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Options analysis model for Water Demand Management

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To cope with the needs of increasing urban populations amidst negative impacts of climate change will require mainstreaming water demand management (WDM) in urban water management strategies for the city of the future. There are a variety of options for WDM: urban water managers, engineers and planners need to make correct choices of the most viable options that fit within the socio-cultural, political, economic and environmental context. Ideally, these choices take into consideration the vision of the key city stakeholders and identified scenarios over the longer-term period. This paper describes a simple model developed as one of the outputs of the WDM research under the EU-sponsored SWITCH project, to be used as a decision support tool by urban engineers, planners and managers, with no skills in linear programming. The model uses a VENSIM modelling shell that is freely available on the internet. Application of this tool will make it easier to mainstream WDM options in strategic planning processes for the city of the future.

Need for Water Demand Management

While the population in many industrialised countries is either decreasing or constant, the population in most developing countries is increasing rapidly, resulting in an overall global population increase. The current global population is estimated to be 6.9 billion people, of which 82% live in developing countries (UN-HABITAT, 2009). Consequently, per capita water availability is steadily declining. The water scarcity situation is compounded by the major impacts of climate change on the water resources, and the practical distribution problems concerned with time, space and affordability, leading to a widening gap between demand and supply in many parts of the world. The water scarcity situation will escalate in the urban areas of less developed regions where it is estimated the urban population will increase from about 2.57 billion in 2010 to 3.95 billion in 2030, accounting for 94% of the global urban population growth in the period 2010-2030 (ibid).

The situation calls for mainstreaming Water Demand Management (WDM) in the strategic plans of cities. WDM may be defined as the development and implementation of strategies, policies and measures aimed at influencing demand, so as to achieve efficient and sustainable use of the scarce water resource (Savenije and van der Zaag, 2002). Another commonly used definition of WDM is '...adaptation and implementation of a strategy by a water institution to influence the water demand and usage in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services and political acceptability' (Jalil and Njiru, 2006, p.45). Most definitions of WDM allocate the initiative for WDM to the service provider, which is expected to develop policies and invest into measures to achieve efficient water use both within the water distribution network (i.e. management of non-revenue water) and at the end-users' premises. WDM contrasts with the conventional supply-driven approach to water resources management, whose response to the ever increasing water demand is development of new water sources.

There are five major categories of WDM measures (White and Fane, 2001): those measures that (i) increase system efficiency at the utility level; (ii) increase end use efficiency; (iii) promote locally available resources not currently being used, such as rainwater harvesting; (iv) promote substitution of resource use, e.g. use of waterless sanitation; and (v) use economic instruments to bring about an improvement in resource

usage, such as use of tariffs. A service provider could implement and/or promote a combination of one or more options that exist under each category. Urban water managers and policy makers need to make correct choices of the most viable options that fit within the socio-cultural, political, economic and environmental context. Ideally, these choices take into consideration the vision of the key city stakeholders and identified scenarios over the longer-term period. This paper presents a decision support tool for urban water managers and planners, developed under the EU-funded SWITCH research project, for use in the 'city of the future'. The five-year SWITCH (Sustainable Water management Improves Tomorrow's City Health) project aimed at developing efficient and interactive urban water systems and services in the city's geographical and ecological setting, which are robust, flexible and responsive to a range of global change pressures.

The SWITCH research work on WDM adopted the Integrated Resource Planning (IRP) approach that embraces wider strategic planning principles and fits well with the integrated urban water resources management framework. First applied in the energy sector, IRP is an approach in which a full range of both supply-side and demand-side options are assessed against a common set of planning criteria. IRP is a systematic planning process that identifies the most efficient means of achieving the goals, while considering the costs of the project impacts on other societal objectives and environmental management goals. The main steps of carrying out an IRP process include (Turner et al, 2006): (i) analysis of the situation to identify factors influencing the supply-demand balance; (ii) forecasting future demand; (iii) setting planning objectives; (iv) considering a wide range of potential options, i.e. options analysis; and (v) planning to implement, undertaking a pilot programme and scaling up. The remainder of this paper focuses on the options analysis stage and describes a VENSIM model, a fairly simple decision support tool that uses a common cost metric to compare various options that may be adopted over a long-term planning horizon.

Introduction to the WDM Model in VENSIM

The WDM model was developed based on a scoping study carried out in Alexandria, Egypt, in which feasible options were identified through a participatory workshop attended by water managers, engineers and planners in the city. Figure 1 shows a mind map that was drawn to guide the development of the model. It shows WDM options feasible in a hypothetical city, our study setting. The Ventana Systems Environment (VENSIM) platform was chosen for developing the WDM model. VENSIM is a visual modelling tool that serves to conceptualize, document, simulate, analyse and optimise models of dynamic systems (VENSIM 1998). The VENSIM tool has been used in a broad range of disciplines such as business, scientific, environmental, and social systems.



VENSIM fitted well with the requirement of the SWITCH research outputs, as it is simple, easy-to-use, interfaces with Excel input data, is user-built, and therefore is flexible. The model is constructed by entering and defining causal relationships between system variables. This information is used by the equation editor to define the relationships as formulas. The model can be changed, tested and analysed throughout the building process and the model allows its user to thoroughly explore the behaviour of the model. The VENSIM software has been used previously to develop an urban water balance modelling tool and was successfully applied in Hyderabad, India (van Rooijen et al. 2005). Other notable examples are modelling of water-energy systems (Medeazza & Moreau, 2006); simulation of soil erosion and nutrient impact (Ye, Wang & Yu, 2006) and evaluating the impact of inpatient payment strategy on hospital behaviour (Rauner and Schaffauser-Linzatti, 2002).

The WDM model has been developed for a hypothetical city. The time frame of the model was set for a period of 30 years, say from 2010 to 2040. Some of the data used were obtained from the City of Alexandria, through a 'quick and rough' participatory scoping study. A significant amount of data inputted into the model are based on assumptions developed through a literature review of previous WDM measures in other countries such as the US, Europe and Australia. The cost-effectiveness of WDM options are very much dependant on local circumstances which vary for each city. To apply the model correctly, it is therefore important to collect the necessary sets of data pertaining to the city of interest.

Model structure, input and output data

The model consists of three levels, the *variable* level, the *option* level and the *options category* level, as illustrated in Figure 2. The number and type of variables may differ from one option to another. The variables shown in Figure 2 are with respect to the option of shower retrofits. The final outputs from each option however, are similar, and are expressions of 'water saved' and 'costs' of the respective option. The categories for the options were based on the four areas in which the measures could be taken for the hypothetical city. Similarly, it has been assumed that there are 12 feasible WDM options for this hypothetical city, categorised as shown in the mind map (Figure 1).



The model runs on a set of input data most of whose values are location specific. Other values are assumed constant. In the model, some data remain constant during the modelling period, while others always behave as variables. Model inputs consists of data for programme costs, water use (and savings) and response variables. In the absence of real data, assumptions were made, based on data and information from cities in a comparable context or calculated based on other data. These assumptions were informed by a combination of data in international literature, personal experience and expert opinion. The process of obtaining the variable data shown in Figure 2 above is described in more details in the following paragraphs.

Costs of option

These are costs of the programme, incurred by the utility to implement or promote an option during the 30year project period. Some options require high start-up costs with little or no follow up investment. Examples are retrofits of water saving devices such as toilet cisterns - with a long life time, which may not need further investments. On the other hand, some options, such as active leakage management of distribution networks require investments throughout the project period, probably at a decreasing scale. The Net Present Value (NPV) for each of the costs are computed for each year and summed up over the project period. The discount rate used for computing NPV is dependent on the social rate of return applicable to the study area. A figure of 7% was assumed for the hypothetical city. Cost figures used in this model were assumed based on parallel surveying with cities where WDM options studies have been carried out.

Response

The response variable represents the potential for uptake of the options. For options leading to water conservation at the end-use level, it is expressed as a fraction (%) of the target 'audience' for effecting change, such as households. In the case of storm water harvesting, the response variable is expressed as 'reuse factor', which shows the extent to which collected storm water may be used to save potable water.

Water saved

This is the amount of water saved per year as a result of a specific WDM option being implemented. These figures are estimated based on empirical data obtained through previous WDM studies conducted in various parts of the world, especially Australia and the USA. The input data depends on the option under consideration. Notable examples are described below:

- *Water saved through use of efficient water devices.* The volume saved will be directly proportional to the unit savings for each type of water device (e.g. showers, toilets, and taps) and response factor (i.e. the number of end users signing up) for the programme per year.
- Water saved through behavioural change due to an increase in tariffs. The water saved per household will depend on the average price elasticity of demand (E_d) in a given city. Water saved (ΔQ_d) will be determined by the function for E_d provided below, where P is the initial price, Q_d is the initial demand, and ΔP is the change in price. E_d is estimated through parallel surveying with comparable cities where tariff studies have been carried out (e.g. Arbues & Villanua, 2006):

$$E_d = \frac{\% \text{ change in quantity demanded}}{\% \text{ change in price}} = \frac{\Delta Q_d/Q_d}{\Delta P/P}$$

- *Water savings through behavioural change due to public education.* Empirical studies (e.g. Renwick and Green, 2000) have been conducted to estimate the effect of public education, and coefficients of water saved have been estimated. This information has been adapted for the hypothetical city, in order to estimate the potential water savings as a result of public education.
- Water saved through source substitution in the household such as rainwater harvesting and grey water reuse. Various studies (e.g. Dixon, Butler & Fewkes, 1999) have been carried out to estimate the potential for water source substitution at household level. Our assumed figures the potential average savings per household per year are based on empirical data from these case studies.
- Savings from storm water reuse. In a similar manner, empirical data from previous studies (e.g. Hatt, Deletic & Fletcher, 2006) have been used to estimate the fraction of storm water collected that could be reused per year in a city of a given surface area with specific physical characteristics, which receives a given average annual rainfall.

The input data are entered into an Excel spreadsheet. Colour coding is used to clarify the origin of the input data: those cells that require user-input are marked in light blue; cells that feed into the VENSIM model are marked in pink; and those marked in green are calculated by Excel and VENSIM. The model outputs for each of the WDM options are:

- Net Present Value of 'Water Saved' in m³, considered as a stream of benefits over the WDM project period;
- Net Present Value of 'Cost of Programme' in currency units (e.g. Euros for this hypothetical city), considered as a stream of costs over the WDM project period;

- The sum of 'Water Saved' in m³ during the project period;
- The sum of 'Cost of Programme' in currency units (e.g. Euros for this hypothetical city);
- The Average Incremental Cost (AIC) or levelised cost: Net Present Value of 'Cost of Programme'
- divided by Net Present Value of 'Water Saved'.

Other outputs of the model are the sums of 'Water Saved' and 'Cost of Programme' for all the WDM options for the whole project period. The VENSIM model outputs can be displayed in various forms of table and chart formats. Figure 3 shows an Excel sheet with data inputs and outputs.



Comparison of WDM Options

The depth of analysis of options may vary depending on the planning goal as determined by the needs of the key stakeholders, the quality and scope of data inputted into the model, and the capacity of the team carrying out the analysis. Among the questions that could be answered by the WDM model are those indentified by Turner et al (2006) as:

- What suite of demand-reducing options can meet the WDM target?
- How much will these programmes cost the community as a whole and what level of investment in WDM is cost-effective in a specific region?
- What suite of options will best meet the long-term requirement for balancing supply and demand in this region at the lowest cost to the community?

Different cost perspectives may be applied for analysing WDM options. A financial analysis is usually undertaken to obtain the cost perspectives with respect to service providers, which provides an overview for cash flow analysis, so that appropriate arrangements may be put in place to meet their revenue needs. On the other hand, an economic analysis considers the net benefit to society as a whole, and includes the service

providers' externality costs. The IRP approach strongly recommends application of economic analysis of WDM, since it seeks to determine which set of options have the greatest net benefit to the economy and society as a whole (ibid).

The Net Present Value (NPV) is the preferred method for comparing a suite of WDM options, mainly because it provides a monetary value that is comparable to currently known costs and benefits in the present. It is also a standard method used by national governments and international agencies to evaluate and compare programmes. Furthermore the use of Average Incremental Method (AIC) provides an equivalent 'constant price' comparison across scales, taking into consideration the timing of the service. As described above, the NPV of programme costs, potential water savings and AIC or levelised cost for each option are computed by the model. These values can also be displayed in graphical format, for ease of comparison. Figures 4 to 6 show examples of graphics plotted by the model from the hypothetical city data, through which comparison of the various WDM options can be displayed.







Limitations of the WDM Model

Similar to all other models, the quality of the output data is as good as the input data. This WDM model requires lots of data, some of which may be difficult to collect, particularly for urban water utilities in countries of the less developed regions, where management information systems may be underdeveloped. The model for the hypothetical city was developed using a series of assumptions based on review of international literature. This model has been developed only for illustration purposes, and its output data are deemed inaccurate.

This model was developed as a simple decision support tool that can be applied by urban water managers, engineers and planners with no skills of linear programming. Although the VENSIM models are systemdynamic and are capable of simulating continuously-varying systems, they do not typically incorporate uncertainty about internal or external attributes of the systems, nor can they represent discrete events.

Conclusion

Often, decision support tools developed by research institutions are complex and sometimes inaccessible to practitioners. The WDM options model developed by WEDC as part of an output for the SWITCH Project is a simple decision support tool that urban water engineers, planners and managers can use relatively easily for ranking WDM options based on an economic cost benefit analysis. The WDM options model in VENSIM compares the costs and benefits of each option over a long term horizon, making it a good management tool for making strategic decisions. The model characteristics presented in this paper only gives an example of what can be modeled, as they are based on data assumed for a hypothetical city.

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Notes

This model utilises a modelling shell made freely available by the VENSIM software owners at <u>http://www.vensim.com/freedownload.html</u>. The relevant files for running this model in its present illustrative format are available at the SWITCH website <u>www.switchurbanwater.eu</u>. To modify the model structure, one would require a professional version of the software, which can be purchased from Ventana Systems Inc. at a modest fee. The information on costs of VENSIM Professional is available <u>http://www.vensim.com/buy.html</u>. VENSIM Professional allows the user to add and modify the model settings, configurations, equations, etc. An extensive modelling guide is also available for free download at <u>http://www.vensim.com/documentation.html</u>.

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strategic planning, water demand management, options analysis, modelling

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