URBAN WATER BALANCE LEVELS AND CORRESPONDING EVALUATION METHOD

W.M. Yu[1], and J. Schubert[2]

(1) College of Environmental Science and Engineering, Tongji University, Siping Road 1239, Shanghai, 20092 China, yuyuyuf630@163.com
(2) Urban Water and Waste management, University of Duisburg-Essen, Universitätsstr. 17, 45117 Essen, jochen.schubert@uni-due.de

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 and tested by a calculating example.

Key words: water balance, water system, alternative evaluation, AHP

1. INTRODUCTION

Water influence world development, when water crisis hit population density area, the problem will be enlarged as a disaster. Take China for instance, during last decades, urbanization has been taken place rapidly, which pressured water resources deadly. Worse still, food scary is defined as a follower of water problem (Hoekstra and Chapagain, 2007). 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 suggests a systematic analysis method for water management. By building reasonable water balance levels, water management could meet different potential objectives. Chapter 2 develops urban water system models, starting from house level, where water is imported, used and maybe recycled, and finally waste water discharged outside of the house boundary. Then the model is expanded to property lever, district level. Finally, a city level is achieved, including residential area, industrial area, and public area. Chapter 3 introduces an evaluation method called Analytic Hierarchy Process (AHP), which is relatively simple and practicable. It could be employed for ranking options for water management possibilities.

2. OBJECTIVES OF WATER BALANCE ON DIFFERENT LEVELS

Usually, a clear objective could guide planning. Four water balance levels are defined both in time and spatial extension. It is the basic of setting alternatives in water planning. Therefore, goals of different water balance level are suggested 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	<500m^2
Property	1. Saving irrigation water 2. Recharge ground water	Season year	<20,000m^2
Developed district	1. Water resource conservation 2. Economic saving 3. Sustainable development	year year >30 years	>20,000m^2 < 1km^2
City	1. Water resource conservation 2. Economic saving 3. Sustainable development	>30 years year >30 year	> 1km^2 < 1000km^2

2.1. House level

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.

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. Average water resource is less than 300 m^3/cap. Therefore 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. As a result, 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. Employing water facility such as retention tank could save irrigation water by reclaiming rain water and realize ground water recharge. In order to simplify water balance analysis, only outdoor water system in a property area is analyzed. And time span could be one day or just few minutes rain event. For a season or year case, same calculation formula could be employed in an enlarged time zone. 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 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.

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 $0.2m^3$, surplus part of retained water would be used as reclaiming water. Only more than $5m^3$ 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

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.

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.

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. 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. Within 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.

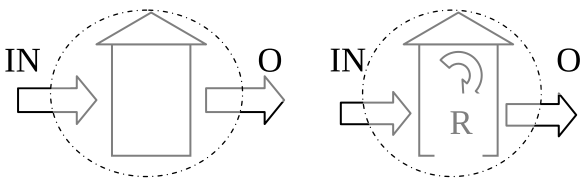
According to Water Resource Planning in 21st Century, Beijing water consumption of environment part and residents' part will increase from 2005 to 2010. Therefore popularizing design in development district level could contribute a lot in water saving. On the other hand, water demanding decreases in industry and agriculture might be the result of increasing reuse percentage in respective section and exchange between different sections. 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%, with an aim to reach 90%.

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. 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 should be employed.

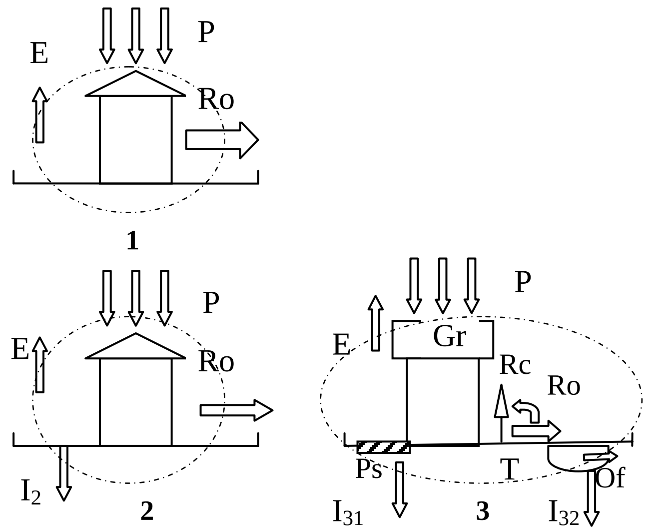
2.5. Water balance figure and formula

Water balance level and their alternatives described before 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 3 Develop water balance in different level

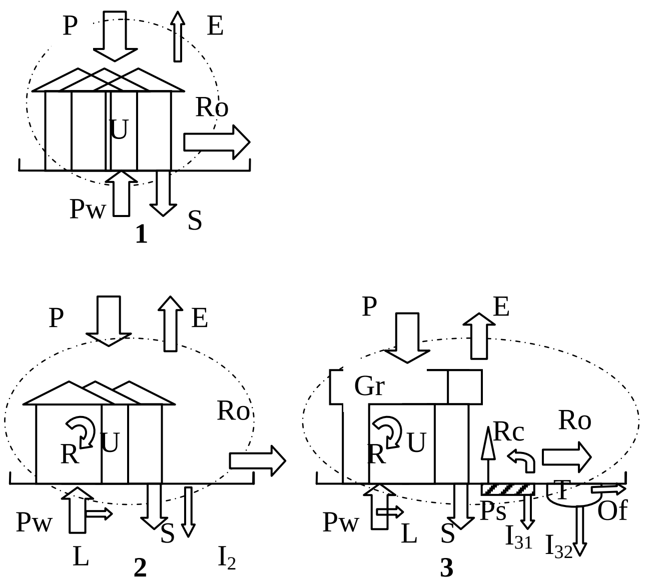
Level	**Formula**
House level  **1** **2**	**1:** IN = O, **2:** IN = O. **Comparison between 1 and 2:** $IN_1 > IN_2$, $IN_1 = IN_2 + R_2$, $O_1 > O_2$, $O_1 = O_2 + R_2$.

Property level



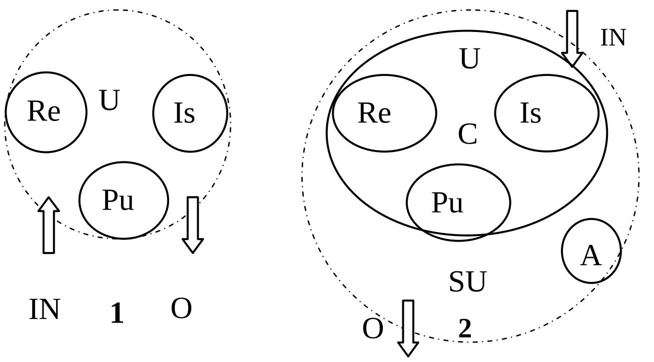
1: $P = Ro + E$,
2: $P = Ro + I_2 + E$,
3: $P = Ro + I_{31} + T + E + Gr$,
$Ro = T + Of + I_{32}$.
Comparison among 1, 2 and 3:
$Ro_1 > Ro_2 > Ro_3$,
$I_2 < I_{31}$,
$E_1 < E_2 < E_3$.

Developed district level



1: $P + Pw = Ro + S + E$.
2: $P + Pw – L = Ro + S + E + I_2$.
Process 2:
$P = Ro + I_2 + E$,
$U = Pw – L + R$.
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,
	Re—residential areas,
erp—exchange between residential areas and public areas,	Pu—public areas,
eip—exchange between industrial areas and public areas.	A—agriculture areas.

3. POTENTAIL APPLICATIONS

In chapters 2, a balance approach for urban water system planning has been developed step by step. Though it sounds simple to apply last alternative in each level, it is hard to adapt to local developing plan or too demanding for a local financial budget. Therefore it is necessary to choose a practicable assessment for each alternative developed in water balance levels. To achieve the environmental friendly objectives, social and economic aspects also should be considered. As discussed above, many elements contained in the water balances, thus water quantity and water fee in various alternatives could be calculated. For realize the design and weighting various water management decisions, Analytic Hierarchy Process (AHP) is suggested to rank different planning options. This hierarchy can consists of as many levels as possible, with each level influencing the paramount level and being influenced by the subordinate level (Merz and Buck, 1999). Method is designed as firstly set up scenarios and their index. Secondly, determine the relative weights of each of the comparison attributes, which know as number from 1 to 9 values. Using single criterion synthesizing approaches assume that decision makers have a clear idea of the utility of criteria values and related preference weight. Thus combining AHP with levels and objectives developed in former chapter. A simply assumption is taken as an example, within which level 1 is list in Table 4. From priority value in Table 5, ranking is available among scenarios. From table 6, Scenario I is loosely 0.438 - 0.341 = 0.097, or 9.7 percent better than scenario III. Some literature argues that the 3-decimal precision of the data is somewhat deceptive (McCaffrey, 2005). Thus more levels or other evaluation method should be employed to make comparison.

Table 4 Comparison scenarios in level 1

	Recycling water	**Regeneration groundwater**	**Substances into groundwater**	**Household finance**	**Facility cost**
scenario I to I	1	1	1	1	1
scenario II to I	1/3	7	1/9	3	1/6
scenario III to I	1	9	1/9	5	1/9
scenario II to III	1/3	1/2	1	1/2	3

Table 5 Results of calculation in AHP

	Level 1			Level 2	Level 3
Indicator	Scenario I	Scenario II	Scenario III	Water issue	Integration
Recycling water	0.429	0.143	0.429	0.333	0.333
Regeneration groundwater	0.057	0.346	0.597	0.333	0.333
Substances into groundwater	0.818	0.091	0.091	0.333	0.333
Household finance	0.1095	0.309	0.582	1	0.333
Facility cost	0.770	0.162	0.068	1	0.333
Priority	0.438	0.221	0.341		
Ranking	1	3	2		

4. CONCLUSION AND FURTHER RESEARCH

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

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REFERENCE

Construction, D. N. and Monitor, D. Q. (2006): *Code for design of outdoor water supply engineering*. **China Planning, 7 pp.**

Hoekstra, A. Y. and Chapagain, A. K. (2007): Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resource Management*, **21: 35-48.**

McCaffrey, J. (2005): The Analytic Hierarchy Process. *MSDN Magazine*, **20(6): 139-144.**

Merz, R. and Buck, W. (1999): *Integrierte Bewertung wasserwirtschaftlicher Maßnahmen.* **Bonn, 48 pp.**

Thomas, J. F., Gomboso, J., et al. (1997): *Wastewater Re-use Stormwater Management and the National Water Reform Agenda*. **National Library of Australia Cataloguing in Publication Entry, Australia, 54 pp.**