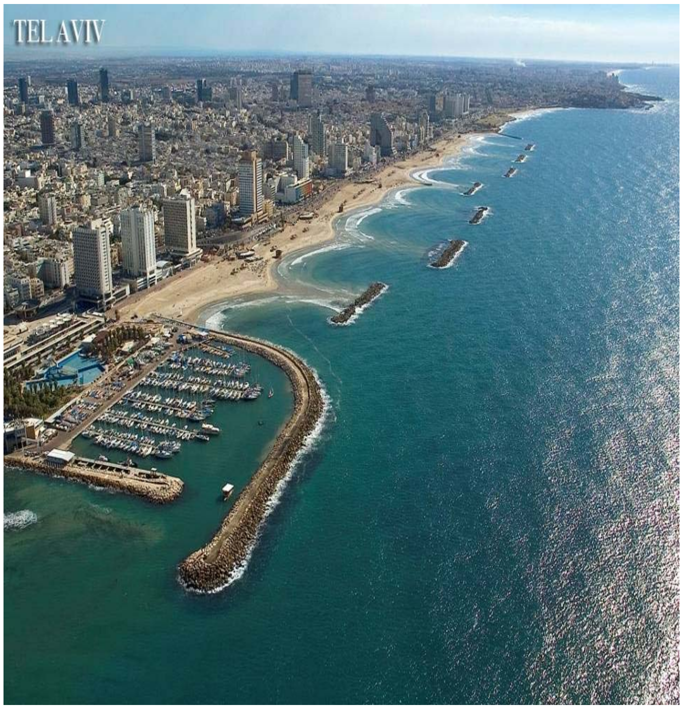
UNESCO - IHE
INSTITUTE FOR WATER EDUCATION



Application of a Total Urban Water Cycle Model to Develop Urban Water Management Strategies for Tel Aviv, Israel, Water Balance and Energy Consequences

Tong Thi Hoang Duong

MSc Thesis ES 09.23
April 2009

UNESCO-IHE
Institute for Water Education

SWITCH

Application of a Total Urban Water Cycle Model to Develop Urban Water Management Strategies for Tel Aviv, Israel, Water Balance and Energy Consequences

Master of Science Thesis

by

Tong Thi Hoang Duong

Supervisors

Dr.N.Peter van der Steen (UNESCO IHE)

Prof. Kala Vairavamoorthy (UNESCO IHE)

Prof. Avner Adin (The Hebrew University of Jerusalem)

Examination Committee

Prof. Kala Vairavamoorthy (UNESCO IHE), Chairman

Prof. Avner Adin (The Hebrew University of Jerusalem)

Dr.N.Peter van der Steen (UNESCO IHE)

This research is done for the partial fulfillment of requirements for the Master of Science degree at the UNESCO –IHE Institute of Water Education, Delft, the Netherlands

Delft
April, 2009

This work is dedicated to my Father and my Mother, whom I miss always.

ABSTRACT

Nowadays, there is an increasing necessity for the improvement of urban regions in order to reach a sustainable development because there are global change pressures which will also affect cities in the near future such as: climate change, population growth and urbanization…

In this context, one of the most urgent issues is the expanding water demands in urban regions. Current urban water management aims to make more usage of the total water resources available to urban areas and the alternative approach is to consider storm water and wastewater as potential water resources. Therefore, this research is developed to investigate the effect of different urban water management strategies on the sustainability of Tel Aviv' s urban water system as measured by a set of sustainability indicators.

In this study, a daily water balance model (Aquacycle) was used for simulating water use, wastewater production and storm water discharge in Tel Aviv city. Firstly, the model was calibrated against measured data; so that it was able to predict logically the total water consumption in the city as well as the wastewater output. Alternative strategies were also formulated and simulated involving the application of wastewater treatment and reused, rainwater & stormwater harvesting and permeable pavement technologies. And finally. an inventory of energy balance was developed for the entire system. The energy use of water and wastewater services was evaluated and compared with that of 4 other cities. It was found that the wastewater reuse and rainwater harvesting strategies can reduce a modest quantity of water consumption in the city and reduce the total energy consumption of the system; It is also demonstrated that the permeable pavement option results in a reduction on stormwater discharge and an increase of groundwater recharge.

Keywords: Urban water management, Aquacycle, water and energy balance

ACKNOWLEDGEMENTS

I would like to acknowledge the support I received from my supervisors, Dr Peter van der Steen and frequent exchange of research ideas. His suggestions, advices and comments helped me to overcome many problems during this study. My sincere appreciations also go to Prof Avner Adin who gave me much of care, encouragements and ideas. His supports during the time I was in Israel facilitated my work and encouraged me very much. My thanks are given to Prof Kala Vairavamoorthy for sharing his ideas about the model.

Thanks to NUFFIC program and SWITCH project for the financial support during my study in Netherlands and my research in Israel.

I would also like to thank to all the staffs of the Tel Aviv Municipality Water Department for helping me to collect required data. My sincere gratitude goes to Mr. David Jackman who gave me much of time & support, and impressed me by his valuable stories, his friendliness & care.

My acknowledgements come to all Switch partners in Israel and my friends in Rehovot campus (The Hebrew University of Jerusalem) for the research information and friendship. Especially, I would like to express my sincere appreciations to Avital's family for the warm welcome, my comfortable accommodation and interesting travels in Israel.

My thanks to all the ones who make my study in Netherlands become such a pleasure memory, to Thuy Mai for her valuable experience and advices.

Last but not least, I send my special thanks to my Dear who always being there with big love, sharing and valuable suggestions, to my Sister and Brother for their efforts in Vietnam to keep my mind on my study in Netherlands.

ABBREVIATIONS

m^3	cubic meter
hm^3	1,000,000 m^3
m^2	square meter
ha	hectare
KWh	kilowatt hour
MCM	million cubic meters
CM	cubic meter

IUWM	Integrated urban water management
WWTP	Wastewater treatment plant
NWC	National water Carrier
UWC	Urban water cycle
UWS	Urban water system
WW	Wastewater
WWT	Wastewater treatment
TA	Tel Aviv
IPCC	Intergovernmental Panel on Climate Change

TABLE OF CONTENTS

TABLE OF FIGURES

TABLES OF TABLES

CHAPTER 1 INTRODUCTION

1.1. Introduction

Current pressures of global change, escalating costs and other risks inherent in conventional urban water management are making it increasingly difficult to efficiently manage scarce water resources. Also, satisfying water demand and wastewater disposal without creating environmental, social or economic damage is a growing challenge.

In order to develop urban water management strategies, SWITCH has been established. SWITCH is the name of a five year action research programme, 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. SWITCH aims to bring about a change in urban water management away from existing ad hoc solutions and towards a more coherent and integrated approach. The vision of SWITCH is for sustainable integrated urban water management in the 'City of the Future'. Tel Aviv is one of 13 cities selected by SWITCH for carrying out its research.

The major water issues in Tel Aviv are related to water scarcity which is a problem popular for arid countries. Existing pressures of the city such as population growth, urbanization… may deepen this problem. In order to reach a sustainable development, Tel Aviv should focus efforts to develop more water resources available. And therefore, this research is to developed to investigate the effect of different urban water management strategies on the sustainability of Tel Aviv' s urban water system as measured by a set of sustainability indicators. The alternative approach here is to consider storm water and wastewater as potential water resources for Tel Aviv.

Aquacycle is one of models which is being used by Switch project to assess the total quantity of water moving through the urban water cycle. It is developed to provide a holistic view of an urban water system, allowing water supply, water disposal and storm water to be considered as components within a single framework(*Switch, 2006a).*

1.2. Case Study and Problem Statement

Tel Aviv is the commercial centre of Israel with population of over one million arriving to the city on each working day. Population estimated around 371,400 inhabitants for an area of municipal jurisdiction of 51.76 km^2 (area of dwelling 77.3 km^2) with a high population density (7200 persons/km^2). The annual growth rate of the population is lately 2.2% with

150,100 households (average persons/household is 2.2). As the Mediterranean seashore town, the climate in Tel Aviv is mild, average rainfall is 530 mm/year (*Switch, 2006a).*

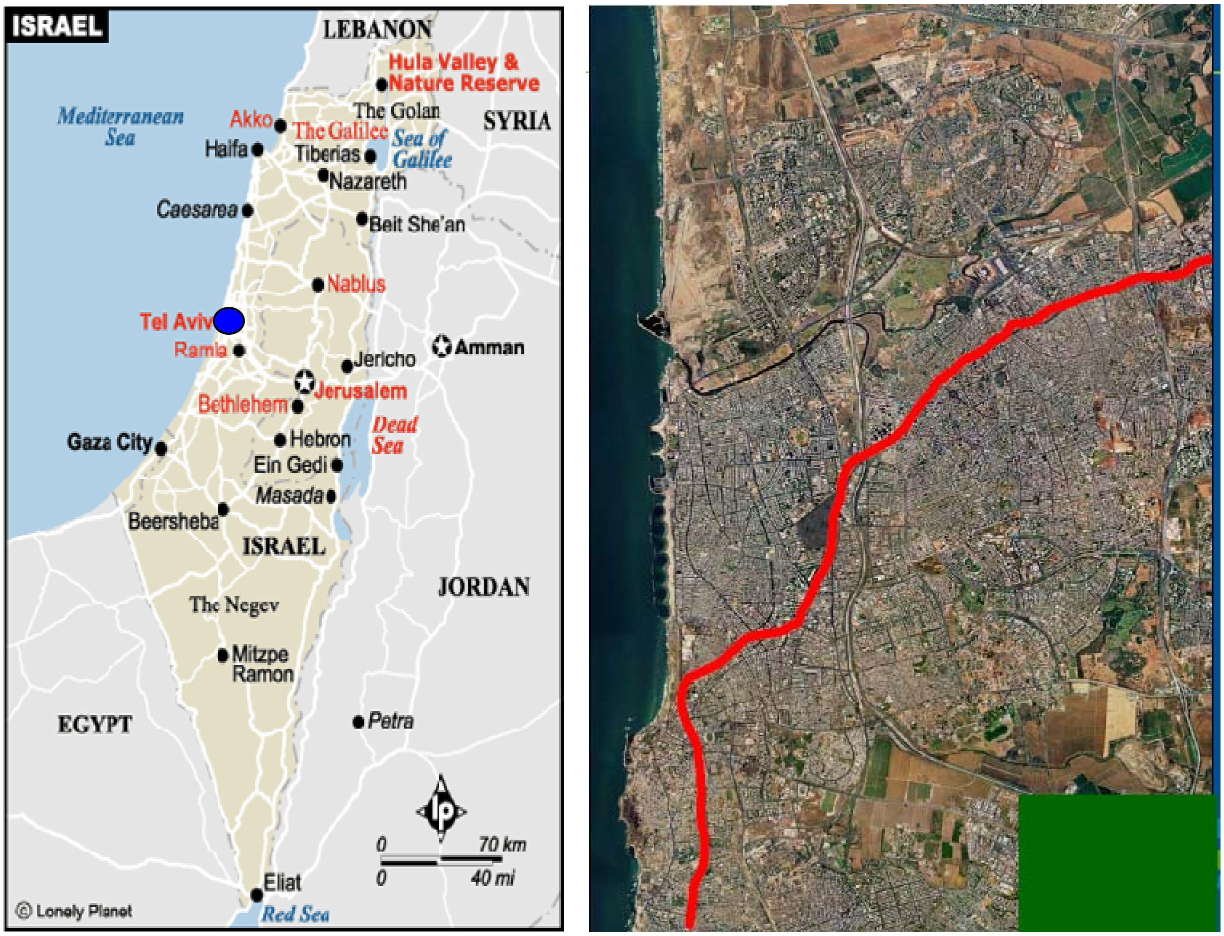


Figure 1. 1 The study area, Tel Aviv city, Israel

The main water issues of Tel Aviv city are water shortage and growing water demand. These are typical issues in arid countries and the increasing demand for water caused by the population growth and the rising of standard of living, has led to over use of its renewable water resources. The urbanization impedes natural recharge of aquifer from rainfall. On the water quality aspect, the quality of the groundwater in Tel Aviv is being degraded by seawater intrusion & leakage from sewer system. The Mediterranean Sea is also polluted by discharge of untreated storm water from the city.

Tel Aviv gets it drinking water mainly from the Lake of Galilee & various aquifers and constructed desalination plant through a National Water Carrier (NWC). It can be expected that the energy consumption of Tel Aviv's water system is significant because of the long

distance from the water sources to the city (150 km) and the energy intensive desalination. In addition, the wastewater treatment plant of Tel Aviv - Shafdan, based on an activated sludge process that incorporated additional nitrogen removal also consumes energy at high level.

The existing drainage system is discharging storm water directly to the Sea and there is not yet any monitoring system or research to evaluate the amount of storm water generated from the city. The effluent from the city is discharged to Shafdan wastewater treatment plant (WWTP) in the South. In the meantime, the main sources of water supply of the city are groundwater from local wells and surface water bought from National Water Company which is also under pressure of shortage. It is likely that Tel Aviv is overlooking the potential of water resources from its storm water and wastewater.

In general, Tel Aviv's urban water system is an advanced system because it satisfies the demand of its citizens at reasonable costs and applies technical & management methods to protect the environment. However, because of global change pressures which will also affect Tel Aviv in the near future such as, climate change, population growth and urbanization…, Tel Aviv's water management needs to be improved in order to reach a sustainable development. The main water pressures now in Tel Aviv are water shortage which is also a typical issue in arid countries. The 2.2 % increase rate of population annually and urbanization of Tel Aviv may make the problem become more serious. Moreover, there is an imbalance in Tel Aviv between the obvious needs for improvement and the actual implementation with respect to water infrastructure rehabilitation and the integration of urban water management with ecological requirements.

1.3. Objectives of the Study

From the problems which are identified above, objectives of this research are developed. The general objective is to investigate how different urban water management strategies (such as rainwater harvesting, storm water collection and use, decentralized wastewater treatment and reuse) will affect the sustainability of the urban water system of Tel Aviv as measured by a set of sustainability indicators linked to the water balance and energy consumption in Tel Aviv's urban water system)

Specific objectives are:

- To develop a sketch of Tel Aviv's water system, in term of spatial distribution of population land use, water systems elements: sewers, pumping stations, water reservoirs etc.

- To formulate several future scenarios of Tel Aviv including factors such as urbanization, climate change, power availability and price, sea level rise and population growth.

- To estimate the water balance by applying Aquacycle model for Tel Aviv’s urban water system to understand and predict the performance of the integrated system.

- To propose alternative strategies based on the output of Aquacycle simulation to deal with existing problems of the water system in different scenarios (decentralized wastewater treatment and reuse; water resource conservation, rainwater harvesting, stormwater collection and use).

- To formulate a set of sustainability indicators to evaluate alternative strategies.

- To propose a spreadsheet of energy balance for Tel Aviv’s urban water system to quantify the energy use of the system.

CHAPTER 2 LITERATURE REVIEW

2.1. Urban water management – conventional & integrated approach

2.1.1. The Urban Context

It is reported that, urbanization is increasing worldwide. Urban centers are characterized by negative environmental impacts including escalated flood risks, polluted surface waters, modification of the urban climate and increase water and energy consumption (*Centgraf, 2005).*

If one looks at the cities of both developed and developing countries it becomes apparent that rather urgent decisions must be made with regard to such overriding freshwater problems as increasing demands for water for various users; changes in the physical environment altering the water balance; and the disposal of wastes that may contaminate streams and groundwater. (*Maksimovic, 2001).*

Urban population is growing at an accelerating pace and simultaneously, sources of water supply decreases or, at the best, remain constant in quantity but decrease in quality. *(Niemczynowicz, 1999).* With population densities increasing (particularly in urban areas) and constrains on funding, it is becoming increasing evident that the present management practices of urban water resources and system will not be suitable models for service provision into 21^{st} century and that increased emphasis will have to be placed upon the use of groundwater reserves *(Eiswirth et al., 2004).*

2.1.2. Conventional & Integrated Approach to Urban Water Management

Urban water in context

In industrialized countries, water and sanitation is an integrated part of the urban planning and service to citizens. In most cases, the sector is conservative and characterizes by business as usual. Further development is initiated by the connection of newly built or peri – urban areas to the existing systems, or by minor adjustments, such as the addition of new treatment steps, made necessary by new regulations or emerging problems discovered in sector – limited investigations.

Urban water system in Western Europe and North America seldom suffer from an acute crisis related to water provision and basic management including operation and maintenance. Nevertheless, there is an imbalance between the obvious needs for improvement and the actual implementation, with respect to water infrastructure rehabilitation, upgraded wastewater treatment, and the integration of urban water management with ecological

requirements, which include the recycling of nutrients from wastewater and a decrease of diffuse pollution. In developing countries, one of the greatest challenges of population growth and urbanization is the supply of water and sanitation services. (*Malmqvist et at., 2006).*

According to *(WHO and UNICEF, 2000)*, 2.4 billion people lacked access to improved sanitation at the beginning of 2000. The Millennium Development Goals strongly emphasize two specific goals related to water:

To halve by the year 2015 the proportion of people who are unable to reach or to afford safe drinking water; and

To stop the unsustainable exploitation of water resources by developing water management strategies, at the regional, national and local levels, which promote both equitable access and adequate supplies.

Conventional & Integrated Approach to Urban Water Management

The traditional approach of urban water management is to consider the infrastructure that delivers potable water, separately from the infrastructure that disposes of wastewater and separately to the provision of drainage for stormwater. There is growing need to re-evaluate this approach in order to seek ways to, minimize the environmental impacts of urban areas on supply sources and receiving waters. *(Markopoulos et al., 2008).*

According to *(Mitchell, 2004)*, the technical literature contains many examples of adverse economic, social and environmental impacts associated with the traditional approach to water service provision and these include followings:

- Impairment of aquatic habitat and modifications to natural ecosystems due to reduced environmental flows

- Increased waste disposal, resulting in negative consequences for native flora and fauna and stream flow quality of river basins and coastal waters.

- Inadequate handling of contaminants and nutrients

- Significant energy and chemical usage (chlorine)

- High economic cost of rehabilitation and replacement of ageing water infrastructure in highly developed urbanized areas, which in many cities, is approaching the end of its useful service life.

Therefore, there is great interested in approaches to providing water systems that lower the impact on the natural environment and control expenses.

Recently, wastewater and rainwater were considered waste streams that needed to be conveyed away from the urban environment and disposed of. However, they are increasingly

being seen as resources that need to be exploited rather than unavoidable by–products of urbanization. Planning and operating the system separately, foregoes the potential for utilization of urban water storm and disregards the fact that these system are inter–connected and inter related *(Markopoulos et al., 2008)*

The main objective of sustainable urban water system is to satisfy the water related needs of the community at the lowest cost to society whilst minimizing environmental and social impact. *(White et al., 2003).* In order to reorientate 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. Integrated urban water management take a comprehensive approach to urban water services, viewing water supply, drainage and sanitation as components of an integrated physical system, and recognizes that the physical system sits within an organizational framework and a broader natural landscape. *(Mitchell, 2006).*

The principles of integrated urban water management can be summarized by *(Mitchell, 2004)*:

- 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 key to IUWM is that individual processes should be planned and managed in such a way that the collective impact is minimized and the collective system efficiency be maximized as much as practically possible. The most important benefit of an integrated approach to urban water system is the potential to increase the range of opportunities available in order to be able to develop more sustainable systems. The primary aim of IUWM is to enable multi–functionality of urban water services to optimize the outcomes achieved by the system. The dimension of this multi– functionality include: affordability, amenity, including recreation, community satisfaction, ecosystem protection, energy usage and greenhouse gas emissions, equity, groundwater management, maintenance of biodiversity, pollution prevention and control, public health protection and sanitation, sharing of water resources with other users, including the environment, storm water flow management, including flood protection, storm

water quality management, waste minimization including solid waste recycling and management and water supply *(Mitchell, 2006).*

There are a broad range of tools which are employed within integrated urban water management, including, but not limited to water conservation and efficiency; water sensitive planning and design, including urban layout and landscaping; utilization of non–conventional water sources including roof runoff, storm water, grey water and wastewater; the application of fit–for–purpose principles; storm water and wastewater source control and pollution prevention; storm water 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 *(Mitchell, 2006).*

2.2. Switch Vision and Strategic Approach for IUWM

2.2.1. Switch Approach for Strategic Planning

Strategic urban planning is not one of–off undertaking, but a continuous management process, a process of cumulative learning, analysis of issues, repetitive review and updating. Strategic city plans provide decision makers with a tool that make it possible for those in the driver seat to respond effectively to changing circumstances.

The following paragraphs describe the various phases of the strategy development process in the cities:

- *Learning alliances:* is a platform where stakeholders come together and together go through a strategic planning exercise. Only a shared vision for the future of the city and a broadly supported strategic plan can drive the city toward sustainability.

- *Visioning:* Having a shared vision may provide the drive to a society or to a city to move forward. The absence of it may results in stagnation and deadlock. A vision is a picture of a desired future, in this case for the water system of the city.

- *Scenario development:* Scenario building is essentially a team exercise that can help a group of stakeholders to come to terms with uncertainty and risk in a planning process. In particular, scenarios can be used to identify the most uncertain and most important factors that are outside the direct control of stakeholders. Scenarios are developed in workshops.

- *Strategy development:* After the development of a number of plausible scenarios, the learning alliance is ready to think about the response. Which strategy should be implemented to achieve the vision?

The outcome of a strategy is most likely to be different under different scenarios. The outcome of the various scenarios can be scored in different ways, for instance by applying a cost–benefit methodology, some other assessment method or an evaluation based on the use of sustainability indicators. The assessment of the various outcomes and strategies is not so much to find the optimal solution, but rather to provide the stakeholders with information about all options. The stakeholders can use this information in the discussion and come to a decision. One way to present this information to stakeholders is the use of so–called "sustainability indicators".

2.2.2. Switch vision and strategic approach for IUWM

The project wants to develop a new approach to integrated urban water management. This approach will have to result in new ways of planning the urban water system for the future, to address adjustments needed to address global change pressures. All this aimed at increasing the sustainability of the urban water system and reducing the risks.

The Switch vision for 2035 for a truly sustainable urban water system was formulated in the form of a set of sustainability objectives. A city that wishes to achieve sustainability for its urban water system should set itself the following objectives:

General:

- To have citizens that are aware of "water and sustainability" and where the authorities will involve the public in decision making.

- To manage its urban water system in an integrated way; integrating aspects of water supply, storm water management, wastewater collection, wastewater treatment and wastewater reuse.

- To use a set of sustainability indicators for decision making and planning

- To have a strong scientific basis for decision making concerning the management of its urban water system. To ensure equity in assess to water, as well as to irrigated green areas.

- To minimized the energy consumption in the urban water system.

Water supply and sanitation:

- To supply water of good quality to its citizens in sufficient qualities at the lowest possible costs.

- To give priority to water demand management over development of new water resources

- To provide all its citizens with proper sanitation, at the lowest possible costs.

- To give priority to pollution prevention over end–pipe treatment.

- To reduce the net waste output from the city to the environment to below the carrying capacity of the receiving environment. Furthermore, it will enhance the self purification capacity of the receiving environment by eco–hydrology.

Storm water management and reuse:

- To reduce the risk of flooding in vulnerable areas to levels acceptable to all stakeholders, even under future climate change scenarios.

- To protect and enhance the water quality and ecological status of urban receiving waters, both surface and groundwater.

- To apply source control techniques to enable storm water to contribute to the quality of life in the urban environment.

- To harvest rainwater and storm water for non–potable reuse purposes.

- To utilize storm water to re–establish a balanced natural water cycle in conjunction with landscape development. *(Switch, 2008).*

**** Switch approach to strategic planning for IUWM***

A strategy is a long term plan of action designed to achieve a particular goal–specific scenario in this research. Scenario is qualitative and quantitative description of the future external situation that the city and its habitants will face. Strategies are developed which describe the various general strategic approaches which could be followed under certain scenarios to achieve the vision *(Switch, 2008).*

The formulation of scenarios and strategies for Tel Aviv’s water system is based on the background of the city, knowledge of stakeholders, vision of decision makers, experience of other case studies and Switch approach to strategic planning for integrated urban water management. Therefore, it would be helpful to understand the cause–effect relations that are part of today’s realities, the root sources of the change (driving forces), the resulting pressures on the urban water system, the resulting conditions of the system (state), and the effects of changes in conditions (impacts) *(Switch, 2008).*

*Scenarios

- *Climate change* is an important driver that affects the pressure on and the state of the urban water system. Change in precipitation patterns towards more intense storms lead to an increase risk of flooding. Cities in delta regions may have to cope with significant sea level rises. This may lead to extreme high water levels and flooding or during low discharge periods to the invasion of saline water. While storm events may become stronger, at the same time, it is expected that dry periods will become longer, which could lead to increase water

scarcity *(Switch 2008)*. Tel Aviv is a city located in coastal plain so the impacts of climate change should be considered.

- *Population growth and urbanization*: An unprecedented growth of the urban population is a major driver for urban water management, especially in the developing world. Increased urban water demand may lead to large infrastructural works to transport water from longer and longer distances, creating environmental damage in the cities hinterland. Groundwater table lowering due to over abstraction is already reality in many cities *(Switch 2008)*.

- *Energy cost:* recently energy costs have surged to unimaginable heights and this will only increase the realization that the urban water system is a small but significant energy consumer. Water supply and wastewater management consume energy to the equivalent of about 5 – 10% of total domestic electricity consumption. The water can therefore not be ignored in initiatives to reduce overall energy consumption (*Switch, 2008)*.

**Evaluate strategies using indicators*

When a city has decided to adopt strategic planning, it starts an iterative process, with a cycle of 3 – 10, typically 5 years. After the first strategic plan has been finalized and has been translated into operational plans for the various water sector organizations, one may expect that this response is going to affect to state of urban water system. It therefore makes sense to set up a monitoring system that will be measure the state of urban water system in term of sustainability indicators. The score of the indicators in time will indicate the effectiveness of the strategy and the sum of all activities and projects undertake by the water sector, as well as the effects of external factors. Sustainability indicators are tools that aim to measure sustainability and to address the question: is the city moving towards the sustainability vision. Sustainability indicators indicate to what extent the vision has been reached *(Switch, 2008)*.

Lundin (1999) suggested a core set of criteria which can be identified and can guide the sustainability indicators (Sis) selection for urban water system. Sustainability indicators should ideally:

- Be relevant for the indicators users and for sustainable development

- Be simple to allow understanding, interpretation and presentation

- Rely on data that is reliable and relatively easy to collect

- Be predictive (do they provide and early warning)

- Be possible to relate to reference values and targets.

2.3. Urban water system & Aqua cycle model

2.3.1. Urban water cycle and the effects of urbanization on UWC

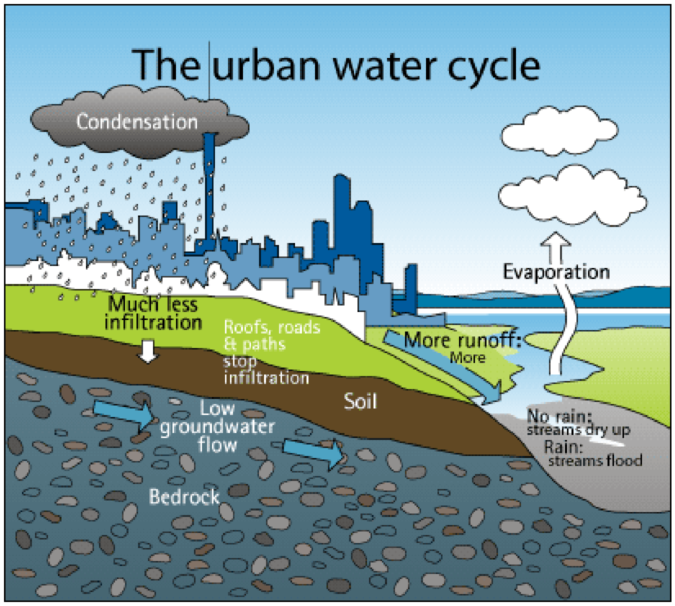


Figure 2. 1 Outline of an urban water cycle

According to *(Maksimovic, 2001)*, urban water systems are required in developed urban areas because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from the natural cycle to provide a supply for human life and the covering of land with impervious surfaces that divert rainwater away from the local natural system of drainage.

Urban development significantly increases the amount of storm water and the frequency of extreme hydrological events experienced by a City's catchments. The increased runoff causes more intense local flooding, while droughts during dry weather are deeper and longer. Runoff amounts typically 10 – 20% of the average annual rainfall in rural areas. In urban areas, where surfaces are highly impervious, typical runoff volume ranges between 60 – 70% of the average annual rainfall.

Urbanization is finished by the addition of more roads, houses, and commercial and industrial buildings. More wastewater is discharged into local streams. New water supply and distribution systems are built to supply the growing population. More pavement means less water will soak into the ground, meaning that the underground water table will have less water to recharge it. This will lower the water table. The runoff from the increased pavement goes into storm water sewers, which then goes into streams. This runoff which is used to soak into the ground now goes into streams, causing flooding. (*Van der Steen, 2002)*.

2.3.2. Urban water system in outline

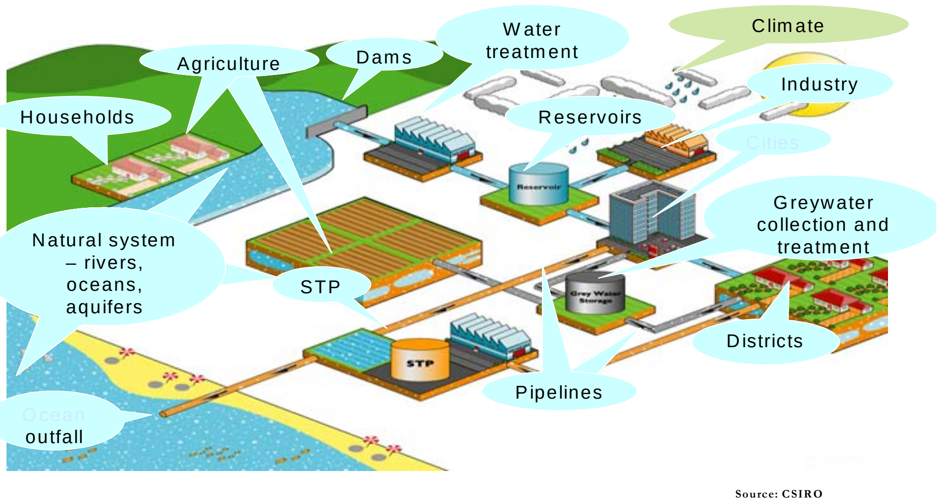


Figure 2. 2 A typical urban water system
(Switch 2008)

Urban water system typically starts at water collection and storage facilities at source sites (rivers, oceans, and aquifers). Water is transported via aqueducts (canals, pipelines) from source sites to water treatment facilities, water treatment storage and distribution networks. After used at residential, industrial, public and agricultural sectors, water is collected by wastewater collection system (sewage) and coming to wastewater treatment plants before discharged into received water bodies. Stormwater and rainwater if not to be collected and reused also come into sewage systems, contributing to the urban wastewater flow.

According to (*Van der Steen, 2002*), a typical urban water system includes the following components:

-" *Water resource and intake": *The water quality of water resource affects directly the extent to which treatment is required in order to achieve drinking water standards as well as the type of treatment technology required. The distance (and its elevation) from water intake to the city strongly affects the cost of water supply. Proper waste management may reduce costs for water supply and pollution increases the costs of water supply.

-"*Water treatment and distribution": *Costs of water treatment are directly related to water source quality and to pollution of these water resources. In addition, in some cities in developing countries, 30 – 50 % of treated water is lost in the distribution network through leakages. Integrated urban water management would not only try to optimize the water treatment process itself but also try to increase the efficiency of the distribution. By reducing water leakage in the distribution network, one may prevent postpone costly investment in water treatment technology.

- *"Water use":* Water use patterns and habits of both domestic and industrial water users have a pronounced effect on all urban water cycle stages. The quantity of water taken from the source is affected by the demand from consumers, especially in water scare areas. Water demand by consumers may be affected by various means for instance via tariffs and awareness rising. Rising awareness or installing equipment in the households and domestic and industry that use less water is one of the tools to reduce the production of wastewater.

-*"Water reuse":* Reuse of treated wastewater for purposes within the urban center or in agriculture may release some of pressure on fresh water resources, by replacing part of fresh water taken from that resource. Reuse of wastewater may protect the water resources from pollution and may save on treatment costs.

- *"Wastewater collection":* The size of wastewater collection system is directly related to the quantity of water use. Wastewater collection systems are in most cases required for reuse in agriculture or industry, to transport the waste to the reuse location. However, wastewater collection itself does not solve pollution problems; it only transports the problem to another location. A sewer system by itself may improve public health and prevent groundwater pollution, but may worsen the pollution of a river

-*"Wastewater treatment":* The size of wastewater treatment infrastructure is dependent on the quantity and quality of the wastewater. Therefore not only effluent criteria, but also water use habits determine what kind of wastewater treatment is required and what the flow it should be able to handle. Integrated urban water management does not see waste wastewater treatment in isolation (end of pipe approach) but tries to identify how the urban water cycle should be designed or adjusted to prevent water pollution.

-*"Discharge into water resource":* Since the water resource into which wastewater is discharged (either the ground or surface water) is often the starting point for a new urban water cycle, it is not only important that the effluent quality is as good as possible but also that the natural barrier between discharge and new intake is optimized. This barrier can be optimized at the one hand by maximizing the distance between discharge and intake and at the other hand by optimizing the self purification capacity of the receiving ecosystem.

2.3.3. Introduction of Aqua cycle model

There are a large number of models available for describing the urban water system. Graham (1976) developed a simple generic total water balance, based on empirical equations with a daily step and in a catchment scale. Grimond (1986) developed a generic water balance model, which include an evapotranspiration model, requiring estimates on aerodynamic characteristics. However, in the past, the interactions among the potable water supply,

wastewater discharge and the rainfall–storm water runoff networks were rarely considered within the same modeling framework *(Karka et al., 2007).*

In addition, there is a need to take a more holistic view, allowing water supply, wastewater disposal, and storm water drainage to be considered as components within a single system. In order to address this need, a simulation model, Aqua-cycle, has been developed. By looking at urban water demands and storm–water and wastewater output at a variety of spatial scales and at a daily time step, a cleaner picture of the performance of storm–water and wastewater utilization schemes is afforded (*Mitchell et al., 2001).*

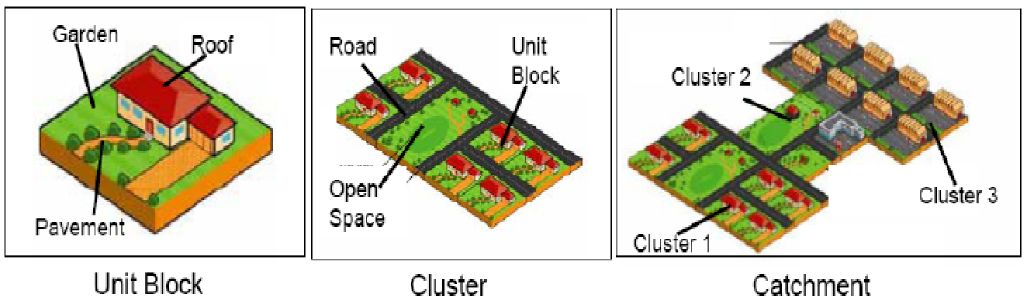


Figure 2. 3 Spatial scales used in Aquacyle
(Karka et al., 2007).

The modeling approach accounts for all stages in the passage of water through the urban water cycle, including water supply, waste water production and storm water runoff system. The "cycle" starts with water entering as precipitation or (fresh) water imported in order to meet the indoor and outdoor water use requirement. It then passes through the urban water system and exits in the form of evapotranspiration, storm water and wastewater.

Aqua cycle operates on three different scales (unit block, cluster and catchment) in order to enable the modeling the alternative system configurations and the evaluation of alternative recycle and reuse scheme (Figure 2.3). The unit block can refer a single household, industrial site, a public or a commercial facility. This scale represents the smallest unit for the management of water supply, disposal, and recycle–reuse operation and spatially divided into roof, garden and pavement areas. A cluster represents a group of uniform unit blocks that can form a local neighborhood or suburb. In addition to unit block, it includes roads and open public spaces and is used to represent the spatial scale at which community water servicing operation are managed. Finally, the catchment is made up of a group of clusters.

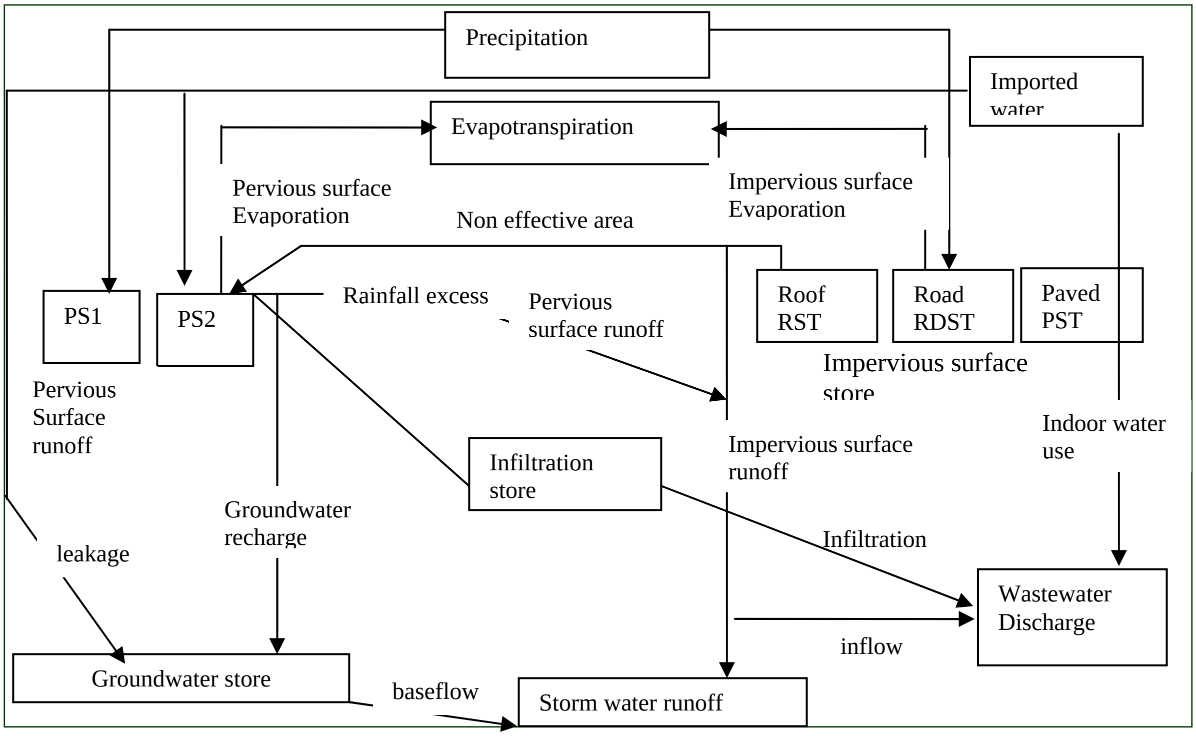


Figure 2. 4 Structure of the UWC represented by Aquacycle
(Mitchell, 2001)

In Aquacycle, water flows through different processes (stores) that are part of the urban water cycle. The urban water cycle is approached by considering all water pathways in two subsystems: the rainfall runoff (urban drainage system) and the water supply & wastewater system. In both subsystems, water balance is estimated taking also into account the interactions between them. The overall conceptual representation is illustrated in Figure 2.3. The processes of interception, infiltration, storage, inflow and drainage are modeled using conceptual storage with parameter can either be calibrated or introduced by the users. Such parameters include the percentage of area of water stores, roof area initial losses, effective area and initial losses for roof, pavement and roof area, the base flow index and the base flow recession constant, the percentage of runoff that inflows into the wastewater system, the infiltration index and infiltration stores recession constant and the trigger to irrigate ratios for garden and open space. The model receives the input both from precipitation and imported water as well as indoor water use requirements and evapotranspiration data.

In Aquacycle, surfaces are divided into two categories: pervious and impervious. Impervious surfaces (roofs, roads and paved areas) are represented as single stores that overflow when full. Pervious areas are divided into areas which produce runoff during a rainfall even and those that do not. Water evaporation from both pervious and impervious areas is calculated according to daily evapotranspiration values. The algorithms calculate the total amount of water discharged as storm water runoff from road, roof, and paved areas and pervious areas.

The amount of water imported into an area is a sum of indoor water use, irrigation and leakage. The total wastewater discharge from the catchment is the sum of indoor water use, infiltration and inflow from storm water drainage system *(Karka et al., 2007)*.

2.4. Energy consumption of urban water system

There is a strong nexus between water and energy. Water is required for production of energy and particularly electricity and energy is consumed in providing vital urban water and wastewater services.

Recently energy costs have surged to unimaginable heights and this will only increase the realization that the urban water system is a small but significant energy consumer. Water supply and wastewater management consume energy to the equivalent of about 5 – 10 % of total domestic electricity consumption. The water sector can therefore not be ignored in initiatives to reduce overall energy consumption *(Switch, 2008)*.

A strong connection exists between water provision and energy consumption. Worldwide, 2 – 3% of energy consumption is used to pump and treat urban water. As readily available water source are depleted, future supply options will likely have higher energy requirements *(Stokes et al., 2006)*.

** Urban water system components using energy*

The energy consumption in an urban water system is required for every stage: water source & intake, water use, water reuse, wastewater collection, wastewater treatment all need energy for operation. Energy is consumed for pumping, transporting water from water source to users or from users to wastewater treatment, for heating water in residential sector. In addition, the stage of wastewater treatment also consumes a large amount of energy for its operation and maintenance. Figure 2.4 is an example of water cycle and urban water components evaluated for energy use in the study of urban water's energy consumption in cities in Australia. (*Kenway et al., 2008)*.

The energy consumption is evaluated for three "system boundaries". The first boundary was the centralized system for the provision of urban water services. (See the circle 1 in Figure 2.5) and included all energy use including bulk water harvesting, transfers, contracted treatment operations and wastewater discharge. The second boundary was focus on energy use associated with the resident water use, particularly heating. The third boundary attempted to quantify total urban energy use.

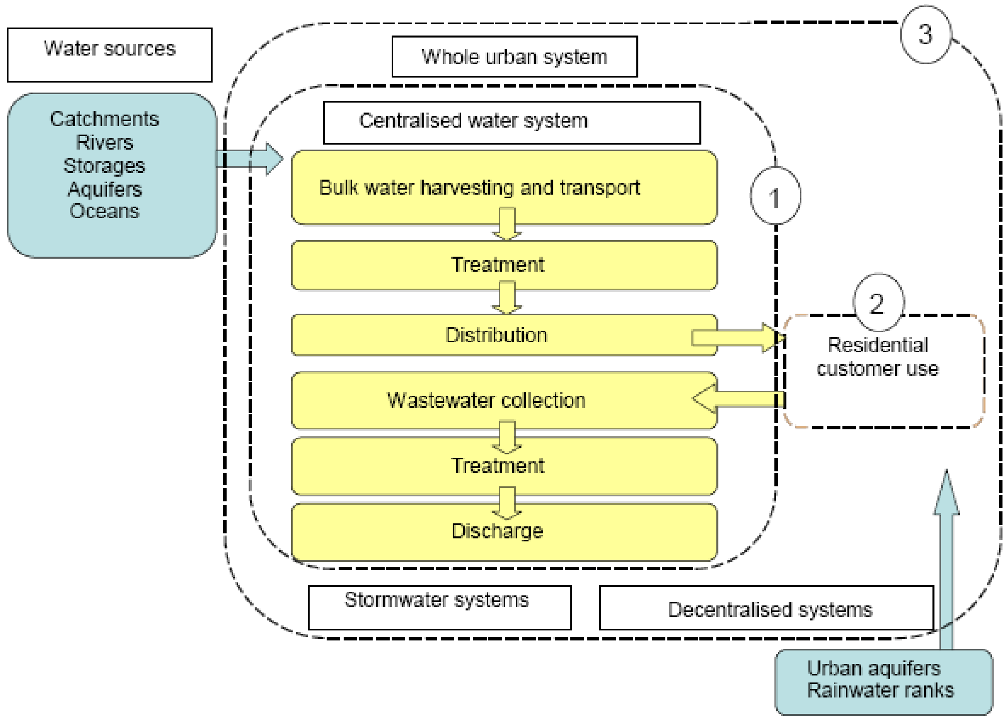


Figure 2. 5 Water cycle and urban water system components evaluated for energy use

** Characteristics of water utilities and residential sector*

According to Kenway et al. (2008), energy use for pumping and treating supply water varies significantly from city to city. Local conditions including water use, topography and water source have a major influence on energy use value. Pumping water from sources located at considerable distance from cities contributes significantly to energy use in cities.

Treating wastewater to a tertiary standard requires substantial energy compared to primary and secondary treatment. On average, energy intensity doubles between primary and secondary treatment and doubles again between secondary and tertiary treatment. If tertiary treatment is required, reuse opportunities may be come more cost–effective as the additional energy required for reuse may be relatively minor depending on energy requirements after treatment (e.g. for pumping).

For residential sector, in the case studies in Sydney, Melbourne, Perth, Gold Coast and Adelaide, it was found that energy use for residential water heating represented 1.3% of energy use in total urban system. Residential hot water uses on average 6.5 times the energy that is used to delivery urban water services.

Increasing population and economic activities are reasons of increasing urban water consumption and municipal wastewater. Pumping, transporting water from original sources is more difficult because of exhaust of water resource and therefore consumes more energy.

Growing water demand and shrinking water supply are driving the need for new water sources in many part of the world (*Stokes et al., 2006)*. Therefore, stormwater and wastewater may be new options of water sources. Considering the energy aspect, these options will reduce the energy consumed in water extraction, distribution and wastewater treatment. Energy balances of the urban water system of Tel Aviv under different scenarios with different strategies will be carried out in this research.

CHAPTER 3 DESCRIPTION OF THE URBAN WATER SYSTEM IN TEL AVIV CITY

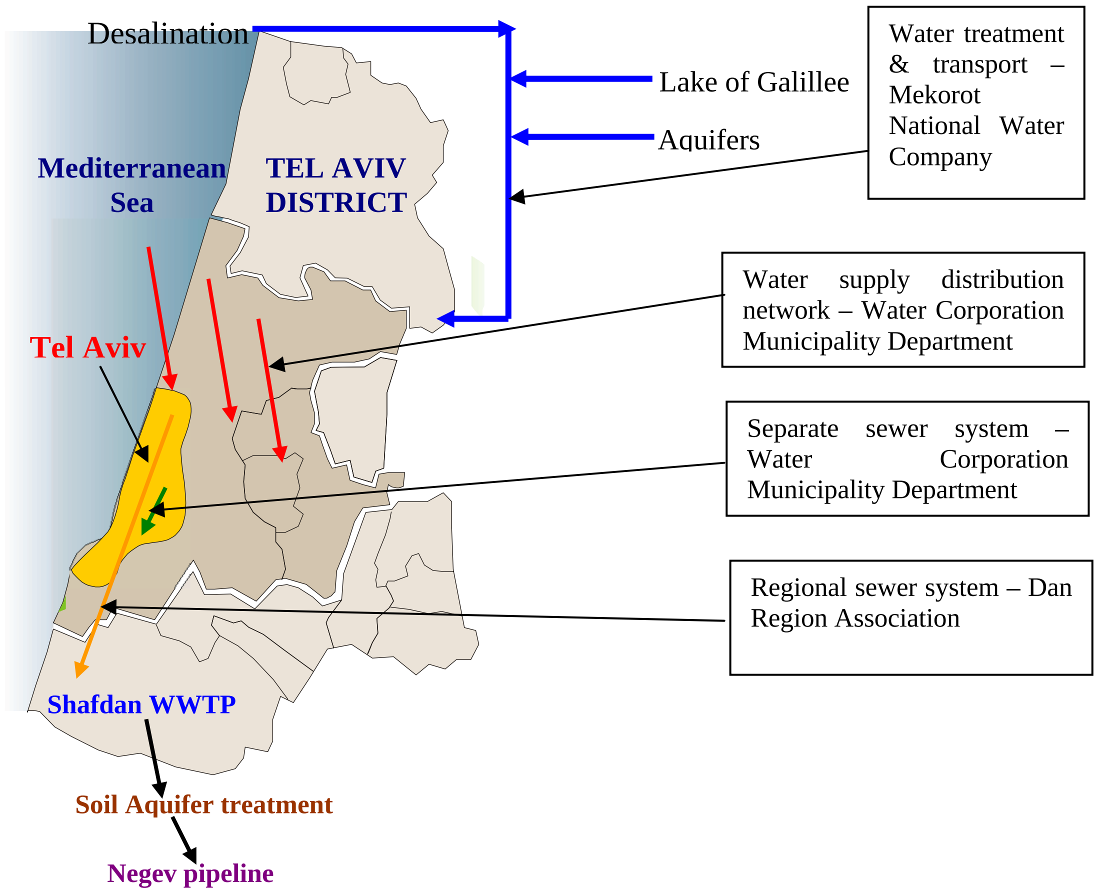


Figure 3. 1 Tel Aviv's urban water system with institutional responsibilities

The outline of Tel Aviv's urban water system is shown in Figure 3.1. Water supply is treated and transported to Tel Aviv city by Mekorot Company. Tel Aviv Water Corporation is responsible for distributing water within the city and also collecting wastewater to separate sewer pipeline. This wastewater is charged into the regional sewer system which is the responsibility of Dan Region Association before going to Shafdan WWTP. Treated wastewater is transferred to Negev region for irrigation.

3.1. Water supply system

Water sources of Tel Aviv include surface water, ground water and desalinated water. The major proportion of drinking water (90%, 45 MCM) is supplied by Mekorot National Water

Company. The other, 10% is supplied by local wells and desalinated sea water (specifically during the short winter season). Tel Aviv Municipality is responsible for extraction of ground water from local wells while Mekorot Company is responsible for treating and supplying desalinated water to the city. (*Switch LA- Tel Aviv, 2008).* The distribution of Tel Aviv's water sources is shown in Figure 3.2.

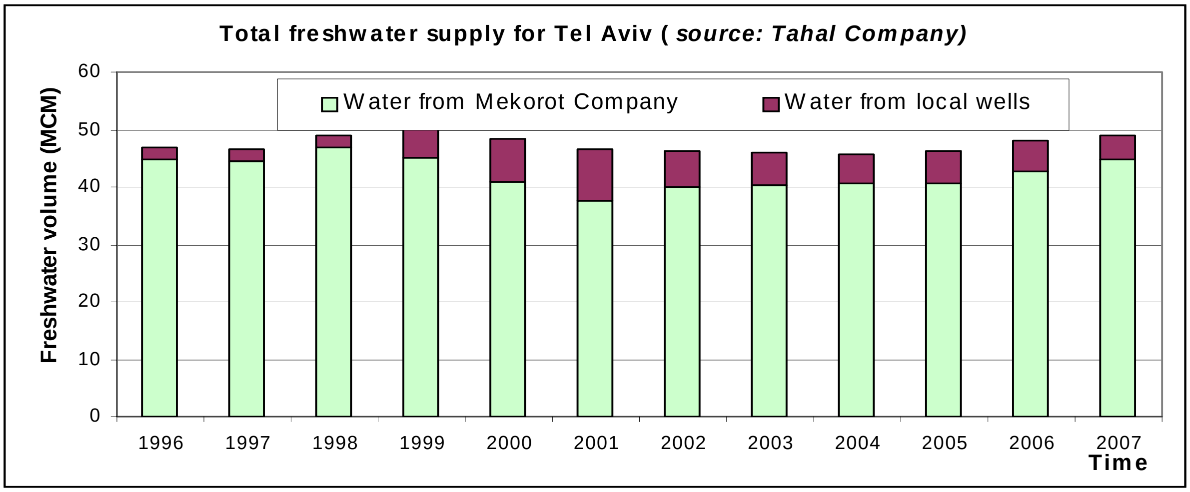


Figure 3. 2 Total freshwater supply of Tel Aviv

Mekorot is Israel's National Water Company, responsible for most of the supply and maintenance activities including the operation of the National Water Carrier (NWC) and the Shafdan wastewater treatment plant. The NWC transfers water from the Sea of Galilee in the North to the center and the South of the country–Negev (*European Commission, 2002).* In the year 2007, Tel Aviv Municipality had bought an amount of 44,795,231 m^3 of drinking water from Mekorot (nearly 92% of total urban drinking water consumption). There are three reservoirs of the water from Mekorot Company in which two 25,000 m^3 reservoirs and one reservoir of 10,000 m^3 (*Tel Aviv Municipality*).

Another fresh water source is groundwater from the coastal aquifer. Currently, Tel Aviv Yafo is extracting fresh water via ten local wells. The amount of groundwater exploited in the year 2007 was around 4,038,403 m^3 *(Tel Aviv Municipality*).

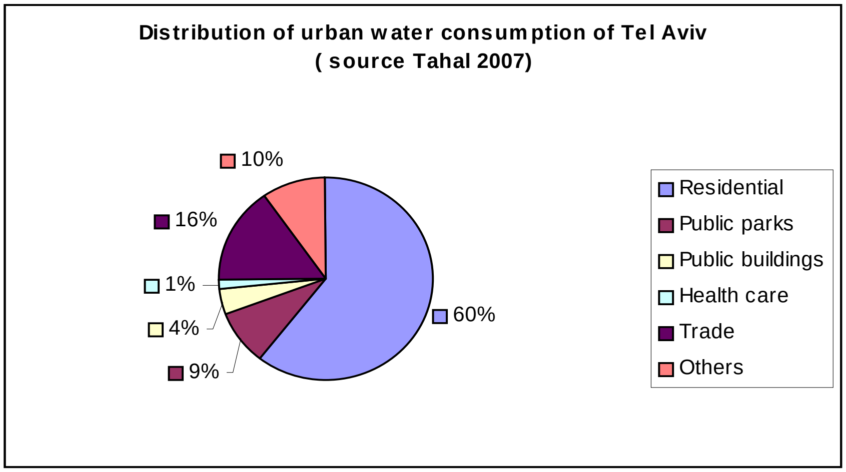


Figure 3. 3 Distribution of urban water consumption of Tel Aviv
(Source: Tel Aviv Municipality

The coastal aquifer is the largest reservoir of natural water in the country. The available storage capacity is 20,000 hm^3. The annual renewal from precipitation is 300 – 400 hm^3, which is also the average annual pumping rate. As a result of over pumping during 1990s, the surface level descended with penetration of seawater, and the salination level of the aquifer has increased, affecting several wells (*European Commission, 2002)*. Tel Aviv's domestic consumption is similar to the national average – 119m^3/capita.yr (*Tahal, 2007*). This consumption is expected to increase by 20% with the development of metropolitan parks and the improvement in quality of life. The distribution of Tel Aviv's urban water consumption in the year 2007 is shown in Figure 3.3. The detailed data on the distribution of urban water consumption from year 1997 to year 2007 can be found in appendix 3. It can be seen that the largest share of water consumption is in households with 60.3%, followed by water use in commercial establishments (15.6%) and water use for public park irrigation (9%). The quality of the fresh water is good. In the future, the use of desalinated water will lead to an improvement in the water quality *(Tel Aviv Municipality).*

Table 3. 1 Total freshwater used for irrigation in Tel Aviv City – year 2008
(Source: Tel Aviv Municipality)

	Area of irrigation (x 1000 m^2)	Total freshwater volume used (m^3)
Yarkon Park	2,100	1,098,000
Rest of Tel Aviv city	5,272	2,696,100
Total	7,372	3,794,100

Water from the Lake of Galilee, 150 km far away from Tel Aviv, is distributed to the city through NWC. In addition, the Tel Aviv Municipality manages the supply of drinking water

within the city. Because of the topography of TA sloping to the Sea, water is distributed to most of areas in the City by gravity. However, there are two small areas at which the City has to use boosters to pump water. One area, in the Northeast of the city (located in cluster 3), 20 – 50 m above sea level is supplied with an amount of 6,570,000 m^3 per year by boosters. The remaining area in the Southeast of the city (located in cluster 1), 20 – 50 m above sea level, is supplied with an amount of 3,504,000 m^3 per year by boosters (*Tel Aviv Municipality*). The maintenance level of the distribution system is not very high. All that can cause biofilm growth and microbial pollution in the distribution system and cause a higher chlorine demand. Also frequent leakages of wastewater distribution system in the drinking water aquifer areas can cause severe pollution. (*Switch LA- Tel Aviv, 2008).*

3.2. Wastewater system

Currently, Tel Aviv is discharging an average of 113,910 m^3 of wastewater per day to the main pipe lines of Shafdan *(Source: Shafdan WWTP).*

Tel Aviv Municipality is responsible for collecting wastewater of the city via local sewage system and discharging wastewater to the main pipeline of Shafdan Company. The length of urban sewage pipe network is 592 km *(TA Municipality).* Also, the wastewater distribution system is 30 – 40 years old and the pipe line renewal rate is low. (*Switch LA–Tel Aviv, 2008).*

Shafdan is the largest WWTP in Israel and the most advanced mechanical biological plant in the Mediterranean region. The wastewater purification process in Shafdan can be found in Figure 5.3. It is responsible for collecting, carrying and removing Dan District's sewage and purifying wastewater for agriculture in the South. The Dan District includes Tel Aviv–Jaffa, Holon, Ramat Gan, Bat Yam, Petach Tikva, Brei Brak and Givatayim. The regional pipe network of Shafdan is approximately 55 km. The carrying and collection system includes six sophisticated pumping stations, all equipped with the most advanced technology. These stations transport approximately 300,000 m^3 of sewage a day into the Shafdan. In the Shafdan, the sewage is purified and turned into almost drinking quality treated water, suitable for agriculture use *(source: Shafdan WWTP).* The region's large population creates the potential for a large supply of recycled water for agriculture. In addition, high quality treated waste water can be used for irrigation of metropolitan parks and for rehabilitation of streams like the Yarkon River.

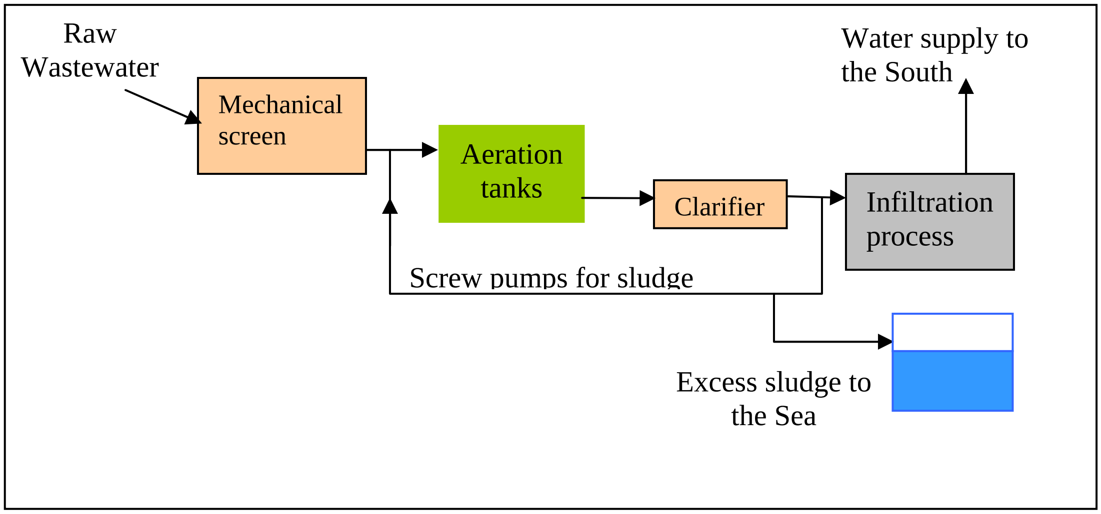


Figure 3. 4 The wastewater purification process in Shafdan WWTP
(Source: Shafdan WWTP)

Several major projects are underway to improve the sewage systems of Dan Region *(source: Shafdan WWTP):*

The Eastern pipeline – sewage carrying pipes for the eastern Dan region: to meet the need of the growing population of the Dan region, the most innovative technology available is being used to lay down the eastern pipeline, which is 25 km long. This pipeline will transport sewage from towns located east of the Dan district.

The Ayalon River – the Ayalon collecting project: This pipeline will reinforce the existing Dan district collection system, strengthening the operational flexibility of the carrying pipes and allowing sewage to be channeled to different sewage collectors as necessary.

Stopping disposal of activated sludge using innovative technologies: Activated sludge contains bacteria accumulated throughout the sewage purification process. This sludge is currently carried out to the sea by an 11 km pipe, 6 over land and 5 at a depth of 40 meters below sea level. The Dan Region Association recently initiated an additional project with the aim of stopping the flow of all excess activated sludge into the sea.

Preventing rainwater from entering the sewage system: the penetration of rainwater into urban and regional sewage systems can cause flooding, resulting from system overflow. Together with local municipalities, the Association has initiated a project to prevent rainwater from running into the Association's systems.

There are three main sewage pipes with a total of 35 connections going through Tel Aviv and two big pumping stations. The Reading station located in the North collects around 13,000 m^3 of wastewater per hour and consumes 49,000 KWh per month. The Bassa pumping station located in the South of the city (near Tel Aviv Jaffa) receives 17,000 m^3 of wastewater per hour and consuming 1,200,000 KWh per month *(Source: Shafdan WWTP).*

3.3. Stormwater system

The Tel Aviv Municipality is responsible for the drainage of storm water together with the Yarkon River drainage authority. There is no monitoring system for storm water in this city so far.

Most of the sewage system and storm water system in Tel Aviv are separated. However, there is a small location (only three percent of total city's area) in the South in which storm water and sewer systems are combined.

The storm water system of the city includes eleven sea-outfalls along the Sea shore and seven drainage pumping stations located along the Yarkon River and Ayalon River.

In the winter season (rainy season), storm water is discharged to the Sea and the Rivers by gravity. There are some "dry weather" pumping stations along the Sea and Rivers which only operate in summer season to protect the Sea and the Rivers from the infiltration of sewage. These pumping stations collect and pump sewage again to the pipelines of sewer system when there is infiltrating of sewage into the Sea and the Rivers.

CHAPTER 4 RESEARCH METHODOLOGY

Based on the specific objectives mentioned above, the detail procedures of the research methodology are described in Figure 4.1.

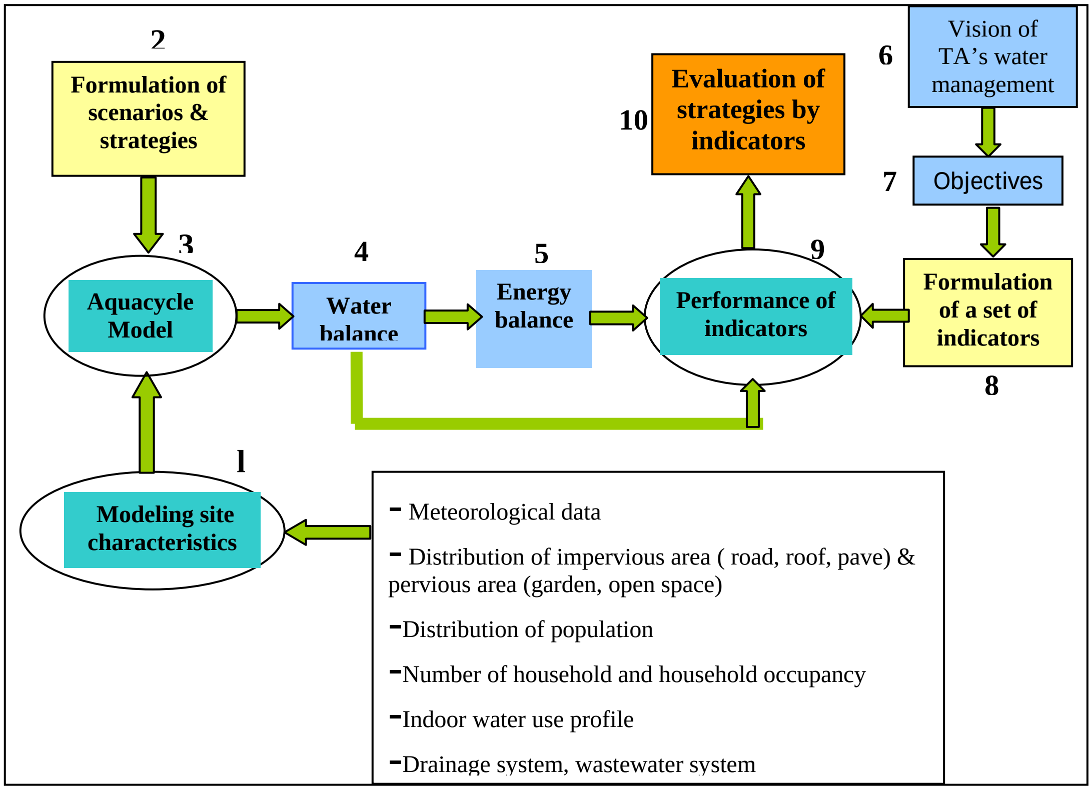


Figure 4. 1 Procedures of research methodology

The first step is to prepare the input data required for Aquacycle model. Site characteristics were modeled as a map with the distribution of impervious area, pervious area, the distribution of population, the layout of wastewater system... And this step was carried out by site visiting.

The next step was to formulate several scenarios and alternative strategies. After that, Aquacycle simulation was conducted with scenarios & strategies.

The result of Aquacycle simulation is the water balance of three main parts: water supply, storm water and wastewater. This water balance coupled with energy consumption data of the city's water system would result in an energy consumption inventory of the whole system.

The existing unsustainable factors of the city's water system were determined to propose a vision and specific objectives for the water system which are the foundation for formulating a set of sustainability indicators for Tel Aviv's water system. And several indicators of those

can be estimated by Aquacycle simulation. These indicators were used to evaluate alternative strategies.

4.1. Site investigation and data collection through field visit

Site investigation and data collection were carried out by 2 months field visit in Tel Aviv. The site visit resulted in a comprehensive understanding of the site's urban water system and getting of available data required for the model. These affairs were conducted by visiting institutions, interviewing local peoples and getting research reports which are related to the study. The record for discussing with local peoples is shown in Table 4.1.

Table 4. 1 Record for meeting with local people

	Time	Institutions	Local People	General content of discussion
1	05/11/08	Tel Aviv water Corporation	Mr. David Jackman (*TA water Corporation)* Mrs. Tami Gavriel *(TA Strategic & long term Planning Department* Switch partners	Introduction about Switch project Ideas on sustainable water management in Tel Aviv objectives and identifying sources of data
2	06/11/08	The Hebrew University of Jerusalem	Prof Avner Adin Prof. Eli Feinerman	Introduction about Switch project indicators
3	09/11/08	Tel Aviv water Corporation	Mr. David Jackman Mr Tzvi Belenki (Director of Engineering Department)	Data of conceptual model for Tel Aviv's water system
4	11/11/08	Tel Aviv water Corporation	Mr Tzvi Belenki	Information of the distribution of drainage system, sewer system, water supply system of Tel Aviv
5	16/11/08	Tel Aviv water Corporation	Mr Tzvi Belenki	Information of the distribution of drainage system, sewer system, water supply system of Tel Aviv
6	20/11/08	The Hebrew University of Jerusalem	Prof Avner Adin	Working progress Communicating with Israel meteorological Services for Climate data and Yarkon Water Authority for information of drainage pumping stations to Yarkon River
7	23/11/08	Tel Aviv water Corporation	Mr Tzvi Belenki	Information of the capacity of drainage pumping stations, sewer pumping stations, local wells, map of boundary urban catchment
8	26/11/08	Shafdan WWTP	Mr. Yoval Sela - Director	Information of the wastewater

				system
9	30/11/08	Yarkon River Authority	Dr David Pergament (*Director)*	Pumping stations along Yarkon River
10	06/12/08	The Hebrew University of Jerusalem	Prof Avner Adin	Primary report on working progress
11	10/12/08	Tel Aviv water Corporation	Mr. David Jackman	Primary report on working progress
12	02/03/09	Tel Aviv water Corporation	Mr. David Jackman	Working progress Information of water distribution system, garden irrigation Energy consumption of components of UWS
13	04/03/09	Water distribution office - Tel Aviv water Corporation		Water distribution system & energy consumption
14	06/03/09	Mekorot Company	Mr Avi Aharoni	Energy consumption of wastewater treatment and pumping
15	08/03/09	Tel Aviv water Corporation	Mr Michael Levy	Data on total water supply
16	09/03/09	The Hebrew University of Jerusalem	Prof Avner Adin	Strategies, imdicators
16	11/03/09	The Hebrew University of Jerusalem	Prof Avner Adin	Presentation practice
17	12/03/09	Tel Aviv water Corporation	Mr. David Jackman Switch partners	Presentation of MSc research Focus on sustainability indicators

4.2. Application of Aquacycle for Tel Aviv's urban water system

The application of Aquacycle in Tel Aviv's water system involved the determination of three groups of data: meteorological data, indoor water use profile and the physical site characteristics. Followings describe in detail the data processing on group.

4.2.1. Meteorological data

Climate data input file is a daily series of precipitation and potential evaporation data. The available data is from year 1994 to year 2007. Precipitation data of Tel Aviv was obtained directly from European Climate Assessment & Data set project (*ECA&D*). Potential evaporation data was estimated by using the formula from *(Global Program, 2005).* In this formula, the monthly heat indexes; the unadjusted potential evaporation values are required and they were calculated by using the daily temperature data which was also collected from ECA&D.

4.2.2. Indoor water use profile

Household water consumption is the only water input in Aquacycle (except precipitation). In the meantime, the total urban water demand involves residential, education, sport, public building, and construction sectors. In order to reflect a more accurate water balance of Tel Aviv by Aquacycle simulation, it was assumed that the water consumption contribution of all sectors was considered as the household water consumption.

According to data from Tahal Company:

Total urban water consumption = (residential + education + sport + public building, healthcare, trading, construction, security, transport) water consumption = 40,369,712 m^3/year (year 2007)

Population of year 2007: 390,068 (TA Municipality)

Therefore, average water consumption per capital per day of Tel Aviv:

(40,369,712/390,068)*1,000/365= 284 liters/capita.day

The indoor water usage profile used in Aquacycle is the domestic water use pattern based on the different indoor water use components: kitchen, bathroom, laundry and toilet with the number occupant of from one to seven. Because of lack of information, the indoor water usage profile of Canberra (*Mitchell, 2005)* was used as reference in this study. The adjustment was based on a 4.8 % increase of average water consumption per capita for Tel Aviv (284 liters/capital.day). The details of the adjustment are given in Table 4.2. In Aquacycle, indoor water usage profile is used for all clusters in the catchment.

Table 4. 2 Indoor water use profile for Tel Aviv (liters/day)

No. of occupants	Kitchen	Bathroom	Toilet	Laundry
1	35.5	107.92	45.44	95.14
2	56.8	174.83	83.61	156.03
3	72.7	237.77	144.64	202.84
4	84.33	280.57	180.81	247.46
5	90.24	308.62	207.93	274.68
6	109.19	348.75	237.03	310.39
7	127.75	390.6	267.85	344.54

4.2.3. Measured parameter input data file

Processing Cluster description data:

Based on satellite image and data from the statistic department of Tel Aviv Municipality, the catchment area was divided into 6 clusters (see Figure 4.2) according to the different spatial characteristics.

In the model, the unit block represents a single household, industrial site, institution or commercial operation. A cluster is a group of unit blocks that forms a local neighborhood or suburb. The urban catchment is represented in the model as a group of clusters. These clusters may relate to the suburb in the catchment or a single land use. The clusters can contain residential blocks, commercial precincts, public open space, and roads.

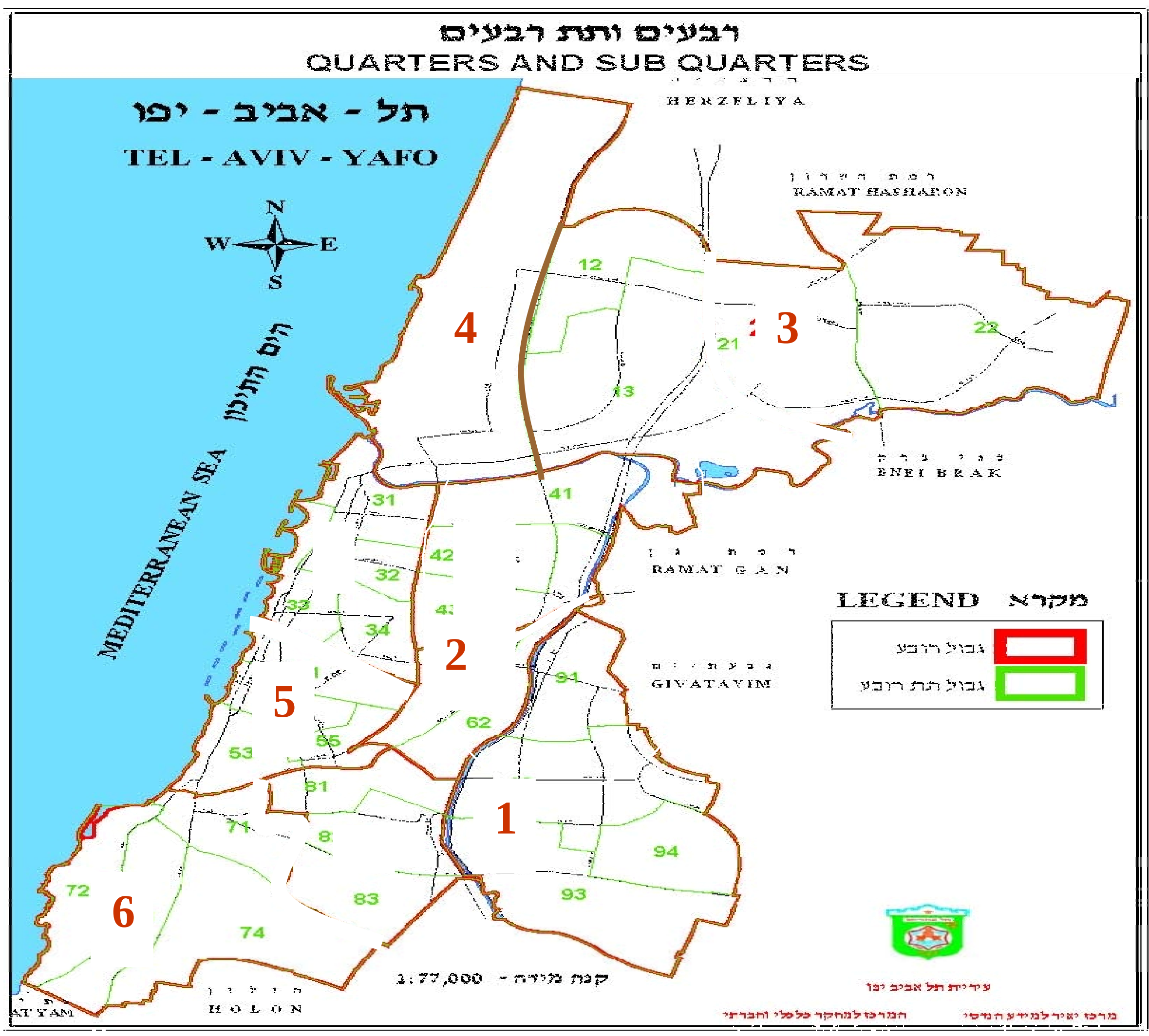


Figure 4. 2 The clusters defined for Tel Aviv Catchment

The characteristics of each clusters is defined in Table 4.3

Table 4. 3 The clusters defined for Tel Aviv Catchment

Cluster	Total area (ha)	Average area of each building (m2)	Characteristics
1	745	514	87% of buildings is residential units
2	648	1657	83% of buildings is residential units
3	1459	1051	
4	659	2459	60% of total area is open space
5	775	775	76% of buildings is residential units
6	985	550	70% of buildings is residential units

Total road area in each cluster is calculated based on satellite image and the detailed information of Strategic plan department of Tel Aviv Municipality (*Municipality of Tel Aviv, 2006).*

The supply of public open space in Tel Aviv is significant in quantity and varied in nature. There are large Metropolitan Parks (Yarkon Park & Begin Park), smaller urban and neighborhoods parks, open areas along the seafront, public squares and boulevards. There are big differences of public open space per resident between different clusters in the catchment: North of the Yarkon River (Cluster 3 and 4) public open space per resident is higher than these others. Due to lack of information, the distribution of open space in clusters was estimated by using map of land use with regard to the total area of the city's open space (around 1028 ha) (*Municipality of Tel Aviv, 2006).*

The distribution of population of each cluster was obtained from Tel Aviv Municipality (*Municipality of Tel Aviv, 2006).*

There are 10 sea outfalls for discharging storm water along the seashore. Also, there are 5 pumping stations of drainage system nearly The Yarkon River and Aylon River. Because cluster 4, 5, 6 are adjacent to the sea, it was assumed that these clusters are discharging storm water to the Sea. The three remaining clusters are discharging stormwater to the Rivers. Therefore, there is no transportation of storm water flow among clusters. In addition, based on the layout of the main pipeline of wastewater system (Shafdan WWTP) and the wastewater flows, the directions of wastewater flows transferring among clusters can be predicted.

Processing unit block description data:

Average occupancy = 2.2 persons/ household (*Municipality of Tel Aviv, 2006)*

Buildings in the study area include residential blocks, commercial and public blocks. Due to data limitations and in order to simplify the catchment representation, the contribution of commercial and public buildings is negligible and the unit block only represents the residential area within each cluster. Most of the buildings in Tel Aviv are apartment blocks *(*75% – *source: Municipality)*, the representative unit block selected in this research was a household. The number of unit block (household) in each cluster was gained from the population of each cluster and the average occupants per household. (See Table 4.4)

Table 4. 4 Number of unit block in each cluster

Cluster	Population of cluster (2007)	Average occupancy per household	Number of unit block
1	80,007	2.2	36,367
2	49,095	2.2	22,316
3	84,834	2.2	38,561
4	14,384	2.2	6,538
5	91,656	2.2	41,662
6	74,964	2.2	34,074

Total area of unit blocks in each cluster was calculated based on the total area of clusters, the area of roads and open spaces in each cluster. The average area of a unit block in each cluster also was obtained from the total area of unit block and the number of unit block within each cluster. The result is given in Table 4.5.

Table 4. 5 Cluster characteristics

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Total area (ha)	745.1	647.7	1,459	659	647	984.6
Open space (ha)	149.02	64.77	292.7	392.7	64.7	64.59
Road area (ha)	113.49	97.57	157.88	24.8	117.97	158.83
Total area of unit block (ha)	482.49	485.36	1008.42	241.5	464.33	761.18

Number of unit blocks	36,367	22,316	38,561	6,538	41,662	34,074
Average area per unit block (m^2)	132.67	217.5	261.51	369.38	111.45	223.39

Due to lack of information, physical characteristics of a unit block were estimated by observation through site visiting. It was assumed that the area percentage of roof, garden and pavement per unit block are 70%, 15 % and 15 %, respectively. Table 4.6 describes the representative unit block characteristics of each cluster.

Table 4. 6 Unit block characteristics

Cluster	Average area of unit block (m2)	Area of roof m2 (70%)	Area of garden m2 (15%)	Area of pavement m2 (15%)
1	132.67	92.87	19.90	19.90
2	217.50	152.25	32.62	32.62
3	261.51	183.06	39.23	39.23
4	369.38	258.57	55.41	55.41
5	111.45	78.02	16.72	16.72
6	223.39	156.37	33.51	33.51

4.2.4. Model Calibration and verification

The calibration of Aqua cycle is not straightforward, due to the three model outputs which are to be fitted to observed values, the influence of a number of parameters on more than one output. Calibration of Aqua cycle is a manual, trial and error process as the model does not have any auto–calibration capabilities (*Mitchell, 2005).*

The calibration process was carried out through trial and error method by determination of parameters which have critical influence on the three outputs of the model: stormwater, wastewater and imported water. In this research, the observed data on water supply and wastewater discharge was selected for the calibration of the model because there has not been any stormwater monitoring system in Tel Aviv so far.

A series of observed data on total monthly imported water from year 2003 to year 2008 was obtained from Tel Aviv Water Corporation.

A series of daily wastewater discharge data for the year 2008 was also obtained from Shafdan WWTP.

Parameters used for model calibration are shown in Table 4.7.

Table 4. 7 Parameters used for the model calibration

Output	Calibration parameter		Units
Stormwater	Percentage area of store 1	22	%
	Pervious storage 1 capacity	32	Mm
	Pervious storage 2 capacity	240	Mm
	Roof area maximum initial loss	0	Mm
	Effective roof area	100	%
	Paved area maximum initial loss	0	Mm
	Effective paved area	100	%
	Road area maximum initial loss	0	Mm
	Effective road area	100	%
	Base flow index	0.55	Ratio
	Base flow recession constant	0.0025	Ratio
Wastewater	Infiltration index	0.095	Ratio
	Infiltration store recession constant	0.12	Ratio
	% of surface runoff as inflow	7	%
Imported water	Garden trigger to irrigate	0.5	Ratio
	Public open space trigger to irrigate	0.5	Ratio

Because the observed data is not sufficient, eleven calibration parameters related to stormwater output were taken from the default initial parameters of Aquacycle.

The "infiltration index" and "infiltration store recession constant" parameters were also taken from the default initial parameters of Aquacycle.

4.3. Scenario formulation

4.3.1. Climate change

Precipitation and evaporation:

According to the report "Israel's adaptation to climate change - impacts and recommendations" (*Israel Ministry of Environmental protection, 2008),* Israel has witnessed a warming trend since the 1970s, with the average temperature expected to rise about 1.5 degrees Celsius by 2020 and up to 5 degrees Celsius by the end of the century. Evaporation will be also affected by temperature.

Recent years, it was observed that there is an increase in the frequency and length of extreme weather events, including years which are either exceeding wet or exceeding dry, with predictions pointing to further increases in the number and frequency of such events (drought years, floods, heat waves). Precipitation is expected to decrease by 10% in the year 2020 and by 20% in the year 2050.

The water balance of Tel Aviv will vary due to the changes of precipitation and evaporation in the future. A decrease of precipitation may reduce the water resources available for Tel Aviv such as: surface water, storm water and groundwater. An increase in evaporation due to increasing temperature trend may accelerate lowering the water level. These changes suggest an overall trend towards a greater water deficit.

Sea level rise

An increase in global mean temperature may cause a rise in sea level due to the melting of glaciers, ice caps, ice sheets, and the thermal expansion of water. The observed trend of rising sea level is expected to continue with the anticipated global warming. This may lead to extreme high water levels and flooding.

Israel Ministry of Environment protection also gives a prediction in a report on (*Israel Ministry of Environmental protection, 2008)* that: "…sea level rise in the Mediterranean is predicted to increase by 0.5 meters in 2050 and one meter by 2100…"

Tel Aviv is situated in the coastal zone, so the impact of sea level rise will be more challenging. Flood risks on settlement areas, incidence of storms and salt water intrusion are major effects of sea level rising on Tel Aviv. Flooding and inundation increasing will have negative impacts on coastal infrastructure and settlement area. Moreover, sea level rise will add aquifer salinization, so the fresh water from ten operating local wells will become brackish and not suitable for potable water quality. The scenario for sea level rise for Tel Aviv is the reduction of imported water from local wells.

4.3.2. Population growth

According to the Strategic Plan of Tel Aviv Yafo, (*Municipality of Tel Aviv, 2006),* Tel Aviv is preparing town planning schemes for residential areas to enable the supply of dwellings for the size of 420,000 residents by the year 2020. Based on the population of 378,902 for the year 2005 and 420,000 for 2020, it can be calculated that the average annual population growth is around 2.7%.

In addition, the demography data from Tel Aviv Municipality also indicates that the annual population growth is 2.2%.

In this research, the population growth scenarios were simulated with 2.2% of growth rate. Therefore, water demand and energy requirements due to population growth will rise rapidly.

* Population growth:

The following equation was used to calculate the projected population:

$$P_p = P_i\,(1+r)\,n$$

P_p: projected population

P_i: initial population

r: population growth rate

n: numbers of year

Increasing population in each cluster results in the change of average occupancy of each unit block.

4.3.3. Urbanization

One of strategic lines of Tel Aviv is to protect and strengthen its centrality. The Municipality has undertaken various courses of action such as preparation of town planning schemes for residential areas with an overall capacity of 50,000 dwellings in the city as a whole, so that the city could attain the size of 420,000 residents by the year 2020. Another strategic line of Tel Aviv is “an attractive urban environment”. In detail, the city will upgrade and enhance the public domain by raise funds for developing and enhancing public open spaces (set up a green fund) *(Municipality of Tel Aviv, 2006).* It can be seen very clearly that the city’s land use distribution will be changed in the future. The increasing residential area will result in creation of impervious areas (roof area, paved area for example) which generates more runoff and decreases aquifer recharge. The developing open public spaces (gardens, parks…) require more water for irrigation. Thus, urbanization has big effect on the water balance of urban water system.

4.3.4. Water demand in Agriculture

Shafdan, the largest WWTP of Israel is responsible for treating effluent for Tel Aviv Metropolitan area and transferring recycled water to the southern region for agriculture use. In the future, with high prices for water and lower prices for agriculture products, the water demand in agriculture sector may reduce. Therefore, Tel Aviv has to find another way to discharge the increasing effluent from the city.

4.3.5. Energy cost

Recently energy costs have surged to unimaginable heights and this will only increase the realization that the urban water system is a small but significant energy consumer. Water supply and wastewater management consume energy to the equivalent of about 5 – 10% of total domestic electricity consumption. The water can therefore not be ignored in initiatives to reduce overall energy consumption (*Switch, 2008).*

Water price is closely related to oil price. Oil is consumed during the transportation of water from water sources to the consumers. The higher the oil price, the higher the water price. Obviously, when water price increases, consumers will take actions to reduce their water demand.

As the global economic slowdown world energy demand, the oil price has decreased from 147 US dollars per barrel in July 2008 to around 40 US dollars in February 2009 *(London AFP).* In future, it is expected for the increasing oil price after world economics' recovery.

4.4. Strategy formulation

Five strategies were proposed for Tel Aviv for the year 2050: Aquifer infiltration, rainwater tanks, wastewater treatment and reuse at unit block and cluster scale, permeable pavement and water conservation.

4.4.1. Aquifer infiltration

Sewage is more reliable than storm water as a source of water supply as it flows everyday and grows with the size of the city, but requires more extensive treatment. Storm water also increases with urbanization but harvesting is irregular and requires surface detention storage, tending to result in smaller scale system. Near urban area, the new dam sites are generally rare and expensive because of population that would be displaced, loss of prime valley floor productive land, and loss of habitat. For this reason, aquifers below cities are becoming highly valued as water can be stored in most cases without any impact on land use. In the past, wells finding brackish groundwater were back filled but now these present an opportunity to store

and recover fresh rainwater, storm water and reclaimed water with minimal pumping and pre-treatment. (*Dillon et al, 2007).*

Aquifer storage and recovery is the process of storage of water in an aquifer for later withdrawal and use. This is done to increase the yield of an aquifer that is already exploited or take advantages of its natural storage capacity instead of relying on surface storage (*Mitchell, 2005)*

Development of irrigation water supplies by injecting stormwater in brackish aquifers is practiced in few places in the world, but may have much wider applications especially in semi arid regions. Examples from South of Australia demonstrate the technical and economic feasibility and environmental sustainability of artificial recharge and recovery of stormwater for urban irrigation water supplies (*Gale, 2000).*

A typical aquifer storage & recovery system consists of the key elements in Figure 4.3.

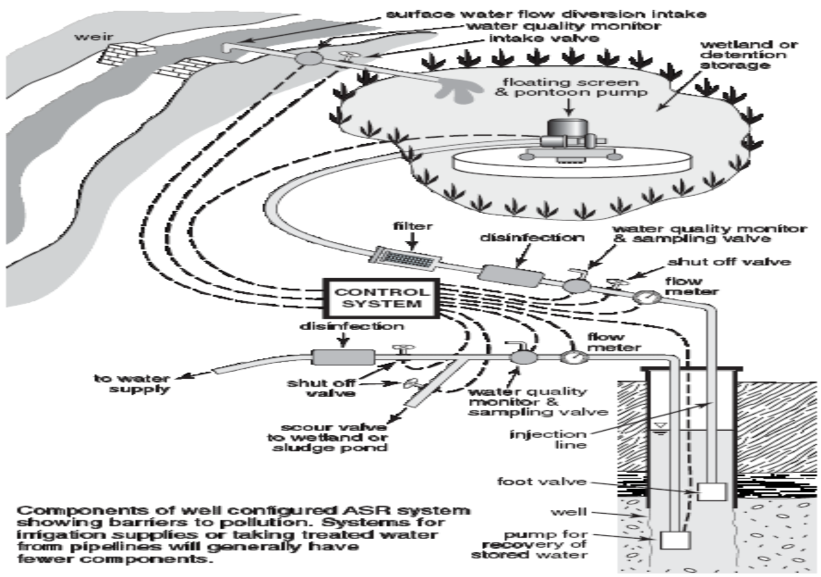


Figure 4. 3 Components of a typical aquifer storage & recovery system
(Peter Dillon, 2006)

4.4.2. Permeable pavement

Permeable pavement is designed to replace effective impervious areas to manage storm water from other impervious surface on site. Use of this technique must be part of an overall on site management system for storm water and is not a replacement for other technique *(Wikipedia)*

Permeable paving is an excellent technique for dense urban areas because it does not require any additional land, so this strategy is likely suitable for such a dense city likes Tel Aviv.

Since impervious pavement is the primary source of storm water runoff, Low Impact Development strategies recommend permeable paving for parking areas and other hard

surfaces. Permeable paving allows rainwater to percolate through the paving and into the ground before it runs off. This approach reduces storm water runoff volumes and minimizes the pollutants introduced into storm water runoff from parking areas. Porous pavement provides groundwater recharge and reduces storm water runoff volume. Depending on design, paving material, soil type, and rainfall, permeable paving can infiltrate as much as 70% to 80% of annual rainfall *(Metropolitan Area Planning Council, 2008)*.

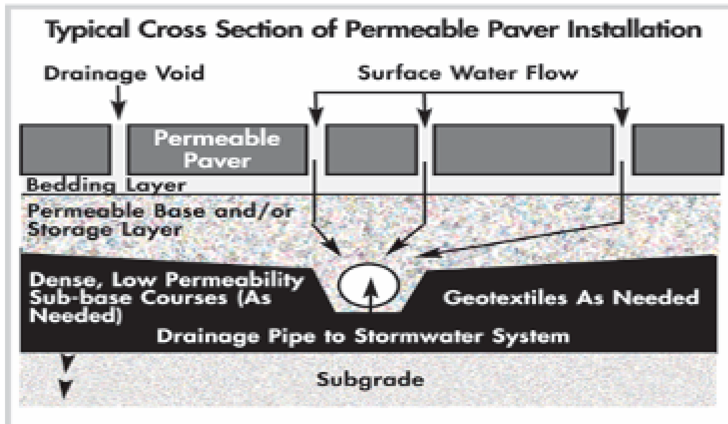


Figure 4. 4 Typical cross section of permeable paver installation (http://www.pavestone.com)

All permeable paving systems consist of a durable, load bearing, pervious surface overlying a crushed stone base that stores rainwater before it infiltrates into the underlying soil. Permeable paving techniques include porous asphalt, pervious concrete, paving stones, and manufactured "grass pavers" made of concrete or plastic. Permeable paving may be used for walkways, patios, plazas, driveways; parking stalls, and overflows parking areas. (*Metropolitan Area Planning Council, 2008).*

In order to estimate the effect of "permeable pavement" strategy on the water balance of Tel Aviv, more namely on the total storm water discharging from the city & groundwater recharge, different scenarios of the change in land use were simulated by Aquacycle. It was assumed that x% of impervious surface area in the city is replaced by permeable surface and in Aquacycle simulation, x% of road area is changed into open space area (cluster scale) and x% of pavement area is changed into garden area (unit block scale).

4.4.3. Water conservation (water demand management)

Water conservation is the most reliable and the least expensive way of stretching the country's water resources and the challenges is being met in all sectors. In the domestic and urban sectors, conservation efforts focus on improvement in efficiency, resource management, repair, control and monitoring of municipal water systems.

The average water consumption in domestic sector of Tel Aviv (68 m^3 of water per capita per year) is much higher than that of Belgium (40 m^3 of water per capita per year) (*Van der Steen, 2007).* It is likely that Tel Aviv should consider the water conservation in domestic use as a key water demand management strategy.

Additional water saving measures include controlled exploitation, spatial distribution of boreholes, application of a block rate pricing system with a penalty for exceeding allocation rights. Promotion of household water pressure reducing devices, dual flush toilets, pull handle taps coupled with increased public awareness and media campaigns play a significant role in reducing domestic water use.

Average Israeli household has 2.2 residents, consuming around 124 m^3 of water per year. Its investment in the commonly used water saving devices is about 85 – 90 USD. Water saving associated with this device is about 80 m^3 per year, implying an annual cost reduction of about 105 USD per household according to the current water price to urban costumers. In other words, at current water prices, investment in water saving devices at household level is very profitable. The investment costs will be recovered within a year, while the technical life span of the saving devices ranges from five to ten years (*European Commission,. 2002*).

4.4.4. Rainwater harvesting (rainwater tank)

Rainwater harvesting is the practice of collecting and using rainwater that runoff of hard surface such as roof. This is an age–old technology that is growing in popularity as people looks for way to use water resource for wisely. Today, many rural areas rely on rainwater harvesting but urban areas that are served by municipal water systems tend to overlook rainwater as a water resource.

Mains water is used for purposes ranging from drinking and food preparation to toilet flushing and garden irrigation. The use of rainwater tank as an alternative source of water for any of these purposes has the potential to reduce pressure on the limited surface and groundwater resources used to supply reticulated water to urban and rural communities. Reduced pressure on the reticulated supply provide by rainwater tanks could alleviate the need for additional dams in growth areas and the increases in cost of producing water for all uses to drinking water standard. One constraint that has been raised is lack of space in large urban center limits the sizes of tanks that can be installed. This problem is being exacerbated by the trend to higher density living. In these circumstances, at best, small–capacity tanks can be installed. (*Australian EnHealth Council, 2004).*

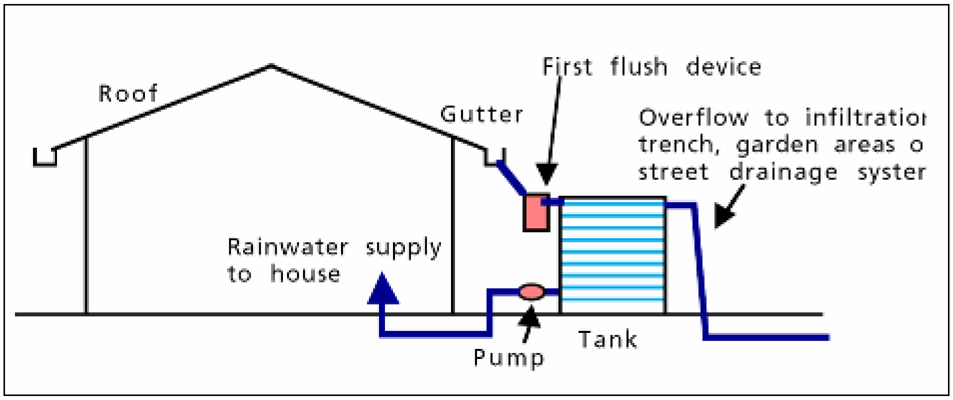


Figure 4. 5 Key elements of a domestic rainwater system

A rainwater harvesting system consists of the key elements as shown in Figure 4.5: house roof, roof gutters, first flush device, rainwater tank, pump, and overflow to garden areas. Depending on site conditions, user requirements & budget, rainwater tank systems can be installed using a variety of different configurations including: installing tanks above or below ground, using gravity or pressure systems; using dual supply system including a detention volume inside the tank for additional storm water management (*Coombes, 2002).*

4.4.5. Decentralized wastewater treatment unit at unit block & cluster level

Compared to stormwater runoff, the discharge of wastewater is constant. Wastewater flowing from kitchen, bathroom, laundry, and toilet can be treated and stored for later using such as toilet flushing and irrigation.

Consideration of economies of scale has lead to so-called ‘centralized’ water treatment and distribution systems, as well as centralized wastewater collection and treatment systems. The advantages may however be offset by the disadvantages of transportation over large distances. Moreover, centralized systems do not benefit from new options for decentralized water production and decentralized treatment and reuse of household wastewater. Therefore cities should consider a strategic choice about whether the decentralized options are going to be implemented seriously and at a large scale. (*Switch, 2006b).*

An onsite sewage management generally consists of 3 main parts: the wastewater source, treatment components and a land application area for the final reuse or disposal. These components are represented graphically in Figure 4.6.

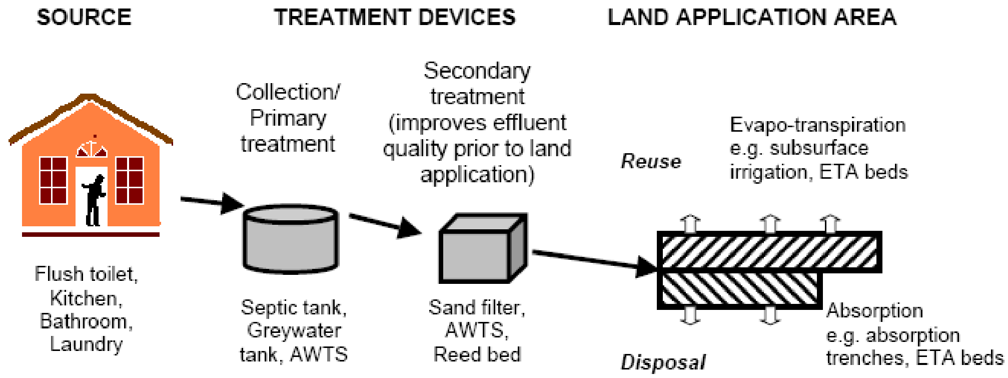


Figure 4. 6 Major components of on site sewage management system
(Byron Shire Council, 2004)

The process of designing an on site sewage management system involves gathering, interpreting and reporting information relevant to each part of treatment train. Thus, designing a suitable OSMS requires a good understanding of the soils and other physical variables of the site (slope, aspect and shape of the land), the wastewater generating of the household and an extensive knowledge of the available treatment and land application options. (*Byron Shire Council, 2004).*

The wastewater treatment unit at unit block level seems more expensive and difficult for application than that at cluster scale because it involves so many units.

4.5. Formulation of a set of sustainability indicators for Tel Aviv' urban water system

4.5.1. Investigation of current unsustainable factors of Tel Aviv's water system

Due to the existing pressures of climate change, population growth and urbanization, Tel Aviv's water system management should be improved to reach a sustainable development. Therefore, the determination of current unsustainable factors of the system is the foundation of the vision and specific objectives for Tel Aviv's water system.

Urbanization and population growth worldwide increases the share of urban water consumption as a fraction of total water demand. Urban water demand therefore becomes more and more important, as compared to other water uses, for instance agriculture. Also in Israel, the share of urban consumption in the overall water balance is slowly increasing (38% in 1999; 40% in 2010). Whereas the water sources are remaining the same or are decreasing in quality and quantity: therefore water crisis and an unsustainable situation are occurring.

Wastewater produced in the city is to a large extent collected, treated and transported to the Negev for irrigation. Storm water is not treated and agriculture in the coastal plain is also contributing to aquifer pollution.

4.5.2. Switch vision for integrated urban water management

The Switch vision for 2035 for a truly sustainable urban water system was formulated in the form of a set of sustainability objectives. A city that wishes to achieve sustainability for its urban water system should set itself the following objectives:

General:

- To have citizens that are aware of "water and sustainability" and where the public is involved in decision making.

- To manage its urban water system in an integrated way; integrating aspects of water supply, storm water management, wastewater collection, wastewater treatment and wastewater reuse.

- To use a set of sustainability indicators for decision making in strategy development and planning

- To have a strong scientific basis for decision making concerning the management of its urban water system; to ensure equity in assess to water, as well as to irrigated green areas.

- To minimized the energy consumption in the urban water system.

Water supply and sanitation:

- To supply water of good quality to its citizens and other stakeholders (industry, companies, agriculture) in sufficient qualities at the lowest possible costs

- To give priority to water demand management over development of new water resources

- To provide all its citizens with proper sanitation, at the lowest possible costs.

- To give priority to pollution prevention over end–pipe treatment.

- To reduce the net waste output from the city to the environment to below the carrying capacity of the receiving environment. Furthermore, it will enhance the self purification capacity of the receiving environment by eco-hydrology.

Storm water management and reuse:

- To reduce the risk of flooding in vulnerable areas to levels acceptable to all stakeholders, even under future climate change scenarios.

- To protect and enhance the water quality and ecological status of urban receiving waters, both surface and groundwater.

- To apply source control techniques to enable storm water to contribute to the quality of life in the urban environment.

- To harvest rainwater and storm water for non–potable reuse purposes.

- To utilize storm water to re–establish a balanced natural water cycle (in conjunction with landscape development).

4.5.3. Determination of specific objectives for Tel Aviv's urban water system

Vision for sustainable urban water management for Tel Aviv

In current water sector policy of Israel, all activities in water sector should be based on a sustainable development which is founded upon three basic components:

- Ensuring water supply
- Social–economic requirements
- Environmental & ecological needs

Based on Switch's view of Integrated Urban Water Management and water policy of Israel mentioned above, it can be formulated a general vision for Tel Aviv's water system management:

"Tel Aviv's water system management will be established based on sustainability indicators and apply an efficient and integrated water management to meet the water demand of citizens and other applications with sufficient qualities and reasonable prices, in the meanwhile assure the natural status of water resources".

Specific objectives for Tel Aviv's water management are proposed in order to improve the current unsustainable system, sketching a picture of the features of a sustainable system for Tel Aviv.

4.5.4. Selection of a set of sustainability indicators for Tel Aviv's water system

Sustainable indicators are tools that aim to measure sustainability and to address the key question: is the city moving towards the sustainability vision or not. It is generally agree that sustainability has financial, social and environmental aspects. The set of indicators that is used to monitor the system therefore ideally includes an equal number of indicators for these three aspects.

There are different frameworks to use indicators. In this research, the simplest framework is used by using a list of a variety of indicators from Switch research.

4.6. Inventory of energy consumption of Tel Aviv's water system

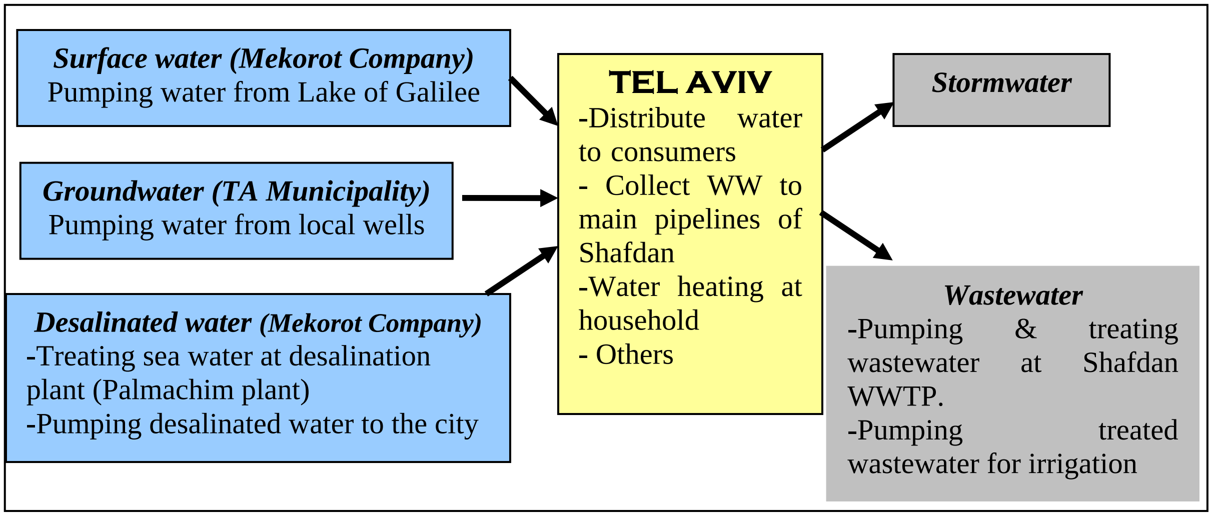


Figure 4. 7 Outline of energy consuming components of Tel Aviv's water system

The approach used to study the total energy consumption of the system is described in Figure 4.7. Due to lack of information, it was assumed that water supply for Tel Aviv from Mekorot Company involves two sources: the Lake of Galilee and desalination plant. Followings present details of processing available data to estimate energy consumption of components of Tel Aviv's water system.

4.6.1. Water supply

Surface water

Pumping water from Sea of Galilee to the city consumes 1.3 KWh per m^3 of water and 90 % of total water supply to Tel Aviv is water from Lake of Galilee (*source:Mekorot Company).*

Groundwater

There are 10 operating local wells in Tel Aviv now and the energy consumption for pumping groundwater of each well (year 2008) is given in Table 4.8.

Table 4. 8 Energy consumption of local wells in Tel Aviv - 2008

(Source: Tel Aviv Municipality)

No. of local wells	1	2	3	4	5	6	7	8	9	10
Energy consumption (KWh/yr)	70,436	201,268	407,656	94,290	174,280	164,608	207,213	86,464	16,448	75,976
Total (KWh)	**1,498,639 / year**									

Amount of water extracted from local wells in Tel Aviv is 4,038,403 m^3 (*Tel Aviv Municipality*), so average energy consumption to pump 1 m^3 of groundwater is:

1,498,639 KWh/4,038,403 m^3 = ***0.371 KWh/m³***

And the distribution of groundwater to total supply water in Tel Aviv can be estimated:

Amount of groundwater/amount of water supply in Tel Aviv (*source: Tel Aviv Municipality)*

= 4,038,403/48,898,054 ~ 8%

Desalinated water

According to data of Mekorot Company, treating energy for 1 m^3 of desalinated water is 3.6 KWh at Palmachim sea desalination plant and energy use for pumping 1 m^3 of desalinated water from Palmachim to the city is 0.3 KWh. Therefore total energy consumption of treating & distributing desalinated water from Palmachim sea desalination plant to entrance of Tel Aviv city is 3.9 KWh/m^3.

4.6.2. Distributing drinking water within the city

All the information of drinking water distribution system of Tel Aviv was obtained from Tel Aviv's water supply operation station–Tel Aviv Municipality.

Total amount of imported water of Tel Aviv = water bought from Mekorot + water extracted from local wells = 44,795,231 + 4,038,403 = 48,833,634 m^3 per year.

As mentioned above, it is consumed 1.3 KWh/ m^3 for pumping water from Lake of Galilee to the city (responsibility of Mekorot Company). And TA Municipality is responsible for distributing water to consumers within the city. Because of the topography of TA sloping to the Sea, most of areas of the City are distributed water by gravity and there is no energy consumption for water distribution. However, there are two small areas of the city at which the City have to use boosters to pump water. One area, in the Northeastern of the city (cluster 3), 20 – 50 m above sea level is supplied with 750 m^3 of water per hours (6,570,000 m^3/year) by boosters. The remaining area in the Southeast of the city (cluster 1), 20 – 50 m above sea level, is supplied with 400 m^3 of water per hour (3,504,000 m^3/year) by boosters. Table 4.9 presents the energy consumption of these boosters for pumping water.

Table 4. 9 Energy consumption of boosters in year 2008

(Source: Tel Aviv Municipality)

Boosters in the Northeast area (cluster 3) 6,570,000 m³/year		**Boosters in the Southeast area (cluster 1) 3,504,000 m³/year**	
No	Total energy consumption (KWh/year)	No	Total energy consumption (KWh/year)
1	110,605	1	153,936
2	142,310	2	272,836
3	218,820	3	124,196
4	2,415		

5	202,236		
6	224		
Total	*676,610*	*Total*	*268,868*
Average	***0.103 KWh/m³***	***Average***	***0.077 KWh/m³***

4.6.3. Heating water at household:

The energy consumption for heating water can be calculated by using the following equation:

$$Q = m.c.\Delta T = m.c.(T_2 - T_1)$$

With:

Q: energy required for heating up m kg of water from the temperature T_1 to the temperature T_1.

m: is the mass of water (in kg)

c: is the specific heat capacity of water and m = 4186 J/kg.K (Wikipedia)

ΔT : The difference in temperature where the initial temperature of the reaction is subtracted from the final temperature (K)

Assuming water in household is heated from 15^{o}C to 50^{o}C, therefore the energy required for heating up 1000kg of water (1m^3) from 15^{o}C to 50^{o}C is:

$$Q = 4186 \text{ J/kg.K} * 1000 * (50 - 15) = 146510 * 10^3 \text{ J}$$

1Wh = 3600 J

Therefore, energy consumption for heating up 1 m^3 of water from 15^{o}C to 50^{o}C:

146510/3600 = 40.7 KWh/m^3

It was assumed that water heating at household is by electricity.

Table 4. 10 Household water use profile of TA and ratio of water heating (liters/day)

No. of occupants	Kitchen	Bathroom	Toilet	Laundry
1	35.5	107.92	45.44	95.14
2	56.8	174.83	83.61	156.03
3	72.7	237.77	144.64	202.84
4	84.33	280.57	180.81	247.46
5	90.24	308.62	207.93	274.68
6	109.19	348.75	237.03	310.39
7	127.75	390.6	267.85	344.54
Ratio from hot water	0.6	0.5		0.25

The household water use profile for 2 occupants was chosen to estimate the percentage of heated water at household:

(56.8*0.6 + 174.83*0.5 + 156.03*0.25)/ (56.8+174.83+83.61+`56.03) = 27%

4.6.4. "Dry Weather" Pumping Stations

In Tel Aviv, in the winter season (rainy season), storm water is discharged directly to the Sea and the Rivers by gravity. There are some "dry weather" pumping stations along the Sea and Rivers which only operate in summer season to protect the Sea and the Rivers from the infiltration of sewage. These pumping stations will collect and pump sewage again to the pipeline system every time there is sewage infiltrating into the Sea and the Rivers. Information of energy consumption of 13 operating " summer" pumping stations in Tel Aviv is shown in Table 4.11*(source: TA Municipality).*

Table 4. 11 Energy consumption of summer pumping stations in Tel Aviv

No	1	2	3	4	5	6	7	8	9	10	11	12	13
KWh	3035	3215	2760	421	5285	1976	9044	5615	3232	1464	4235	5174	9409
Total	***54,883 KWh/y***												

4.6.5. Wastewater

Wastewater collection

The energy consumption for collecting wastewater in Tel Aviv involves two components: pumping wastewater within city to the main pipelines of Shafdan and pumping wastewater from these main pipelines to Shafdan WWTP.

As Shafdan wastewater treatment plant is responsible for effluent from Dan region of towns and effluent from Dan region coming to Shafdan only by one main pipeline system, there is no available data on the amount of wastewater from Tel Aviv. Therefore the amount of Tel Aviv's effluent was estimated based on the data on total wastewater of Dan region and on the supposition that average wastewater production per person in Dan region is equal (see Table 4.12)

Table 4. 12 Estimation of total wastewater production of Tel Aviv

Year 2007	**Population**	**Wastewater coming to Shafdan (m^3)**
Dan region Association of towns	1,747,039	138,700,000 (*source: Shafdan)*
Tel Aviv	394,939	**31,354,789**

+ Pumping wastewater within city to the main pipelines of Shafdan (the responsibility of Tel Aviv Municipality):

The data energy consumption of five sewage pumping stations for pumping wastewater within the city to the main pipeline of Shafdan Company is given in Table 4.12.

Table 4. 12 Energy consumption of sewage pumping stations –2008

(Source: TA Municipality)

No. of pumping stations	1	2	3	4	5
Energy consumption (KWh)	86,996	62,610	53,016	13,476	52,770
Total (KWh/yr)	**1,498,639**				

Therefore, the energy consumption to pump 1 m^3 of wastewater to the main pipeline of Shafdan can be calculated by following equation:

(268,868 KWh/y) / (31,354,789 m^3/y) ***= 0.0086 KWh/m^3 (*)***

+ Pumping wastewater from main pipelines to Shafdan WWTP (the responsibility of Shafdan):

There are two big pumping stations responsible for pumping effluent to Shafdan WWTP (Reading pumping station and Bassa pumping station). The data on energy consumption of these pumping stations was obtained from Shafdan and was used to estimate average energy consumption per m^3 of wastewater (see Table 4.13).

Table 4. 13 Estimation of energy use for pumping wastewater to Shafdan

	Quantity of wastewater (m^3/y)	**Quantity of total energy consumption (KWh/y)**	**Average energy consumption (KWh/m^3)**
Reading station	113,880,000	588,000	***0.00516***
Bassa station	148,920,000	14,400,000	***0.097***

Based on the results of (*) and Table 4.13, total amount of energy consumption for collecting wastewater is: 0.0086 + 0.00516 + 0.097 ***= 0.111 KWh/m^3.***

Wastewater treatment

In the year 2007, Shafdan collected 138,700,000 m^3 of wastewater (380,000 m^3/day) and consumed 58,889,000 KWh for wastewater treatment (*source: Mekorot Company*), therefore the average energy consumption for wastewater treatment per m^3 is: ***0.425 KWh/m^3.***

Pumping treated wastewater for irrigation in the South:

According to data of Mekorot Company, reclaimed water from the exit of the Shafdan WWTP up to the south for irrigation is 1.45 KWh/m^3.

4.6.6. Other energy consumption

Total energy consumption of valves of the system: 11,547 KWh/year.

Other devices: 133,532 KWh/year.

4.6.7. Energy consumption of alternative strategies

Onsite wastewater treatment and reuse strategy

Energy consumption for wastewater treatment and reuse involves two parts: treatment and distribution:

+ Onsite wastewater treatment and reuse at unit block scale (in household):

Energy consumption of this strategy is for treating wastewater. Obviously, the energy consumption in smaller wastewater treatment unit is higher than that in the bigger ones. It was assumed that due to the requirement for improving the quality of treated wastewater for reusing at household and the increasing energy consumption in operating the smaller treatment system, the energy consumption for treating per cubic meter of wastewater at household is 30% higher than that at Shafdan WWTP (0.425*130% = 0.5525 KWh/m^3).

+Onsite wastewater treatment and reuse at cluster scale:

Energy used in this strategy involves collecting wastewater from households to treatment plants, treating it and distributing treated wastewater back to households.

Assuming the energy consumption to collect wastewater from household to treatment units in clusters is similar to the amount for collecting wastewater to Shafdan WWTP (0.111 KWh/m^3).

For treating wastewater at cluster scale, assuming energy consumption increases by 15% of the amount consumed in Shafdan WWTP (0.425*115% = 0.4887 KWh/m^3) because of the increasing energy consumption in the smaller treatment system.

Most of the existing water distribution network supplies water to consumers by gravity; therefore it also was assumed that treated wastewater distribution to households is by gravity.

Rainwater tank

Energy consumption for rainwater tank strategy was estimated as 0.278 KWh/m^3 (*Kenway et al., 2008).*

Wastewater energy intensity is presented per volume of wastewater treated (KWh/m^3) and per customer per year (KWh/capita.year).

The calculation is based on the data derived from Appendix 4 (*Kenway et al., 2008)* and results of energy use inventory in Table 5.1.

4.7. Description of Aquacycle application to simulate alternative strategies under "normal" scenario

In this research, the normal scenario was simulated by Aquacycle from year 2009 to year 2050 with 4 strategies: aquifer infiltration, wastewater treatment & reuse at unit block and cluster scale and rainwater tank. Followings explain briefly the simulation process from year 2009 to year 2050. This period was divided into 3 sub-periods according to the assumptions of climate change and changes in land use. Therefore, each sub – period has its climate data file and measured parameter file. It also should be kept in mind that the climate data is available from 1994 – 2007 (13 years).

**** From year 2009 – 2022***

It was assumed that there is no change in climate. Therefore the climate data file from 1994 to 2007 (13 years) was used as the climate data input file of this sub - period. In addition, there is no change in land use meaning there is no change in road, open space & total unit block area as compared with the baseline situation. The average number of occupant per household in each year was estimated according to the 2.2% of population growth rate annually. The model was run for each year of this sub - period with different climate data, different value of the number of occupants per household.

**** From year 2023 – 2036***

In this period, 10% of open space area in each cluster was replaced by unit block area leading to the change in the number of household in each cluster. The average number of occupant per household in each year was estimated according to the 2.2% of population growth rate annually. The population growth rate is 2.2% per year; the climate data file from 1994 to 2007 was used with 20 % reduction on precipitation and 1.5^{o}C increase of temperature everyday. The model was run for each year of this sub period with different climate data and different value of the number of occupants per household.

**** From year 2037 – 2050***

This period was simulated with the same climate data file of period 2023 – 2036. 20% of open space area in each cluster was replaced by unit block area leading to the change in the number of household in each cluster. The average number of occupant per household in each year was estimated according to the 2.2% of population growth rate annually. The model was run for each year of this sub period with different climate data and different value of the number of occupants per household.

CHAPTER 5 RESULTS AND DISCUSSION

5.1. Scenarios

Four scenarios named as in the Table 5.1 were formulated for Tel Aviv in the year 2050 including seven factors: precipitation, temperature, sea level rise, population growth, urbanization water demand in agriculture and energy cost.

Table 5. 1 Formulation of scenarios for year 2050

	Precipitation	Temperature	Sea level rise	Population growth rate	Urbanization	Water demand in agriculture	Energy cost
Baseline scenario	-	-	-	-	-	-	-
No major change scenario	-	-	-	1%	20% total area of open space is replaced by residential area, road area is not change	-	-
Normal Scenario	- 20%	+ 1.5°C	+0.5 m	+ 2.2%	20% total area of open space is replaced by residential area, road area is not change	-	+100 US dollar per barrel
"Extreme" scenario	- 30%	+ 3°C	+ 1 m	+3%	20% total area of open space is replaced by residential area, road area is not change	- 30%	+200 US dollar per barrel

- *"Baseline" scenario* is the current condition of the system. Baseline scenario represents the present situation of the city. The site description of each cluster on present state is shown in Appendix 5.

Base on Table 5.1, scenarios of Tel Aviv can be described as followings:

- **"***No major change" scenario* is referred to scenario in which in the year 2050, the effects of climate change on Tel Aviv is insignificant. There are no significant changes in rainfall and temperature. Phenomenon of sea level rise is not detected. Tel Aviv does not start work for the development of new infrastructure for the city such as road, new commercial centers due to lack of invested capital. Oil price is stable, therefore Mekorot Company and Tel Aviv Municipality do not need to increase water price, and citizens don't have to consider reducing their water demand. The water demand in agriculture sector does not change because Israeli government continues subsidizing for water price. Population of Tel Aviv of course increases naturally at the growth rate of 1% and 20% of open space area is replaced by buildings in all clusters in order to satisfy the demand of space of increasing population. The site description of each cluster on "no major change" scenario is shown in Appendix 6.

- *"Normal" scenario* is formulated representing the normal variance of Tel Aviv's situation in the year 2050. Rainfall measurements at Tel Aviv Meteorological stations show 20% decline of the amount of precipitation in the region. The observed trend of rising sea level is expected continue with ICCP's forecast of global warming for Mediterranean basin (0.5 m higher in sea level in the year 2050). Also, the increase of 1.5^{o}C in the Mediterranean basin anticipated by ICCP is applied for Tel Aviv in this research. The town planning schemes for employment areas and residential areas have been finished on schedule, 20% of open space area has been replaced by buildings in each cluster. Israeli government continues subsidizing for water price in Agriculture sector resulting in stable demand of recycled wastewater from Tel Aviv for agriculture irrigation in the South. Tel Aviv citizens have to pay a higher price for water because of increasing oil price. Population of Tel Aviv increases naturally at the growth rate of 2.2%. The characteristics of each cluster on "normal" scenario and "no major change" scenario are similar but the average household occupancy in each cluster increases due to the different population growth rate.

- *"Extreme" scenario* is referred an extreme state of Tel Aviv comprising of factors which develop with the similar trend of normal scenario but at a higher rate. In the year 2050, Tel Aviv's meteorological station shows a 30 % decline of rainfall, a 3^{o}C decline of temperature and 1 meter rising of sea level. The town planning schemes for employment areas and residential areas have been finished on schedule, 100 hectares of open public space in the North of the City (cluster) has been replaced by buildings. The recycled wastewater demand of agriculture sector reduces 30% due to the reduction of subsidy for water price from

government. Oil price increases 200 US dollars per barrel. Population growth increases at the rate of 3%.

All of these factors mentioned in Table 5.1 impact directly or indirectly on Tel Aviv's urban water system via the effects on water demand, water resources, water infrastructure, urban land distribution… Four factors (precipitation, temperature, population growth and urbanization) can be simulated by Aquacycle model in order to portray Tel Aviv's water balance in each scenario.

5.2. Formulation of strategies

5.2.1. Aquifer infiltration

In this research, aquifer infiltration projects were proposed for every cluster in the city. Unit block draining and road run off coming to storm water storage of each cluster and reused for toilet flushing, garden & public space irrigation.

The stormwater surface storage in each cluster chosen for simulation is: cluster 1: 15000 m^3; cluster 2: 5,000 m^3; cluster 3:15,000 m^3; cluster 4: 15,000 m^3; cluster 5: 5,000 m^3; cluster 6: 5,000 m^3 (according to the optimization results of Aquacycle). A 10,000 m^3 of aquifer storage was applied for each cluster.

In the winter, the water source for injection here is stormwater runoff derived from surrounding urban surface water (residential area, roads…). Urban stormwater is collected and treated in detention basins & wetland to improve the quality of stormwater and receiving water. The water is then fed by gravity or pump into the injection well via basic treatment system such as screen or filters. The recovered water generally requires no treatment for irrigation using. The recovered water is pump out in the summer to irrigate garden and open space in Tel Aviv.

In the future, before commencing ASR project, detailed hydrologic analyses should be done by information from organization responsible for groundwater management of the city to determine if there are suitable aquifers in the intended area of the proposed project, the environmental values of such aquifers and the potential for storage.

5.2.2. Permeable pavement

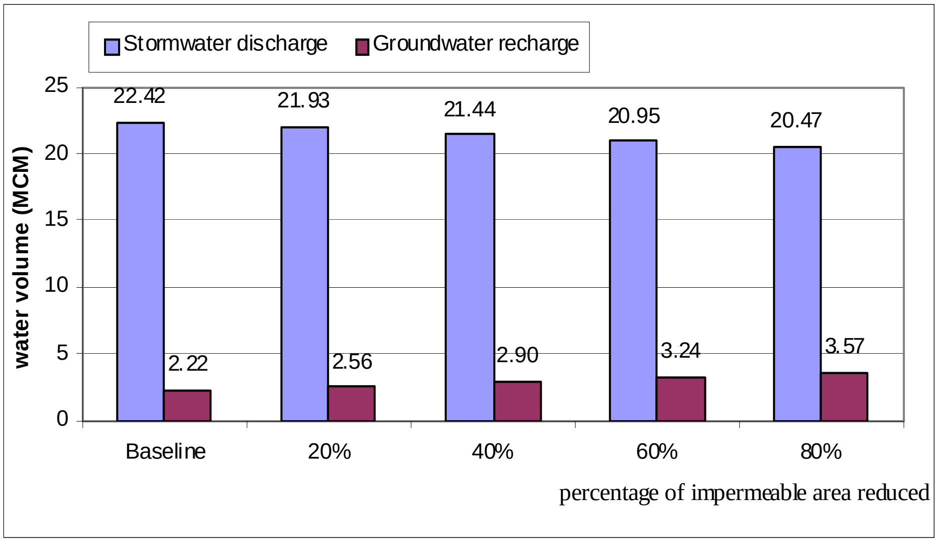
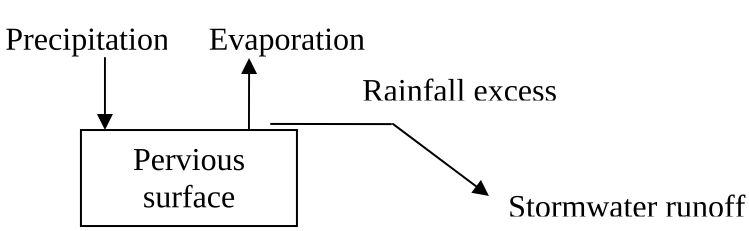


Figure 5. 1 Performance the effect of permeable surface area on quantities of storm water discharge & groundwater recharge in Tel Aviv's water balance

Figure 5.1 presents the effect of permeable surface area on the amounts of storm water discharge and groundwater recharge in Tel Aviv's water balance. Reading from left to right, it is found that the quantity of storm water discharged decreases about 500,000 m3 per year (2%) with every 20% reduction on impermeable surface area. In the meantime, the amount of groundwater recharge increases about 350,000 m3 per year (15%) with every 20% reduction on impermeable surface area. For example, if 60% of road and pavement area in the city is replaced by permeable pavement, storm water discharged volume decreases by 1.5 millions m^3 per year and groundwater recharge volume increases by more than 1 millions m^3 per year. It is not likely a significant value but still have certain contribution to dealing with water shortage in Tel Aviv.

The effect of this strategy on the amounts of storm water discharge and groundwater recharge is so small, even 80% of impermeable area was replaced by permeable surface. This phenomenon can be explained by the conceptual representation of the model:



With a 530 mm of precipitation annually and around 15 rainy days per year, it can be found that the rainy intensity in Tel Aviv is relatively high. It results in a high amount of rainfall excess which afterward comes into stormwater system.

5.2.3. Rainwater tank

In order to simulate the performance of Tel Aviv's water system when applying this strategy, 2 m^3 rainwater tanks are applied for all clusters in the city. Water from rain tank is used for kitchen, laundry, and bathroom, toilet flushing and garden irrigation.

5.2.4. Decentralized wastewater treatment unit at unit block and cluster level

In this research, decentralized wastewater treatment strategies at unit block & cluster scale were chosen to predict their effects on the performance of Tel Aviv's water balance.

For unit block scale, decentralized wastewater treatment units are applied at every household in the city. Wastewater from kitchen, bathroom & laundry are treated and reused for toilet flushing and garden irrigation. Wastewater storage at every household in each cluster is identified according to the optimization results of Aquacycle (200 liters of wastewater storage in cluster 1, 2, 3, 5, 6 and 100 liters of wastewater storage in cluster 4).

For cluster scale, wastewater treatment units are applied at every cluster. Household wastewater draining to cluster wastewater storage will be treated, storage and supplied for toilet flushing and garden irrigation for household and open space irrigation within cluster. The optimization results by Aquacycle simulation for wastewater storage at cluster are followings: cluster 1: 7,864 m^3; cluster 2: 4,638 m^3; cluster 3: 8,349 m^3; cluster 4: 1,319 m^3; cluster 5: 9,059 m^3; cluster 6: 7,247 m^3.

5.3. Formulation of a set of sustainability indicators for Tel Aviv' urban water system

5.3.1. Current unsustainable factors of Tel Aviv's water system

** Infrastructure:*

1. Old water and wastewater distribution system is taking too long and is not methodically done. Tel Aviv's municipality wastewater distribution system is 30-40 years old and the pipe line renewal rate is low *(Switch city story).*

2. The maintenance level of the distribution system is not very high. All that can cause bio-film growth and microbial pollution in the distribution system and cause a higher chlorine

demand. Also frequent leakages of wastewater distribution system in the drinking water aquifer areas can cause severe pollution *(Switch city story).*

* *Administration:*

3. Lack of suitable financial resources of local government makes it harder to keep a good drinking water quality and pollution out of the drinking water wells *(Switch city story).*

4.The Strategic Plan for Tel Aviv has been already developed and implemented for almost 10 years, but the water sector with water issues has not been included in the initial plan. Therefore, there is a potential for having a visible and sustainable impact on water issues in Tel Aviv by developing "water indicators" that will link the water issues to the existing Strategic Plan (*Switch city story).*

* *Drinking water management*

5. The domestic water consumption is higher than the amount that can be sustained from renewable water sources (aquifers and the surface water Lake of Galilee). This consumption is expected to increase by with the development of metropolitan parks and the improvement of life.

6. Urban parks in Tel Aviv are still irrigated with fresh water.

* *Wastewater management*

7. Most of the urban and industrial wastewater generated is not utilized for agriculture irrigation within the region itself but treated in the Shafdan WWTP and after that exported to the southern region for agriculture use. The question here is how Tel Aviv municipality can be assured that the farmers will not reduce usage suddenly (due to an economic crisis for example) and leave the city with treated waste water that they can not dispose of.

8. The disposal of activated sludge containing bacteria accumulated from Shafdan WWTP into the Mediterranean is now causing marine pollution. The Dan Region Association recently initiated and additional project with the aim of stopping the flow of all excess activated sludge into the sea.

9. Tel Aviv is causing marine pollution by discharging of untreated stowmwater via 10 sea outfalls along the sea shore.

* *Storm water management*

10. The existing drainage system is discharging stormwater directly to the Sea and there have been no any monitoring system or research to evaluate the amount of stormwater generated from the city. It is likely that Tel Aviv is overlooking the potential for a non conventional water resource including roof runoff, road runoff. In this research, strategies for recycling and

reusing stormwater such as aquifer infiltration, rainwater tank were simulated by Aquacycle model to see the performance of water system and affirm the role of stormwater reuse in the development of a sustainable urban water system in Tel Aviv.

11. The penetration of rainwater into urban and regional sewage systems can cause flooding resulting from system overflow.

** Energy consumption of the whole system:*

12. Tel Aviv water system is consuming a significant amount of energy to transport fresh water for far way & low water sources (The Sea of Galilee). In addition, desalination is a technology requiring energy at high level.

5.3.2. Specific Objectives of Tel Aviv's water system

Based on the current state of the city's system, specific sustainability objectives for Tel Aviv are chosen from the list of sustainability objectives of Switch mentioned above and shown in Table 5.2.

Table 5. 2 Specific sustainability objectives for urban water system of Tel Aviv

	Objectives	Current State of Tel Aviv	Response
General			
1	TA will rise citizen's awareness of "water & sustainability" and where the authority will involve the public in decision making	The level of awareness and the extent to which individual citizens & NGOs are involved in decision making	Awareness raising activities & public meetings as integral part of the decision making process
2	TA will manage its urban water system in an integrated way; integrating aspects of water supply, stormwater management , wastewater collection, treatment and reuse.	Management of the urban water system is done at the level of sub-system & therefore non - optimal	The ideas of integrated urban water management are incorporated in new policies & master plans of the water sector institutions
3	TA will use a set of sustainability indicators for decision making & planning	Decision making are non – transparent and the rational of decision is not always	Sustainability indicators are used for decision making processes and

		clear	planning
4	TA will have a strong scientific basis for decision making concerning the management of its Urban water system	Decision makers do not always use the latest scientific results (new technologies and methods)	Decision making in the water sector is based on scientific research
Water supply			
5	Tel Aviv will renew the operation of the city's contaminated wells	Pollution in drinking water aquifer areas	Rising the drinking water quality
6	Maintenance of water supply system to reduce water losses and improve water quality		
7	Tel Aviv will give the priority to water demand management over development of new water resources	Water shortage	Water demand management programs
Stormwater management & harvesting			
8	Stormwater & drainage management via criteria for construction of new houses and buildings		
9	Tel Aviv will harvest rainwater and stormwater for non – potable reuse purposes	Rainwater and stormwater are collected and drained directly from urban area	Rainwater and stormwater projects
10	Tel Aviv will utilize stormwater to re–establish a balance natural water cycle (in conjunction with landscape development)	Increased overland flow and evaporation losses compared to reductions in groundwater recharge.	Re–establish pre–development water balance

Wastewater management – treatment & recycling			
11	Sewage collection, treatment and reuse within the city for non–potable purposes	Water shortage	
Environmental protection			
12	Tel Aviv will restore & protect its surface water (Yarkon river)		
13	Tel Aviv will reduce the total energy consumption of the urban water system		
Social & Economic			
14	TA will supply water of good quality to its citizens at reasonable price, in sufficient qualities.		
15	TA will ensure equity in the access to water, as well as to irrigated green areas.	The investments made per citizen for water supply & sanitation are unequal	Each citizen is equally served by the Municipality institutions on terms of water supply and irrigated green areas

5.3.3. Sustainability indicators of Tel Aviv's water system

These following sustainability indicators can be used to monitor to what extent the urban water system in Tel Aviv is satisfying the vision. These indicators can be directly linked to the sustainability objectives which were formulated in Table 5.2 and described in details in Table 5.3.

It can be seen from the list of sustainability objectives mentioned in Table 5.2, the objectives on water supply; wastewater and stormwater management sectors (objective number 5 to 11) have a common target which is the reduction of fresh water consumption (water demand management). In this research, to facilitate the formulation of indicators which can be

estimated by Aquacycle simulation, these objectives were translated into “water demand management” objectives.

Table 5. 3 Sustainability indicators for urban water system of Tel Aviv

	Objective	Indicator	Unit
	Water Policy and General		
1	TA will raise awareness among its citizens about 'water and sustainability' and will involve the public in decision making	The number of citizens that will participate in consultative meetings.	Number of citizens per year
2	TA will manage it urban water system in an integrated way; integrating aspects of water supply, stormwater management, wastewater collection, wastewater treatment and wastewater reuse.	The production of an integrated urban water management plan for the city at 2 years intervals.	
3	A set of sustainability indicators will be accepted and these indicators will be used for decision making and planning.	References in policy documents and government decisions to the sustainability indicators.	
4	TA will strengthen the scientific basis of its decision making concerning the management of its Urban Water System.	The number of municipality staff that is using results from scientific research in their daily work.	Number of staff
	Water Demand Management		
5	The total demand in TA for fresh water from the national system is to be reduced by 10% by 2050?	The water volume imported from the national water carrier	m^3/year
6	Rainwater and stormwater harvesting for non-potable reuse in the domestic sector will be	Availability of a study on rainwater and/or stormwater harvesting in TA. The number of house ready to	

	investigated and applied if overall sustainability of the system is increased.	collect rainwater	
		The volume of rainwater and/or stormwater collected and used for non-potable use	m^3/year
7	TA will phase out the irrigation of urban parks with fresh water and will only use recycled wastewater for this purpose.	The volume of fresh water/recycled wastewater used for park irrigation	m^3/year
		Percentage of total area irrigated by freshwater	%
8	TA will infiltrate x% of the stormwater generated in its area into the aquifer, hereby reducing the spill of water to the sea, reducing the hydraulic load to the WWTP and contributing to aquifer replenishment. TA will take care that the stormwater is not polluted.	The percentage of stormwater that is infiltrated into the aquifer	%
	Environmental Protection		
9	TA will restore and protect its surface water (Yarkon River).	The water quality of the Yarkon river expressed in commonly used water quality parameters (BOD, COD…)	various
10	TA will minimize the energy consumption in the urban water system	The quantity of energy from non-renewable sources used to operate the urban water system, including water heating in the households.	KWh/year
	Socio-economy		
11	TA will supply water of good quality to its citizens at reasonable price in sufficient qualities	The fraction of samples analyzed by the Ministry of Health that does not satisfy the health criteria.	%
		The frequency of supply interruptions	Downtime per year

12	TA will ensure equity in the access to water, as well as to irrigated green areas.	The spatial distribution of water quality and frequency of service interruptions in the city	Map with water quality and service interruption frequency
		The green area available per person and its spatial distribution	Map with M2 green area/capita
13	TA will reduce the risk of flooding in vulnerable area's to not more than once per x years, even under future climate change scenarios	The number of people affected by flooding per year	Number of people per year
		The economic damage caused by flooding	NIS/year

5.4. Inventory of energy consumption of Tel Aviv's water system

Results of the energy consumption estimation of components were assembled in the Table 5.4

Table 5. 4 Energy consumption inventory of Tel Aviv's water system

		Energy consumption (KWh/m^3)	**Proportion of total amount of water (%)**	**Energy consumption (KWh/y)**
WATER SUPPLY				
Water from Lake of Galilee	Pumping water from Lake of Galilee to the city	1.3	90%	
Desalinated water	Treating sea water at Palmachim sea water desalination plant	3.6	2%	
	pumping water from desalinated water plant to the city,	0.3		
Groundwater	Pumping groundwater out of aquifers	0.371	8 %	

Distribution	Pumping for distribution drinking water within the city	0.103	13.45%	North area
		0.077	7.18 %	South area
	Heating water in household	40.7	27%	
"DRY WEATHER" PUMPING STATION				
	"dry weather" pumping stations		0	54,883
WASTEWATER				
	Wastewater collection	0.111	100%	
	Wastewater treatment	0.425	100%	
	Pumping treated wastewater for irrigation	1.45	100%	
OTHER ENERGY CONSUMPTION OF TA'S WATER SYSTEM				
	Valves			11,547
	Other devices			133,532
ALTERNATIVES STRATEGIES				
	Wastewater treatment & reuse at unit block	0.5525		
	Wastewater treatment & reuse at cluster scale	0.5997		
	Rainwater tanks	0.278		

Energy use for pumping and treating supply water & wastewater varies significantly from city to city. Local conditions including water use, topography and water sources have a major influence on energy use values (*Kenway et al., 2008).*

Based on the energy consumption inventory of Tel Aviv water system, it can be seen that storm water component does not have a significant contribution to the total energy use value. In order to have a general view of energy use situation of Tel Aviv's water system, the energy

consumption of supply water and wastewater components of the city was brought into comparison with that of four other cities: Sydney, Melbourne, Perth and Adelaide.

Water energy intensity is presented per volume of water supplied (KWh/m^3) and per customer per year (KWh/capita.year).

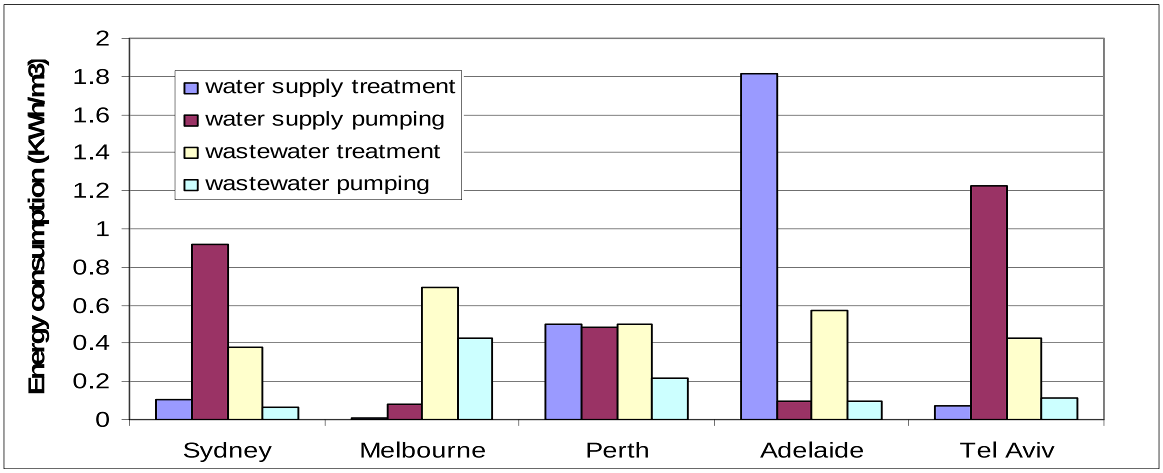


Figure 5. 2 Energy use intensity of water and wastewater services by city

Figure 5.2 provides an alternative perspective of the individual energy consumption of each city. The high energy requirement for pumping water supply in Tel Aviv is apparent. Specific Tel Aviv's conditions should be considered when interpreting the data. For example, relatively high amount of energy is used for water supply pumping because of the distant location of water source – the Lake of Galilee from the city (150 km). The relatively low energy use in water supply treatment and wastewater treatment & pumping also can be seen clearly from Figure 5.2.

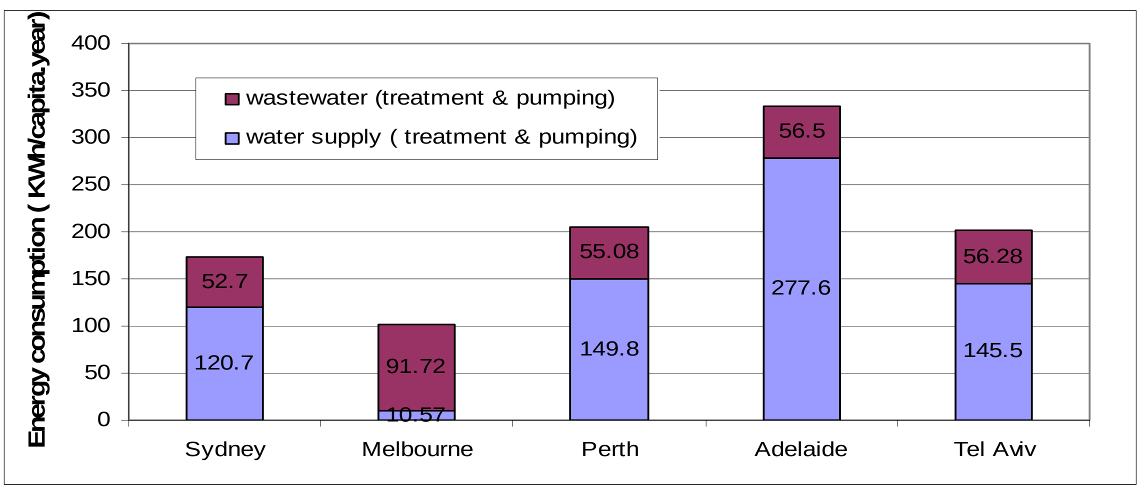


Figure 5. 3 Energy use for water and wastewater services by city

Figure 5.3 provides an aggregation of data for each city broken down into the individual demands for energy. Tel Aviv uses relatively similar amount of energy per customer with Perth and more energy per capita than Sydney and Melbourne. In addition, the energy use per person for water supply in Tel Aviv is nearly equal with that in Sydney and Perth.

5.5. Result of model calibration and discussion

In this research, the calibration of Aquacycle was based on water supply data from Tel Aviv Municipality and data on wastewater production obtained from Shafdan WWTP.

The data on wastewater production from Shafdan WWTP is the total wastewater production of Dan District. Table 5.5 is the distribution of population of regions in Dan District. In order to estimate the wastewater production of Tel Aviv, it was assumed that the average amount of generated wastewater per capital is similar in Dan District.

Table 5. 5 Population distribution of Dan District

	Dan District						
	Tel Aviv	Bnei Brak	Ramat Gan	Petach Tikva	Givatayim	Bat Yam	Holon
Population year 2008	406,242	154,322	136,334	193,056	50,691	131,940	172,513
Total	**1,245,098**						

From Table 5.5, it can be estimated that Tel Aviv population is 32.6% of total population of Dan District. Therefore, the amount of wastewater generated from Tel Aviv is 32.6% of total wastewater production of Dan District.

5.5.1. Model calibration for water supply data

A series of observed data on total monthly fresh water supplied the city from year 2003 to year 2008 was obtained from Tel Aviv Water Corporation and given in Appendix 2.

The result of model calibration on water supply is shown in Figure 5.4.

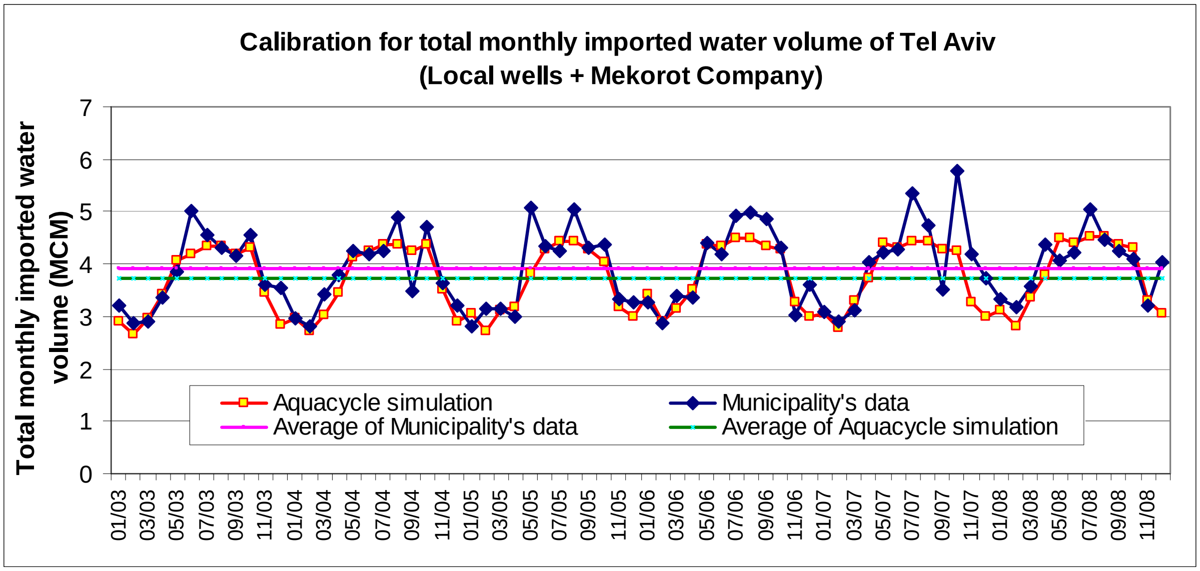


Figure 5. 4 Measured and simulated imported water volume

It can be seen from Figure 5.4 that, from May to October of each year, the amount of fresh water consumption is maximal while at the beginning and the end of each year, the amount of freshwater consumption is much lower than the other periods. It can be explained by the timetable of rainy season and dry season in Tel Aviv. In dry season (from May to October), the water use for garden and open space irrigation is higher than that in rainy season. On average, the maximum water consumption during six year is 4,478,715 m^3 per month and the minimum water consumption is 3,341,818 m^3 per month.

As shown in Figure 5.4, the simulated results is also plotted to compare with the Municipality's data. It is found that the maximum water consumption obtained from Aquacycle simulation is lower than that of observed measurement. However, there is a reasonable agreement between the measured and simulated results. The model can simulate well the performance of total water consumption of the city in rainy season.

Some big errors between them (more than 20%) occur in dry seasons. It can be explained that the model does not provide for temporal variation in the indoor water use profile (for example increasing water consumption for washing and showering during summer season) and in irrigation demand (increasing water consumption for parks and garden irrigation during summer season).

5.5.2. Model calibration for wastewater production data

A series of daily wastewater generation data of Tel Aviv city for year 2008 obtained from Shafdan WWTP is given in Appendix 2 and the performance of daily wastewater production is given in Figure 5.5.

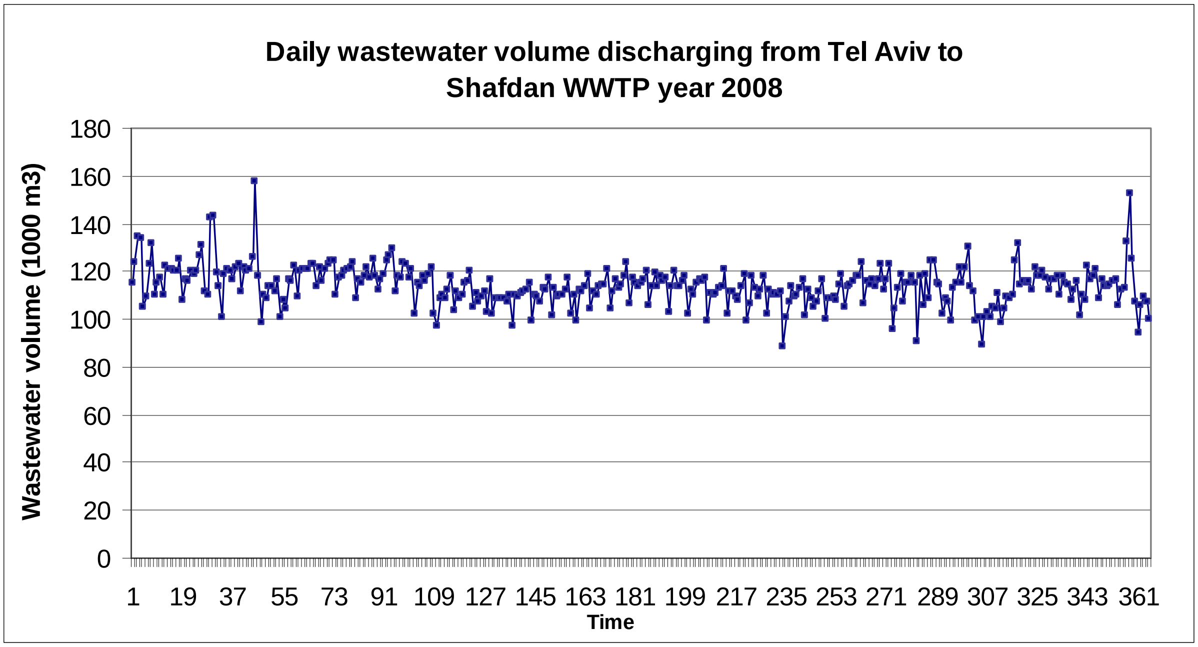


Figure 5. 5 Measured daily wastewater volume – year 2008

It can be seen from Figure 5.5 that the daily wastewater generation varies slightly (the average amount of wastewater: 113,910 m^3 per day), except in some days there are significant increase in wastewater discharge, for examples: 30th January: 143,370 m^3; 14th February: 158,010 m^3; 24th December: 152,662 m^3.

In order to calibrate the model, the monthly wastewater volume was used to compare with simulated data in Figure 5.6.

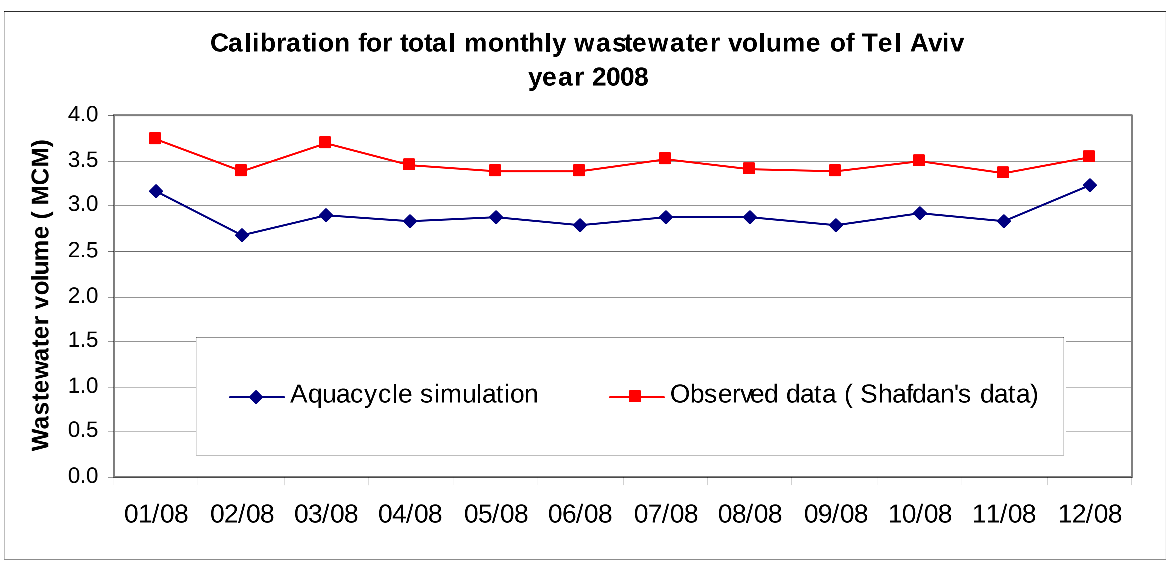


Figure 5. 6 Measured and simulation monthly wastewater volumes

From Figure 5.6, it is found that the average value of observed data is about 3,480,000 m^3 per month while the average value obtained by Aquacycle simulation is about 2,890,000 m^3 per

month. However, the measured data and simulated data show a similar tendency. The higher amount of wastewater in several rainy months can be explained by the stormwater infiltration into the wastewater system. For example, according to Aquacycle simulation, there are 249,592 m^3 of stormwater in January and 313,375 m^3 of stormwater in December infiltrating to the wastewater system.

The error between observed data and simulated data may result from the lack of accurate data on wastewater production of Tel Aviv. The assumption of equal wastewater amount per capital per year in Dan District is not likely so accurate. In reality, this value of Tel Aviv may be lower than the average value of Dan District.

Table 5. 6 Estimated error between observed data and simulated data on WW volume

Year 2008	Wastewater volume Observed data (m^3)	Wastewater volume Simulated data (m^3)	Error (%)
January	3,744,160	3,164,482	15.48
February	3,376,823	2,666,730	21.03
March	3,686,700	2,900,232	21.33
April	3,445,877	2,818,828	18.20
May	3,391,516	2,882,366	15.01
Jun	3,371,236	2,789,387	17.26
July	3,517,702	2,882,366	18.06
August	3,405,349	2,882,366	15.36
Sep	3,382,221	2,789,387	17.53
Oct	3,487,000	2,924,259	16.14
Nov	3,363,350	2,831,992	15.80
Dem	3,529,563	3,236,811	8.29

With the value of standard deviation is very small (3.35 %), it can be seen that the error between observed data and simulated data is constant. Therefore, in future the error can be reduced much if the data on wastewater production of Tel Aviv can be measured more accurately.

5.6. Evaluation of alternative strategies by some indicators

In this research, some indicators which can be simulated by Aquacycle were used to evaluate alternative strategies including onsite wastewater treatment & reuse at unit block; onsite wastewater treatment & reuse at clusters; rainwater tanks, storm water storage and permeable pavement. The following indicators were performed from year 2009 to year 2050 under "normal" scenario:

- "Total freshwater consumption of the city" indicator
- "Treated wastewater reused volume per year" indicator
- "Total Energy consumption" indicator

5.6.1. Performance of total freshwater consumption indicator

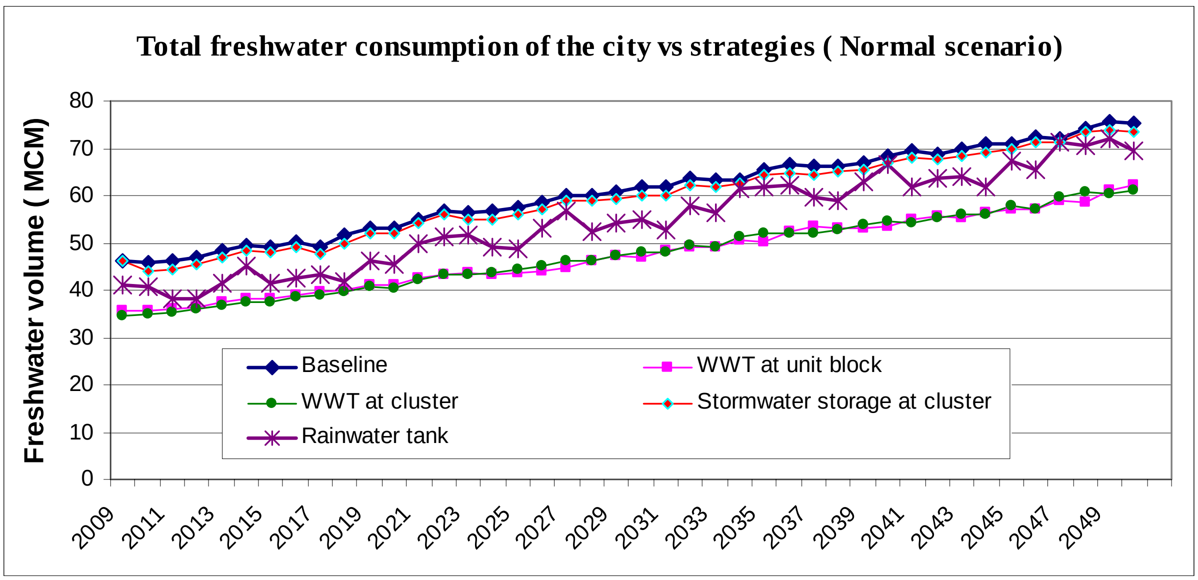


Figure 5. 7 The performance of Tel Aviv's total freshwater consumption over time

In Figure 5.7, the total freshwater consumption is performed from year 2009 to year 2050 with five alternative strategies.

From the Figure 5.7, an increasing trend of the amount of fresh water consumption of the city overtime can be observed under all alternative strategy application due to population growth (2.2% per year). In general, four "strategy" lines and the "baseline" line show a similar tendency. However, "rainwater tank" line performs a more fluctuant variation than the others because the freshwater consumption in this strategy is much more affected by the amount of rainfall than that in other strategies.

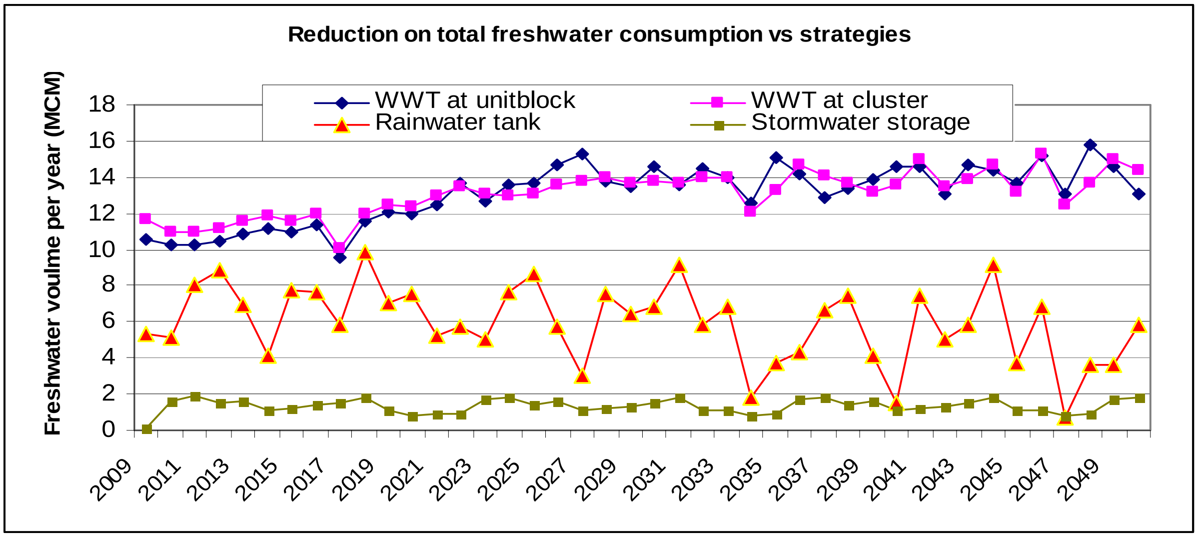


Figure 5. 8 Reduction on total freshwater consumption per year vs. strategies

In Figure 5.8, the reduction on total freshwater consumption per year as compared with baseline scenario is performed from year 2009 to year 2050 with four alternative strategies.

The "storm water storage at cluster scale" strategy does not show a significant reduction on the amount of freshwater consumption of the city when compared with the "baseline" strategy (2.2% per year on average).

The two strategies "on-site wastewater treatment & reused" at unit block and cluster scale perform a more significant reduction on the amount of freshwater consumption of the city when compared with the "baseline" strategy (21.8% per year for unit block scale strategy and 21.9% per year for cluster scale strategy on average).

For the "rainwater tank" strategy, from year 2009 to year 2050, the average reduction on the total freshwater consumption is 10.2 % as compared with the "baseline" strategy. However, it can be seen from Figure 5.8 that in several years, there is very small reduction on the total freshwater consumption (for example: 2.93% in year 2034; 2.19% in year 2040; 1% in year 2047).

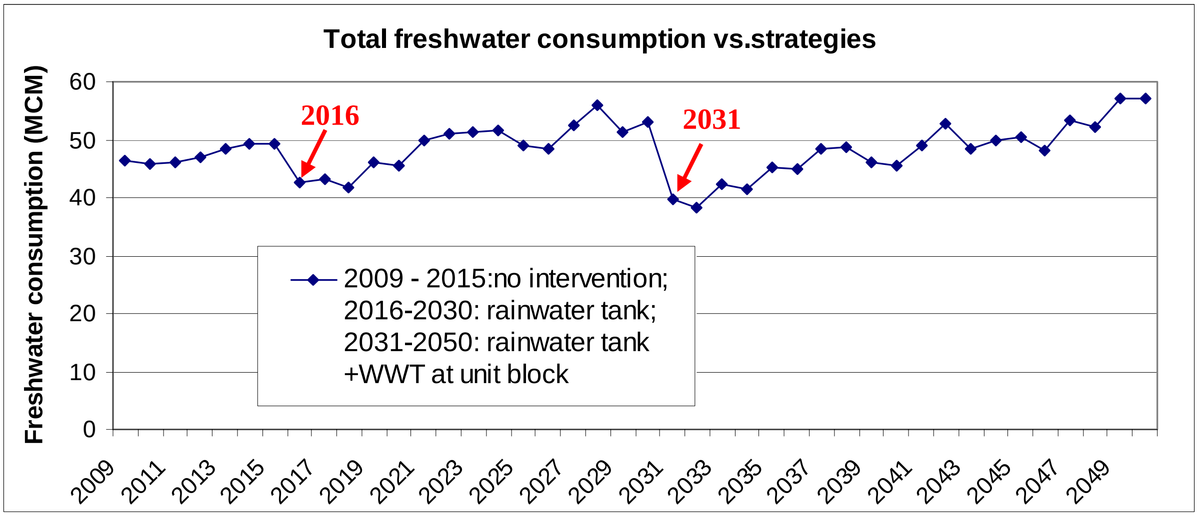


Figure 5. 9 The performance of Tel Aviv's total freshwater consumption

In Figure 5.9, total freshwater consumption from 2009 to 2050 is performed. It was assumed that, from 2009 – 2015 there is no intervention in the water system so the amount of water consumption increases over time due to population growth. From year 2016, "rainwater tank" strategy was applied and the amount of water consumption drop down at the beginning and after that stays at the similar amount of year 2015 until year 2027. From year 2031, "WWT & reuse at unit block strategy" was added to the system. It can be found from Figure 5.9 that the amount of water consumption from 2031 to 2046 does not higher than that of year 2015.

5.6.2. Performance of treated wastewater reused indicator according to alternative strategies

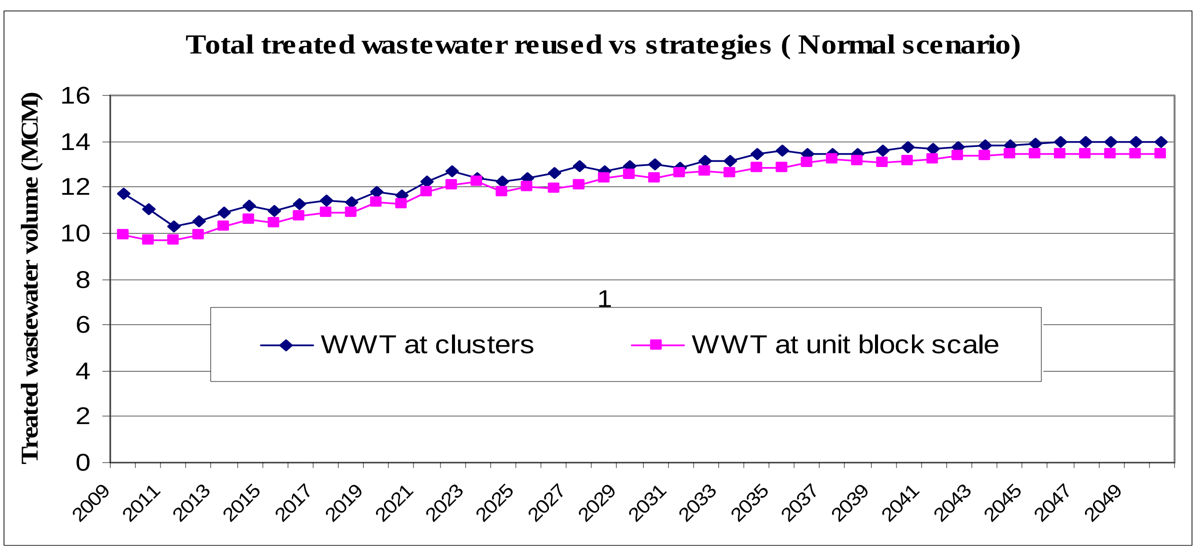


Figure 5. 10 The performance of total treated wastewater reused volume over time

In Figure 5.10, total treated wastewater volume reused is depicted from year 2009 to year 2050 with two alternative strategies: on-site wastewater treatment and reused at unit block scale and cluster scale.

The simulation of these two alternative strategies gives approximate amounts of treated wastewater reused volume (on average 12.2 millions m^3 per year for unit block scale strategy and 12.7 millions m^3 per year for cluster scale strategy). The similar purposes for reusing treated wastewater can interpret this phenomenon. Cluster scale strategy gives a little higher result than that of unit block scale because of an extra purpose for open space irrigation.

Figure 5.10 shows a similar tendency between performances of two alternative strategies. The total treated wastewater volume reused value increases at the beginning of period (from year 2009 to year 2035) and varies slightly from year 2036 to year 2050. This trend can be explained by the population growth resulting in the increase of treated wastewater reused volume and the limitation of wastewater storage devices' capacity resulting in the stability of treated wastewater reused volume in the ending years of period. Therefore, it can come to a suggestion that this stability is the maximal amount of treated wastewater reused with respect to alternative strategies in this case. (13.96 million m^3 for "treated wastewater cluster scale" strategy and 13.44 million m^3 for "treated wastewater unit block scale" strategy).

5.6.3. Performance of energy consumption indicator

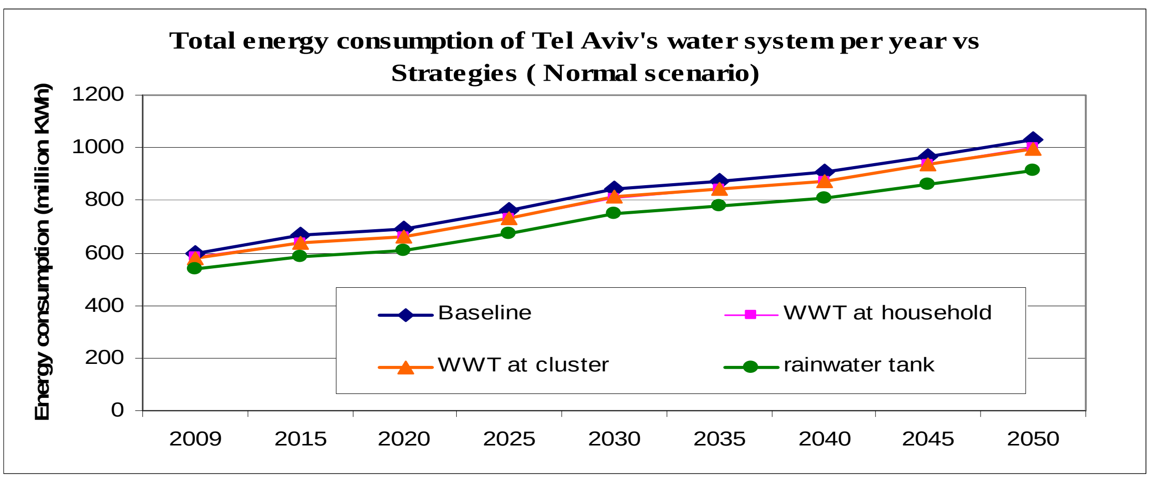


Figure 5. 11 Performance of total energy consumption of the city's water system
(Including household water heating)

In Figure 5.11, the total energy use per year is performed from year 2009 to year 2050 with a 5 year time step for four alternative strategies: "baseline" strategy; "wastewater treatment & reuse at cluster and unit block scale" strategies and "rainwater tanks" strategy.

Reading from left to right, an increasing trend of the total energy consumption of the city can be observed under all alternative strategy applications due to population growth (2.2% per year). In general, four "strategy" lines and the "baseline" line show a similar tendency.

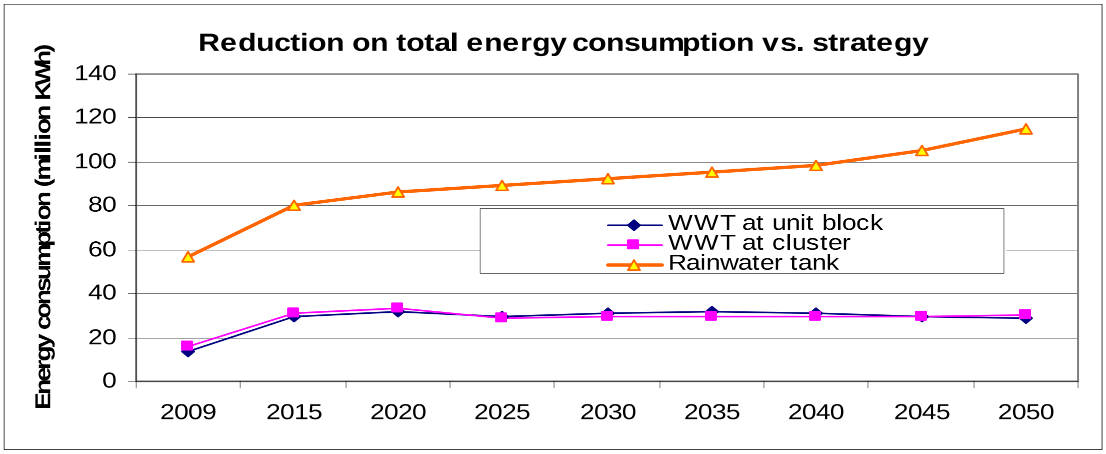


Figure 5. 12 Reduction on total energy consumption per year vs. strategies

In Figure 5.12, the reduction on total freshwater consumption per year is performed from year 2009 to year 2050 with three alternative strategies. The two "wastewater treatment and reused" strategies do not result in a significant reduction on total energy consumption per year as compared with baseline strategy (around 28 million KWh per year - 3.6 %). The "rainwater tank" strategy has the highest energy reduction (around 91 million KWh per year – 11.3%) as compared with baseline strategy.

5.6.4. Evaluation of alternative strategy using all proposed indicators

The "wastewater treatment and reuse at unit block" strategy was evaluated by using all indicators proposed in Table 5.3. The evaluation was conducted based on the results of Aquacycle simulation & energy balance inventory and also the objective opinion of the system's responses to the strategy application. (See Table 5.7).

Table 5. 7 Evaluation of "WWT & reuse at unit block" strategy by indicators

	Responds		Indicator
	Water Policy		
1	Good effect	Public meetings for raising awareness of water & sustainability	The number of citizen participating in consultative meetings will increase
2	Good effect	The ideas of integrated UWM are incorporated in new policies & master plans of the water sector institutions	The production of an urban water management plan integrating aspects of water and WWT & reuse for the city will increase
3	No effect	Do not result in the application of sustainability indicators for decision making processes and planning	References in policy documents and government decisions to the sustainability indicators
4	No effect	Do not results in decision making in the water sector based on scientific research	The number of municipality staff that is using results from scientific research in their daily work
Water Demand Management			
5		The decrease of total water volume	The water volume imported from the

	Good effect	imported from NWC as compared with that of baseline scenario	NWC (m^3/year)
6	No effect	No application of rainwater & stormwater harvesting	The volume of rainwater and/or stormwater collected and reuse (0 m^3 per year)
		No application of rainwater harvesting	The number of houses ready to collect rainwater (0)
		No application of them, therefore no study on rainwater & stormwater harvesting	Availability of study on rainwater and/or stormwater harvesting in TA.
7	Good effect	Application of recycled wastewater for irrigation parks & garden, result in the reduction on percentage of area irrigated by freshwater	The volume of fresh water/recycled wastewater used for park irrigation
			Percentage of total area irrigated by freshwater
8	No effect	No application of stormwater infiltration	The percentage of stormwater that is infiltrated into the aquifer (0%)
Environmental Protection			
9	No effect	Do not result in a protection of its surface water (Yarkon River).	The water quality of the Yarkon river expressed in commonly used water quality parameters (BOD, COD…)
10	Moderate good effect	Application of WWT & reuse strategy results in the moderate reduction on energy requirement (results of Aquacycle simulation & energy balance inventory)	The quantity of energy from non-renewable sources used to operate the urban water system, including household water heating (KWh/year)
Socio – Economic			
11	-	In order to supply water of good quality to its citizens in sufficient qualities, it depends on the technological &maintenance aspects	The fraction of samples analyzed by the Ministry of Health that does not satisfy the health criteria
			The frequency of supply interruptions
12	Good effect	Equity in the access to water,	The spatial distribution of water quality and frequency of service interruptions in the city
	No effect	No result in the equity in the access irrigated green areas	The green area available per person and its spatial distribution
13	No effect	Can not reduce the risk of flooding in the future	The number of people affected by flooding per year
			The economic damage caused by flooding

From Table 5.7 it is likely that this strategy has relatively good effects on water policy and water demand management aspects and does not have clearly effects on environmental protection and socio–economic aspects. However, this strategy should be given the priority of consideration for further study on sustainable development of Tel Aviv' water system.

CHAPTER 6 CONCLUSIONS

Based on the investigation of Tel Aviv's urban water system and the simulation results of Aquacycle, there are some conclusions resulting from this study as follows:

1. Sufficient data is available to feed Aquacycle. The model was able to describe/predict reasonably well the total water consumption in the city, as well as the wastewater output. Although the calculated amount of stormwater is high significant (23 millions m^3 per year) but it has not yet evaluated as an important resource for urban water usage

2. Several limitations of Aquacycle may affect the results of simulation and limit the analyzing capacity. For example, the model does not address short term change in water uses (monthly population change, variation in indoor water use profile), therefore it can not estimate peak flows and simulate under water shortage and water cut conditions.

3. One indoor water use profile is used for the whole city while in reality it should be differentiated between clusters.

4. Tel Aviv could make steps towards sustainability by improving its water system in various ways. Sustainability indicators were identified to monitor the city's progress based on the basic data of the city and Aquacycle is able to help predict a several number of those indicators.

5. Future scenarios are characterized by factors such as population growth, reduction of precipitation and temperature increase, resulting in increasing water demand while water availability is reduced.

6. Strategies to deal with water shortage were formulated based on the approach to new water sources in the city: treated wastewater, rainwater and stormwater. Decentralized wastewater treatment and reuse at household and neighborhood scale strategies shows a 22% reduction of the total freshwater consumption in the city; rainwater harvesting and storm water storage and reuse strategies indicate less reduction of the total freshwater requirement (10.2 % and 2.2% respectively). For permeable pavement strategy, storm water discharged decreases about 500,000 m^3, groundwater recharge increases about 350,000 m^3 per year with every 20% reduction of impermeable surface area.

8. A combination between rainwater tank and wastewater treatment & reuse strategies can keep the total freshwater consumption of the city not increase until year 2046.

9. A significant reduction of total freshwater consumption can not be demonstrated by the application of rainwater and storm water use strategies as it was expected. This can be

explained by the high rainfall intensity and the low number of rainy days per year. In order to take advantage of this water resource, it requires huge storage.

10. Total energy consumption in the water system (from source to tap, from consumer to irrigation) is estimated at 1,448 KWh/person.year (including household water heating) and 288 KWh/person.year (not including household water heating).

CHAPTER 7 RECOMMENDATIONS

The improvement of this research is necessary for further study on the sustainable development of Tel Aviv's urban water system. The major recommendation of this research is wider consideration, analysis and monitoring of the city's characteristics and alternative strategies. This research makes the following recommendations:

1. In the future, data on water use profile of neighborhoods within the city should be studied and Aquacycle should be applied for smaller neighborhood scale to have a more accurate and more detailed prediction.

2. Information of strategic planning in land use of the city should be considered in formulating scenarios to better predict water balance performance of the system.

3. There is a demand for further research on feasibility of alternative strategy application.

4. Wider study to find solution for taking advantage the large amount of storm water in the city (23 millions m^3 per year by Aquacycle simulation) should be seriously considered as the water resources for urban water usage.

5. Broader analysis of the energy use in household & in decentralized system such as wastewater treatment & reuse, rainwater tanks will help find solution to simultaneously reduce freshwater demand and energy consumption.

6.Wastewater treatment and reuse strategy should be given the priority of consideration for further study on sustainable development of Tel Aviv' water system.

REFERENCE

Lundin, M. (1999).” Indicators for measuring the sustainability of urban water system – A life cycle approach”. Environmental system analysis, Chalmers University of Technology.

Niemczynowicz, J. (1999). "Urban hydrology and water management - present and future challenges." Urban Water 1(1): 1-14.

Gale, J. (2000). “Strategies for managed Aquifer recharge in semi arid areas”, http://www.iah.org/recharge.

WHO and UNICEF (2000). “Global water supply and sanitation Assessment 2000 report”. WHO, Geneva, Switzerland. ISBN 9241562021.

Mitchell, V. G., R. G. Mein, et al. (2001). "Modelling the urban water cycle." Environmental Modelling and Software 16(7): 615-629.

Maksimovic, C. & Jose Alberto Tejada Guibert (2001). “Frontiers in Urban Water Management”, UNESCO & IWA publishing, ISBN 1900222760.

European Commission, (2002).”Water Strategy Man” project,http://environ.chemeng.ntua.gr

Coombes, P.(2002). “Rain water tank”, Practice No.4, http://www.rainharvest.com/more/4_rainwater_tanks.pdf.

White, S. & Turner, A.(2003). ” The role of effluent reuse in sustainable urban water system: Untapped opportunities”, Institute for sustainable future, University of Technology,Sydney. http://www.isf.uts.edu.au/publications/whiteturner2003effluentreuseopportunities.pdf)

Mitchell, V.(2004).“Integrated urban water management: A review of current Australia practice”. CSIRO, CMIT-2004-075.

Eiswirth, M., L. Wolf, et al. (2004). "Balancing the contaminant input into urban water resources." Environmental Geology 46(2): 246-256.

Byron Shire Council,(2004).”Design guidelines for onsite sewage management for single household”, http://www.clearwater.asn.au

Australian EnHealth Council,.(2004). “Guidance on use of rainwater tanks”. ISBN 0642824436. http://enhealth.nphp.gov.au/council/pubs/documents/rainwater_tanks.pdf.

Wolff G, Cohen R and Nelson B (2004), . “

Mitchell, G.(2005).“ Aquacycle user guide: A daily urban water balance model”. CRC for catchment hydrology.

Global Program,(2005). “Modeling your water balance learning activities”, http://www.globe.gov

Centgraf, S.,C.,& Schmidt,M. (2005). “Water management to save energy, a decentralized approach to an integrated sustainable urban development”. Technical University of Berlin, Germany.

Mitchell, V. (2006)."Applying Integrated Urban Water Management Concepts: A Review of Australian Experience." Environmental Management 37(5): 589-605.

Switch (2006 a).” An overview of existing tools, data needs and demo cities”.

Switch (2006b). “Deliverable D1.1.1: Report providing an inventory of conventional and of innovation approaches for urban water management”

Stokes, J. and A. Horvath (2006). "Life Cycle Energy Assessment of Alternative Water Supply Systems (9 pp)." The International Journal of Life Cycle Assessment 11(5): 335-343.

Alon, T. (2006). "Seeking sustainability: Isreal's evolving water management strategy." Science 313(5790): 1081-1084.

Municipality of Tel Aviv. (2006). “City – The Strategic plan for Tel Aviv Yafo”.

Dillon, P., &Molly, R. (2006), “Technique Guidance for ASR”, CSIRO land & water client report.

Malmqvist, P.,A. et al. (2006).“Strategic Planning of Sustainable Urban water management”. ISBN13: 9781843391050.

Karka, P. et al. (2007). “A case study on integrated urban water modelling using aquacyle”. CEST2007 – Cos Island Greece.

Van der Steen, P. (2007).” Integrated urban water management”. LN0320/07/1 Unesco-IHE library.

Dillon, P. et al. (2007). “Urban groundwater recharge enhancement & water recycling”. http://www.uow.edu.au/science

Switch (2008).”Switch approach to strategic planning for Integrated urban water management (IUWM)”.

Makropoulos, C. K., K. Natsis, et al. (2008). "Decision support for sustainable option selection in integrated urban water management." Environmental Modelling & Software 23(12): 1448-1460.

Kenway,S.,J. et al.(2008). “Energy use in the provision and consumption of urban water in Australia & Newzeland” Water for a healthy country Flagship report series ISSN: 1835 – 095X CSIRO.

Switch LA- Tel Aviv (2008).”Influencing urban water management through learning alliances: A mid –term reflection on the process in Tel Aviv, Israel”.

Israel Ministry of Environmental protection. (2008).”Israel’s adaption to climate change – Impacts and recommendation”, http:// www.sviva.gov.il

Metropolitan Area Planning Council, (2008). “Low Impact Development”, http://www.mapc.org

Adin, A. “Israel – A world water leader”, Ministry of foreigner affairs: MASHAV center for

International co-operation. (http://singapore.mfa.gov.il/mfm/Data/114128.pdf)

Auerbach.O & Karassin.A.“Management of water resources in Israel”, http://www.hillel.org/NR/rdonlyres).

ECA&D, “European Climate Assessment & Data set”, http://eca.knmi.nl

APPENDIX

Appendix 1:

Total monthly water volume supplied the city from year 2003 to 2008 (Tel Aviv Water Corporation)			
	Bought from Mekorot Company (m3)	Extract from local wells (m3)	Total per month (m3)
2008			
Month			
1	3,195,210	125,200	3,320,410
2	2,902,820	263,607	3,166,427
3	3,307,880	255,240	3,563,120
4	4,110,440	257,724	4,368,164
5	3,835,411	230,231	4,065,642
6	3,955,340	265,304	4,220,644
7	4,719,360	331,310	5,050,670
8	4,176,320	271,882	4,448,202
9	3,842,330	400,730	4,243,060
10	3,752,890	343,860	4,096,750
11	2,703,510	494,318	3,197,828
12	3,235,040	806,965	4,042,005
2007			
Month			
1	2,845,690	229,119	3,074,809
2	2,663,100	239,495	2,902,595
3	2,798,290	325,822	3,124,112
4	3,733,750	312,931	4,046,681
5	3,912,850	303,864	4,216,714
6	3,913,730	352,209	4,265,939
7	4,963,230	381,642	5,344,872
8	4,411,310	319,861	4,731,171
9	3,297,460	221,487	3,518,947
10	5,493,861	275,673	5,769,534
11	3,951,770	231,697	4,183,467
12	2,810,790	908,423	3,719,213
2006			
Month			
1	2,771,590	511,088	3,282,678
2	2,393,759	478,632	2,872,391
3	2,940,330	457,113	3,397,443
4	2,859,240	492,283	3,351,523

5	3,906,280	507,795	4,414,075
6	3,844,040	355,740	4,199,780
7	4,505,530	413,527	4,919,057
8	4,386,580	597,505	4,984,085
9	4,318,930	528,774	4,847,704
10	3,944,130	353,446	4,297,576
11	2,630,410	395,235	3,025,645
12	3,316,280	304,786	3,621,066
2005			
Month			
1	2,470,154	354,790	2,824,944
2	2,664,006	492,558	3,156,564
3	2,636,390	514,010	3,150,400
4	2,542,690	438,679	2,981,369
5	4,514,510	572,360	5,086,870
6	3,859,120	476,032	4,335,152
7	3,739,650	512,988	4,252,638
8	4,597,340	437,401	5,034,741
9	3,730,290	567,155	4,297,445
10	3,948,261	438,065	4,386,326
11	2,822,200	516,291	3,338,491
12	2,963,260	319,853	3,283,113
2004			
Month			
1	2,562,850	393,970	2,956,820
2	2,526,830	271,975	2,798,805
3	3,082,290	342,929	3,425,219
4	3,518,660	267,984	3,786,644
5	3,956,800	300,880	4,257,680
6	3,629,090	560,043	4,189,133
7	3,742,330	517,031	4,259,361
8	4,398,320	484,757	4,883,077
9	3,114,300	380,349	3,494,649
10	4,125,060	572,883	4,697,943
11	3,194,919	439,848	3,634,767
12	2,774,701	445,410	3,220,111
2003			
Month			
1	2,830,759	376,865	3,207,624
2	2,573,974	285,307	2,859,281
3	2,653,438	262,070	2,915,508
4	2,974,618	390,169	3,364,787
5	3,211,760	628,121	3,839,881

6	4,119,270	884,161	5,003,431
7	4,085,540	479,962	4,565,502
8	3,659,690	643,262	4,302,952
9	3,642,100	526,860	4,168,960
10	4,052,499	491,106	4,543,605
11	3,339,776	262,395	3,602,171
12	3,199,545	339,720	3,539,265

Appendix 2

Total daily wastewater volume generated from Dan District - year 2008 (Shafdan wastewater treatment plant) - m3/day												
day	Jan	Feb	March	April	May	Jun	July	August	Sep	Oct	Nov	Dec
1	353,376	349,056	335,232	365,472	355,104	347,328	349,056	370,656	333,504	319,680	273,888	354,240
2	380,160	310,176	369,792	382,752	368,928	336,096	353,376	314,496	321,408	346,464	310,176	350,784
3	412,128	363,744	371,520	389,664	321,408	338,688	358,560	342,144	329,184	363,744	315,360	330,912
4	411,264	370,656	370,656	396,576	339,552	336,960	368,064	342,144	341,280	329,184	308,448	343,872
5	323,136	368,928	371,520	342,144	329,184	343,872	324,864	336,096	356,832	353,376	321,408	355,968
6	336,096	357,696	378,432	362,880	335,232	359,424	348,192	330,912	306,720	353,376	319,680	311,904
7	376,704	374,112	378,432	360,288	342,144	312,768	367,200	349,056	332,640	362,880	340,416	337,824
8	403,488	376,704	348,192	380,160	315,360	336,960	348,192	363,744	332,640	353,376	303,264	331,776
9	337,824	343,008	374,112	378,432	357,696	304,128	361,152	305,856	336,096	278,208	319,680	375,840
10	354,240	372,384	355,104	360,288	313,632	344,736	355,968	327,456	331,776	362,016	336,096	357,696
11	359,424	369,792	371,520	371,520	332,640	343,008	360,288	362,016	351,648	324,000	334,368	362,016
12	336,960	371,520	377,568	314,496	332,640	349,056	315,360	346,464	365,472	363,744	338,688	370,656
13	374,976	386,208	382,752	353,376	332,640	365,472	349,920	335,242	322,272	333,504	381,024	333,504
14	370,656	484,704	381,888	348,192	333,504	319,680	368,064	344,736	349,056	381,024	405,216	356,832
15	371,520	361,152	338,688	361,152	330,048	341,280	349,056	361,152	351,648	381,024	350,784	349,056
16	369,792	303,264	360,288	355,104	336,960	338,688	349,920	312,768	355,968	352,512	355,104	349,920
17	369,792	336,960	362,016	365,472	297,216	349,056	355,104	345,600	362,016	351,648	352,512	350,784
18	384,480	332,640	368,928	372,384	336,960	351,648	362,880	337,824	362,880	313,632	355,104	355,104
19	330,912	349,920	371,520	314,496	336,096	351,648	313,632	340,416	380,160	334,368	343,872	356,832
20	357,696	348,624	373,248	298,080	340,416	371,520	345,600	337,824	326,592	328,320	373,248	325,728
21	355,104	341,280	380,160	333,504	343,008	320,544	338,688	343,008	355,968	305,856	362,880	345,600
22	369,792	356,832	334,368	336,960	345,600	341,280	352,512	271,728	351,648	347,328	362,016	347,328
23	365,472	308,448	356,832	334,368	354,240	357,696	358,560	309,830	358,560	354,240	369,792	406,080
24	369,792	330,912	354,240	343,872	305,856	346,464	355,104	329,184	349,056	372,384	359,424	468,288
25	387,936	319,680	361,152	362,880	338,688	351,648	360,288	349,920	358,560	352,512	345,600	383,616
26	400,896	357,984	372,384	318,816	336,096	362,016	305,856	335,232	377,568	374,112	356,832	329,184
27	341,280	355,104	360,288	343,008	330,048	379,296	340,416	338,688	343,872	399,168	358,560	289,440
28	336,960	374,976	383,616	333,504	346,464	326,592	337,824	347,328	358,560	349,920	362,880	324,000
29	437,184	381,888	361,152	336,960	344,736	359,424	340,416	358,560	378,432	341,280	338,688	336,096

30	439,776		344,736	353,376	359,424	354,240	346,464	311,040	292,896	304,128	362,016	330,048
31	366,336		358,560		311,904		349,920	344,736		309,312		305,952

Appendix 3: The distribution of urban water use in Tel Aviv

Year	Urban Water Demand	Residential Demand	Education	Sport	Public Parks	Public Building	Health Care	Hotels	Trade	Security and transport	Construction
	CM	CM	CM	CM	CM	CM	CM	CM	CM	CM	CM
1996	38450391										
1997	40905852	25883921	807188	473891	3009829	2495037	490215	1330424	5573012	481253	361082
1998	42663581	26729035	870301	437268	3455443	2614512	472438	1288267	5944653	542676	308988
1999	43132501	26484007	957878	462508	3822771	2398152	711922	1303759	6156195	519480	315829
2000	40939232	25402190	633285	452001	3568380	2315509	571892	1266891	5919850	514066	295168
2001	41350352	26084940	696183	464158	3633082	2094140	619800	1098379	5831883	504139	323648
2002	41971571	25434609	716406	444865	3361433	2028541	693565	939189	5605270	432572	315121
2003	42393932	25739168	559767	450756	3915288	2125874	551889	909192	5494334	428101	363349
2004	42706699	25773492	546558	376455	4180056	2029733	547614	1005482	5551539	408855	286915
2005	42463543	25758350	530867	345017	4040406	2023419	562446	991276	5565427	392797	253538
2006	43183870	26341478	459080	373288	3807943	1906234	599794	1011768	6010306	420714	253265
2007	46547103	28050025	495891	359650	4177391	1929791	542866	1083810	7242650	391184	273845

Appendix 4: Energy and water use in several cities in Australia

Table 1 Energy and water use by city (2006/07)

	Sydney	Melbourne[1]	Perth	Brisbane[2]	Gold Coast	Adelaide[3]	Auckland[4]
Population served	4 300 000	3 621 000	1 538 000	1 006 000	492 000	1 095 000	1 232 000
Water supplied (GL)							
Total	507	412	235	113	65	159	136
Residential water	315	257	170	61	40	112	83
Indoor water use (%)	65	84	53	–	–	–	–
Wastewater collected (GL)[2]	508	296	119	86	47	89	104
Total energy (GJ)							
Water supply							
Pumping	1 687 960	125 355	423 000	28 245	39 416	1 041 901	44 460
Treatment	186 009	12 860	409 000	246 337	9 234	55 418	56 749
Wastewater							
Pumping	119 916	459 713	92 800	39 726	50 030	32 064	42 697
Treatment	698 205	739 243	213 000	138 028	119 389	185 194	273 593
Other energy demand	250 838	131 728	162 700	49 070	39 461	123 240	23 157
Total energy demands[6]	2 942 929	1 468 900	1 300 500	501 406	257 530	1 437 817	430 504
GHG emissions for energy-related sources (k t CO_2-e)[5]	774	302[6]	313	138	75	392	31[7]

Appendix 5 Physical characteristics of clusters in baseline scenario

Cluster	Total Area (m2)	Population	Total area of unit block (m2)	Number of unit block	Average area per unit block m^2	Road area (m^2)	Public area (m^2)
1	7451000	80007	4824900	36367	132.67	1134900	1490200
2	6477000	49095	4853600	22316	217.50	975700	647700
3	14590000	84834	10084200	38561	261.51	1578800	2927000
4	6590000	14384	2415000	6538	369.38	248000	3927000
5	6470000	91656	4643300	41662	111.45	1179700	647000
6	9846000	74964	7611800	34074	223.39	1588300	645900

Appendix 6 Physical characteristics of clusters in "no major change" scenario

Cluster	Total Area (m2)	Population	Total area of unit block (m2)	Number of unit block	Average area per unit block m^2	Road area (m^2)	Public area (m^2)
1	7451000	122730	5122940	38613	132.67	1134900	1193160
2	6477000	75311	4983140	22911	217.50	975700	518160
3	14590000	130134	10669600	40799	261.51	1578800	2341600
4	6590000	22064	3200400	8664	369.38	248000	3141600
5	6470000	140598	4772700	42823	111.45	1179700	517600
6	9846000	114993	7740980	34653	223.39	1588300	516720

Appendix 7: Energy consumption of Tel Aviv's water system (baseline strategy)

Baseline Scenario					
Year	Water supply (KWh/year)	wastewater discharge to Shafdan (KWh/year)	Household heating water (KWh/year)	Other (valve, other devices) (KWh/year)	Total (KWh/year)
2009	46,560,909	72,102,413	478,638,252	199,962	597,501,536
2015	63,765,316	79,864,146	523,127,063	199,962	666,956,487
2020	68,634,425	87,217,367	536,933,936	199,962	692,985,690
2025	74,437,336	88,749,288	596,763,717	199,962	760,150,303
2030	79,973,446	95,081,228	665,798,081	199,962	841,052,716
2035	84,842,554	102,128,064	687,275,438	199,962	874,446,019
2040	88,444,361	107,847,236	707,985,747	199,962	904,477,306
2045	91,846,067	113,668,535	759,377,995	199,962	965,092,560
2050	97,715,678	121,430,268	808,469,098	199,962	1,027,815,006

Appendix 8: Energy consumption of Tel Aviv's water system (WWT & reuse at unit block)

WWT at unit block						
Year	Water supply (KWh/year)	wastewater discharge to Shafdan (KWh/year)	Wastewater reuse (KWh/year)	Household heating water (KWh/year)	Other (valve, other devices) (KWh/year)	Total (KWh/year)
2009	46,356,584	53,106,593	5,496,578	478,638,252	199962	583,797,969
2015	49,491,490	58,927,893	5,750,901	523,127,063	199962	637,497,310
2020	53,159,997	64,544,936	6,208,094	536,933,936	199962	661,046,926
2025	56,695,103	70,570,492	6,643,158	596,763,717	199962	730,872,433
2030	61,030,611	76,391,792	6,858,287	665,798,081	199962	810,278,733
2035	65,232,719	82,927,988	7,094,917	687,275,438	199962	842,731,023
2040	69,501,527	88,442,903	7,268,948	707,985,747	199962	873,399,087
2045	74,170,535	94,059,947	7,423,741	759,377,995	199962	935,232,180
2050	80,707,147	102,332,320	7,431,549	808,469,098	199962	999,140,076

Appendix 9: Energy consumption of Tel Aviv's water system (WWT & reuse at cluster)

WWT at cluster scale						
Year	Water supply (KWh/year)	wastewater discharge to Shafdan (KWh/year)	Wastewater reuse (KWh/year)	Household heating water (KWh/year)	Other (valve, other devices) (KWh/year)	Total (KWh/year)
2009	44,955,882	50,859,776	7,009,174	478,638,252	199,962	581,663,045
2015	48,757,789	57,089,588	6,557,597	523,127,063	199,962	635,731,999
2020	52,559,696	63,217,272	6,994,002	536,933,936	199,962	659,904,867
2025	57,428,805	69,549,212	7,427,142	596,763,717	199,962	731,368,838
2030	62,097,813	75,370,511	7,792,390	665,798,081	199,962	811,258,757
2035	67,567,223	82,008,835	8,151,599	687,275,438	199,962	845,203,058
2040	70,835,529	87,523,751	8,225,479	707,985,747	199,962	874,770,467
2045	74,770,836	93,038,666	8,347,579	759,377,995	199,962	935,735,039

2050	79,039,644	101,106,783	8,382,610	808,469,098	199,962	997,198,097

Appendix 10: Energy consumption of Tel Aviv's water system (rainwater tank strategy)

Rainwater tank						
Year	Water supply (KWh/year)	wastewater discharge to Shafdan (KWh/year)	Rainwater tank (KWh/year)	Household heating water (KWh/year)	Other (valve, other devices) (KWh/year)	Total (KWh/year)
2009	53,159,997	7,118,326	1,379,689	478,638,252	199,962	540,496,226
2015	53,760,298	7,894,499	2,024,960	523,127,063	199,962	587,006,783
2020	58,896,207	8,629,821	1,964,341	536,933,936	199,962	606,624,267
2025	63,165,015	8,793,226	2,286,090	596,763,717	199,962	671,208,011
2030	71,102,329	9,426,420	1,991,955	665,798,081	199,962	748,518,748
2035	80,040,146	10,120,891	1,647,040	687,275,438	199,962	779,283,477
2040	86,510,057	10,703,021	1,009,704	707,985,747	199,962	806,408,492
2045	87,043,658	11,274,938	1,803,155	759,377,995	199,962	859,699,709
2050	90,178,564	12,051,112	2,174,593	808,469,098	199,962	913,073,328