A Conceptual Model for Water Sensitive City in Surabaya

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Abstract. Frequent inundated areas, low quality of water supply, highly dependent water sources from external are some key problems in Surabaya water balance. Many aspects of urban development have stimulated those problems. To uncover the complexity of water balance in Surabaya, a conceptual model for water sensitive city is constructed to find the optimum solution. A system dynamic modeling is utilized to assist and enrich the idea of conceptual model. A secondary analysis to a wide range data directs the process in making a conceptual model. FGD involving many experts from multidiscipline are also used to finalize the conceptual model. Based on those methods, the model has four main sub models that are; flooding, land use change, water demand and water supply. The model consists of 35 key variables illustrating challenges in Surabaya urban water.

1. Introduction
Surabaya is a capital city of East Java Province and also the second largest city in Indonesia. The fast growing economic in Surabaya can be seen from percentage of economic growth around 6-7% annually [1]. The impacts of its economic performance are varies in terms of development. To some extent, the good economic performance leads to the increasing investments particularly for trading and housing investments. In other words, Surabaya becomes one of the interesting cities for investments. From 2010-2015, a steady increase of high-rise building indicates that the development process in Surabaya is at high rate. Consequently, the high demand will need a high supply of infrastructures including managing water.

In terms of water management, water sensitive city (WSC) has considered 6 stages of city form in terms of water management (Brown et al., 2009) as on Figure 1 [2].

Water Supply City
The Water Supply City represents the first modern urban water city-state in Australia, reflecting the colonization of Australia by Europeans in the early 1800s. The normative underpinning at the time was the effective provision of safe and secure water supplies for a growing urban population, and centralized provision, particularly for the elite, where the social movement of cleanliness was strongly linked with social status.

Sewered City
In concert with some of the newly developing American cities, from the late 1800s Australian cities invested in separate sewerage systems to avoid pathogen infection from wastes and industrial effluents in combined sewerage. Many cities also invested in on-site septic systems due to the perceived prohibitive cost of providing this infrastructure.
Drained City

Australia was a strong innovator in the professional community – focused on developing techniques and models that enabled the rapid and efficient conveyance of storm water out of cities, to receiving waterway environments. This substantially impacted the development patterns of Australian cities, with numerous waterways piped and located underground, and river systems channelized to allow for more urban development in floodplain areas. Many houses at this time were constructed facing away from waterways, which were often perceived as waste dumping grounds, and were therefore not a socially valued part of the urban landscape.

Waterways City

In this phase, water began to be integrated into planning functions as important visual and recreational features for communities, and measures were taken to reduce pollutant inputs into waterways, which involved regulating environmental discharges from wastewater treatment plants and industrial processes as well as replacing septic tanks with centralized sewerage systems. Science revealed the impact on waterways from diffuse-source storm water pollution, prompting researchers and practitioners to develop new technologies such as wetlands and bio-filtration systems to protect receiving waterways.

Water Cycle City

The Water Cycle City is a response to the recognition of the current ‘limits’ to traditional water sources for supplying ever growing populations and urban development, as well as the limits to waterways being able to assimilate pollution. It also reflects the growing normative acceptance of the need for social, economic and environmental sustainability.

Water Sensitive City

Water Sensitive City concept is a form of integration among the normative values of environmental repair and protection, supply security, flood control, public health, amenity, livability and economic sustainability, amongst others. Communities would be driven by the normative values of protecting intergenerational equity with regards to natural resources and ecological integrity, as well as by concern that communities and environments are resilient to climate change.
Surabaya has experienced in between of a water supply and a drainage water city level. It indicates that many program of infrastructure occurred in providing water supply and draining the water to avoid floods. Surabaya government has “Master Meter” program that provided clean water from PDAM to household [3]. Other programs that indicate a more sensitive water management are still in pilot project or in a small-scale program.

On the other hand, the city problem related to water is increase. Inundation is still key issues in Surabaya City. Although the average of height, duration and areas of inundation are decreases as in Table 1, number of inundation is still increase [4]. The case of inundation in Surabaya is still problematic.

### Table 1 Inundation recapitulation in Surabaya from 2010-2015

| Year | Total Inundation | Total Inundate Area (Ha) | Inundate Average Period (Minutes) | Inundate Average Depth (cm) |
|------|------------------|--------------------------|-----------------------------------|-----------------------------|
| 2010 | 148              | 2183.07                  | 59.27                             | 20.36                       |
| 2011 | 172              | 2213.00                  | 54.25                             | 18.64                       |
| 2012 | 195              | 1613.78                  | 58.00                             | 19.66                       |
| 2013 | 195              | 1371.71                  | 57.63                             | 17.70                       |
| 2014 | 195              | 1303.13                  | 55.15                             | 16.82                       |
| 2015 | 195              | 1270.55                  | 53.38                             | 16.40                       |

Source: BAPPEKO Surabaya, 2015

One of the challenges is the impact of climate change to the variability of rainfall. Pamungkas, 2013 [5] indicates that the rainfall pattern will have similar total amount of water for rainfall in a year with less numbers of rainfall days compare the previous years. Consequently, the number of extreme rainfall in a day will have higher probability than before. This phenomenon will challenge the Surabaya government in managing its run off to avoid inundation.

Furthermore, the challenge of water management is also arising in water supply. Kalimas River as the main source of water supply has a limited volume to support a fast-growing need of water in Surabaya. Even though, the coverage if water supply in Surabaya has 95.51% of the population in 2016 based on PDAM Surabaya City Profile, 2016 [6], the fast-growing city may cause Surabaya has limitation in supporting the water supply in the future. A new promising water supply from Umbulan is also still in a questionable stage as the construction of the spring water is still in discussion among related municipalities, even Umbulan have maximum production 4000 liter/second that can be used by Surabaya 1000 liter/second, but nowadays Surabaya use 500 liter/second [7]. Supply from outside of Surabaya is indicated a non-sensitive city since it causes a dependency to outside of Surabaya. The worst situation for water supply is on the quality of water provided by Surabaya. In 2014, Department of Health Surabaya had a water quality inspection in 3 ways are microbiology, chemistry and physics. Based on the quality inspection in microbiology are 86.85% in good quality, in chemistry are 82.19% in good quality and in physics are 100% good quality [8]. The ideal water quality as drinking water is still far behind resulting the community has to buy other good quality water for drinking and cooking. It results a highly cost of living for Surabaya residents or poor quality of health related to water use.

Those complex problem based water in Surabaya indicates that Surabaya needs to evaluate their business process in managing the water. A modeling process is one of decision support systems (DSS) that can evaluate a system in an objective manner. It can also make an optimization in finding the most effective combination for a complex system such as water. Therefore, modeling in water to make Surabaya as water sensitive cities is important. This paper will explain the modeling process particularly in conceptual model building.
2. Methods
To have an urban water model that values the goals of water sensitive cities in Surabaya, we build a hypothesis model based on rational basis. This hypothesis is then assessed and formulated to reflect the real situation of urban water management in Surabaya as well as framing the water sensitive cities concept via serial group discussions. Serial group discussions consider many aspects of urban waters, that are; water resources, water quality, water quantity, weather, infrastructures, demography, social cultural, economic, engineering aspect, land use change, urban policy and technology. To increase validity, government and non-government publication in supporting the conceptual model accompany the rational basis judgments in serial group discussion. At this stage, the formulation on conceptual model of urban water in Surabaya is the key output of the research.

3. Result and Discussion
In building a conceptual model in Surabaya, we value catchment areas boundaries as the main significant division since water will follow the physical characteristics. Three main segments of the areas can be divided that are; from upper catchment to Jagir floodgate, local system which is around from Jagir floodgate to the estuaries, and around coastal areas. Those segments have difference characteristics and are very important to be considered for making a water sensitive city.

3.1 Upper Catchment Area up to Jagir Floodgate
This segment highlights that a vast catchment area called by Brantas Catchment Areas affect the Kalimas River. The main concern on this is the quantity of run off. Run off from Brantas River is divided into two main rivers before arrive in Surabaya, that is: Wonokromo River and Porong River in Sidoarjo. If the run off in Brantas River is in high volume, it could inundate the catchment in Porong and Wonokromo. Therefore, limited run off is needed to maintain the balance between water debit and river capacity in both rivers. To limit the debit of run off, the model will consider several key variables, those are;

1. Land use in non-local areas. Most of the land use in upper catchment is open space. An issue of deforestation due to the need of land for development has been escalated in all the municipalities in the upper catchment. Since there is a large of land conversion, the debit of run off in the river is increase. In terms of the land uses, Brantas catchment area has 280.258 ha critical areas. The critical areas indicate an alarming condition for run off. Among the critical areas, the middle critical dominated the areas [9]. Therefore, considering the land use in non-local areas is one of the key variables in building the model.

| No | Area                              | Critical Forest Area (Ha) | Total |
|----|-----------------------------------|--------------------------|-------|
| 1  | Protected forest                  | 4.706                    | 5.406 |
| 2  | Conservation forest               | 7.067                    | 10.997|
| 3  | Production forest                 | 26.339                   | 47.338|
| 4  | Protected area outside the forest | 4.300 9.046 674          | 14.476|
| 5  | Agricultural cultivation          | 47.216                   | 158.948|
| 6  | River border                      | 18.530                   | 21.907|
| 7  | Green open space at the urban     | 1.014                    | 2.829 |
|    | settlements near the beach        | 1.815                    |       |
| 8  | Flood area                        | 158                      | 158   |
|    | Total                             | 26.267 93.469 120.953    | 280.258|

Source: Balai Besar Wilayah Sungai (BBWS) Brantas, 2011
2. Rainfall. In terms of meso-level, rainfall data will have a different pattern than before. Some of the situation highlight that the rainfall will have a high degree of variability. To capture rainfall variability, we use rainfall data daily then grouped into monthly data. For average rainfall, Brantas catchment area has 2,000 mm/year. In addition, average rainy day is 61-150 day/year and mostly occurs in rainy season [9].

3. Land Characteristics. As the fertile land in upstream, most of land in the upper catchment has high ratio of infiltration. The infiltration rate is a converse version of run off. Therefore, the original type of land in upper catchment can reduce the run off. Most of the type of land in Brantas catchment area is alluvial, which has erodibility between 0,12-0,17 and occupies the area until 320.285 Ha [9].

4. Water usage in upper catchment can affect the debit of water in the river. To date, the water usage in upper catchment areas can be in the form of irrigation and water supply. Water usage in Brantas catchment area is such as irrigation, domestic, non-domestic, industry and fishpond [9].

The interaction among those variables in debit of run off in upper catchment can be seen on Figure 2.

![Figure 2 Conceptual Model for Debit Run off in Upstream](image)

In terms of water quality, we value the quality of water in the Brantas River since the same water is used for water resources in Kalimas River. We consider several variables related to water quality, are:

1. Erosion. Erosion in upstream will make sedimentation in the river. The sediment in river will cause poor quality of water. The erosion will be depended on land use types and land characteristics. Since most of the land in Brantas catchment areas is alluvial, the possibility of erosion and sedimentation is high. Based on Table 3, we can see that the sedimentation level is high in upper catchment areas. This sedimentation is a result of erosion in land areas of upper catchment areas. The high sedimentation will directly affect the water quality [9].

2. Dumping waste along the river. Dumping waste could be from two main sources that are residential areas and industrial areas. Current situation indicates that the point sources pollution from both land uses is high. In residential areas, education, culture, urban system, and number of population of residents along the rivers influence the number of wastes dumping in the river. Numbers of industries, types of industries, law enforcements are some variables influencing the number industrial waste dumping on river. Those two types of point
source pollution will influence the quality of water [9]. For industry, Brantas catchment area has 483 industries that can be dumping waste on river. Based on Surabaya River Pollution Control Action Plan Study in 1999, BOD net from industry is 125 ton BOD/day and for domestic, BOD net is 205 ton BOD/day. These number of BOD based on Ministry of environment Regulation no 1 2010 about water pollution control, Allocations above allowable pollutant load.

The interaction among those variables in water quality before Surabaya segment can be seen on Figure 3.

### Table 3 sedimentation caused by erosion in Upper Brantas Catchment Area

| Basin Block   | A=RKLSCP (t/ha/year) | M³/km²/year | M³/year | M³/year |
|---------------|----------------------|-------------|---------|---------|
| Upper Brantas | 108,2                | 6,009,2     | 6,0     | 1,093,679 |
| Bango-Sari    | 60,1                 | 333,760     | 3,3     | 874,454  |
| Amprong       | 172,5                | 9,595,6     | 9,6     | 3,335,779 |

*Source: Balai Besar Wilayah Sungai (BBWS) Brantas, 2011*

Since Umbulan spring water is going to be operated, the upstream system particularly in Umbulan will also influence urban water in Surabaya. The supplies of Umbulan for Surabaya will depend on;

1. Spring water debit of Umbulan. Debit of Umbulan in the beginning is around 6,000 L/sec, but now, it is around 5,000 L/sec. among them, only 10% is used for water supply and 90% is discharge to the river (PDAM Surabaya, 2016). The debit of spring water will be a main consideration for allocating water for Surabaya. These sources will become significant additional sources for Surabaya.

2. Commitment among municipalities. Since Umbulan will support some municipalities including Surabaya, the commitment among parties will define the water allocation for Surabaya. Project that support umbulan is National Showcase Project which use method of Public Private Partnerships/PPP [10].

3. Infrastructure capacity. The dimension in every infrastructure built in connecting Umbulan to Surabaya will also influence the debit water for Surabaya. It also will influence the timing.
aspect on providing additional water sources for Surabaya. Umbulan has transmission system and off take system. Those systems distribute water to Surabaya area. The interaction among those variables in Umbulan water source can be seen on Figure 4.

![Conceptual Model for Umbulan Water Source](image)

**Figure 4** Conceptual Model for Umbulan Water Source

### 3.2 In local system

In the local system, we highlight some kinds of matters for urban water in Surabaya. Inundation is still one of the most problematic for Surabaya. Water supply and water use are other things for consideration in managing urban water in Surabaya.

For inundation, the related variables for the model are:

1. **Drainage system.** Most of the problematic condition related to inundation is drainage system. Within the system, there are primary, secondary and tertiary drainage. In Surabaya based on SDMP, there are 5 catchments for drainage service areas, that are: Rayon Wiyung, Rayon Tandes, Rayon Genteng, Rayon Gubeng and Rayon Jambangan. Rayon Wiyung have 38 sub-catchments, Rayon Tandes have 39 sub-catchments, Rayon Genteng have 12 sub-catchments, Rayon Gubeng have 15 sub-catchments, Rayon Jambangan have 11 sub-catchments. Figure 5 illustrates the drainage sub catchments in Surabaya [11].

2. **Local rainfall.** The variability of rainfall also occurs in local rainfall. Therefore, to consider local rainfall, we will highlight the variability of daily rainfall and sum up for monthly rainfall [12].

3. **Local land characteristics.** Inundation in Surabaya is also caused by local land characteristics. Mostly, in Surabaya, the land is formed from clay, which has limited capability to absorb the run off [13]. In addition, the low groundwater causes low level of infiltration in the area. The flat land in majority of Surabaya area makes Surabaya easily to be inundated.

4. **Debit from Kali Brantas River.** Since Kalimas River is connected with Kali Brantas River, some of the kalimas river capacity is used by water from kali brantas. The fluctuated pattern of brantas water discharge in Brantas will affect to the idle capacity of Kalimas River. Therefore, the idle capacity for local run off will be very much depended on the water from kali brantas.
Figure 5 Drainage Sub Catchments Delineation in Surabaya
Source: Surabaya Drainage Master Plan, 2005

Table 4 Total Rainy days and Rainfall in Surabaya 2012-2014

| No | Month    | Rainy days (days) | Rain fall (mm) |
|----|----------|-------------------|----------------|
|    |          | 2012  | 2013  | 2014  | 2012 | 2013 | 2014 |
| 1  | January  | 28    | 26    | 29    | 499  | 648.7| 302  |
| 2  | February | 22    | 20    | 23    | 273.8| 197.3| 266  |
| 3  | March    | 22    | 20    | 19    | 315  | 197.3| 251  |
| 4  | April    | 12    | 12    | 19    | 60.3 | 141  | 253  |
| 5  | May      | 9     | 16    | 13    | 70.6 | 179  | 51   |
| 6  | June     | 4     | 17    | 13    | 3.1  | 235  | 68   |
| 7  | July     | 1     | 9     | 9     | 0    | 91   | 6    |
| 8  | August   | 0     | 0     | 0     | 0    | 0    | 0    |
| 9  | September| 0     | 0     | 0     | 0    | 0    | 0    |
| 10 | October  | 5     | 5     | 1     | 57.3 | 6    | 8    |
| 11 | November | 13    | 13    | 13    | 49   | 80   | 70   |
| 12 | December | 26    | 26    | 24    | 215.4| 371  | 337  |
|    | Average  | 12    | 14    | 14    | 129  | 179  | 161  |

Source: Surabaya dalam Angka, 2015
5. Local land cover. Most of the inundation problems relate to the run off in Surabaya relates to local land cover. The land cover and soil types based on the Darcy Law define the run off itself. In Surabaya, since the rapid growing of build-up areas make the run off increase. Describe a fast conversion level in Surabaya. Residential has a very significant growing number resulting high run off. For the soil types, it has been discussed in point no. 3.

6. Outtake for water use. In Surabaya, outtake water from river is used for local water supply. This water supply covers all type of areas in Surabaya including residential, commercial, and industrial areas. Only limited number for irrigation since there is not many land for agriculture in Surabaya. The main agriculture is aquaculture in which the need of water is supplied by sea tide.

Figure 6 Monthly Brantas Water Discharge

Figure 7 Land Cover Conversions in Surabaya 2001-2015

*Source: Extract Citra Landsat*
The interaction among those variables in inundation can be seen on Figure 8.

![Figure 8 Conceptual Models for Inundation](image)

For water supply, some key variables are discussed as follows;

1. River debit. Kalimas debit will be depended on water from Kali Brantas, intake water from local catchment areas and also the drainage capacity connecting to the main river. PDAM fulfill their need of water supply from two rivers, those are Surabaya River and Kali Wonokromo River. Kali Wonokromo has more supply with 0.425 m³/sec than Surabaya River with 0.119 m³/s.

   | River          | Length (m) | Debit (m³/sec) |
|----------------|------------|----------------|
| Kali Surabaya  | 17,400     | 0.119          |
| Kali Wonokromo | 12,100     | 0.425          |

*Source: PDAM Surabaya*

2. Water production. Debit in Kalimas River is purified to produce clean water. The production of clean water is varying from month to month indicating fluctuated production relies on river debit [14].

   Within the production on Figure 9, Surabaya water supply can cover the boundaries of adequate water supply in general. But, two months in 2015, the water supply is not adequate supplied with current system. In general, the set boundary for water supply is minimum 210 L/person/day. The boundary is from national guideline on construction and building (National Planning Department, Deputy of Water and Irrigation, 2006) [15].

3. Purification technology. Surabaya Local Water Enterprise (PDAM) uses Kali Surabaya and Kali Wonokromo as the main sources of water. The efficiency of water purification will be depended on the current water quality in both rivers and advance technology used in PDAM. In terms of water quality, since the intake of PDAM is just at the border of local system and Kali Brantas, the water quality will be considered following the discussion of water quality on
Figure 10. For the advance technology, purification technology will affect the amount of water can be used for water supply.

![Clean Water Production 2015](image)

**Figure 9** Clean Water Production in 2015  
Source: PDAM Surabaya, 2015

| Month | Total production | Monthly water supply l/person/day | Adequacy (>210 l) |
|-------|-----------------|-----------------------------------|-------------------|
| Jan   | 25,028,242      | 214.5                             | adequate          |
| Feb   | 22,539,675      | 193.2                             | inadequate        |
| Mar   | 25,051,053      | 214.7                             | adequate          |
| Apr   | 24,454,682      | 209.6                             | inadequate        |
| Mei   | 25,317,308      | 217.0                             | adequate          |
| Jun   | 24,522,337      | 210.1                             | adequate          |
| Jul   | 25,330,335      | 217.1                             | adequate          |
| Aug   | 25,676,845      | 220.0                             | adequate          |
| Sept  | 24,937,971      | 213.7                             | adequate          |
| Oct   | 25,965,589      | 222.5                             | adequate          |
| Nov   | 25,290,201      | 216.7                             | adequate          |
| Dec   | 26,508,732      | 227.2                             | adequate          |
| Total | 300,622,970     | 2576.1                            |                   |

**Table 6** Adequacy of Water Supply in Surabaya

*Source: Analysis, 2016*

4. Pipeline system. The leakage is always one of the main problems for water supply in Indonesia. The usage, water quality, construction issues are the main causes for leakage. In
Surabaya, the percentage of leakage is still considered as at the level of reasonable. Water leakage consists of some types of leakages, those are: physical leak caused by the seepage or pipe leak and operational leak caused by waste water excess in operation process, and wasting water [16]. Based on PDAM, the percentage of leakages for whole Surabaya clean water system are 34%.

The interaction among those variables in water supply can be seen on Figure 10.

![Conceptual Models for Water Supply](image)

For water use, some key variables for urban water model in Surabaya are:

1. Population. Surabaya has varies increases in population growth. Most of the population has positive growth in the periphery of Surabaya while some decline indicates in the central of Surabaya. Based on Kota Surabaya dalam Angka BFS, In 10 years, Surabaya population has increased from 2,522,028 to 2,722,876 by growth 1% per year. The number of births and immigration causes the growth percentage [17]. It also has wide difference in terms of daytime population and nighttime population. Daytime population indicates actual residents with additional people moving in to Surabaya for working while nighttime population indicates Surabaya residents only. Those two characteristics of population will impact to the water demand in Surabaya.

| No | Sector PDRB | 2010      | 2011      | 2012      | 2013      | 2014      |
|----|-------------|-----------|-----------|-----------|-----------|-----------|
| 1  | Agriculture | 431,542.7 | 440,989.2 | 467,099.5 | 504,369.8 | 522,264.9 |
| 2  | Mining and Quarrying | 16,714.4 | 17,134.8 | 17,440.3 | 18,095.3 | 18,674.9 |
| 3  | Manufacturing | 45,351,158.5 | 47,601,826 | 51,100,743.7 | 54,450,456.3 | 53,358,226.5 |
| 4  | Electricity and Gas | 1,948,227.1 | 1,828,007.4 | 1,643,231.5 | 1,610,562.4 | 1,59,076.3 |
| 5  | Water supply, Sewerage, Waste Management and Remediation Activities | 416,581.9 | 451,699.8 | 460,964.6 | 470,737 | 474,422.9 |
| 6  | Construction | 23,729940.1 | 25,457.717 | 27,182,986.4 | 29,357,611.8 | 31,368,882.7 |

Table 7 Surabaya GDP from 2010 to 2014
2. Economic growth. The need of water will also be influenced by the economic growth. Point 1 indicates a need of population on water from quantity aspect while economic growth indicates a need of population on water from quality aspect. Growing economy can boast the need on water since it will make impact to the land uses character. In terms of economic growth, Surabaya economic growth in 2014 is around 6.73%. It shows that the growth is getting low compared to 2013 (7.58%). However, the growth is still remaining around 6-7% indicating a stable and manageable development growth. Based on Table 7, we can conclude that the economics of Surabaya is dominated by wholesale and trade with more than 28% of the total Surabaya GDP. Meanwhile, industrial sector takes the second place with around 17% [18].

3. Water usage habitual. The water use will also be very much influenced by water usage habitual from residents. Efficiency will be the key of habitual. The habit can be generalized into several groups such as high-income earners families, low-income earners families, industrial activities, commercial activities and residential activities.

Table 8 Land use change from 2001 and 2015

| Land Use                  | 2001   | 2015   |
|---------------------------|--------|--------|
| Housing                   | 42.01% | 42.00% |
| Urban Farming             | 16.28% | 16.24% |
| Fishpond                  | 15.27% | 15.20% |
| Commercial Use            | 1.76%  | 10.76% |
| Industrial                | 2.37%  | 7.30%  |
| Vacant Land               | 1.78%  | 5.50%  |

Source: *PDRB Kota Surabaya, 2015*
4. Land uses. Since water usage in general can be calculated based on land uses, the changes on land uses can be one of the key variables in predicting water use in Surabaya. The land use characteristics in Surabaya are dramatically changes especially for the growth of commercial and residential areas. Based on the data, the highest land use change occurs in retail sector which is increases from 1.7% until 10.7% up to the total land use in Surabaya. While land use for housing and moor are still constant. Land use for industry and non-productive land increase around 5% in the last 15 years [19]. Those changes lead to the escalated needs of water.

5. 3R culture. The water usage in a city is also influenced by 3R culture of society [20]. Reduce-reuse-recycle is part of cultural aspect in making efficiency in water usage. The 3R culture can be divided into several categories that are local 3R culture, industrial 3R culture, and commercial 3R culture. In local 3R culture, income and understanding are the key variables for efficiency in water usage. For commercial and industrial, a regulation and government incentives can be part of key variables for successes of water usage efficiency.

6. Government regulation. The efficiency of water usage can be established by implementing the supportive government regulation. The regulation of no ground water usage in Surabaya has increased the use of runoff water for daily use. Therefore, the government regulation plays important role in regulating water usage. Since 2012, Surabaya government does not allow the usage of ground water and the regulation is still discussed.

7. Water pricing. Water usage can also be influenced by the price of water. The low price of water can encourage community to have more water than the high price. The prices of water are varying from the type of usage.

8. Pipeline is one of the key variables that have been discussed in earlier section (water supply in local system).

| No | Classification | Pricing code | Usage | Water pricing | Usage/month |
|----|----------------|--------------|-------|---------------|-------------|
| 1  | Classification I | 1            | Non-progressive | 600 | 10 |
| 2  | Classification II | 2A          | 0-10          | 350 | 10 |
|    |                 | 11-20        | 600 |  | |
|    |                 | 21-30        | 900 |  | |
|    |                 | >30          | 1,800 |  | |
| 3  | Classification III | 2B          | 0-10          | 500 | 10 |
|    |                 | 11-20        | 1,000 |  | |
|    |                 | >20          | 2,250 |  | |
| 4  | Classification IV | 3A          | 0-10          | 500 | 10 |
|    |                 | 11-20        | 1,200 |  | |
|    |                 | >20          | 1,900 |  | |
| 5  | Classification V | 3B          | 0-10          | 1,500 | 10 |
|    |                 | 11-20        | 3,500 |  | |
|    |                 | >20          | 6,000 |  | |
| 6  | Classification VI | 3C          | 0-10          | 2,300 | 10 |
|    |                 | 11-20        | 4,000 |  | |
|    |                 | >20          | 5,500 |  | |
| 7  | Classification VII | 4A         | 0-10          | 1,000 | 10 |
|    |                 | 11-20        | 1,500 |  | |
|    |                 | >20          | 2,500 |  | |
| 8  | Classification VIII | 4B         | 0-10          | 1,500 | 10 |
|    |                 | 11-20        | 2,500 |  | |
|   | Classification IX | 4C | 0-10 | 4.000 | 10 |
|---|-------------------|----|------|-------|----|
| 9 |                   | 11-20 | 6.000 |       |    |
|   |                   | >20 | 7.500 |       |    |
| 10 | Classification X | 4D | 0-10 | 6.000 | 10 |
|    |                   | 11-20 | 8.000 |       |    |
|    |                   | >20 | 9.500 |       |    |
| 11 | Classification XI | 5 | Non-Progressive | 10.000 | 10 |

*Source: PDAM Surabaya, 2008*

The interaction among those variables in water usage can be seen on Figure 11.

![Figure 11 Conceptual Models for Water Usage](image)

### 3.3 Around coastal areas

In around coastal areas, key variables in affecting urban water model are:

1. **Sea tide.** In Surabaya coastal areas, the tide gap only 2-meter difference between high tide and low tide (Figure 12). Since the Surabaya lies in the low-lying areas, this tide can still affect the water discharge system from river to the sea. Based on Meteorological, Climatological and Geophysical Agency in Surabaya, we can get the average value for the sea tide each day. The highest tide occurs at 10 p.m., meanwhile the lowest occurs at 6 a.m. every day [21]. Therefore, considering the tide in Surabaya coastal areas for urban water management is important.
2. Debit in Kali Surabaya and Kali Wonokromo. The debit in both river will depend on the level of sea tide. Currently, some local floods occur caused by large amount of local run off and worst by high sea tide for some areas near the coastline. The interaction among those variables in around coastal areas can be seen on Figure 13.

![Figure 12 Sea Tide in Surabaya Coastal Areas
Source: BMKG Surabaya, 2005](image)

![Figure 13 Conceptual Model for Around Coastal Areas](image)

From those 7 figures above on the conceptual model, we can outline the conceptual model for the whole of urban water management in Surabaya as on Figure 14. The conceptual model has 35 key variables for all the three segments of urban cycle for Surabaya. It also covers the key challenges of urban water in Surabaya that are; inundation, water supply, 3R in water usage, technology, high demand due to urban development, tidal flood and run off.
Figure 14 Conceptual Model on Water Sensitive City in Surabaya
4. Conclusions
The conceptual model has been built by understanding the characteristic of urban water in Surabaya. Some supporting data are used to ensure the validity of conceptual model. In addition, we also include some experts in constructing the conceptual model. A variety of experts also validate the conceptual model.

Within the model, 35 key variables are used to uncover the system in three main water segments that are: upper catchment area up to Jagir floodgate, local water system and around the coastal areas. By highlighting the three main key segments, the conceptual model also response to local challenges that affect Surabaya urban water.

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