APPLICATION OF CITY WATER BALANCE MODEL TO DEVELOP STRATEGIES FOR URBAN WATER MANAGEMENT IN HANOI

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SUMMARY

Urban water management is facing with a couple of problems such as inadequate water supply, untreated wastewater disposal and stormwater management. Particularly, in developing countries it seems a long way to overcome these problems. Integrated urban water management (IUWM) is considered as one of the powerful management approaches to solve those problems. This approach links water supply, wastewater and stormwater issues as one unit of management. Like many urban area in the developing world, Hanoi is dealing with pollution in receiving water bodies, ground water depletion and flooding. City Water Balance model (CWB), being used in SWITCH project, is used in this research to assess the water and contaminant balance for a typical catchment in Hanoi urban water system. A specific answer to water and contaminant flows of the catchment was clarified. A range of sustainable urban water management applications including rain water harvesting, wastewater recycling and green roof is presented. Implementation of $1m^3$ rainwater tank will saved 31% water supply for non-potable purposes and 540l/day of grey water recycling will be sufficient for toilet flushing. In addition, "Towards sustainability for Hanoi urban water management" strategy was proposed. Based on these findings the research is valid reference for policy-makers working on Hanoi's water sectors.

Keywords: **Contaminant fluxes, Hanoi, Urban Water Management, Water Balance, Water Cycle Model.**

I. INTRODUCTION

Rapidly urbanizing areas all over the world, but especially in the developing world, are challenged to design and operate urban water systems that provide safe drinking water, protect citizens from flooding and deal with wastewater in such a way that the health and environmental impact is minimized and resources are recovered. Increasingly engineers and scientists are convinced that end-of-pipe measures are not a general solution, but rather emphasis should be put on measures in households or neighborhoods, at a decentralized level. Such measures would reduce demand for piped supply of drinking water or make fit-for-use water available for non-potable uses. For wastewater and sanitation, such measures would prevent waste close to the source and recycle 'used water'. Treatment of wastewater would need to recover resources that are present in wastewater (nutrients, chemical and thermal energy, water).

Integrated urban water management (IUWM) is considered a promising management method to solve urban water problems. The approach links water supply, wastewater and stormwater as one unit of management. Interactions among the urban components are explicity considered in order to maintain effective, efficient and safe water services. The perspective of the urban water cycle was found to be important in the development of IUWM strategies (Tong et al, 2011).

In order to develop decentralized solutions it is necessary to have better insight into the flows of water, nutrients and energy in the urban environment. This information is increasingly available and therefore could be used to model the urban environment to test innovative household or neighborhood scale solutions. These models exist: AquaCycle (Tong et al. 2011), UVQ, UWOT and others. In this research a free-ware model, CWB (Mackay and Last, 2010), is applied to a neighborhood in Hanoi, to assess water and contaminant balance within the urban water system. It provides a holistic view of urban water system management. In this research, the model was used as a tool to simulate the current situation of Hanoi's water system. Rainwater harvesting, grey water recycling and green roof applications were formulated as alternative urban water management options. The purpose of this article was to propose sustainable strategy for Hanoi' urban water management based on above applications. This is done through combination of a literature study and CWB outputs that was applied for the study area.

II. METHODOLOGY

Description of study neighborhood

The study neighborhood, located in the Dong Da district in Hanoi capital, Vietnam, is around 2.4 hectares with an estimated population of 2221 inhabitants (Table 1). The area is representative for Hanoi in terms of infrastructure and water system. The area is an urban sub-catchment with one outlet to monitor wastewater and stormwater discharge for the CWB calibration process.

Table 1. Key features of the study area in Hanoi, Vietnam

Total population	2221 inhabitants	
Mean annual temperature and precipitation	24.7°C and 1630 mm (period 2005 - 2010)	
Land use	Residential, services (hair salons, private offices, groceries etc.)	
Sealed surface	100%	
Total water supply (2010)	121,924 m^3, 100% domestic	
Water supply source	100% ground water through the cities' central distribution network	
Per capita use	150 (liter/capita/day)	
Indoor water use profile (liter/capita/day)	Toilet flushing	15
	Kitchen	20
	Bathroom	51
	Laundry	15
	Others (cooling, dust reduction, bonsai irrigation; motorbike washing)	49.4
Drainage system	Combined sewerage system	
Wastewater quality and quantity	100% of untreated domestic wastewater is discharged through septic tank before entering to the receiving water body	

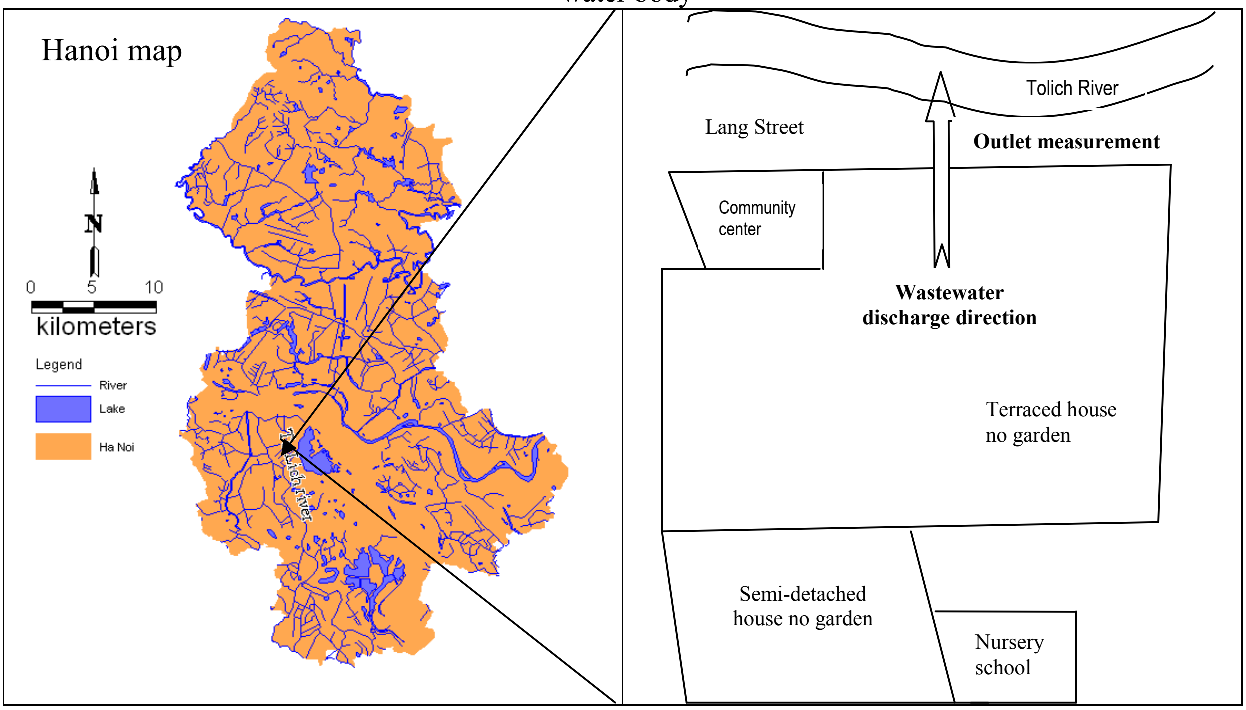

Figure 1. Schematic overview of the study neighborhood, Dong Da district, Hanoi, Vietnam

Data collection

The wastewater flow from the catchment was measured during 17 rainless days on an hourly basis from 6am to 8 pm, during a 3 month period in 2010/2011. The combined wastewater flow was measured during 1 precipitation event, every 30 to 60 minutes till the rain stopped. Flows were calculated based on the continuity equation through measurement of velocity and cross-sectional area. Flows between 9pm and 5am could not be measured, but were estimated based on published typical dry weather flow diurnal profiles of 61 households in Hanoi (Nguyen, 2009). Total daily discharge was calculated by taking the time-proportional average of measured and calculated flows.

Wastewater grab samples were taken coinciding with flow measurements and stored in 500 ml plastic bottles. Samples were brought to the laboratory for analysis. The grab samples of one day were mixed and a 500 ml volume was taken as a representative combined sample for that particular day. Chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN) and ammonia nitrogen (NH_3-N) was measured.

City water balance model

General model features

CWB was used to simulate the water and pollutant fluxes for the current situation in the study neighborhood (Figure 2). The model describes the urban water system at 4 levels: the unit-block, the mini-cluster, the sub-catchment and the study area. A mini-cluster consists of a number of unit-blocks, roads and public open spaces. A sub-catchment consists of a number of mini-cluster, and the study area is the sum of a number of sub-catchments. A unit-block refers to a plot for a single house, an industrial site or a public or commercial operation. The unit-block area includes the roof, the garden and paved areas. This scale represents the smallest unit of urban water management including the three main components: water supply, wastewater disposal and recycle-reuse operations. The unitblock scale allows to evaluate the cumulative effect of individual actions on for example of wastewater andstormwater flows at higher levels (mini-cluster, etc).

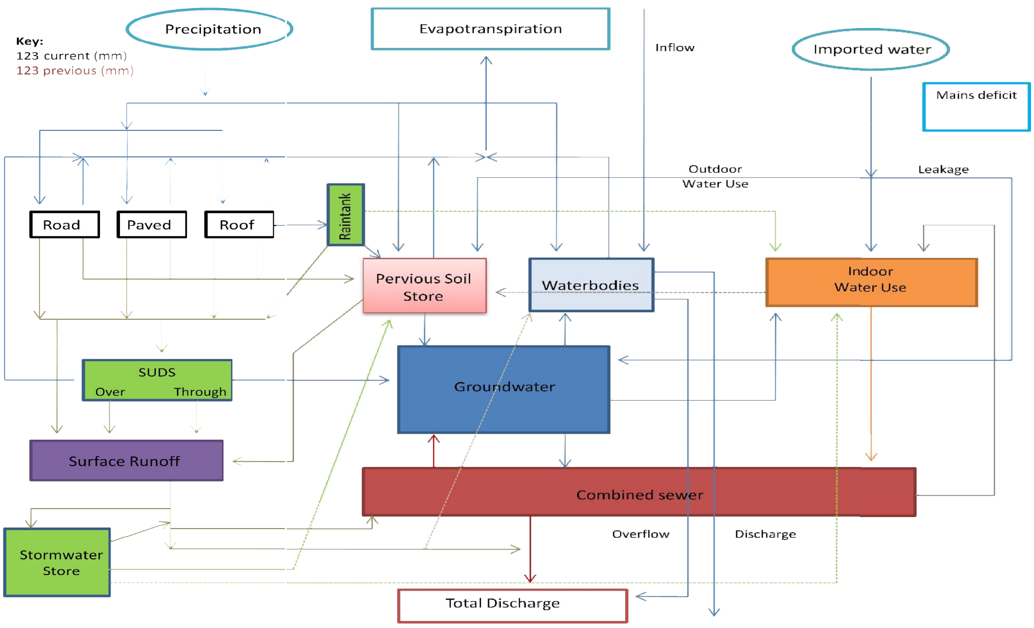

Figure 2. City Water Balance Flow diagram

Meteorological data

The climate data input file for CWB is a series of daily precipitation and potential evaporation from 2005 to 2010. Precipitation data from 2005 to the middle of October 2010 was obtained from Lang meteorological station, which is about 3km from the neighborhood. Precipitation for the remainder of 2010 was measured by the author with a rain gaugeclose to in the study area. Potential evaporation was calculated based on mean daily air temperature and relative humidity by the Hamon method (Chang, 2006).

Indoor water uses

Household water uses in CWB is divided in use for Toilet, Kitchen, Bathroom and Laundry respectively. Unfortunately CWB does not allow including water uses that are common in the study neighborhood, such as cooling of buildings in summer, dust reduction, bonsai irrigation and washing of motorbikes. The total urban water consumption in the year 2010 was collected from Hanoi Water Companyand divided by the total population in the city to get the average water consumption per capita per day. Due to lack of specific information about the water uses in the neighborhood, a study of 20 typical householdin Hanoi (CEETIA, 2006) was used as an estimated for the study neighborhood.

Physical characteristics

Based on site visits, the study neighborhood was identified as a sub-catchmentand was divided into 4 mini-clusters (Figure 1). Information about population, area and land uses in the mini-clusters was collected or measured by the author during site visits. The average occupancy per household was obtained from the total population and the number of unit-blocks in the mini-clusters. The average area of one unit block was the total area of unit blocks divided by the number of unit blocks within the mini-cluster. The area of roads and pavements were collected from reports of group leaders and measurements.

Water management options

CWB allows the evaluation of a large number of water management options at different scales. In this research rainwater harvesting, wastewater recycling and green roofsat unit-block scale were evaluated.

III. RESULTS AND DISCUSSION

CWB setup

Characteristic of mini-clusters and unitblocks are given in Figure 2. Mini-cluster number 1 and 4 consist of only one unit-block, they refer to one nursery and one community center, respectively. Mini-cluster 2 and 3 are semi-detached houses without garden and terraced houses without garden, respectively. No public open (green) space was recorded. These two types of houses and the virtual absence of pervious area are very common in Hanoi.

Table 2. The mini-clusters and unit-blocks defined for the study neighborhood (sub-catchment)

Mini-cluster number	Total area (m^2)	Number of unit-blocks	Average area of roof (m^2)	Average occupancy per household	Average area of pavement (m^2)	Road area (m^2)
1	280	1	40	0	240	0
2	17090	470	33.4	3.6	0.62	1102
3	6422.7	147	38.1	3.6	0.82	702
4	270	1	195	152	75	0

Flow measurements

Dry weather discharge varied from 130m^3/day to 386m^3/day, due to the fact that daily demand is affected by holidays and weekends. The average flow was 215m^3/day. The wet weather flow (659m^3/day) after a rain event of 9 mmwas 3 times higher than the average of 17 dry flows (215m^3/day) (Figure 2). It confirms that in combined sewage systems, stormwater comprises the largest fraction of the total flow, especially in countries with rainfall as high as in Vietnam (1700 mm precipitation per year in Hanoi). Clearly, a large amount of rainwater with quite good quality could potentially be used for beneficial purposes. The flow pattern during the dry days was similar as the pattern that is often observed in urban areas (Metcalf and Eddy, 2002), except that in the study neighborhood the infiltration of groundwater is apparently very low, as indicated by the very low nighttime flows.

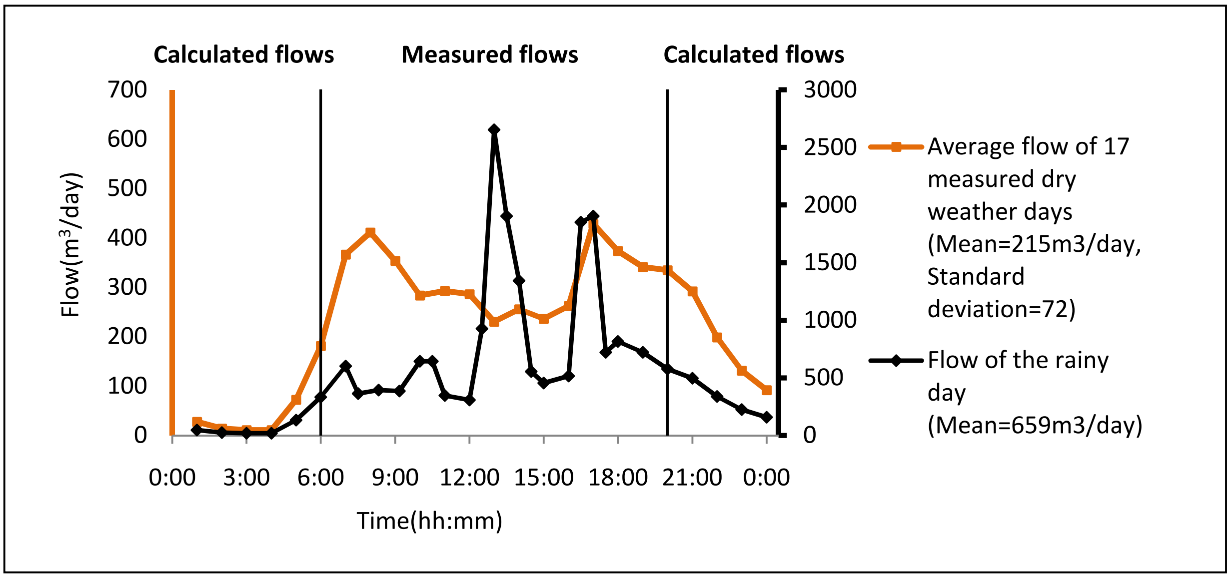

Figure 3. Daily average flow fluctuation of 17 dry weather days and one rainy day

Calibration process

Flow calibration

Default parameter values of CWB values were used to predict the dry weather and wet weather flow of combined wastewater from the sub-catchment. The predicted values were compared to the measured values and where necessary the calibration parameters were adjusted. For dry weather flow, it was assumed that 33% of water was used for the outdoor uses that could not be included in CWB (described above) and that do not generate wastewater. If in addition 5% of the water use in the kitchen was lost through bonsai irrigation, then the simulated discharge reproduces satisfactorilythe measured discharge. Satisfactorily was defined as a maximum difference of 10% between measured and simulated values (Table 3).

Table 3. Measured and simulated discharge

Dry weather discharge (m^3/day)		Difference (%)	Wet weather discharge (m^3/day)		Difference (%)
Measured	Simulated		Measured	Simulated	
215.0	238	10	659.0	452	31

The wet weather flow is affected by the extreme imperviousness of the sub-catchment, which was set to 99% in the calibration process and in accordance to field observations. 98%

ofroofs and paved areas at uniblock scale and roads at mini-cluster scale are estimated to be impermeable and connected to the drainage system. The initial losses from impermeable surface were defined as 0.1mm. Even after calibration the simulated storm discharge (452m^3/day) was one third smaller than the measured value (659m^3/day). The difference may be explained by stormwater overflow from a neighboring area (which is at a slightly higher altitude). Unfortunately there are no detailed sewerage maps available for this part of Hanoi. Based on comparison between observed and simulated discharge quantities, an estimated 30% of measured stormwater could be overflow.

Table 4. Overview values of default and calibration parameters required for CWB in study neighborhood in Lang, Hanoi

Parameter		Unit	Default value	Calibrated value
Effective roof area		[0-1]	0.95	0.98
Effective paved area		[0-1]	0.4	0.98
Roof initial loss		[m]	0.0005	0.0001
Paved initial loss		[m]	0.0035	0.0001
Proportion of surface runoff as inflow (impermeability)		[0-1]	0.6	0.99
Effective road area		[0-1]	0.75	0.98
Road initial loss		[m]	0.0035	0.0001
Road runoff	COD	[mg/L]	107	170
	TP		0.4	0.9
	TN		3	6
	NH_4-N		0.5	4
Roof first flush	COD	[mg/L]	132	190
	TP		0.4	0.9
	TN		12	20
	NH_4-N		6.8	10
Roof runoff	COD	[mg/L]	66	95
	TP		0.2	0.5
	TN		6	10
	NH_4-N		3.4	5
Pavement runoff	COD	[mg/L]	66	95
	TP		0.4	0.9
	TN		3	6
	NH_4-N		3.4	5
Toilet flushing load	COD	[mg/c/d]	18000	20500
	TP		560	350
	TN		6362	2750
	NH_4-N		5075	800
Kitchen load	COD	[mg/c/d]	7000	No change
	TP		30	
	TN		110	
	NH_4-N		26	
Bathroom load	COD	[mg/c/d]	8000	No change
	TP		10	
	TN		214	
	NH_4-N		62	
Laundry load	COD	[mg/c/d]	10000	No change
	TP		360	160
	TN		152	No change
	NH_4-N		16	No change

Contaminant calibration

The COD load predicted for dry weather days by CWB using default values was significantly lower than the load measured. This could be caused by CWB using a COD removal % in the septic tanks that is much higher than reality, due to improper maintenance and desludging of the tanks. Therefore calibration (Table 4) started by changing the COD load from septic tank, r, since the efficiency of septic tank will be reduced by the time usage if the maintenance does not care properly. In contrast, the load of TN, TP, NH_4-N predicted for dry weather based on default values was higher than the measured values. The reason for this is unknown, though it is generally known that local diets cause differences between countries. In addition, the Vietnamese government has recently enforced the minimization of phosphorous compounds in detergents, which could be another reason for the lower values that were observed (Nguyen, 2009). Calibration included the lowering of the TP load from laundry from 360 to 160 mg/capita/day. After calibration the model was able to simulate the dry weather output satisfactorily (Table 3).

By contrast, for wet weather model was failed to simulate concentrations and loads during rainy event, its prediction matched only around 50% compared to measurements. This result directly neglects two first reasons stated in the wet flow calibration part. Since rainfall quantity and total study area will not much affect on contaminant loads, it contributes quantity of stormwater instead quality. The overflow stormwater from the adjacent catchment and first flush could be a reasonable explanation for this poor simulation. Theoretically, the concentrations and loads from stormwater normally are lower than pure sewage because they would be diluted by rain water. However the first flush could contribute more polluted, especially after long time it has no precipitation so contaminants will be accumulated. Moreover, if the overflow occurred the contaminants could be added to the drainage system of the study area. However, no experiment carried out to clarify this amount.

Table 5. Measured and simulated concentrations

	Dry weather (mg/l)			Wet weather (mg/l)		
	Measured	**Before calibration**	**Simulated**	**Measured**	**Before calibration**	**Simulated**
COD	502	382	455	522	308	285
TP	6.0	8.6	5.6	5.2	6.5	3.2
TN	37.0	64	35.5	37.0	50	23
NH_4-N	8.6	46	8.6	11.0	1.2	6.9

Depending on surface materials, the service road and roof and paved area is very similar; they all covered by thin layer of cement and brick. Default contaminant concentrationsof road and roof runoffs were referred from P.Gobel(2006) and Stephen Cook (2010). Since data available limitation, the contaminant concentrations were assumed quite higher than default values because this time was dry season this rainy event was the first one after a long time no rain. Therefore, on surface of roof, road and pavement could be accumulated pollutants.

Urban water management options

In this research, urban water management applications focus on household scale only.

Rainwater harvesting

For rain water used for flushing toilet only, water supply can be saved 11%, 12%, 13%, 14% when set up tank 1m^3, 3m^3, 5m^3, 10m^3 volume respectively. As we know that in this case study water for this purpose was 33m^3/day (equal nearly 14%) so apparently the tank with 10m^{3}volumes could be a best choices. However, increase rain tank volume 10 times for instance from 1m^3 to 10m^3 but water supply replaced by rainwater slightly increase with only 1.27 times, or in other words, small amount of collected rainwater was used for flushing toilet while the rest was overflowed. Therefore, in economical aspect setting up 1m^3 of tank volume is much better than tank with 10m^3. It means that efficiency of rainwater use is not always proportional with the tank volumes. This is also proved by Tong (2011) in application of rainwater harvesting in Tel Aviv's.

As the assumption made before, 33% of water supply could be used for the other purposes (bonsai irrigation, water-cooling, dust reduction and motorbike washing) and their wastewater were evaporated. Hence, in fact the overflow will be lower than the values stated in the table 6or stormwater discharge minimized.

For rainwater used for all indoor water consumptions (for use1 and use2 and use3 and use4), so water supply can be replaced 32%, 39%, 43%, 48% by rainwater with 1m^3, 3m^3, 5m^3, 10m^{3}tank volume respectively. With the same previous argument, the tank 1m^3 is encouraged to set up.

As a result, the overflows will be drastically decreased; these numbers and the amount of water consumption were proportional. The more rainwater can be used the more water supply can be saved and the less stormwater overflow. This observation supported that rain water harvesting plays a key role not only stress diminution for water supply source but also is solution for over capacity of the drainage system. It is illustrated by lower volumes of stormwater discharge.

Table 6. Results of rainwater harvesting, wastewater recycling and green roof at household scale

Application		Unit	Baseline	Rain water harvesting tank (m^3)								Wastewater recycling (m^3/day)		Green roof
				For use 1				For use 1 and Use 3 and Use 4						
				1	3	5	10	1	3	5	10	0.054	0.3	
Water consumption		m^3/day	238	213	209	206	204	179	159	152	143	203	203	
Reduction water supply		m^3/day	0	25	29	32	34	59	80	86	96	35	35	
Total discharge		m^3/day	351	326	322	319	317	293	272	266	256	316	316	
Stormwater discharge		m^3/day	115	90	86	83	79	57	36	30	20			73
Rainwater overflow		m^3/day		83	79	75	74	49	28	22	12			
Overflow of treated grey water												0	150	
Contaminant loads	COD	kg/day	118									96	87	
	TP	kg/day	1.4									1	0.9	
	TN	kg/day	9.5									8.1	7.9	
	NH_4-N	kg/day	2.5									2.5	2.5	
Evaporation		m^3/day	1											44

Benefits from rainwater harvesting were proved in many areas in the world. Tokyo is one of such area, the water practices have met 20-60% of their local water demand (Furumai,

2008) comparing to the study area this value were 32%. Furumai also stated that at large-scale storage rainwater is a very useful measure for water demand in emergency cases. Additionally, in Tokyo rainwater harvesting is part of environmental education to create awareness on sustainable urban water management. In the same way, one research carried out in Metropolitan Area of Barcelona (Spain) showed that rainwater can meet more than 60% the landscape irrigation demand in both single and multi-family buildings (Domènech and Saurí, 2011)., In addition, in Jordan by collecting rainwater from roofs of residential buildings helped saving 5.6% of total domestic water supply (Abdulla and Al-Shareef, 2009). Thisinformationis only few evidences to confirm that stormwater collection has been contributing large benefits. Therefore, by implementing rainwater collection in Hanoi significant benefits can be achieved. Hanoi has high potentiality to apply this option with annual precipitation around 1700mm, so rainwater can be collected with high volume to the storages and directly distributed to households for non-potable water use purposes.

Wastewater recycling

In this research, the wastewater recycling option conducted from grey water will be treated and reused for flushing toilet. Beforehand, grey water characteristics were recalculated based on information from calibrated model.

In table 6, the reduction requirement calculated based on the difference between the contaminant concentrations and the proposed non-potable water criteria. These values 0.38, 0.83, 0.73 and 0.82 for COD, TP, TN and NH_4-N respectively were applied for treatment efficiency in the later simulations (these numbers were calculated from needing reduction of contaminant of grey wastewater quality to meet the rainwater quality).

The grey water equals 80% of water supply (excluding water used for other purposes). As calculated before, around 14% (or 33m^3/day) of total water consumption was used in toilet flushing that relatively 17% of grey water should be treated for the replacement or relatively 0.054m^3/day per household. As a result, partly grey water was recycled and reused for flushing toilet, the rest continues discharging to the sewage system.

The assumption made that 110m^3/day of water supply was used for the other purposes. As a light, if each house clean 100% (equal 0.3m^3 or 185m^3/day/study area) of grey water then water supply for flushing toilet and for the other purposes will completely replaced. That was proved by reduction water supply and overflow volumes in Table 6laid out that COD, TP, TN and NH_4-N loads went down varied from contaminant to contaminant. The load reductions of 0.054m^3 grey recycling were 18%, 31%, 15% and 0% respectively compared to baseline. There was a varied load reduction because one hand the different treatment efficiencies were set up on the other hand the different loads from grey water compared to black water of the contaminants. For instance, COD emission from three first uses was 25g/c/d that is 10% higher than emission from toilet (20.5g/c/d) but the removal was only 0.38. While TN loaded from grey water was 60% lower than from black water and the removal was 0.73. Consequently, the higher load reduction of TN compared to COD was presented.

Table 6 showed that quantity of the grey water recycling of second option (0.3 m^3) was almost 6 times higher than the first option (0.054m^3) but a small different load between two options were reported. This can be explained that most of contaminant was from toilet whereas these options did not be apply for black water. Furthermore, the overflow of treated grey water (150m^3/day) mixed with effluent of septic tank. Appropriately, the contaminant loads were diluted a bit compared to the compound of non-treated grey water and septic tank output. However, in reality the overflow of treated grey water will not be recommended discharge to sewage, it should be used for the non-potable purposes instead.

Wastewater recycling showed that it can significantly contribute not only to imported water reduction but also to reduction of contaminant loads in the study area. There are many published reports proved that the potable water was saved through reclaimed wastewater. EnedirGhisi stated that by using treated grey water the potable water savings range from 28.7% to 34.8% in a multi-storey residential building in Florianopolis, Brazil (Ghisi and Mengotti de Oliveira, 2007). It was reported that 48% fresh water supply by Nagpur Municipal Corporation can be saved by using treated grey water in Nagpur, India (Mandal, Labhasetwar et al., 2011). Additionally, the implications of household grey water treatment and reuse helps saving of up to 43% potable water in Denmark. Likewise, for the study in Hanoi, 43% of imported water can be saved if 100% of grey water is treated and reused for non-potable purposes. However, in Hanoi reclaimed wastewater has not been considered as an alternative water source for non-potable purposes. So far it has been used directly for agriculture irrigation but that can have potential health risks when using these agriculture products. In Hanoi domestic wastewater is discharged to the receiving water bodies and we have been paying for that. Most of receiving water bodies is polluted even worse they become open sewage drainages for whole city. It is time for re-thinking about the importance of wastewater treatment and reuse. The results about decentralized wastewater recycling and reuse at unitblock and mini-cluster scale in this study are useful reference for water' policy-makers in Hanoi. They can be used as potential options in seeking sustainable water management for domestic wastewater problems in Hanoi.

Green roof

There are many green roofs can be set up depending on substrates, plants or designs. For example, soil types and thickness of soil layers. In CWB green roof was set up with 3 parameters: roof recovery (%), soil thickness (m) and drainage rate (m/day). In the study area, around 30% of total roof area occupied by water supply tank so 70% covered roof area will be performed. Together with 0.35m of soil layer and 0.15 m/day of drainage rate were tested.

The modeled results showed that the green roof operation produced44times evaporation higher baseline scenarios and consequently stormwater discharge decrease 37% compared to baseline.

Roof-greening benefits have proved in many areas in the world. Kohler (2005) found out that in hot and humid tropical countries green roof significant improves microclimate and cut the peak load. For microclimate improvement he showed that surface-temperature of household was lowers since higher evaporation. For instance with 10cm of substrate, an evapotranspiration of 90% of the summer precipitation and 75% of the annual precipitation. Furthermore, by comparing surface temperature of a greened roof with a conventional tarboard roof Centgraf(2005) stated that missing evapotranspiration increases the thermal radiation caused by higher surface temperature, paved area like concrete and the ability of such surfaces store heat. Hanoi has very high proportion of pavement and conventional roof area, in this study they made up 100% and 89% of total area respectively. This area can be a heat storage that contributes unpleasant air condition especially in summer in Hanoi. This suggests that roof-greening option could be a good application for Hanoi's house temperature control. In fact, this research showed that by implementing greened roofs, evaporation increased 44 times higher than conventional roofs. Moreover, green roof was also contributing in overflow slowing down because the runoff on pervious surface was slower than pavement area. Bustorf (1999) proved that depending on the soil layer and the saturation of the soil the intensity of stormwater runoff from green roofs can be 80% lower than from conventional flat roofs. That is meaningful for Hanoi because it has a high density of precipitation that causing flash flood. Thus overflow often occurs in the combined drainage system. It suggested that greened roof application can be help to cut the flash flood if it is applied in Hanoi. In brief, roof-greening means much more than such conventional surfaces.

Proposed strategies for urban water management in Hanoi

From the obtained results of the water management options, the overall proposed strategy named "Towards sustainability for Hanoi urban water management" will be recommended. This strategy aims to plan forstormwater harvesting, wastewater recycling and roof-greening operations in Hanoi properly from starting point to wishing point. The strategy was clarified to two stages. Stage 1 assigned "Testing and Learning" and could be implemented in 5 years period. Stage 2 was "Widen implementations", and time was proposed fifth years onwards.

For stage 1, set up experiments for stormwater harvesting, wastewater recycling and green roof at unit block and mini-cluster scale. The overall objective of this stage is to public ideal models of the water management options at the small and larger scale;to suggest advantages and suitable solutions for those applications. Testing and Learning period could be concretized by two plans called Volunteer and Demonstration. Volunteer plan, basically, as name itself, were built up voluntary of the involvers who willing to take activities to support community in environmental improvement. In this case those people who care about water environment will be major "champions". For instance, for rainwater harvesting implementation, the first step is a selection some volunteer households to set up rainwater tanks. For houses with 3 or 4 inhabitants tank volume can be $1m^3$ (reference from the results of rainwater harvesting at unitblock scale). However, this is flexible depending on precipitation and consumption quantity. The next step is selection and adaptation of rainwater harvesting technique for the experiment location. The involvement of scientist, engineer inside or outside of Vietnam and local people will be clarified. Those people who can do jobs related to their background. Monitor rainwater quality, quantity and treatment can be done by environmentalist while engineer can satisfy technical parameters to operate the tank etc. This plan could be carried out at least one year to monitor how collected rainwater can be used to supply in both dry and wet weather seasons. At the end all results in term of cost-benefit analysis, technology will be integrated and published through different performance such as media, user manual, handbook, technical design criteria or scientific article.

For demonstration plan, in principle this is similar the Volunteer plan. However, boundary and organization are more upgraded. Results of this plan will introduce an ideal model of rainwater harvesting. Here, every people interested in rainwater collection feel free to come, learn and be transferred technology. Location to carry out the plan is the whole area, could be 2 or 3 hectares as the study area of this research (consider as mini-cluster scale) instead of the some volunteer houses as former plan. The local government can play a crucial role to ensure the plan worked out properly. Their responsibilities are preparation and setting up the whole package such as call fund, concretize plan, and organize involvers. Consequently, rainwater-village will be widely presented.

For stage 2, the aims areto widen the urban water management options for whole Hanoi. From households to buildings, from offices to hospitals, school etc. could make a plan for the suitable water management options and implementation. To expand this applications, enforcements not only from human resource, technology and finance but also from the government is very important. Government could support tools such as regulation, policy and law.

How stormwater harvesting, wastewater recycling and roof-greening operation can contribute IUWM in Hanoi and how the proposed strategy can contribute IUWM? If the first question is answered patently the second question will be solved because this strategy was proposed to support those water management options. Review current Hanoi's water practices and zoom in to the study area characteristics in section 3. In general, they seem failed in all water management sectors. Unsustainable water supply in term of quality and quantity, ground water going down fast, contaminants was recorded (NH_4-N) and also dealing with lack of energy for the treatment and distribution. Also, small amount (7%) of domestic wastewater is treated consequently serious pollutions in the receiving water bodies. Furthermore, stormwater is wasted and considered as stress for the combined drainage system. This situation has to be switched off and the alternative water management needs to be carried out.

Table 7. Relevance of the water management options and IUWM features

Urban water management options	IUWM features	Total urban water cycle benefits for thestudy area
Stormwater harvesting	Stormwater used for toilet flushing and the other purposes (bonsai irrigation, water-cooling, dust-reducing, motorbike washing). Source control of stormwater.	Depending on tanks volumes and residential demands. For instance, with 5m^3 tank volume, 97% and 69% of water use for toilet flushing and for other uses purposes respectively can be saved. Reduction in stormwater discharge by 28%.
Wastewater recycling	Treated water uses for toilet flushing, and the other purposes. Improve wastewater quality and flow management.	Estimated 100% of water supply for toilet flushing can be replaced by reusing treated grey water. Estimated 18%, 31%, 15% of COD, TP, TN loads respectively can be reduced from wastewater discharge leaving the site.
Green roof	Use roof-greening for house temperature control. Storm water flow management.	Evaporation can increase 44% compared to baseline, reduce stormwater discharges and cut the peak load during rainy event.

(Adopted from V.G. Mitchell, 2006)

Table 7 showed that how the water management options related to IUWM features, it was illustrated by positive effects on total urban's water cycle benefits for the study area. Mitchell (2006) stated that the most important benefit of an integrated approach to urban water systems is the potential to increase the range of opportunities available lead to more sustainable systems. The above urban water management options are the potential ways to consider all the available opportunities for improving the urban water cycle the study area. As a results, increase water supply source, reduce wastewater discharge in both quality and quantity to receiving water bodies and closer to natural water cycle by increasing evaporation.

IV. CONCLUSION

The results of this research can be summarized as follow:

Data was sufficient and reliable to feed CWB. The CWB model was able to describe/simulate satisfactorily the urban cycle in dry weather days. However, it was not successful to simulate in the wet weather day.

Water supply can be saved 31% for all non-potable purposes by implementation of $1m^3$ tank per household. Amount of grey wastewater recycling and reuse was sufficient for toilet flushing and for the other uses. 18%, 31%, and 15% of COD, TP and TN loads respectively can be reduced by applying this urban water management option. Green roof had positive effects on urban water cycle through the increase evaporation 44 times in comparison with the conventional roofs.

The "Towards sustainability for Hanoi's urban water management strategy" could be considered as alternative approaches to obtain IUWM.

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ỨNG DỤNG MÔ HÌNH CÂN BẰNG NƯỚC ĐÔ THỊ (CWB) NHẰM XÂY DỰNG CHIẾN LƯỢC QUẢN LÝ MÔI TRƯỜNG NƯỚC THÀNH PHỐ HÀ NỘI

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TÓM TẮT

Quản lý nước đô thị thường xuyên phải đối mặt với ba vấn đề cơ bản: nhu cầu cung cấp nước sạch, xử lý nước thải sinh hoạt và quản lý nước mưa. Đặc biệt, ở các nước đang phát triển những vấn đề này càng thách thức nhà quản lý. Mô hình quản lý nước đô thị tích hợp (IUWM) được coi là một trong những phương pháp tiếp cận hiệu quả để giải quyết cùng lúc các vấn đề trên. Cách tiếp cận này liên kết các vấn đề cấp nước, nước thải và nước mưa trong một đơn vị quản lý. Thành phố Hà Nội hiện đang phải đối phó với tình trạng ô nhiễm tại nguồn tiếp nhận nước thải, cạn kiệt nguồn nước ngầm và ngập úng trong mùa mưa. Mô hình cân bằng nước đô thị (CWB), phát triển và sử dụng bởi dự án SWITCH, được áp dụng trong nghiên cứu này nhằm đánh giá các vấn đề về nước nêu trên và cân bằng chất gây ô nhiễm cho một khu vực nghiên cứu điểm thuộc hệ thống nước đô thị Hà Nội. Nghiên cứu đã cung cấp ứng dụng quản lý nước đô thị bền vững bao gồm thu hoạch nước mưa, tái chế nước thải và mái nhà có thảm thực vật. Theo nghiên cứu này với 1m 3 bể tích nước mưa sẽ đủ cấp 31% cho các mục đích sinh hoạt hàng ngày (trừ ăn uống) và nếu tái chế 540L/ngày nước xám sẽ là đủ cung cấp cho xả nhà vệ sinh. Ngoài ra chiến lược về “Hướng tới phát triển bền vững cho quản lý nước đô thị Hà Nội” cũng được đề xuất trong nghiên cứu này.

Từ khóa: Cân bằng nước, Hà Nội, mô hình vòng tuần hoàn nước, quản lý nước đô thị.

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