg/l
	Roof runoff	0.06	0.01	0.002	mg/l
	pavement runoff	0.2	0.012	0.067	mg/l
	Use 1 load	1139	0	0.84	mg/unit/day
	Use 2 load	569	0.001	0	mg/unit/day
	Use 3 load	569	0	0	mg/unit/day
	Use 4 load	569	1.3	0.84	mg/unit/day

Proper model calibration could not be achieved due to serious limitations/reliability in the calibration data sets. Results of the model calibration are as shown in figures 4.7 & 4.8 below. From both figures it can be seen that runoff and pollutant load patterns predicted by the model are in line with rainy and dry days in Tel Aviv for that month.

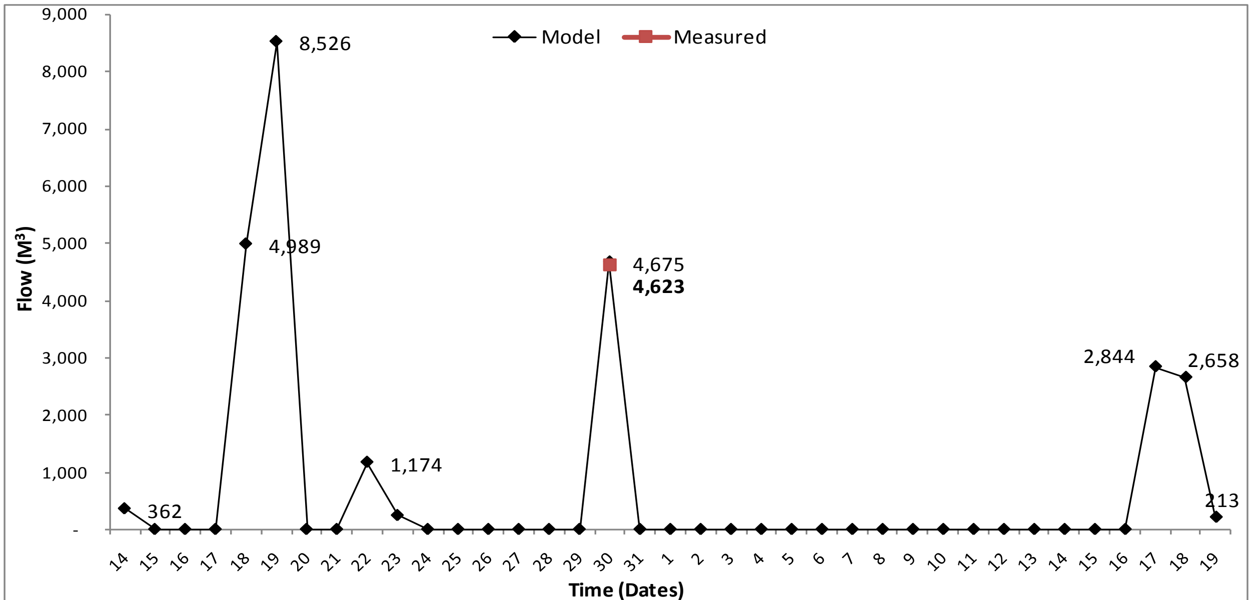


Figure 4.6 Predicted alongside measured flow for the period of 14th December '09 to 19th January '10

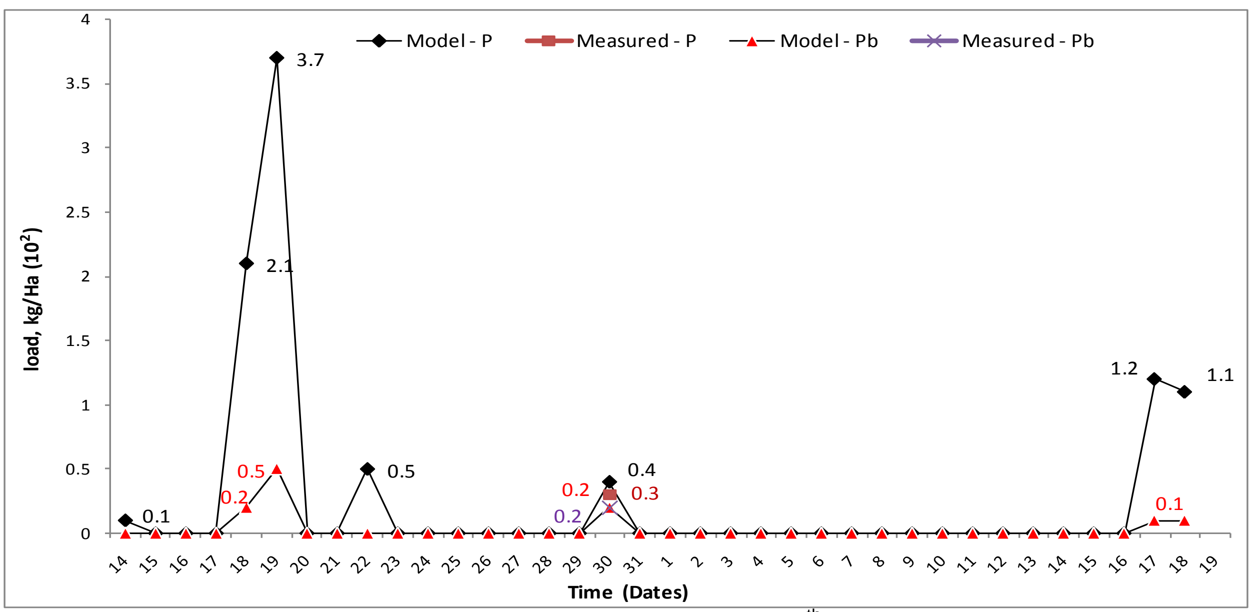


Figure 4.7 Predicted alongside measured loads for the period of 14th December '09 to 19th January '10

The model was then used to predict stormwater runoff for a year. On average, the discharge was predicted as 19 MCM (pre-sewage inflow loss) and 16 MCM (post-sewage inflow loss).

4.4 Proposed strategies

4.4.1 Introduction

In Tel Aviv municipality the responsibility to manage urban water systems is fragmented. The water company of Tel Aviv municipality is charged with the responsibility of water distribution and city drainage. Natural systems i.e. Yarqon and Ayalon rivers are managed by an independent authority i.e. the Yarqon river authority. 97% of the city's drainage systems are separate, with the wastewater being treated outside the city by the Shafdan WWTP owned by the IGUDAN. The WWTP effluent is further reclaimed for agricultural use in the south of the country. Approximately 16 MCM/year of stormwater is discharged untreated to the natural systems.

A number of both stormwater and wastewater reuse methods have been chosen to represent a range of possible approaches to stormwater and wastewater utilization for Tel Aviv. They all relate to different spatial scales at which water can be managed. While formulating these strategies, Stormwater sensitive urban design principles which are based on the concept of SUDS were used. Further, the possible interrelation of strategies with the general urban planning was also considered. Owing to economic issues and land availability, the emphasis is on implementation of the strategies at a small scale (decentralization) and in phases. A general limitation for the implementation of these management options is the hesitance in investing on highly costly infrastructure whose functionality is based on statistical occurrences. As such, design parameters such as; storage volumes, water savings, efficiency, overflow volumes should be based on long-term simulation of several years' rain data.

It is expected that each of the proposed strategies will have a significant effect on the total water supply, stormwater, waste water and the associated contaminant loads. The impact of each strategy on total water balance and contaminant fluxes was estimated by the use of CWB model, and results presented and discussed. The proposed strategies are discussed in the following sections.

4.4.2 Constructed Wetlands treating both stormwater and sewage

4.4.2.1 Treatment at tertiary levels

The quality of stormwater from the northern part of Tel Aviv catchment can be improved through treatment at tertiary levels. The process involves collection and transportation to a Constructed Wetland (CW) that is designed to treat secondary effluents from: Kfar-Saba/Hod Ha'Sharon and Ramat Ha'Sharon WWTPs at tertiary level. The two WWTP have been in existence and their secondary effluents have been a source of water for the Yarqon. The main purpose of this wetland is to further improve the quality of the secondary effluent hence protect the Yarqon River from advance effects of the unsuitable discharge. It is an ecological filter which uses water and marsh plants and has a treatment capacity of 56.7 m^3/day (*to find out*). Further, it is believed that the water undergoes natural purification as it flows through the River (for aprox. 16 km) before abstraction for use at the lower sections (Pergament personal communication). The treatments stages are as shown in Figure 4.8. Among the substances removed are; nutrients, traces of pesticides, hormones, medicinal compounds, dyes, some of which are prominent constituents of stormwater runoff.

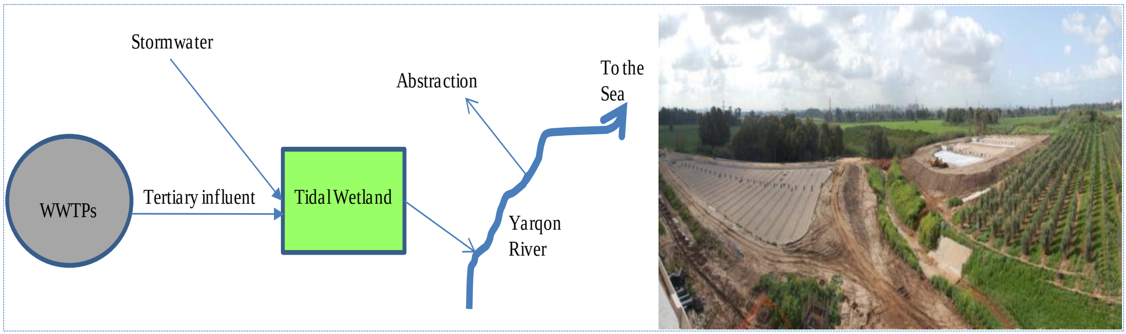


Figure 4.8 Schematic flow of the CW and inset the Wetland

[*Source:* Adopted from Yarqon River Authority]

Adopting this method as one of the management strategies has the advantage of allowing for quality improvement of stormwater runoff from Tel Aviv at relatively lesser cost for additional infrastructure since; the wetland is already in place and existing infrastructural facilities e.g dry weather pumping stations can be incorporated in the system. Further, it improves the quantity and quality of water to be used for recreational facilities, agriculture and irrigation of parks and POS, as well as contributing to the rehabilitation of the ecosystem of the Yarqon River.

4.4.2.2 Primary treatment

Wetlands treating both stormwater and grey water from residential areas in Tel Aviv could be adopted as a way of decentralizing stormwater management options within the city. One way of doing this is by adopting the concept of an existing CW in the town of Ganei Tikva, to the east of Tel Aviv and implement it at miniclusters scale for new neighborhoods under construction. It is therefore proposed that their application is taken into consideration within the strategic plan of the municipality during the preparation of town planning schemes for residential areas. The CW in Ganei Tikva treats grey water and has a design capacity of 100m^3/day serving 550 unit blocks. It combines both UV treatments with natural biological treatment (see figure 4.9). Plants used in the system; cyperus sedges, irises, sedges and butomus flowering rushes serve the role of treatment and aesthetics. Amongst the contaminants removed are nutrients, trace elements, BOD, TSS and E. coli (Hayward, 2009).

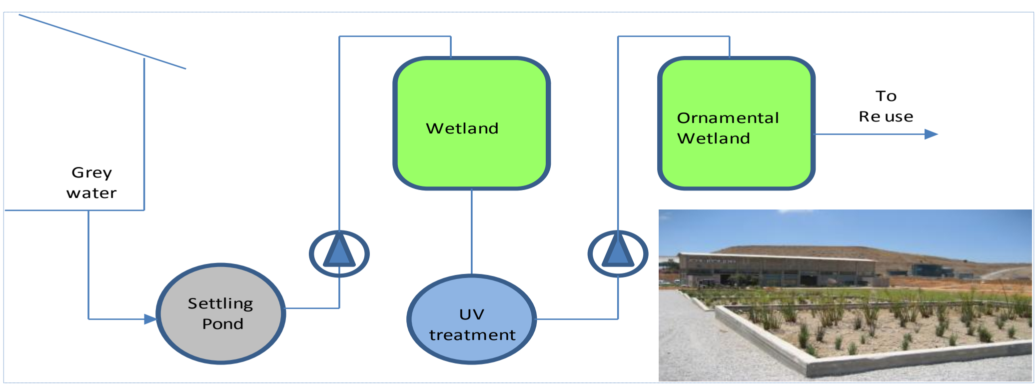


Figure 4.9 Schematic flow of a CW and the wetland in the inset

[*Source:* Adopted from www.ayala-aqua.com/content.aspx?lang=en&id=109]

Such CW provide a dual- reticulated supply in the non-potable system for hot water systems in the house, toilet flushing, garden and open space irrigation. Further, they have additional environmental and landscape/passive recreational values, suitable for Tel Aviv as it is situated in an arid and semi arid region. Finally since Israel is well known for it's extensive re use of wastewater, exploring the use of wetlands in Tel Aviv serves as an extension of the re use schemes in an urban environment.

4.4.3 Infiltration - Aquifer recharge

Infiltration of water is an important component of stormwater management. The infiltration practices include; infiltration basins, stormwater infiltration wells (subsurface injection), bioinfiltration and porous paving. Among the benefits of infiltration are; protecting surface waters from the effects of runoff; in terms of quality as well as reducing and delaying runoff volumes, and enhancing aquifer recharge (USEPA, 1995).

Aquifer recharge offers the opportunity to store and recover any form of reclaimed water for later withdrawal and reuse while employing minimal pumping and pretreatment activities. In most cases aquifer recharge is done to increase the yield of an aquifer that is already exploited and contaminated e.g. through sea water intrusion or take advantage of its natural storage capacity instead of relying on surface storage (Kurtizman Personal communication).

Aquifer recharge is widely practiced in Israel with wastewater from Tel Aviv and the Dan region in general being treated in the Shafdan, and the effluent undergoing further treatment through recharge of the aquifer and subsequent recovery for agriculture. This practice is however outside Tel Aviv city and in the far south. Adopting the technique of stormwater infiltration through wells within the urban centre would therefore contribute to the recharge of the aquifer within the coastal city. Water could then be pumped out through the existing borehole systems (whose yield over the years has substantially declined) (Jackman 2010), for water supply. Further, groundwater within the coastal aquifer of Israel is observed to contain high levels of nitrates and chlorides. The levels of such specific contaminants could be reduced through the infiltration of stormwater by dilution processes, since stormwater from Tel Aviv recorded low amounts of such major ions as compared to the ground water. Infiltration wells are less complex since they incorporate existing infrastructure (for the case of Tel Aviv) as compared to complete aquifer storage and recovery systems. They can also be more decentralized since they occupy less space.

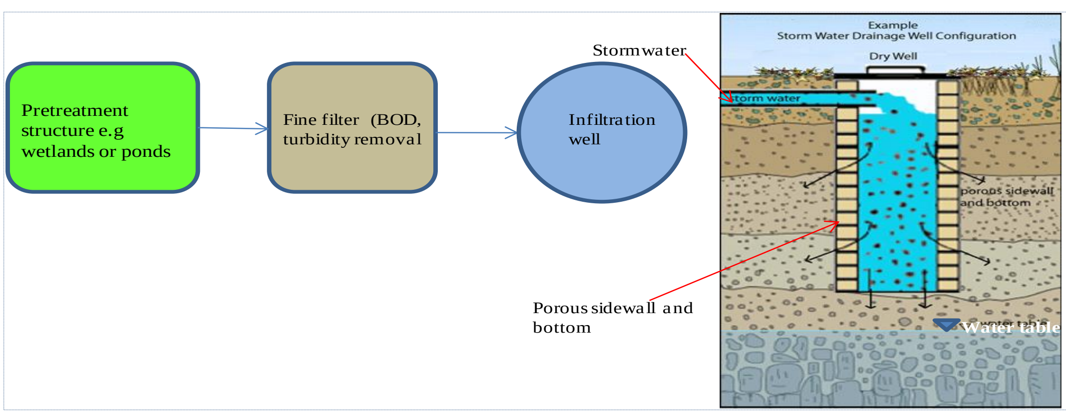


Figure 4.10 Schematic recharge well treatment system and the well inset

[*Source:* Adopted from Sheffield, 1995]

4.4.4 Mixing of stormwater with sewage incorporating decentralized storage tanks

Increasing the loading of WWTP during wet-weather events enables the improvement of the quality of water discharged to the receiving water as well as increasing the amount of recycled water. In addition it provides for stormwater treatment with the installation of additional facilities being rather basic since the wastewater facilities are in most cases well established, especially in existing sewer systems (Fletcher et al., 2008; Rauch et al., 2005).

For dense urban centers, where hardly any space is available for additional structures within the existing network, for example Tel Aviv, the mixing of stormwater with sewage could be more effectively realized with decentralized detention basins (tanks) being introduced in the system. Significant storage volumes can be reconciled with a very wide range of operations e.g. Sports facilities, pleasure pools, squares, parking areas and meeting places (see Figure 4.11).

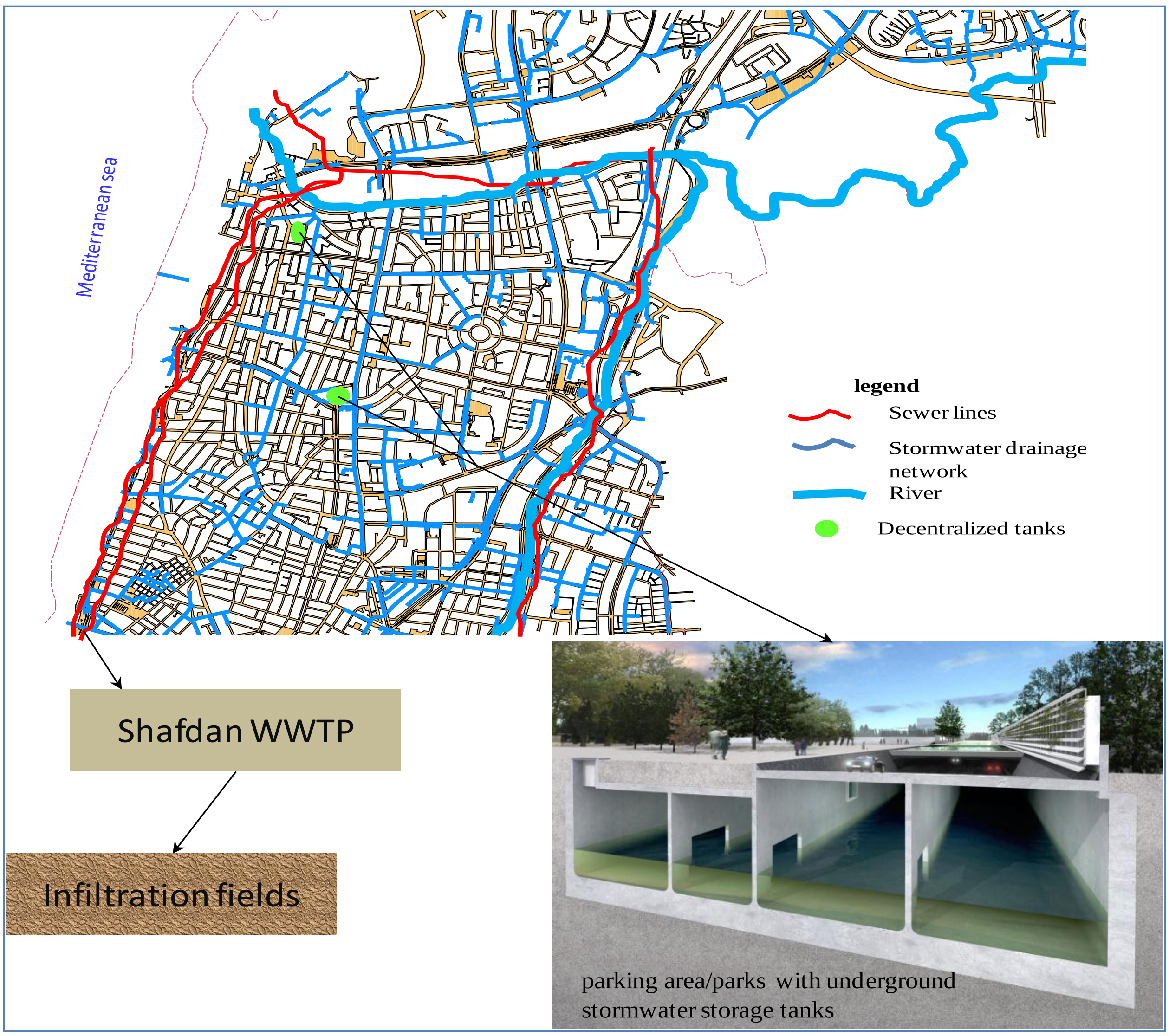


Figure 4.11 Drainage network including decentralized tanks for Tel Aviv

[*Source:* Adopted from Tel Aviv Yafo Municipality, 2010; Van de Steen, 2010]

Detention basins further help to reduce pipe diameters and pumped volumes on the respective drainage systems. For example reservoirs whose storage totals up to 1,200,000 m^3 and pumping rates of about $100m^3/s$ can be built (Roche et al., 2001). In order to allow for the mixing of stormwater with sewage the pipe network from these tanks should be constructed such that it provides for cross connections or diverting stormwater to the sewer systems during sewage low flows which are mostly during the night.

Treatment and transportation infrastructure for wastewater is well established in Israel since re use of wastewater is practiced extensively and more specifically in Tel Aviv where wastewater from 97% of the city coverage is directed to the Shafdan WWTP in Reshion Lezion region for treatment and further reclamation in infiltration fields. Meaning that, adding infrastructure for combining stormwater with wastewater along with storage facilities would relatively be straight forward. Further, existing summer pumping stations can be incorporated for pumping stormwater to the sewer pipes mainly during sewage off peak flow hours for treatment. This technique has the significant advantage of allowing for infiltration of stormwater (recharging the groundwater aquifer) away from the city since in Tel Aviv land is a premium. Additionally, it allows for further treatment of stormwater thus reducing its impact to the receiving environment. Increasing the groundwater recharge is a big boost to the coastal plain aquifer (considered to be the most important aquifer in Israel) which is rapidly deteriorating in terms of water volume and quality.

4.4.5 Combined runoff and rainwater harvesting tanks

Rainwater harvesting is a technique used for collecting and storing rainwater from rooftops pervious and impervious surface runoff or rock catchments by use of decentralized simple techniques such as pots and tanks as well as more complex techniques such as advanced eaves gutters and underground decentralized storage tanks. It has a long tradition in many developing countries, remote places and small islands, and is currently considered as a significant opportunity for decentralized community centered water management options aimed at dealing with water shortages (Butler and Maksimovic, 2001; European Commission, 2006).

Figure 4.12 presents' basic rainwater harvestings systems complete with first flush and overflow devices. Overall efficiencies of the system are dependent on the specific consumption rates.

Rainwater harvesting techniques can be easily retrofitted within existing properties (Mitchell, 2004). This makes them suitable for a dense city like Tel Aviv with a considerable percentage of residential housing units having their roofs connected to the stormwater drainage system (Pargament personal communication). The harvested stormwater can be used as a non-potable system for hot water systems in the house, toilet flushing, garden and open space irrigation. Harvesting rainwater is also an excellent approach of helping to solve stormwater-drainage problems frequently experienced in Tel Aviv, as well reduce the requirements for additional stormwater infrastructure. In the years 2006-2009, 41270 calls were received in the municipal telephone service center regarding flooding of apartments, roads, shops etc (Ben-Sasson et al., 2010). It also plays a significant role in creating efficiency and appropriate water usage in the society for sustainable urban future.

It is proposed that, these techniques are adopted as retrofit programs at unit block and miniclusters scale, as well as incorporated within the strategic plan of the municipality during the preparation of town planning schemes, and that, the municipality promotes their installation by giving incentives or subsidies.

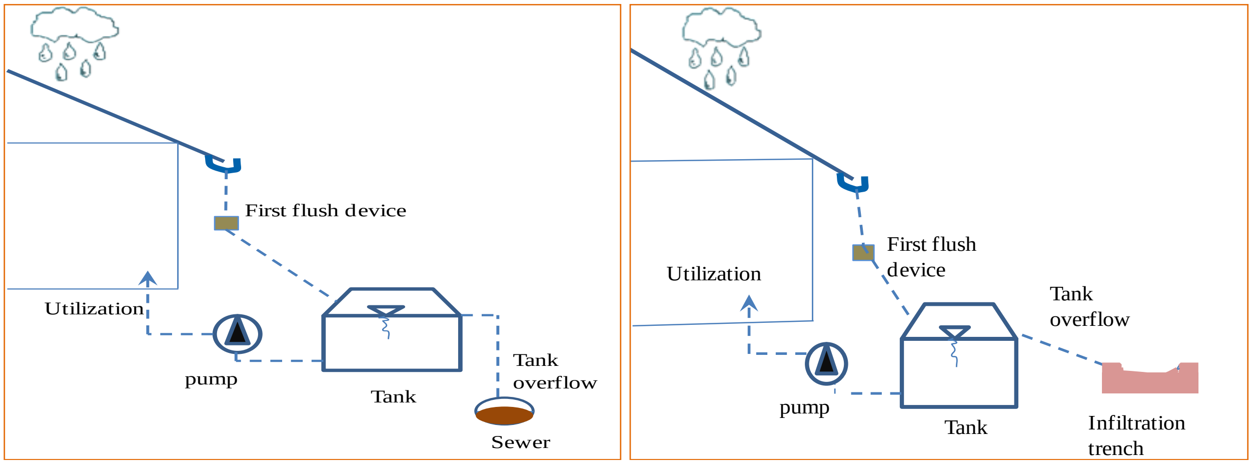


Figure 4.12 Typical rainwater usage systems

[*Source:* Adopted from Hermman and Schmida, 2000]

4.4.6 Permeable pavement for infiltration, treatment and storage for reuse

Permeable pavements have been in use for decades in both stormwater management and environmental protection. They are appropriate for a variety of uses, such as pedestrian walkways, parking lots and residential roads. The traditional design consists of a layer of porous matter resting on crushed stone or any filter layer (bedding material). Beneath the bedding material is a porous/water proof material, a geo textile for example. In other cases a branch drain connected at the sub base forms part of the structure (Pratt, 1999; Fletcher et al., 2008). The operation of permeable pavements is determined by its application, as explained below;

i. Storage and Infiltration of stormwater

The water passes through the porous surface and is stored in the underlying crushed rock storage reservoir where it slowly filters to the underling soils through the porous geo textile filter fiber placed on the floors and sides of the recharge bed (see Figure 4.8).

ii. Stormwater storage (permanent or temporary)

The water passes through the porous surface to the underlying crushed rock layer, where it is either permanently stored or is directed to a side drain for storage elsewhere. The water proof geo textile fiber placed on the floors and sides of the recharge bed serves two purposes; first, to prevent infiltration and secondly to direct the retained water to a side drain (see Figure 4.1). The water collected can be supplied for hot water systems in the house, toilet flushing, garden and POS irrigation at unitblock or minicluster scales. The water collected can be supplied for hot water systems in the house, toilet flushing, garden and POS irrigation at unitblock or minicluster scales. In both cases stormwater quality is improved as they offer some degree of treatment.

The amounts of water that a porous pavement can infiltrate or store are determined by; design specifications, paving material, soil type and rainfall event. Infiltration capacities of > 4500 mm/h for new pavements can be achieved. In cases where a sub-base thickness of 300-400mm is used, it provides around 100mm effective depth of water storage, assuming a 30% void ratio amounts to 100 litres/m^2 of pavement (Newton et al., 2003; Pratt, 1999; Pratt et al., 1995).

The ability of permeable pavement to provide for stormwater reuse through collection, treatment and storage within the existing impervious surface without requiring additional land makes it a suitable method for dense urban areas like Tel Aviv. Further, given that Tel Aviv experiences storm events during winter season which in most cases result in significant amounts of surface runoff (Duong et al., 2010), additional underground tanks of appropriate sizes should be added to the system.

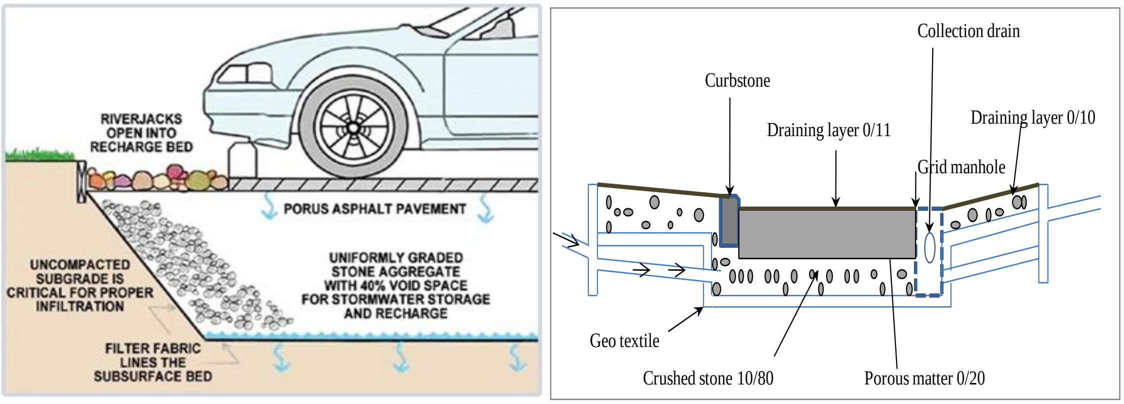


Figure 4.13 permeable pavements for storage & infiltration (left) and for stormwater storage (right)

[*Source:* Adopted from Liebl, 2007; Roche et al., 2001]

4.4.7 Porous pipe retrofits

In stormwater management there is need always a need for technologies that allow for technologies that allow for integrated stormwater harvesting, treatment, storage and distribution systems to be retrofitted into existing dense urban areas e.g. Tel Aviv. Some of the retrofit technologies have been discussed in the above discussions e.g. rainwater harvesting systems. Another technology that can be applicable in Tel Aviv is porous pipe work. It can be retrofitted in the existing drainage network, thus providing for aquifer recharge and recovery at a later stage.

Others

- **Landscape restoration;** to restore landscape within the city that can bring about more infiltration into the city. E.g. Tel Aviv Yafo Municipality can have a rule where for every plot being developed 20% of the area is left pervious. Stormwater that infiltrates recharges and hence gradually restores the coastal aquifer. Consequently the boreholes yields will increase.

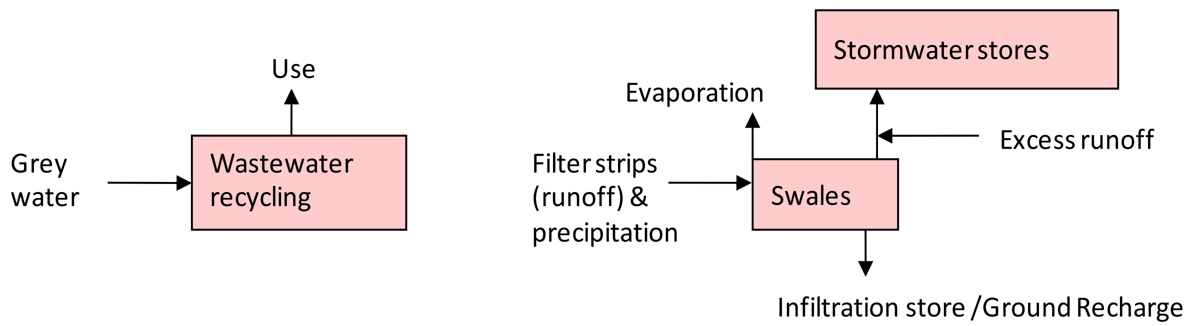
4.5 Assessment of Strategies

Assessment of strategies for the catchment of Tel Aviv was done as per sub catchment. This is because the sub catchments were different in physical attributes and hence were expected to have varied effects on water and contaminant balance.

4.5.1 Constructed Wetlands treating both sewage and stormwater

Primary treatment level

The management options suitable for simulating this strategy were both wastewater recycling stores and swales at minicluster scales. Swales did not allow for direct re use of stormwater (see conceptual representations below), as such, sufficient assessment was not achieved. Nevertheless, results from the two simulations where combined to get the effect of the strategy on the water and contaminant balance of Tel Aviv.



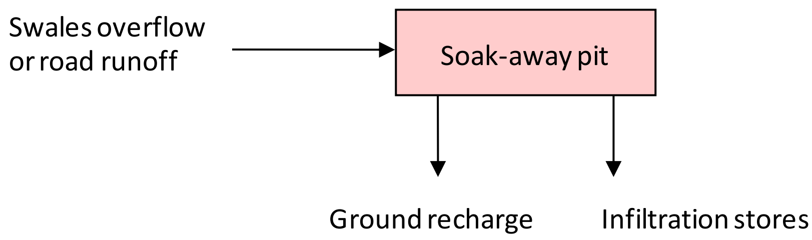
The capacity of a swale used was 300 m^3/day. Grey water storage tanks of 1,000, 1,500, 5,500 and 8,500 m^3 were simulated. Treated water is proposed for use in hot water systems in the house, toilet flushing, garden and PS irrigation.

Tertiary level

The strategy was modelled as stormwater stores, since stormwater was combining with secondary effluent from WWTP treating wastewater outside Tel Aviv. The capacity of a swale was 300 m^3/day. Treated water is pumped to the Yarqon River and later pumped out after traveling for several kms mainly for PS irrigation within or outside Tel Aviv. Similar tank sizes as those in strategy 4.5.3 were used in simulation hence similar results obtained.

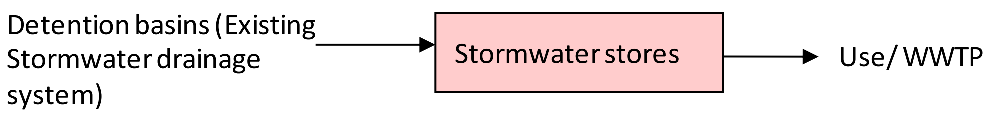
4.5.2 Aquifer infiltration

The management options suitable for simulating this strategy were soak-away pits and boreholes at minicluster scale. Soak-away pit capacities used were > 10m^3 and infiltration coefficients of 1m^3/day. However, the model gave a non number value, hence the strategy could not be assessed. The conceptual representation is as below.



4.5.3 Combining stormwater with sewage while incorporating decentralized tanks

The strategy was simulated at minicluster scale as stormwater stores and therefore, in addition to reduction in runoff discharge, its effect in Tel Aviv mains water supply was also assessed (see conceptual representation below). There was no treatment within the stores.



While considering the sizes of stores, findings by Duong et al., 2009, where put into consideration. Tank capacities of 2,000, 5,000, and 10,000, 20,000 m^3, were simulated. In actual designs sizes of the storage tanks shall also be determined by existing facilities since they are as a result of reconciliation of significant storage volumes with a very wide range of operations.

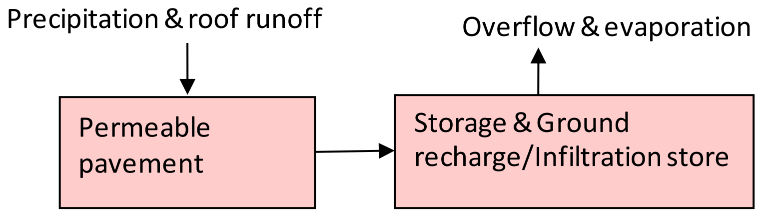
4.5.4 Rainwater harvesting tanks

In order to simulate this strategy, rainwater tanks with storage capacities of 400, 750, 1000, 1200 & 2000 litres were applied at unitblock scale in the city. Harvested water is proposed for use in hot water systems in the house, laundry, toilet flushing and PS irrigation.

4.5.5 Permeable pavements

Storage and Infiltration

In the previous study by Duong, 2008 permeable pavements for infiltration had insignificant effect on stormwater discharged and groundwater recharge. In this study, permeable pavements were for both storage and subsequent infiltration. The conceptual representation is as below;



For simulation in CWB; a constant 100mm effective depth of storage was used. Assuming a 30% void ratio in the sub base amounted to 100 litres/m^2 of pavement. Of the existing impervious areas the amount of area converted to permeable pavement was varied from 20% to 60%.

Storage for re use

The effect of permeable pavement as stormwater stores in the water and contaminant balance of Tel Aviv could not be studied as none of the management options was situated to simulate it.

4.6 Evaluation of strategies by use of measured indicators

In the evaluation of alternative strategies; wetlands combining both stormwater and sewage at primary level, decentralized tanks, rainwater harvesting tanks and permeable pavements, indicators that can be simulated in CWB were used. The indicators were performed for the year 2009 and are as listed below;

- Amounts of pollutants reduced "treatment efficiency" indicator
- Total mains water supply reduction indicator
- Total amount of runoff discharge reduction indicator
- Increment in groundwater recharge indicator

A similar trend on the measured indicator was observed in all sub catchments. For presentation and discussion of results, one sub catchment therefore was chosen (sub catchment 1).

4.6.1 Reduction in pollutant levels evaluation indicator.

Table 4.6 below presents the impacts of four strategies on pollutant loads for P, Cu and Pb. Amount of pollutant loads removed (%) varied according to the management strategy. For pollutant reduction in stormwater, in the two strategies where treatment is applied, e.g, permeable pavement, Pb removal efficiency was highest; 16% followed by P, 7% and Cu, 4%. This values are quite low compared to results of other related studies e.g for P; 65% (Pratt et al., 1995). In wetlands treating sewage and stormwater at primary levels removal efficiency for all pollutants was 100%. High removal efficiencies are expected in wetlands. 100% efficiency is likely due to the low pollutant load levels.

In raintanks and combining stormwater with sewage while incorporating decentralized tanks strategies, no treatment is expected and amounts of loads removed are mainly depended on the amount of stormwater harvested and used. Generally pollutant load removal was higher in the later; (88, 77 and 82%) than in the former; 3, 8 and 1%. This could be explained by the fact that decentralized tanks had more storage capacities hence, diversion of the stormwater in large amounts for storage and re use.

Ground water pollutant loads removal efficiencies varied according to the management strategy. Constructed wetlands had highest removal efficiencies; 100% for all pollutants. 100% efficiency is likely due to the low pollutant load levels as well as low amounts of infiltrated stormwater (see section 4.6.4). Permeable pavement removal efficiencies were also noteworthy; 44 13 and 38% respectively, implying that permeable pavements can significantly reduce groundwater pollution.

Table 4.6 Treatment/removal efficiencies of P, Pb and Cu loads in stormwater and ground recharge

	Pload (kg/ha)			Cu load (kg/ha)			Pb load (kg/ha)		
Management option	Initial	Final	% reduction	Initial	Final	% reduction	Initial	Final	% reduction
Stormwater									
Raintanks	0.092	0.089	3	0.026	0.024	8	0.067	0.066	1
Wetlands (primary level)	0.092	0	100	0.026	0	100	0.067	0	100
Permeable pavements (infiltration)	0.092	0.086	7	0.026	0.025	4	0.067	0.056	16
Combining stormwater with sewage incorporating decentralized tanks	0.078	0.009	88	0.022	0.005	77	0.056	0.01	82
Groundwater									
Permeable pavements (infiltration)	0.034	0.019	44	0.008	0.007	13	0.034	0.021	38
Wetlands	0.034	0	100	0.008	0	100	0.034	0	100

4.6.2 Reduction in mains water supply

Figure 4.14 below shows the effect of three strategies as compared to a baseline situation on the amount of fresh water supplied for the year 2009. Installation of raintanks at unitblock scale reduces mains water supplied by 19% (160,000 CM), while combining stormwater with sewage while incorporating decentralized tanks strategy was by 17% (145,000 CM). Wetlands combining grey water and stormwater at minicluster scale had the highest effect of 23% (191,000 CM). This value could have been higher if simulation of swales in CWB had an option for direct re use. In previous research work by Hoang 2009, amount of mains water supply reduced by grey water reuse at cluster scale was double that by rainwater harvesting (quite high as compared to this study where difference in the two is 4%). This could be explained by the fact that grey water reuse simulations in CWB had usage of only toilet and PS irrigation.

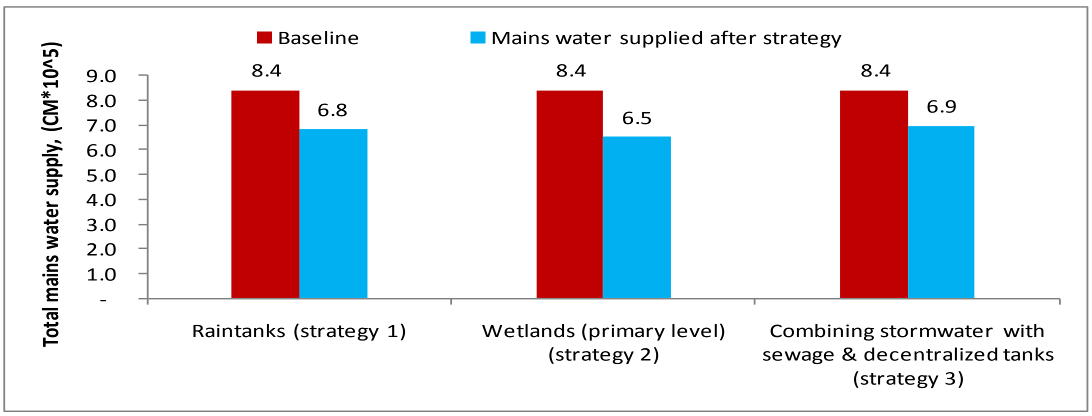


Figure 4.14 Total mains water supply in sub catchment VS selected strategies for year 2009

Storage tank efficiencies

The efficiency of storage tanks within the three strategies above was calculated and results are as presented in figure 4.15. An increase in capacity of tanks in any of the strategies increases the amount of mains supply saved, but reduces the efficiencies.

For CW (strategy 2) stormwater and grey water storage tanks of capacity 1,000 m^3 (approximately 0.5m^3/household) and 1,500 m^3 (approximately 1.2m^3/household) the amounts of mains water saved was 191017 CM (22%) and 191103 CM (22.7 %) respectively. The savings on imported water per unit volume of storage tank was 191 m^3/m^3/yr for the smaller tank and 127 m^3/m^3/yr for the larger tank, implying that the small tank has higher efficiency. Further, the efficiencies are much higher than those for the other two strategies (figure 4.16), hence, this strategy has a higher potential for saving on imported water, mainly because supply of wastewater to the storage tanks is less fluctuating. This is inline with previous research findings by Duong et al., 2009 on Tel Aviv catchment.

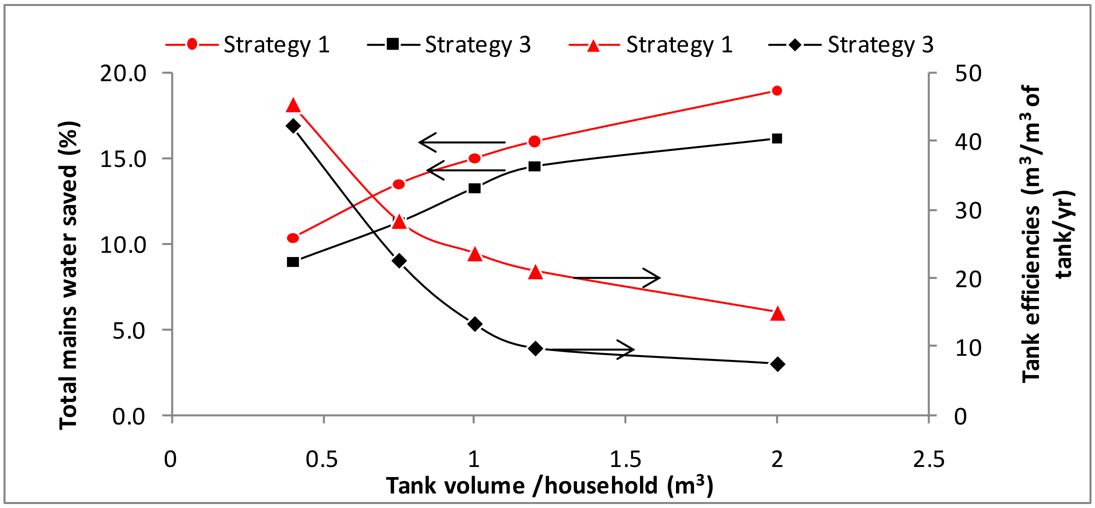


Figure 4.15 potential for water saving by strategies for year 2009

4.6.3 Reduction in runoff

Figure 4.16 presents effects of strategies on total runoff generated. Rainwater tanks had the highest effect on stormwater discharged 48% (143,500 CM). Combining stormwater with sewage strategy including decentralized tanks strategy had an impact of 30% (88,000 CM). This strategy was expected to be highly effective (perhaps even higher than raintanks) in reducing runoff quantities (capacities of decentralized tanks are quite large-15000m^3) as well as efficient; since instead of spillage during peak floods excess water can as well be released directly to the sewage system especially during sewage off peak hours. However proper simulation could not be achieved since CWB allowed for modeling as stormwater store with limited uses for the water i.e toilet flushing and PS irrigation, hence reduced quantities of the amounts of stormwater used. In addition most of the irrigation is carried out in summer. Even though permeable pavements had the least impact 10% amounting to 30,805 CM, this was considered to be rather significant since it approximately amounted to 5MCM per yr (figure to be re-confirmed once simulation of the whole city is completed) for the whole of Tel Aviv. On the other hand Wetlands had a significant effect on the amount of stormwater discharged; 23% (67,900 CM).

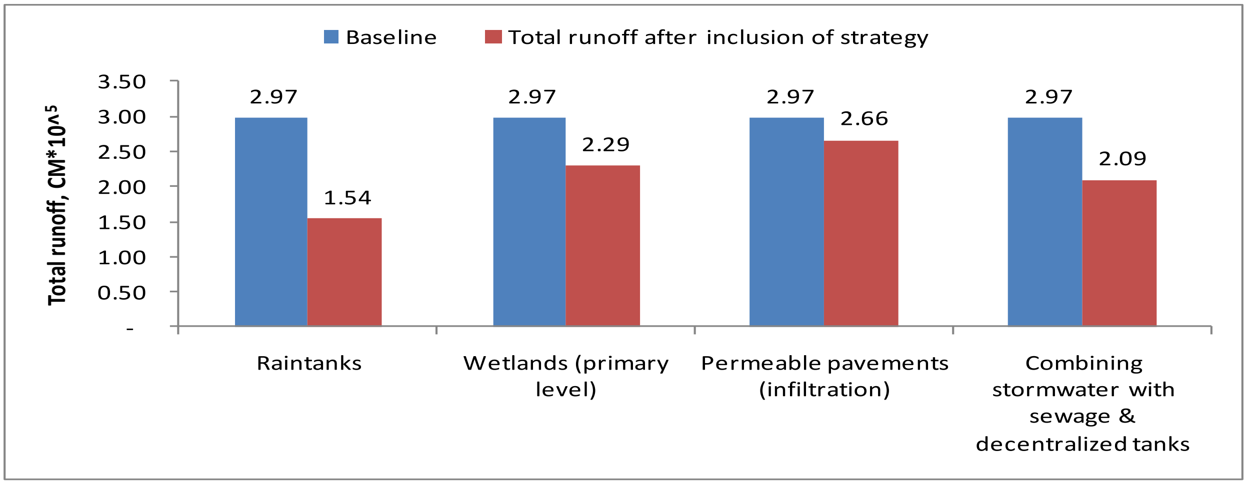


Figure 4.16 Total runoff in sub catchment VS selected strategies for year 2009

4.6.4 Increment in groundwater recharge indicator

Figure 4.17 presents effect of permeable pavement and CW on groundwater recharge. If 40% of the pavement is permeable, ground water recharge is increased by 19% (29,200 CM), with an increment of 20% on permeable area, groundwater recharge increases by 10% (15,000CM). Permeable pavement can therefore be said to significantly increase groundwater recharge relative to the storage and infiltration areas. On the other hand for a CW of 300m^2 surface area, ground recharge increases by 0.4 % (700 CM). A significant reduction of surface area to 100m^2, has a small effect on recharge increment; 1% (1,700CM), which is attributed to reduced total evaporation due to reduction in surface areas. CW therefore, cannot be considered as significant ground water recharge strategies in Tel Aviv. Other options e.g. those of soak away pits and boreholes need to be explored.

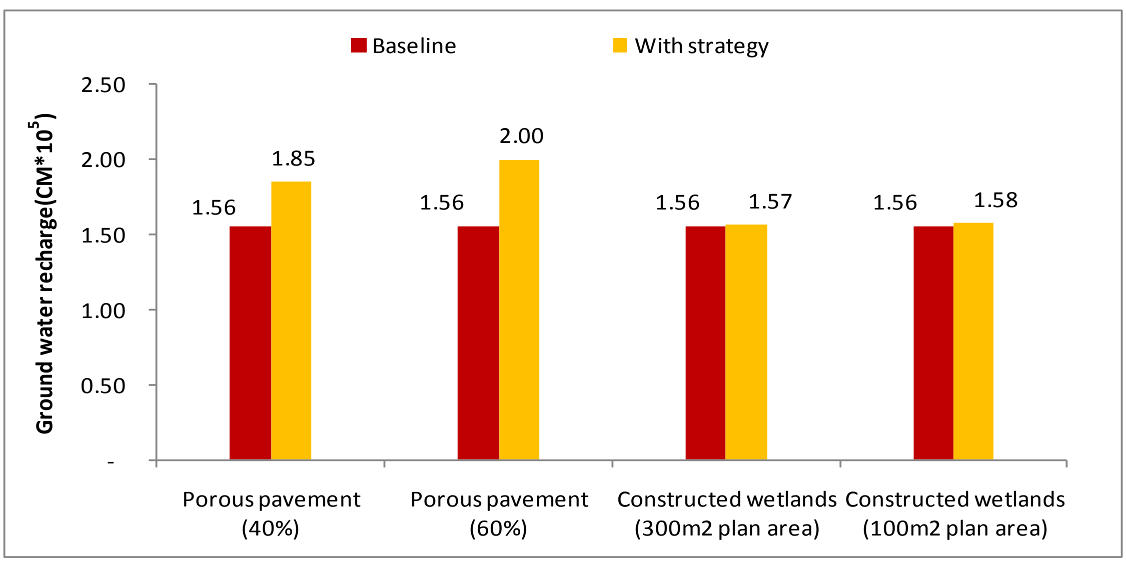


Figure 4.17 Ground water recharge VS selected strategies for year 2009

4.6.5 Evaluation of strategies for the whole of Tel Aviv catchment

An evaluation of one strategy in the entire catchment of Tel Aviv was done in addition to that of Sub catchment 1, discussed in the sections above. This was to give an idea of the effect of strategies on water and pollutant balance for the entire catchment. Constructed Wetlands were found to significantly affect the total runoff generated, pollutants and mains water supply (see Table 4.7).

Table 4.7 Percentage reduction of; pollutant loads in runoff, runoff and mains water supply

		Baseline	***After strategy***	***% reduction***
Pollutants (kg/ha)	**P**	0.6	0.02	100
	Cu	0.2	0.01	100
	Pb	0.5	0.02	100
Total Runoff (MCM)		16,060,620	12,900,100	20
Total mains supply (MCM)		34, 900,700	21, 800, 500	38

5.0 CONCLUSIONS

From the findings in this study the following could be concluded;

1. By use of CWB to carry out an MFA analysis of stormwater pollutants and water balance, it was possible to view the systems of Tel Aviv city in the context of the total urban water system (from the anthropogenic to the receiving environment).
2. Stormwater runoff pollutant loads predicted by CWB from the urban catchment of Tel Aviv where within the typical ranges as published in literature. This showed the significant of stormwater as a non point source to the contamination of the receiving waters in Tel Aviv.
3. Stormwater management systems proposed for Tel Aviv have varied impacts on pollutant fluxes e.g wetlands treating grey water and stormwater at minicluster scale removal efficiency for Cu was 100%, for raintanks 12%, combining stormwater with sewage while incorporating decentralized tanks at large scale by 8%, and permeable pavement (with storage) by 8%. Wetlands had the highest removal efficiencies for most pollutants (100%).
4. Wetlands combining grey water and stormwater at minicluster scale had the highest effect in reducing mains water supply; 23% (191,000 CM), followed by raintanks at unitblock scale 19% (160,000 CM). On the other hand, in stormwater discharge reduction, rainwater tanks had the highest effect of 48% (143,500 CM), while wetlands had a significant effect of 23% (67,900 CM). As mentioned before with proper simulation the effect of wetlands would have been higher in both cases. It is proposed that these two strategies are implemented in order of priority i.e Wetlands being given a priority.
5. Combining stormwater with sewage while incorporating decentralized tanks is another viable option mainly for stormwater discharge reduction; 30% (88,000 CM), a figure that could possibly be higher if proper simulations are done. Lastly permeable pavements can also be recommended for installation since they are also significant in stormwater reduction 30,800 CM.

6.0 RECOMMENDATIONS

General

1. CWB to be used in future to incorporate the cost of the strategies, since it gives an idea of the economic implications for the new and on existing structures e.g. on the Shafdan WTTP.
2. Proper simulation of ground recharge and borehole extraction should be carried out.
3. Further investigations into the runoff quality for TS, COD, TN, TP and TSS. All these parameters serve as good indicators of urban runoff quality to the effect that TS represents the total soluble and insoluble solute and pollutants, TSS represents sediments, COD represents organic loading and oxygen demand and TN and TP represents nutrients. This will provide a more appropriate data set for defining management strategies as well as for comparison with raw sewage for concentration values, unit loadings and variability. A better way of carrying out these investigations is by putting in place a comprehensive stormwater monitoring system for Tel Aviv Yafo, since long-term monitoring is needed to determine the appropriate pollutant unit load.
4. Tel Aviv Yafo municipality to split up charges for urban drainage in a consumption-dependent amount for wastewater and an impervious surface-area-dependent amount for stormwater that way there is a permanent incentive to disconnect the roofs from the sewers hence assist in avoiding the frequently experienced overflow of sewers due to illegal roof connections and also increase pervious areas for infiltration.
5. If strategies are to be implemented, then there is need to flex current guidelines, standards and regulations which have been developed for the conventional urban water systems, and as a result are not appropriate for proposed strategies which have adopted an integrated approach.

Concerning CWB

1. Water management options within CWB balance should allow for simulation of viable stormwater harvesting techniques e.g wetlands. Further the existing stormwater stores at large scale should allow for water use at large scale including direct emptying to the combined sewer system
2. Experiments require to be carried out in order to obtain values for the case specific parameters. These experiments should be performed for a period of time in order to cater for the effect of time variability.
3. Contaminants input files should allow for several pollutant types since currently input is limited to three.

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APPENDICES

Appendix 1:

Chemical Parameters in Drinking Water
Data Source: Mekorot NWC and Tel Aviv Yafo Municipality

Parameters	Units	Std value (WHO)	Average Value	Min Average Value for a month	Max Average Value for a month
Silver	µg/l	10	0	0	0
Arsenic as As	µg/l	50	0.1	0	0.4
Barium as BA	µg/l	1000	61.1	54.7	74.1
Cadmium as CD	µg/l	5	0	0	0
Cyanide as CN	µg/l	50	0	0	0
Chromium as CR	µg/l	50	0	0	0
Mercury as Hg	µg/l	1	0	0	0
Nickel as Ni	µg/l	50	0.1	0	0.4
Nitrate as NO_3	mg/l	70	1.5	0.5	3.4
Lead as Pb	µg/l	10	0	0	0
Selenium as SE	µg/l	10	0.2	0	0.8

Parameters	Units	Std value (WHO)	Average Value	Min Average Value for a month	Max Average Value for a month
Benzene	µg/l	10	0	0	0
Benzopyrene	µg/l	0.7	0	0	0
Carbon Tetrachloride	µg/l	5	0	0	0
CIS-1, 2 Dichloroethylene	µg/l	100	0.12	0	0.45
Chloroform	µg/l	100	0	0	0
Dichloroethane 1,2	µg/l	5	0	0	0
Dichloroethylene 1,1	µg/l	30	0	0	0
Monochlorobenzene	µg/l	300	0	0	0
Dichlor Benzen 1,2	mg/l	1000	0	0	0
Dichlorobenzene 1,4	µg/l	300	0	0	0
Styrene	µg/l	50	0	0	0
Trichloroetane 1,1,1	µg/l	200	0	0	0
Trichloroethylene	µg/l	50	0	0	0.1
Tetrachloroethylene	µg/l	40	0	0	0
Toluene	µg/l	700	0	0	0.1
Xylene	µg/l	1000	0	0	0

Parameters	Units	Std value	Average Value	Min Average Value for a month	Max Average Value for a month
Alachlor	µg/l	20	0	0	0
Atrazine	µg/l	2	0	0	0
Chlordane	µg/l	2	0	0	0
Dibromo-3-Chloropropan	µg/l	1	0	0	0
Endrin	µg/l	2	0	0	0
Ethylene Di Bromide	µg/l	0.05	0	0	0
Heptachlor	µg/l	0.4	0	0	0
Lindane	µg/l	2	0	0	0
Methoxychlor	mg/l	20	0	0	0

Parameters	Units	Std value	Average Value	Min Average Value for a month	Max Average Value for a month
Calcium as CA	mg/l	No std*	60	53	77
Chloride as Cl	mg/l	600	228	176	251
Copper as Cu	µg/l	1400	0.5	0.1	1.4
Iron Total as Fe	µg/l	1000	23.4	21.1	35.4
Hardness as CaCo3	mg/l	No std*	287	267	339
Detergents as LAS	µg/l	1000	0	0	0
Magnesium as MG	mg/l	150	33	32	36
Manganese Total as MN	µg/l	500	4.4	2.3	6.6
Oil and Grease	µg/l	300	0	0	0
Phenols as C6H5OH	µg/l	2	0	0	0.04
Sulfate as SO4	mg/l	250	65.6	52.8	70.6
Dissolved Matter at 180	mg/l	1500	627	607	688
Zinc as Zn	µg/l	5000	16.5	14.2	23.1

No std* Israel waters have a lot of this value and in drinking water it is of no harm						
microgramm/l = p.p.b						
miligramm/l = p.p.m						

Appendix 2:

Performance of Mechanical Biological Treatment Plant- Large Waste Water
Data Source: (Shafdan WWTP)

i) Basic Waste Water Parameters

Parameter	Units	(Yearly average concentration in 2008) Raw Sewage	MBTP Effuent	Removal Efficiency %
BOD	mg/l	375	5	99
BOD f	mg/l	156	1	99
COD	mg/l	863	40	95
COD f	mg/l	267	33	88
DOC	mg/l	78.2	10.8	86
UV 254 absorbance	$cm^{-1}X10^3$	474	212	55
Suspended Solids 105	mg/l	400	5	99
Detergents	mg/l	1.69	0.14	92
Fats	mg/l	82.9	2.4	97
Mineral oils	mg/l	<6.0	<0.8	87
Phenols	µg/l	1,523	4	>99
Kjeldahl Nitrogen	mg/l	63.9	5.6	91
Kjeldahl Nitrogen f	mg/l	46.5	5	89
Ammonia, as N	mg/l	42.1	3.5	92
Total Nitrogen	mg/l	63.9	7.2	89
Total Nitrogen f	mg/l	46.5	6.6	86
Phosphorus	mg/l	13	1.4	89
Phosphorus f	mg/l	8.7	1.3	85
Phosphate, as P	mg/l	8.4	1.2	86
pH	_	7.36	7.56	_
Alkalinity, as $CaCO_3$	mg/l	387	251	35
Temperature	^oC		23.2	

ii Water quality Parameters

Parameter	Units	(Yearly average concentration in 2008) Raw Sewage	MBTP Effuent	Removal Efficiency %
Total Bacteria	No./1 ml	7.18	5.72	1.46
Coliforms	MPN/100 ml	7.96	5.38	2.58
Faecal Coliforms	MPN/100 ml	7.18	4	2.82
Strep. Faecalis	MPN/100 ml	6.61	3.71	2.9

iii Trace elements

Parameter	Units	(Yearly average concentration in 2008) Raw Sewage	MBTP Effuent	Removal Efficiency %
Arsenic	µg/l	<2	<2	
Cadmium	µg/l	<9	<0.2	98
Cyanide	µg/l	<1	<7	
Lead	µg/l	<16	<2	88
Mercury	µg/l	<0.57	<0.1	82
Selenium	µg/l	<2	<2	
Chromium	µg/l	<19	<3	84
Barium	µg/l	81	52	36
Silver	µg/l	<9	<1	89
Copper	µg/l	146	25	83
Iron	µg/l	1208	89	93
Manganese	µg/l	44	22	50
Zinc	µg/l	396	48	88
Boron	mg/l	0.22	0.19	12
Cobalt	µg/l	<3	<3	
Nickel	µg/l	<25	8	<68
Strontium	µg/l	737	656	11
Molybdenum	µg/l	5	<3	>40
Lithium	µg/l	7	<5	>29
Aluminum	µg/l	598	36	94
Tin	µg/l	12	<5	>58

Appendix 3:

Relevant key individuals and organizations

Organization	Conduct person
Tel Aviv Yafo Water Company	Mr. David Jackman, Mr Tzvi Belenki & Mr Michael Levy
Shafdan WWTP	Eng Tomel & Dr. Haim Chikurel
The IGUDAN	Mr. Daniel Solomon
Mekorot NWC	Mr. Avi Aharon
Hayarkon River Authority	Dr David Pergament & Mr. Yonathan Raaz
The Hebrew University of Jerusalem	Prof Avner Adin & Dr. Daniel Kurtzman

Appendix 4:

Miniclusters assignments

MC	Unitblock type	Total no.	MC Area (m^2)	GIS calculated
Sub Catchment 7 (Quarter 3 & 4)				
1	1	1	33,712	
2	2	181	19,432	
3	8	3,274	375,380	
4	9	6,917	626,478	
5	11	430	44,923	
6	12	1	2,499	
7	13	1	102	
8	14	2	4,998	
9	15	1	191	
10	19	457	73,008	
11	20	1	2,836	
12	23	5	10,320	
13	24	4	1,007	
14	25	1	10	
15	3	3,274	375,380	
	Total MC Area		**1,570,276**	**1,568,500**
Sub Catchment 1 (Quarter 7)				
16	1	1	28,093	
17	9	8,734	1,140,036	
18	11	319	39,051	
19	19	910	170,185	
20	21	103	332,704	
21	23	2	5,398	
22	24	1	295	
23	27	6	82,320	
24	28	1	49,392	
	Total MC Area		**1,847,475**	**1,876,200**
Sub Catchment 2 (Quarter 7)				
25	4	1935	232486	
26	7	1935	356884	
27	9	968	126294	
28	11	143	17444	
29	12	2	5858	
30	18	1	2666	
31	19	143	26650	
32	21	50	161507	
33	23	1	2699	
34	24	2	590	
35	27	2	27440	
			933,078	**923,800**

MC	Unitblock type	Total no.	MC Area (m^2)	GIS calculated
Sub Catchment 3 (Quarter 8 & 6)				
36	1	1	28093	
37	4	14976	1799336	
38	9	576	75189	
39	11	890	108982	
40	12	10	29291	
41	15	1	224	
42	19	2758	515699	
43	21	25	80753	
44	23	10	26990	
45	24	5	1475	
46	25	2	167	
47	26	2	4760	
			2,670,960	**2,665,900**
Sub Catchment 4 (Quarter 7 & 8)				
48	1	2	56,187	
49	4	14,607	1,755,032	
50	7	7,447	1,373,495	
51	9	8,594	1,121,761	
52	10	2	465	
53	11	1,741	201,845	
54	12	1	2,929	
55	14	1	2,344	
56	16	1	259	
57	17	1	2,155	
58	19	4,125	771,445	
59	21	40	129,205	
60	23	15	40,485	
61	24	3	885	
			5,458,493	**5,449,500**
Sub Catchment 5 (Quarter 7)				
62	1	1	28,093	
63	7	4,521	833,835	
64	10	1	233	
65	14	1	2,344	
66	15	1	224	
67	19	450	84,158	
68	21	20	64,603	
69	23	1	2,699	
70	24	1	295	
71	25	1	83	
			1,016,567	**1,011,300**

MC	Unitblock type	Total no.	MC Area (m^2)	GIS calculated
Sub Catchment 6 (Quarter 5)				
72	1	2	56,187	
73	4	9,458	1,136,360	
74	9	9,458	1,234,609	
75	11	961	117,643	
76	12	5	14,646	
77	16	1	259	
78	19	3,844	718,893	
79	20	20	66,501	
80	21	99	319,783	
81	23	8	21,592	
82	24	15	4,425	
83	25	4	333	
			3,691,231	**3,693,000**
Sub Catchment 8 (Quarter 4 & 6)				
84	1	2	56,187	
85	3	16,371	2,704,948	
86	9	2,108	275,170	
87	11	529	64,759	
88	17	1	2,155	
89	19	1,187	221,989	
90	20	1	3,325	
91	23	1	2,699	
92	24	1	295	
			3,331,526	**3,320,200**
Sub Catchment 9 (Quarter 3)				
93	1	1	28,093	
94	9	9,755	1,273,313	
95	11	490	69,158	
96	14	1	2,826	
97	15	1	224	
98	16	1	259	
99	19	1,182	221,054	
100	20	20	66,501	
101	23	12	32,388	
102	24	2	590	
103	25	2	167	
104	27	1	13,720	
			1,693,818	**1,694,500**

MC	Unitblock type	Total no.	MC Area (m^2)	GIS calculated
Sub Catchment 10 (Quarter 1)				
105	1	1	28,093	
106	2	47	7,978	
107	5	6,646	1,385,983	
108	10	1	225	
109	11	71	8,692	
110	16	1	259	
111	17	3	6,466	
112	20	5	16,625	
113	21	1,570	5,073,235	
114	22	1	57,330	
115	23	1	2,699	
116	24	1	295	
			6,587,881	**6,581,400**
Sub Catchment 11 (Quarter 1)				
116	1	5	140,466	
117	2	47	6,616	
118	5	15,670	3,267,954	
119	11	419	51,293	
120	12	2	5,858	
121	13	1	121	
122	16	1	259	
123	17	30	64,662	
124	19	772	144,495	
125	21	210	678,586	
126	23	32	99,577	
127	24	2	680	
			4,460,568	**4,479,600**
Sub Catchment 12 (Quarter 2)				
128	1	2	56,187	
129	6	13,916	2,978,469	
130	11	109	13,343	
131	15	1	224	
132	19	201	37,590	
133	23	5	13,495	
134	24	1	295	
135	25	1	83	
			3,099,604	**3,140,100**

MC	Unitblock type	Total no.	MC Area (m^2)	GIS calculated
Sub Catchment 13 (Quarter 2)				
136	1	6	168,560	
137	6	9,307	1,991,996	
138	11	109	13,343	
139	17	1	2,155	
140	19	318	59,471	
141	20	1	3,325	
142	21	55	177,725	
143	23	5	13,495	
144	24	1	295	
145	27	5	72,459	
			2,430,366	**2,435,500**
Sub Catchment 14 (Quarter 2)				
146	1	1	28,093	
147	6	6,347	1,358,515	
148	11	109	13,343	
149	19	318	59,471	
150	21	85	274,666	
151	23	5	13,495	
152	24	1	295	
			1,719,785	**1,719,900**
Sub Catchment 15 (Quarter 2)				
153	1	1	28,093	
154	2	238	38,625	
155	6	4,654	995,998	
156	11	214	30,133	
157	19	214	46,035	
158	21	50	161,568	
159	23	5	13,495	
160	24	1	295	
161	27	4	57,967	
			1,285,854	**1,292,900**

MC	Unitblock type	Total no.	MC Area (m^2)	GIS calculated
Sub Catchment 16 (Quarter 2)				
162	6	2,327	497,999	
163	21	10	32,314	
164	23	2	5,398	
			535,711	**525,200**
Sub Catchment 17 (Quarter 1)				
165	1	5	140,466	
166	16	2	519	
167	17	1	2,155	
168	21	55	177,725	
169	23	2	5,398	
170	26	1	2,380	
			328,643	**320,400**
Sub Catchment 18 (Quarter 4)				
171	1	5	140,466	
172	9	1,081	141,044	
173	11	159	19,464	
174	21	25	80,784	
175	23	1	2,699	
176	27	1	2,380	
			386,838	**387,000**
Sub Catchment 19 (Quarter 4)				
178	1		28,093	
179	3	3,113	514,272	
180	11	109	13,343	
181	12	1	2,929	
182	19	174	32,541	
183	21	45	145,411	
184	23	6	16,194	
185	26	1	2,380	
			755,164	**746,100**
Sub Catchment 20 (Quarter 9)				
186	1	1	28,093	
187	2	237	38,462	
188	3	2,367	391,012	
189	4	2,367	284,330	
190	11	143	17,444	
191	19	143	26,650	
192	23	3	8,097	
193	24	1	295	
			794,384	**746,400**

MC	Unitblock type	Total no.	MC Area (m^2)	GIS calculated
Sub Catchment 21 (Quarter 9)				
194	1		28,093	
195	4	56	6,743	
196	11	285	34,889	
197	19	86	15,990	
198	23	1	2,699	
			88,414	**391,600**
Sub Catchment 22 (Quarter 9)				
199	1		28,093	
200	3	3,150	520,468	
201	17	2	4,311	
202	11	53	114,327	
203	19	157	29,315	
204	23	3	8,097	
205	24	1	2,701	
			704611.2348	**688,800**
Sub Catchment 23 (Quarter 9)				
206	1	2	56,187	
207	3	3,150	520,468	
208	8	3,150	520,468	
209	11	171	20,933	
210	19	285	53,300	
211	21	9	29,082	
212	23	1	2,699	
213	24	1	295	
214	27	2	4,760	
			1,208,192	**1,239,100**
Sub Catchment 24 (Quarter 9)				
215	1		28,093	
216	4	1,989	238,914	
217	8	1,989	328,556	
218	11	157	19,189	
219	12	1	2,929	
220	19	181	33,850	
221	23	1	2,699	
			654,231	**540,100**

MC	Unitblock type	Total no.	MC Area (m^2)	GIS calculated
Sub Catchment 25 (Quarter 9)				
222	1		28,093	
223	3	1,854	306,374	
224	4	1,854	222,784	
225	11	157	19,189	
226	12	2	5,858	
227	19	157	29,315	
228	21	25	80,784	
229	23	1	2,699	
230	24	1	295	
			695,392	**692,900**
Sub Catchment 26 (Quarter 9)				
231	1		28,093	
232	3	4,725	780,702	
233	8	4,725	780,702	
234	11	56	6,871	
235	13	1	120	
236	14	1	2,344	
237	15	1	224	
238	19	95	17,767	
239	21	10	32,314	
240	23	1	2,699	
241	24	1	295	
			1,652,131	**1,651,800**
Sub Catchment 27 (Quarter 9)				
242	1	1	28,093	
243	7	3,977	733,502	
244	8	3,977	657,112	
245	10	1	225	
246	12	1	2,929	
247	19	53	9,912	
248	21	1	3,231	
249	23	1	2,699	
250	24	1	295	
			1,437,998	**1,280,700**
Sub Catchment 28 (Quarter 9)				
251	1	2	56,187	
252	7	56	10,351	
253	15	1	224	
254	21	160	517,018	
255	23	1	2,699	
256	27	1	2,380	
			588,859	**589,400**

Appendix 5:

Distribution of urban water use in Tel Aviv per Unit Block
Data Source: Tel Aviv Yafo Municipality

Year	Residential	Institutional/Educational	Others	POS	Public Buildings	Health Centres	Hotels	Trade	Securty & Transport	Construction	Total (CM)
1996											38,450,391
1997	25,883,921	807,188	473,891	3,009,829	2,495,037	490,215	1,330,424	5,573,012	481,253	361,082	40,905,852
1998	26,729,035	870,301	437,268	3,455,443	2,614,512	472,438	1,288,267	5,944,653	542,676	308,988	42,663,581
1999	26,484,007	957,878	462,508	3,822,771	2,398,152	711,922	1,303,759	6,156,195	519,480	315,829	43,132,501
2000	25,402,190	633,285	452,001	3,568,380	2,315,509	571,892	1,266,891	5,919,850	514,066	295,168	40,939,232
2001	26,084,940	696,183	464,158	3,633,082	2,094,140	619,800	1,098,379	5,831,883	504,139	323,648	41,350,352
2002	25,434,609	716,406	444,865	3,361,433	2,028,541	693,565	939,189	5,605,270	432,572	315,121	41,971,571
2003	25,739,168	559,767	450,756	3,915,288	2,125,874	551,889	909,192	5,494,334	428,101	363,349	42,393,932
2004	25,773,492	546,558	376,455	4,180,056	2,029,733	547,614	1,005,482	5,551,539	408,855	286,915	42,706,699
2005	25,758,350	530,867	345,017	4,040,406	2,023,419	562,446	991,276	5,565,427	392,797	253,538	42,463,543
2006	26,341,478	459,080	373,288	3,807,943	1,906,234	599,794	1,011,768	6,010,306	420,714	253,265	43,183,870
2007	28,050,025	495,891	359,650	4,177,391	1,929,791	542,866	1,083,810	7,242,650	391,184	273,845	46,547,103
2008	26,831,126	491,867	370,519	3,416,737	1,786,000	541,593	1,018,888	6,451,672	373,915	239,121	41,521,438
	0.603	0.011	0.008	0.090	0.041	0.012	0.023	0.156	0.008	0.006	
%	**60.26**	**1.07**	**0.77**	**8.97**	**4.15**	**1.17**	**2.33**	**15.56**	**0.84**	**0.59**	
Ratio to residential		0.0177	0.0128	0.1489	0.0688	0.0194	0.0386	0.2582	0.0139	0.0098	
Use 1	60	1.06	0.77	8.94	4.13	1.16	2.32	15.49	0.84	0.59	
Use 2	30	0.53	0.38	4.47	2.06	0.58	1.16	7.75	0.42	0.29	
Use 3	60	1.06	0.77	8.94	4.13	1.16	2.32	15.49	0.84	0.59	
Use 4	8	0.14	0.10	1.19	0.55	0.15	0.31	2.07	0.11	0.08	

Appendix 6:

Table a to g; data sets used for the set up of CWB model

a. Study area Scale

File type/Parameter listing	*Unit*	*Data Source /Data processing*
File: Study area		
• Total no. of mini clusters	nb	Digital Landparcel map (buildings and roads), tourist map, local data
% of demand met by mains water	%	Mekorot NWC
File: Sub catchment flows		
• Number of sub catchments	nb	Digital stormwater drainage map, GIS analysis,
• Flow network within sub catchments	nb	Digital stormwater drainage map, GIS analysis, MS office Word

b. Climate Data

File type/Parameter listing	*Unit*	*Data Source /Data processing*
• Rainfall	mm	European Climate Assessment & Data set project (*ECA&D*)
• Potential Evaporation	mm	Calculated from monthly heat indexes and unadjusted potential evaporation

c. Unit Block Scale

File type/Parameter listing	*Unit*	*Data Source /Data processing*
File: Unit block defaults		
• Roof area	m^2	Digital analysis of building layer
• Paved area	m^2	Estimates
• Pervious space	m^2	Tourist map, local data
• Effective roof area	%	Literature
• Effective paved	%	Literature
• Roof initial loss (m)	mm	Climate file (potential Evapotranspiration)
• Paved initial loss (m)	mm	Climate file data (potential Evapotranspiration)
• Proportion irrigated	%	Tel Aviv Yafo Water company & Rehovot campus
• Trigger to irrigate	ratio	Literature
• Occupancy factor/ floor area as multiplication factors	nb/m^2	Digital Landparcel map (buildings), GIS analysis, Local Data
• Proportion of use hot (2,3,&4)	ratio	Default value
• Unit demands (1, 2, 3 & 4)	l/day	Tel Aviv Yafo Water company

d. Miniclusters Scale

File type/Parameter listing	*Unit*	*Data Source /Data processing*
File: Mini cluster-defaults		
• Proportion of surface runoff as inflow	ratio	Tel Aviv Yafo Water company (Pumping rates data), Ms Office Excel
• Sewer exfiltration proportion	ratio	Default value
• Infiltration store recession constant	ratio	Default value
• Woods intercept	m	Literature, daily rainfall averages
• Woods potential evapotranspiration	m/day	Literature
• Leakage proportion	ratio	Tel Aviv Yafo Water company (water loss data), Ms Office Excel
• Road initial loss	mm	Climate file
• Effective road area	ratio	Tel Aviv Yafo Water company
• Recharge index	nb	Literature
• Infiltration store index	nb	Literature
File: MC _assigns		
• MC numbering	nb	MS office Excel
• Assigning UB defaults to MC	nb	MS office Excel
• Assigning MC to sub catchments	nb	Digital stormwater drainage map, tourist map, local data
• Determining MC area	M^2	Digital Landparcel map (buildings and roads), GIS analysis, Local data
• Road areas	M^2	Digital analysis of the road layer
• POS area	M^2	Digital Landparcel map, GIS analysis, tourist

		map
• Proportion of woods	%	Tel Aviv Yafo Water company
• Proportion of POS irrigated	%	Tel Aviv Yafo Water company
• Trigger to irrigate for POS	nb	Tel Aviv Yafo Water company
• Supply garden With imported water	nb	Tel Aviv Yafo Water company
• Supply POS with imported water	nb	Tel Aviv Yafo Water company

e. Contaminant Loads

File type/Parameter listing	***Unit***	***Data Source /Data processing***
• Road runoff	Mg/l	Literature, measured data
• Roof first flush	Mg/l	Literature, measured data
• Roof runoff	Mg/l	Literature, measured data
• Pavement runoff	Mg/l	Literature, measured data
• Fertilizer to garden	Mg/l	Literature, measured data
• Fertilizer to POS	Mg/l	Literature, measured data
• Evaporation	Mg/l	Calculated based on evaporation & rainfall data
• Loads on waste streams per unit block type split into the 4 usages	Mg/l	Literature, UNESCO-IHE Scientific Presentations
• Groundwater	Mg/l	Mekorot NWC, Tel Aviv Yafo Water company
Treatment efficiencies		
• Soil store	%	
• UB WW	Ditto	
• UB Rain tank	Ditto	
• UB Septic tank	Ditto	
• UB Green roof	Ditto	
• UB Swale		
• UB Porous paving	Ditto	Mekorot NWC, Tel Aviv Yafo Water company, Shafdan WWTP
• UB Borehole	Ditto	
• MC SS	Ditto	
• MC WW	Ditto	
• MC PA		

• MC filter strip	Ditto	
• MC Swale	Ditto	
• MC soak away	Ditto	
• MC pond	Ditto	
• Large SS	Ditto	
• Large WW	Ditto	
• Large Borehole		
Uniform contaminants for study area;		
• In rain fall	mg/l	Literature, Mekorot NWC
• Imported water	mg/l	Literature, Mekorot NWC

f. Soils

File type/Parameter listing	***Unit***	***Data Source /Data processing***
File: Cell groundwater		
• Capacity of pervious store 1	m	Literature
• Capacity of pervious store 2	m	Literature
• Pervious store 1 area proportion	nb	Literature
• Field capacity factor	nb	Literature
• PS 1 drain max	mm	Literature
• PS 1 drain max	mm	Literature
• PS 1 drain factor	nb	Literature
• PS 2 drain factor	nb	Literature
• Initial level PS 1	m	Literature
• Initial level PS 2	m	Literature

g. Water bodies

File type/Parameter listing	***unit***	***Data Source /Data processing***
File: River input		
• Number of river	nb	Yarqon River Authority
• Length	m	Yarqon River Authority
• Width	m	Yarqon River Authority
• Width riparian zone	m	Yarqon River Authority
• Max. depth	m	Estimates
• Initial depth	m	Estimates
• Manning coefficient	m	Literature
• Av. hydraulic conductivity of bed	nb	Literature

• Thickness bed to aquifer	m	Estimate
• Longitudinal slope	ratio	Literature
• Receive from water body number (tributaries)	nb	Yarqon River Authority
• Default input flow rate	m^3/s	Yarqon River Authority
• Flow into water body number	Ditto	Yarqon River Authority
File: River receive		
• River segments (segment number	nb	Yarqon River Authority
• Number of MC receiving from	nb	Yarqon on River Authority
• MC number	nb	Estimate
• Proportion	nb	Yarqon River Authority

Appendix 7

Determination of Woods Intercept based on daily rainfall values for 2009
Data Source: ECAD

Date	1-Jan	8Jan	11-Jan	12-Jan	17-Jan	18-Jan	1-Feb	10-Feb	11-Feb	14Feb	16-Feb
Rainfall (0.1mm)	1	20	1	1	1	101	87	120	90	1	10
Date	17-Feb	18Feb	20Feb	21-Feb	22-Feb	23Feb	27Feb	28-Feb	1-Mar	2-Mar	3-Mar
Rainfall (0.1mm)	40	3	290	110	180	30	120	340	220	16	15
Date	9-Mar	10Mar	14Mar	15-Mar	23-Mar	24Mar	27Mar	29Mar	16-Apr	13Sep	20-Sep
Rainfall (0.1mm)	3	20	11	70	60	160	10	5	7	3	80
Date	7-Oct	29Oct	30Oct	31-Oct	2-Nov	3-Nov	13Nov	14Nov	17-Nov	18Nov	24Nov
Rainfall (0.1mm)	90	60	580	5	340	190	10	5	104	10	10
Date	25-Nov										
Rainfall (0.1mm)	1										
Total Rainfall					**3631**						
Total days					**45**						
Calculated Woods intercept value					**0.00113**						

Appendix 8

Sample analysis results (raw data)

Table 1; Values, ranges and mean concentrations of Temp, pH, EC and major ions concentrations in stormwater samples

Sampling Date	sample no.	Time	parameter values (mg/l where applicable)											
			Temp (^oC)	pH	EC (ms/cm)	HCO_3	CL	NO_3-N	NH_3-N	SO_4	Ca	K	Na	Mg
14/12/09	1	8.45 am	16.20	7.70	0.26	52.46	15.62	1.10	0.80	22.30	27.60	8.90	23.24	5.23
	2	9.30 am	16.10	7.68	0.21	51.24	16.70	1.00	0.60	23.00	17.80	7.79	30.08	5.71
	Maximum			7.70	0.26	52.46	16.70	1.10	0.80	23.00	27.60	8.90	30.08	5.71
	Minimum			7.68	0.21	51.24	15.62	1.00	0.60	22.30	17.80	7.79	23.24	5.23
	Mean			7.69	0.24	51.85	16.16	1.05	0.70	22.65	22.70	8.34	26.66	5.47
	SD			0.01	0.04	0.86	0.76	0.07	0.14	0.49	6.93	0.79	4.84	0.34
18/12/09	1	9.45 am	16.50	7.60	0.23	47.58	55.38	0.20	0.60	62.00	28.20	12.76	148.90	14.13
	2	10.00 am	16.80	7.69	0.35	36.60	66.39	0.60	0.60	80.00	39.10	16.55	248.60	22.00
	3	10.15 am	16.40	8.10	0.05	48.80	55.74	0.90	0.50	13.00	25.38	4.86	12.67	9.14
	4	10.30 am	16.40	8.50	0.03	54.90	55.03	0.30	0.27	4.00	24.50	3.90	23.10	4.48
	5	10.45 am	16.00	8.07	0.38	59.78	77.04	0.70	0.70	80.00	48.50	14.39	269.20	12.87
	6	11.00 am	16.00	8.70	0.17	61.00	77.04	0.50	0.80	48.00	42.74	7.43	113.80	11.01
	7	11.15 am	15.60	8.50	0.17	46.36	84.14	0.60	0.60	41.00	36.73	7.93	129.30	11.43
	8	11.30 am	15.60	8.47	0.03	50.02	33.37	1.10	0.60	11.00	17.80	3.12	14.30	3.44
	9	11.50 am	15.50	8.30	0.04	54.90	23.08	1.20	0.60	13.00	17.10	3.49	17.63	4.31
	10	12.00am	15.20	8.46	0.24	68.32	68.87	0.70	0.60	22.00	30.30	7.29	47.87	9.36
	Maximum			8.70	0.38	68.32	84.14	1.20	0.80	80.00	48.50	16.55	269.20	22.00
	Minimum			7.60	0.03	36.60	23.08	0.20	0.27	4.00	17.10	3.12	12.67	3.44
	Mean			8.24	0.17	52.83	59.61	0.68	0.59	37.40	31.04	8.17	102.54	10.22
	SD			0.37	0.13	8.95	19.49	0.32	0.14	29.06	10.50	4.81	96.88	5.57
30/12/09	1	11.15 am	14.50	8.49	0.12	25.62	25.90	1.80	0.60	6.00	15.39	7.43	9.37	3.01
	2	11.45pm	14.20	8.13	0.20	58.56	30.89	1.00	0.60	12.00	15.01	3.97	21.96	4.23
	3	12.15pm	13.80	7.87	0.17	53.68	26.63	0.70	0.60	9.00	11.10	3.89	15.41	2.91
	4	12.30pm	14.20	7.70	0.27	51.24	46.50	0.60	0.60	22.00	16.50	4.43	28.19	5.42
	5	12.45pm	14.40	7.64	0.25	70.76	38.70	0.54	0.60	21.00	17.26	4.50	24.92	4.84
	6	1.00pm	13.90	7.64	0.33	73.20	153.00	1.40	0.60	80.00	28.00	19.39	403.35	31.77
	Maximum			8.49	0.33	73.20	153.00	1.80	0.60	80.00	28.00	19.39	403.35	31.77
	Minimum			7.64	0.12	25.62	25.90	0.54	0.60	6.00	11.10	3.89	9.37	2.91
	Mean			7.91	0.22	55.51	53.60	1.01	0.60	25.00	17.21	7.27	83.87	8.70
	SD			0.34	0.08	17.15	49.32	0.50	0.00	27.70	5.70	6.08	156.66	11.35
	Contaminant load (kg/d)					186	180	3	2	84	58	24	281	29

Sampling Date	sample no.	Time	Temp (°C)	pH	EC (ms/cm)	HCO_3	CL	NO_3-N	NH_3-N	SO_4	Ca	K	Na	Mg
			parameter values (mg/l where applicable)											
18/01/10	1	9.15am	11.1	7.44	0.16	45.14	24.85	1.40	0.56	17.00	16.00	7.51	14.15	4.11
	2	9.30am	12.7	7.6	0.16	57.34	19.53	1.80	0.48	11.00	16.80	7.53	13.60	3.81
	3	9.45am	13.5	7.48	0.16	51.24	21.30	2.20	0.56	9.00	18.03	7.38	13.37	4.31
	4	10.00am	13.3	7.45	0.17	45.14	21.30	1.50	0.56	12.00	18.23	7.22	13.49	4.21
	5	10.15am	12.8	7.26	0.17	56.12	24.85	1.20	0.72	10.00	28.39	7.30	13.28	6.05
	6	10.30am	13.8	7.46	0.18	65.88	23.08	1.00	0.40	12.00	27.88	7.15	15.07	5.45
	7	10.45am	13.6	7.5	0.84	59.78	94.08	0.90	1.80	53.00	41.08	12.42	151.00	23.97
	8	11.00pm	13.3	7.7	0.21	48.80	23.08	1.40	0.80	11.00	39.60	7.17	16.30	8.03
	9	3.30pm	14.8	7.9	0.19	54.90	31.95	0.80	1.00	16.00	26.35	6.06	18.56	3.79
	10	3.45pm	15.5	7.85	0.17	45.14	33.73	1.20	0.48	13.00	32.44	5.97	16.51	6.40
	11	5.00pm	15.6	7.88	0.17	54.90	30.18	0.90	0.88	18.00	28.18	6.19	15.57	4.78
	Maximum			7.90	0.84	65.88	94.08	2.20	1.80	53.00	41.08	12.42	151.00	23.97
	Minimum			7.26	0.16	45.14	19.53	0.80	0.40	9.00	16.00	5.97	13.28	3.79
	Mean			7.59	0.23	53.13	31.63	1.30	0.75	16.55	26.63	7.44	27.35	6.81
	SD			0.21	0.20	6.73	21.22	0.42	0.40	12.44	8.79	1.75	41.04	5.84

Table 2; Values, ranges and mean concentrations of trace elements in stormwater samples

Sampling Date	sample no.	Time	Cu	Pb	Si	Al	Ba	Fe	PO_4-P
			Parameter values in mg/l						
14/12/09	1	8.45 am	0.03	0.05	1.81	0.43	0.06	0.65	0.12
	2	9.30 am	0.03	0.08	1.75	0.30	0.05	0.50	0.11
	Maximum		0.03	0.08	1.81	0.43	0.06	0.65	0.12
	Minimum		0.03	0.05	1.75	0.30	0.05	0.50	0.11
	Mean		0.03	0.07	1.78	0.36	0.05	0.58	0.11
	SD		0.00	0.02	0.04	0.09	0.01	0.10	0.01

Sampling Date	sample no.	Time	Parameter values in mg/l							Discharge			
			Cu	Pb	Si	Al	Ba	Fe	PO_4-P	Flow rate (m/sec)	Discharge (m^3/min)	X-sect area (m^2)	Discharge (m^3/day)
18/12/09	1	9.45 am	0.02	0.01	3.72	0.64	0.07	0.63	0.12				
	2	10.00 am	0.02	0.05	5.75	2.99	0.14	3.37	0.16				
	3	10.15 am	0.01	0.05	5.82	3.03	0.14	3.41	0.17				
	4	10.30 am	0.09	0.13	1.92	0.30	0.05	0.44	0.08				
	5	10.45 am	0.02	0.05	3.56	1.38	0.08	1.49	0.14				
	6	11.00 am	0.02	0.09	3.70	1.74	0.10	1.88	0.09				
	7	11.15 am	0.03	0.07	3.71	1.73	0.08	1.90	0.09				
	8	11.30 am	0.02	0.05	1.62	0.69	0.06	0.71	0.06				
	9	11.50 am	0.02	0.03	2.44	1.09	0.07	1.18	0.12				
	10	12.00am	0.03	0.05	5.11	2.58	0.09	2.55	0.09				
	Maximum		0.09	0.13	5.82	3.03	0.14	3.41	0.17				
	Minimum		0.01	0.01	1.62	0.30	0.05	0.44	0.06				
	Mean		0.03	0.06	3.73	1.62	0.09	1.76	0.11				
	SD		0.02	0.03	1.48	0.98	0.03	1.08	0.04				
30/12/09	1	11.15 am	0.03	0.07	1.38	0.53	0.05	0.76	0.07	0.67	35.35	0.88	6363.00
	2	11.45pm	0.03	0.05	1.11	0.34	0.06	0.45	0.08	0.46	24.15	0.88	4347.00
	3	12.15pm	0.01	0.05	0.93	0.15	0.04	0.21	0.08	0.39	17.55	0.75	3159.00
	4	12.30pm	0.03	0.04	1.48	0.42	0.06	0.55	0.09	0.12	5.40	0.75	972.00
	5	12.45pm	0.03	0.04	1.31	0.34	0.05	0.35	0.09	0.28	10.63	0.63	1912.50
	6	1.00pm	0.010	0.084	1.570	0.220	0.052	0.253	0.100	0.18	5.40	0.50	972.00
	Maximum		0.03	0.08	1.57	0.53	0.06	0.76	0.10				
	Minimum		0.01	0.04	0.93	0.15	0.04	0.21	0.07				
	Mean		0.02	0.05	1.30	0.33	0.05	0.43	0.09		18.62		3350.70
	SD		0.01	0.02	0.24	0.14	0.01	0.20	0.01				
Contaminant load (kg/day)			0.07	0.2	4.3	1.1	0.2	1.4	0.3				
18/01/10	1	9.15am	0.02	0.05	1.77	0.21	0.04	0.27	0.11				
	2	9.30am	0.02	0.07	1.75	0.18	0.04	0.24	0.11		7.00	1570000	area
	3	9.45pm	0.02	0.14	2.00	0.32	0.05	0.40	0.11				
	4	10.00pm	0.03	0.05	1.95	0.29	0.05	0.36	0.00				
	5	10.15pm	0.06	0.05	2.78	0.88	0.07	1.01	0.14		10,990.00		
	6	10.30pm	0.05	0.05	2.63	0.66	0.07	0.79	0.13				
	7	10.45pm	0.07	0.05	4.00	1.37	0.09	1.66	0.17				
	8	11.00pm	0.08	0.01	3.72	1.41	0.09	1.38	0.15				
	9	3.30pm	0.03	0.05	1.70	0.39	0.06	0.39	0.09				
	10	3.45pm	0.06	0.05	2.64	1.16	0.07	1.23	0.12				
	11	5.00pm	0.04	0.05	2.37	0.55	0.06	0.99	0.11				
	Maximum		0.08	0.14	4.00	1.41	0.09	1.66	0.17				
	Minimum		0.02	0.01	1.70	0.18	0.04	0.24	0.00				
	Mean		0.04	0.06	2.48	0.67	0.06	0.79	0.11				
	SD		0.02	0.03	0.78	0.46	0.02	0.49	0.04				

Appendix 9

First Flash Data
Data Source: Yarqon River Authority

			First Flash -Yargon (2004)								
8	7	6	5	4	3	2	1		בדיקה		י"ח
A.A purple	Neve ne'eman	Farr	RJ at	Seven Mills	Agricultur al Dam	Morad	No frim	תקן הזרמה לנחל	Sapling Point		
1,100,000	21,000	18,000,000	16,000,000	1,000	36,000	110,000	180	200	coli F		no/ 100m"l
336	734	346	1369	86	106	104	121	70	COD		m"g/l
1106	1080	146	1904	104	40	28	41	10	TSS 105		m"g/l
4.9	32.2	13	14.4	21.2	29.6	33	0.05	1.5	N אמוניה	ammonia	m"g/l
0.9	0.9	1.7	4.1	0.16	0.24	0.2	0.21	0.5	דטרגנטים אניונים	detergents	m"g/l
34	91	35	145	1.3	1.5	2	0.5	1	שמן כללי	oil	m"g/l
0.01	0.01	0.01	0.01	0.0005	<0.005	0.0005	<0.005		כסף		Ag
6.86	0.85	0.94	13.33	1.35	1.16	0.258	0.569		אלומניום		Al
<0.02	<0.02	<0.02	<0.02	<0.015	<0.015	<0.015	<0.015	0.1	ארסן		As
<0.1	0.16	0.2	0.15	<0.100	0.1	<0.100	<0.100		בורון		B
0.198	0.066	0.17	0.54	0.07	0.064	0.065	0.093	50	בריום		Ba
<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005		בריליום		Be
260	84.24	190	340	79.38	74.1	76.41	73		סידן		Ca
<0.005	<0.005	<0.005	<0.005	<0.003	<0.003	<0.003	<0.003	0.005	קדמיום		Cd
0.006	<0.005	<0.005	0.016	0.003	<0.003	<0.003	<0.003		קובלט		Co
0.579	0.008	0.015	0.07	0.005	<0.005	<0.003	0.004	0.05	כרום		Cr
0.5	0.065	0.135	0.503	0.01	<0.010	<0.010	<0.010	0.02	נחושת		Cu
8.16	3.19	1.76	21.8	1.69	1.34	0.312	0.545		ברזל		Fe
<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.0005	כספית		Hg
10.87	24.85	26.59	25.69	21.13	26.59	28	7.2		אשלגן		K
<0.01	<0.012	<0.01	0.015	<0.010	<0.010	<0.010	<0.010		ליתיום		Li
26.99	30.36	30.78	32.54	27.6	33.75	34.52	34.13		מגנזיום		Mg
0.29	0.187	0.089	0.678	0.187	0.107	0.057	0.025		מנגן		Mn
0.016	0.008	0.012	0.03	0.0005	<0.005	0.0005	<0.005		מוליבדנום		Mo
2675	200	206	38	81	106	104	77.87	200	נתרן		Na
0.028	0.024	0.02	0.07	<0.010	0.01	<0.010	<0.010	0.05	ניקל		Ni
1.33	10.16	0.647	4.57	4.98	6.4	7.58	0.022		זרחן		P
0.068	0.022	0.022	0.23	0.001	0.001	<0.010	<0.010	0.008	עופרת		Pb
21.69	38.9	41.88	29.18	20.33	22.5	21.82	17.9		גופרית		S
<0.02	<0.02	<0.02	<0.02	<0.015	<0.015	<0.015	<0.015		אנטימון		Sb
<0.02	<0.02	<0.02	<0.02	<0.015	<0.015	<0.015	<0.015		סלניום		Se
13	8.07	8.39	24.17	10.73	10	7.99	7.63		סיליקה		Si
<0.01	<0.01	<0.01	<0.010	<0.005	<0.005	<0.005	<0.005		בדיל		Sn
0.4	0.383	2.1	0.54	0.491	0.585	0.584	0.983		סטרונציום		Sr
0.234	0.029	0.045	0.51	0.036	0.026	<0.005	0.01		טיטניום		Ti
0.036	0.012	0.017	0.079	<0.010	<0.010	<0.005	<0.005		ונדיום		V
0.923	3.2	0.297	1.8	0.047	0.044	0.04	0.022	0.2	אבץ		Zn