URBAN WATER BALANCE LEVELS AND THEIR OBJECTIVES

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ABSTRACT

Facing problems with sustainable urban water systems planning, water balances are developed for different levels. They are formulated, that they can be used as basis for comparing planning alternatives. For evaluation of balance calculations of complex urban water systems the Analytic Hierarchy Process (AHP) – method is suggested.
Key words: water balance, water system, alternative evaluation

1. INTRODUCTION

By 2015, it is estimated that one billion people have no access to clean water, and 2.5 billions people not adequate sanitation. Especially in low-income areas, low economics incline on investment for the protection of water resources, thus aggravating the water crisis. Even more rapid urban growth, i.e. in China over the last decades has pressured water resources.

Years of trial on adopting various water conservation measures aimed for water saving and better use of available resources. Still it seems that planning lacks reliable procedures to cope with the problems. Therefore this research tries to build water balance levels, which allow for alternatives of system design to meet different potential objectives. Chapter 2 and 3 develops urban water system models, which starting from simple and go step by step to more complex. The simplest case maybe considered the house level, where water is imported, used and maybe recycled, and waste water discharged outside of the house boundaries. The next level may be property level. Then the model is expanded to district level. Finally, a city level is achieved, including residential area, industrial area, public area and park area. Chapter 4 introduces an evaluation method called Analytic Hierarchy Process (AHP), which is relatively simple and practicable. It could be employed for ranking options for water supply and drainage.

2. OBJECTIVES OF WATER BALANCE ON DIFFERENT LEVELS

Usually, a clear objective could guide planning. Therefore, goals of different water balance level are supposed in table 1, they are supposed to help building urban water systems.

Table 1 set-up boundary for various goals

Level	Goal	Time unit	Spatial extend
House	Economic saving	month	<200m^2
Property	1. Saving irrigation water 2. Recharge ground water	Season year	<1000m^2
Developed district	1. Water resource conservation 2. Economic saving 3. Sustainable development	year year >30 years	>1000m^2 < 0.1km^2
City	1. Water resource conservation 2. Economic saving 3. Sustainable development	>30 years year >30 year	> 0.1km^2 < 100km^2

Four water balance levels are defined both in time and spatial extend. It is the basic of setting alternatives in water planning.

2.1. House level

House is the unit construction in urban area. House level represents a water balance system in an apartment or a house without garden. Most of water related activities are taken place in house, and daily water consumption are close related to house payment, thus water fee in a house is assessed in this section. Urban water balance levels and their objectives

2.1.1. House level water system

Usually, water system at house level contains three components, which are water input, water consumption and water out. A water balance at house level could be water input equals to water output. Water input contains all kinds of water goes into house, such as piped water, bottled water, even water contained in fruit and so on. After domestic consumption, most of water will leave this system in certain forms, such as evaporation, sewerage, etc.

Most of domestic water consumption depends on habits and customs, thus water daily consumption in a house will increase with living standard enhancing. To realize economic saving, some water saving design should be employed here. Such as equip water recycle facilities.

2.1.2. Financial analysis

Take Beijing, China for instance, in 2004 domestic portable water price contains 2.00 Yuan/m^3 fresh water fee and 0.9 Yuan/m^3 discharge fee. According to domestic water consumption survey, average consumption in Beijing is 104.14 L/cap*d. Usually, household bill is paid monthly, suppose there are 5 persons in a house. Then,

$Q_{demand} = 5*104.14*10^{-3}*30 = 15.6\ m^3/mon$

And payment could be: Pay = 15.6*2.9 = 45.3 Yuan/mon

Beijing located in semi-arid area, where water is scarce. There it is urgent to control water consumption. Some one suggests raising water price, but it will be a heavy load for average salary family. From news report, average practicable income in Beijing is 1303 Yuan/ cap*mon, in 2004. Maybe it will be more efficient if equip water recycle system. Many surveys show that toilet flush takes a large part in water supply. Again, take Beijing for example, in 2003 average house toilet flush takes portion of 25.93% of total daily water consumption; therefore if use grey water for toilet flushing, the economic saving might be:

Save =25.93% Pay = 11.7 Yuan/mon

2.2. Property level

Property here refers to house and garden, it is another kind of water consumption unit in urban area. Building some kinds of water facilities could save irrigation water by reclaiming rain water and realize ground water recharge.

2.2.1. Property level water system

In order to simplify water balance analysis, only outdoor water system in a property area is analyzed. In this section, the water balance model is built on three components, which are precipitation, evaporation and runoff. Therefore the water cycle could be described as precipitation introduces water into property level system, and by means of evaporation and runoff, water out of this system.

Generally, runoff is supposed to be drained out of property area as quickly as possible. But more and more evidences show fast drainage always causes a big problem in urban area. Because first flush usually contains contaminator, it might pollute surface water, and runoff retained in a lower place will lead to flooding, or traffic slack. On the other hand, precipitation could be harvested as a resource. Maybe equip a retention tank for ground water infiltration or storing rain water for irrigation. In addition, building a green roof in one’s property could create a better landscape and reduce runoff onsite.

2.2.2 .Water conservation

In this level, water conservation refers to saving water and recharge ground water. Alternatives could be a property area built retention tank, pervious pavement and green roof. Provided that recharge ground water in each storm event is 0.2m3, surplus part of retained water would be used as reclaiming water. Only more than 5m3 harvesting will create overflow. Parameters and results are presented in table 2:

Table 2 one storm event calculation

Precipitation[mm]	5	Property [m^2]	500
	Greenland	Pervious road	Green roof
Initial loss	2	4	12

runoff [mm]	3	1	0
Area [m^2]	250	100	150
Runoff coefficient	0.5	0.7	1
Precipitation runoff [m^3]	0.375	0.07	0
Harvesting[m^3]	Reclaim [m^3]	Recharge [m^3]	overflow[m^3]
0.445	0.245	0.2	0

From table 2, a 5mm storm event will not cause overflow, and it could contribute to ground water recharge and rain water reclaiming. It suggests that in same climate, one property includes pervious pavement, retention tank and green roof will create less runoff. This alternative not only reduces the risk of flooding and controls first flush pollution, but also conserves ground water.

2.3. Developed district level

A developed district is defined as a system, which combines components of house level and property level. Developed district contains larger population and more municipal construction, therefore, balance counting is considered in a longer time span and in a larger area size. Usually its design should submit to water conservation, economic saving and sustainability. And water balance is always taken place within area less than 0.1km2, time span might be a year period or longer.

2.3.1. Developed district level water system

Water system in developed district is composed by both natural and manmade system. Therefore, this system has many options in construction and design. Unfortunately, potable water has a loss in process of pressure distribution. And complex pipe net some times leads to illicit connection. In China, water leakage should be limited within 10%~12% of municipal supply (Construction and Monitor, 2006). In order to deal with these problems, there are three essential options here.

Alternative 1: initial urban lands plan without any structure water management; it may be works well and need little investment. But as population growth and urbanization, a developing district meets a growth of water demanding. Therefore, developed area should employ water facilities for water conservation.

Alternative 2: employing recycle strategy indoor and building a detention tank outdoor. As a result, the investment in water facilities is higher than option 1. However, recycle facilities might reduce portable water demand; retention structure will lead to less runoff, both of them will benefit to reduce pipe diameter and relieve the costs for municipal construction.

Provided more designs in alternative 3, one of them is the green roof, which create a better landscape and it is benefit for citizen’s aesthetic demanding. What’s more, it has some other environmental benefits, like clearing air, protecting building from burned sun. Pervious pavement is employed for infiltration and first flush control.

2.3.2. Water resource conservation

Due to urbanization, more and more municipal water constructions are required. Therefore, a large pipe system will be built. This situation maybe handled by reducing runoff and increasing reclaimed water source on site. In development district, a larger spatial and longer duration is employed for calculation. As for ground water recharge, method of table 2 could be retrieved.

2.3.3. Potential economic saving

Assume that residential in this developed district is 10 thousands. Then indoor water demand per month could be 200 times of house level:

$Q = 10000/5*Q_{demand} = 2000*15.621m^3/mon = 31242\ m^3/mon$

Symbol meaning is the same with in house level. If recycle water reach 25.93%, then convert water saving into cost, direct water fee saving is

Save =25.93% Pay = 25.93%* 2000* 11.7 = 23493.05 Yuan/mon

Besides this part, economic saving also could be taken place in reducing municipal system construction and maintenance. This part may balance payment on harvesting facilities building.

2.3.4. Sustainable development evaluation

Usually sustainability could be evaluated by social, economic and environmental aspect. In option 3, flood prevention and landscape are benefit for society, less municipal pipeline investment belongs to economic saving, and groundwater recharge may contribute to environmental protection.

2.4. City level

Usually, urban development is the basic development unit of a country. As a fundament part, water takes an important place. To achieve a sustainable development target, the water resource protection, water conservation, economic saving, etc should be contained in city plan.

2.4.1. City level water system

According to different function, a city could be divided into three types of areas, which are defined as residential area, industrial area, and public area. Usually, water cycle in city includes the three major parts: surface and ground water flow, atmospheric circulation, water related substance trading.

With city water system, three function units are taken as separated subsystems; they are residential area, industry area and public area. Within each function unit reusing or recycling could be employed. Also water management could be discovering new water resource, employing facilities to integrate all the resource including grey water, precipitation and parts of waste water which might be reclaim in lower water quality demanding departments. Take a paper industry for example, there are various product line in a paper industry, some parts demand fresh water, while some processes only ask for lower quality water, therefore, water could be reused or reclaimed in some parts, and saving a mount of potable water.

Except these three subsystems and their respective water strategy, city water system has a frequent water exchange with suburban area, especially food trading from agriculture. Thus the alternative contains how to take advantage from virtual water.

2.4.2. Case study

According to Water Resource Planning in 21st Century, Beijing water demanding within different supply guarantee is predicted in table 3:

Table 3 water demanding prediction (Water Resource Planning in 21stCN) (unit: 0.1 billion m3)

District	Section	In 2005			In 2010		
	Guarantee	50	75	95	50	75	95
City	Industry	10.32	10.32	10.32	10.72	10.72	10.72
	Residents	11.72	11.72	11.72	13.35	13.35	13.35
	Agriculture	20.77	22.39	22.39	20.36	21.91	21.91
	Environment	4.46	4.16	4.16	10.60	9.00	9.00
	Loss	2.00	2.00	2.00	2.00	2.00	2.00
	Sum up	49.27	50.59	50.59	57.03	56.98	56.98
Planning district	Industry	5.76	5.76	5.76	5.76	5.76	5.76
	Residents	8.34	8.34	8.34	9.13	9.13	9.13
	Agriculture	2.01	2.14	2.14	1.86	1.97	1.97
	Environment	2.41	2.41	2.41	6.00	6.00	6.00
	Loss	2.00	2.00	2.00	2.00	2.00	2.00
	Sum up	20.52	20.65	20.65	24.75	24.86	24.86

Table 3 shows that water consumption of environment part and residents' part will increase from 2005 to 2010. Therefore popularizing design in development district level could contribute a lot in water saving. On the other hand, water demanding decrease in industry and agriculture might be the result of increasing reuse percentage in respective section and exchange between different sections.

2.4.3. Water source protection

1). Conservation within subsystem

Conservation will protect resource from depletion; recharge method similar to development district should be popularized not only in residential area, but also within whole city and suburban area. Survey in 2005 shows that water reuse in Beijing takes 35% of the whole water consumption.

According to consumption situation (News 2006), Beijing will face a water resource shortage about 1.1 billion in 2008, reuse of claim water should enhance to 50%~60%, and there is an aim to reach 90%.

2). Benefit from exchange and water trade strategy

Water saving also could be realized by importing products that require a lot of water for their production rather than producing them domestically. This leads to real water savings and relieving the pressure on water resources.

2.4.4. Sustainable development evaluation

According to different criteria, sustainable development has different definitions. Therefore there is no definite sustainable urban planning. However, it is necessary to make a choice among various alternatives for urban development. In urban area, the water system is complex as described in city level. In order to evaluate the sustainability of urban planning, some practicable analysis system will be employed; this part will be discussed in detail in chapter 4.

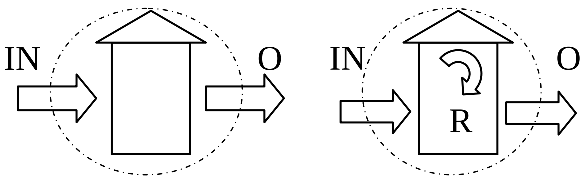
3. DEVELOPMENT OF WATER BALANCE FORMULA

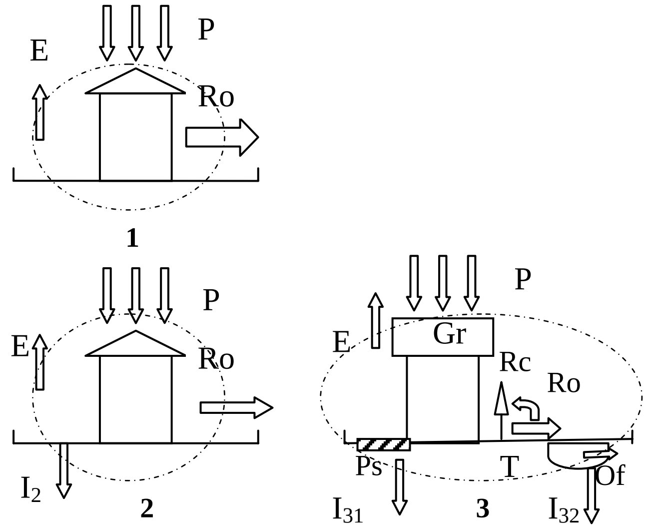
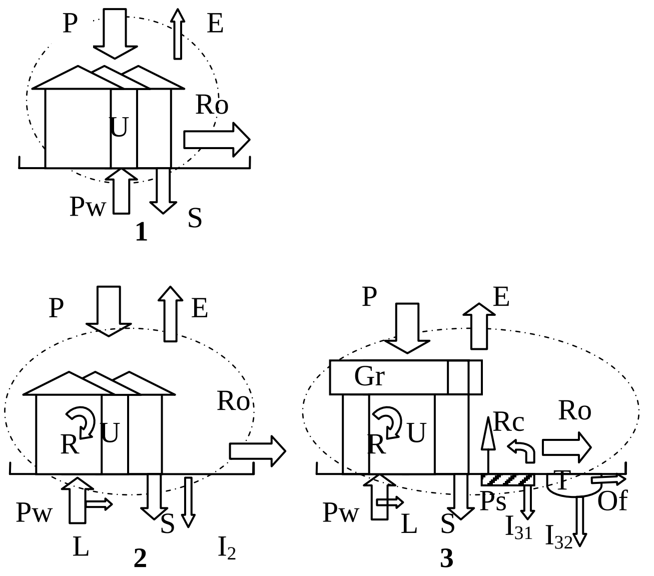
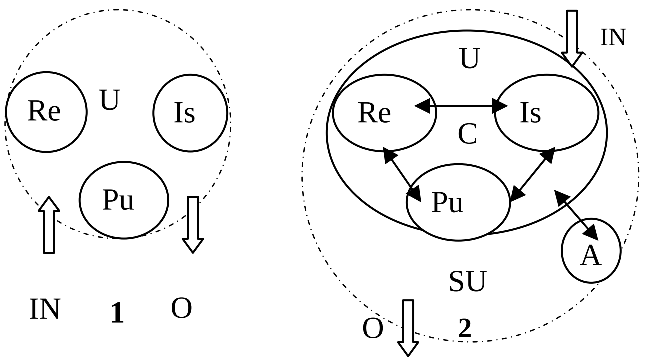
Based on water balance, formula of the relationship between elements is developed in draft on left of the table. Since water systems have been defined, it is possible to calculate water quantity and describe water by water balance.

3.1. Water balance figure and formula

Water balance level and their alternatives described in chapter 2 are drafted in left column, where dashed circle qualifies each system. And right column shows balance equation as well as elements comparison between alternatives.

Table 4 develop water balance in different level

Level	**Formula**
House level  **1** **2**	**1:** IN = O, **2:** IN = O. **Comparison between 1 and 2:** $IN_1 > IN_2$, $IN_1 = IN_2 + R_2$, $O_1 > O_2$, $O_1 = O_2 + R_2$.
Property level	**1:** P = Ro + E, **2:** $P = Ro + I_2 + E$, **3:** $P = Ro + I_{31} + T + E + Gr$, $Ro = T + Of + I_{32}$. **Comparison among 1, 2 and 3:**

	$Ro_1 > Ro_2 > Ro_3$, $I_2 < I_{31}$, $E_1 < E_2 < E_3$.
Developed district level 	**1:** $P + Pw = Ro + S + E$. **2:** $P + Pw - L = Ro + S + E + I_2$. **Process 2:** $P = Ro + I + E$ $U = Pw - L + R$. **3:** $P + Pw - L = Ro + S + E + I_{31} + I_{32} + Gr + T$. **Process 3:** $Ro = Of + I_{32} + Rc + T$, $U = Pw - L + R + Rc$. **Comparison among 1,2 and 3:** $Ro_1 > Ro_2 > Ro_3$, $E_1 < E_2 < E_3$. $L_2 > L_3$
City level 	**1:** $IN = U = Re + Is + Pu = O$, **2:** $IN = Re + Is + Pu + A - eri - erp - eip - eac = O$. $U = Re + Is + Pu + A$ **Comparison between 1 and 2:** Assumption: $U_1 = U_2$, then $IN_1 > IN_2$, $O_1 > O_2$,

Explanations	
1,2,3—draft 1, 2, 3,	Ro— runoff,
IN—water in,	Pw—potable water,

O—water out,	S—sewage,
U—use,	L—leakage,
R—recycle,	Ps—pervious pavement,
P—precipitation,	Of—overflow,
T—tank increased volume,	Rc—reclaim,
E—evaporation,	C—city area,
Gr—green roof retention,	SU—suburban,
eri—exchange between residential areas and industrial areas,	Is—industrial areas,
erp—exchange between residential areas and public areas,	Re—residential areas,
eip—exchange between industrial areas and public areas.	Pu—public areas,
	A—agriculture areas.

3.2. Comparison of elements in each figure

Each level contains at least two alternatives. Basically, alternative 1 in each level is relatively simple; it shows a traditional water system. Comparing to alternative 1, some elements represent new facilities are added in at alternative 2 and 3. These alternatives are developed according to objectives set-up in table 1, which had been described in chapter 2. In right column, a comparison between elements in the same water balances level is given.

House level, water consumption depends on habits which changes little. But fresh water demand may be reduced by recycling, that is alternative 1 will requires more water input, IN 1 > IN 2, as for input directly influences output, then O 1 > O 2.

Property level, supposed same climate condition, precipitation (P) and potential evaporation rate are constant. Thus runoff on sealed road is maximum, while on part pervious pavement could be less, and after green roof retention (Gr), pervious pavement infiltration (I2 or I31), runoff could be reduced largely, i.e. Ro 1 > Ro 2 > Ro 3. In alternative 3, if precipitation extend over the capability of tank (i.e. Ro >T), there might be an overflow taken place (Of). In same storm event, infiltration through pavement is increased from 2 to 3, show as I2 < I 31. In addition, design a retention tank as an infiltration facility, thus part of rain could be harvested as T, part of could be infiltration I32. With these structures, more water are retained in site of property, it means longer duration for evaporation, as a result, E is increasing with draft developing.

Developed level, comparisons of runoff and evaporation are similar to property level, presented as Ro 1> Ro 2> Ro 3, E 1 < E 2 < E 3. But more precise processes in water cycle are taken for analysis. In alternative 2, precipitation turns out to be runoff, infiltration and evaporation, state as P = Ro + I + E. Domestic water used (U) is from municipal supply (Pw), considering portion of leakage (L) and recycling (R), then U = Pw – L+ R. In draft 3, runoff could be stored in tank (T), recharge groundwater through infiltration (I), or overflow (Of), that is Ro = Of + I + T, parts of tank storage is reclaimed for irrigation (Rc), combined with alternative 2 equation, used could be: U = Pw – L + R + Rc. If domestic water consumption custom dose not change much, U in alternative 2 and 3 should be same, then Pw in 3 is less than in 2, and relatively L2 > L3.

City level, domestic water consumption (Re) depends on population and living style, industry water consumption (In) depends on production task, and public water (Pu) depends on landscape and public service, water saving could be realized by recycle, and maybe conserve potable water by reusing or exchanging water between Re, In and Pu, or optimize active change with agriculture (A), between city and suburban area (SU). As discussed in 2.4, IN 1> IN 2 and O1 > O2 could be practical, that is less resource demanding, and less discharge.

4. POTENTAIL APPLICATIONS

In chapters 2 and 3, a balance approach for urban water system planning has been developed step by step. It is necessary to choose a practicable assessment for each alternative developed in water balance levels. As discussed above different alternatives for water systems on house level, property level, district level and city level could be calculated. Many elements contained in the water balances, especially on city level interact in a very complex way. Therefore some assessment methods are retrieved in this chapter. And finally AHP is suggested to rank different planning options.

An applicable approach for integrative evaluation of water systems is the Multi-criteria decision making (MCDM), which allows for multiple objectives and value judgments whereby subject is wanted. These methods differ from others, as they account for multidimensional objectives and criteria, conflicting, and intangibles. MCDM approaches encompass multi-objective decision making (MODM) methods and multi-attribute decision making (MADM) methods. Figure 1 provides an overview of common multi-criteria decision making processes.

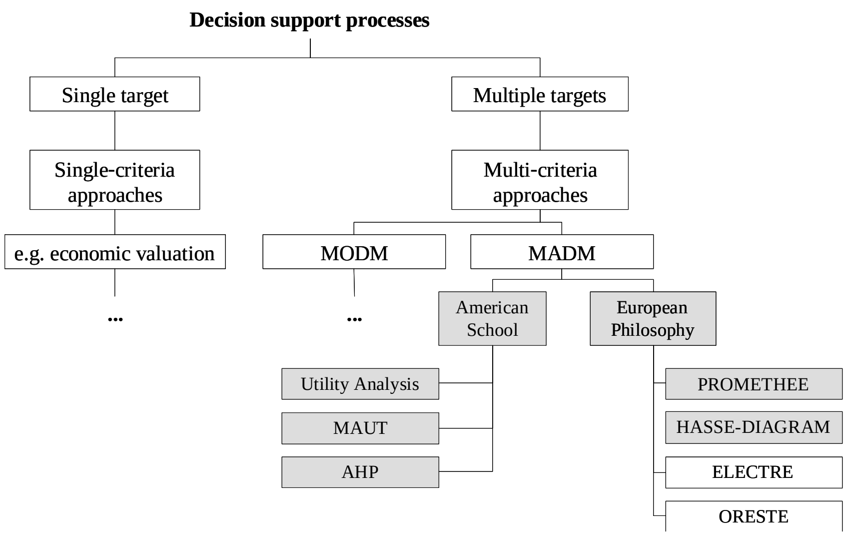


Figure 1 Overview of common multi-criteria decision making processes

MODM and MADM support decision making in case of multiple and conflicting objectives, intangibles evaluation criteria and various points of view. They aim for a clear presentation of potential impacts of different choices assumes that criteria can be partially traded off against each other. MODM methods deal with decision problems where a most promising decision alternative has to be identified from an infinite set of options. MADM methods constitute a methodological framework for ranking a predetermined set of alternatives. The approach to rank a predetermined set of various alternatives is equivalent to the approach to evaluate sustainability for the Olympic project. Thus, MADM methods play an interesting role to evaluate sustainability for the water management concepts.

MADM methods can be divided into two categories. Methods using single criterion synthesizing approaches assume that decision makers have a clear idea of the utility of criteria values and related preference weights. They can be referred to as approaches of the ‘American School’. Outranking methods are approaches of the ‘European Philosophy’, which are based on the assumption that decision makers do not have a clear idea about their preferences and that therefore consequences of different preference weights have to be demonstrated. They consider incomparability of alternatives rather than providing a set of ideal solutions(Fichtner and Geldermann, 2002)

The Analytic Hierarchy Process (AHP) being simple to apply is described in more detail. The Analytic Hierarchy Process (AHP) use matrices and linear algebra for the formalization of a decision process. It allows to structure complex decision problem in a hierarchical order, thus exhibiting the relationship between the decision alternatives, objectives and evaluation criteria. Thus AHP facilitates analysis by transforming a complex evaluation into a hierarchy of smaller more manageable sub-evaluations. A complex dataset is thus decomposed into smaller constituent elements between which pair wise comparison is elicited. AHP is a compensatory decision methodology as alternatives that are deficient with respect to certain objectives can compensate by their performance with respect to other objectives(Marz and Buck, 1999).

To rank the decision alternatives the complex decision situation is structured hierarchically. The top element of the hierarchy represents the overall goal of the decision. The hierarchy decomposes to more specific evaluation attributes such as objectives and manageable decision criteria (sub-objectives) until a level of measurable indicators is met. The final level is constituted by the different alternatives. This hierarchy can consists of as many levels as possible, with each level influencing the paramount level and being influenced by the subordinate level(Marz and Buck, 1999). Thus the Analytic Hierarchy Process (AHP) is applicable method to evaluate sustainability of different water management systems.

5. CONCLUSION AND FURTHER RESEARCH

This research has defined water levels for different scales, and also set boundaries for balance analysis clearly. As analysis in chapter 2, house, property, and developed district level are relatively easy to calculate and assess. However, urban water planning is more complex and requires evaluation procedures like AHP.

Water balance level could be the basic for further urban water research. As time goes by, more water problem turn out. Thus more precise research is demanded, such as water resource protection, waste water treatment etc. Further research on water cycle contains many hydrology and dynamic processes. For the reason that calculation becomes more and more complex, calculations must be done by computer modelling, and maybe further software developed reflecting water cycles and their changes. Thus simulation water models are required for decision making (Helweg, 1985).

In addition, methods introduced in chapter 2 and 3 focuses on water facilities design, which belongs to structural water management. However, some times structural designs can not function well in absent of non-structural management (Thomas, Gomboso et al., 1997). Therefore, in order to achieve sustainability goals, further research should contain non-structural analysis, like politics, regulations and education.

ACKNOWLEDGEMENTS

I appreciate my supervisor Prof. Li Shuping of Tongji University; he gives me this interesting topic. I also thanks to Institute of the Urban Water Management at the University of Duisburg-Essen, give me the opportunity to stay and study in Europe.

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