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**Modelling costs for water and sanitation infrastructure:
Comparing sanitation options for Can Tho, Vietnam**

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Cost effectiveness analysis is a useful tool for comparing water and sanitation infrastructure options. This method was used to compare a range of sanitation options for the rapidly developing area of South Can Tho in Vietnam. The costs of centralised, semi-centralised and decentralised sewer systems were analysed along with several different treatment and stream separation technologies. The process of estimating and modelling costs can be challenging as considerable data is required, however, by using a variety of cost estimation methods it was possible to undertake a detailed costing assessment to compare very different infrastructure options over their lifetimes and with reference to the service they provide. The results, which detail net present values and levelised costs in addition to a range of financial perspectives can provide a valuable basis for decision making.

Introduction

Assessing the cost-effectiveness of water and sanitation infrastructure options can be a valuable aid to decision making, particularly when comparing options with very different technologies, modes of operation, scales (from decentralised to centralised), water sources and wastewater streams. With the growing complexity of infrastructure options, finding a comparable basis is increasingly important. Cost-effectiveness analysis involves accounting for the capital, operating and asset replacement costs as well as the avoided costs and benefits over a period of time and comparing alternative options relative to a base case. In parallel, the demand for water or sanitation services is modelled over time so that the costs of infrastructure can be related to the service provided over its life cycle. Using this method, the costs borne by all parties can be considered, for example: costs to government, the customer, the utility and so on, in order to calculate a total cost to society. The objective is to identify and choose the option with the least cost to society. This is important because investment in infrastructure is often government funded, even in developing country contexts (Hall and Lobina 2010) and governments need to make effective investments across multiple types of infrastructure. This approach of including life cycle costs as well as multiple cost perspectives provides a more holistic view of the costs associated with infrastructure implementation.

Cost-effectiveness analysis was used to analyse a range of centralised and decentralised sanitation options for the peri-urban area to the south of the city centre in Can Tho, Vietnam, referred to as 'South Can Tho'. This analysis formed part of a research project supported by AusAID's Australian Development Research Awards, which included a detailed consultative process with stakeholders and participatory sustainability assessment with relevant agencies. The research was carried out by the Institute for Sustainable Futures (ISF) at the University of Technology, Sydney and Can Tho University (CTU) in collaboration with Can Tho Water Supply and Sewerage Company (CTWSSC) during 2009-2010. The regulatory and institutional context has been discussed in Carrard et al. 2011, the rationale for the costing methodology has been explained in Willetts et al. 2010a, and the costing methodology follows the guidebook: *Costing for Sustainable Outcomes in Urban Water Systems* by Mitchell et al. 2007. This paper focuses on the process of modelling costs and flows to represent various infrastructure options and the challenges this type of modelling presents. Experiences and lessons learnt in South Can Tho are presented as a case study example.

The site

South Can Tho is a rapidly developing area of Can Tho city, which is the major hub within the Mekong Delta in Vietnam. In South Can Tho, around 2000 ha have been set aside for residential development that will eventually house between 150,000 to 270,000 people. Some of these areas are already developed with row houses and apartment blocks. Other areas are characterised by informal settlements, but are earmarked for redevelopment. The newly developed houses are currently connected to septic tank systems, which are standard in Vietnam. A large centralised sewerage system and treatment plant is currently being constructed for the central district of Can Tho city with financial and institutional support from German Development agencies GTZ, DED and KfW. There are currently no plans to connect South Can Tho to this centralised sewerage system, although local authorities are interested in doing so as well as being open to considering alternative options. Whilst older sections of the city have combined stormwater and wastewater, National Decree 88 on Drainage and Sewerage for Urban Areas and Industrial Zones requires separate stormwater and wastewater systems. The South Can Tho study area is delineated in an aerial photo of Can Tho city in Figure 1 below.



Figure 1. Study Area – South Can Tho, Vietnam

Source: Willetts et al. 2010b

The modelling process

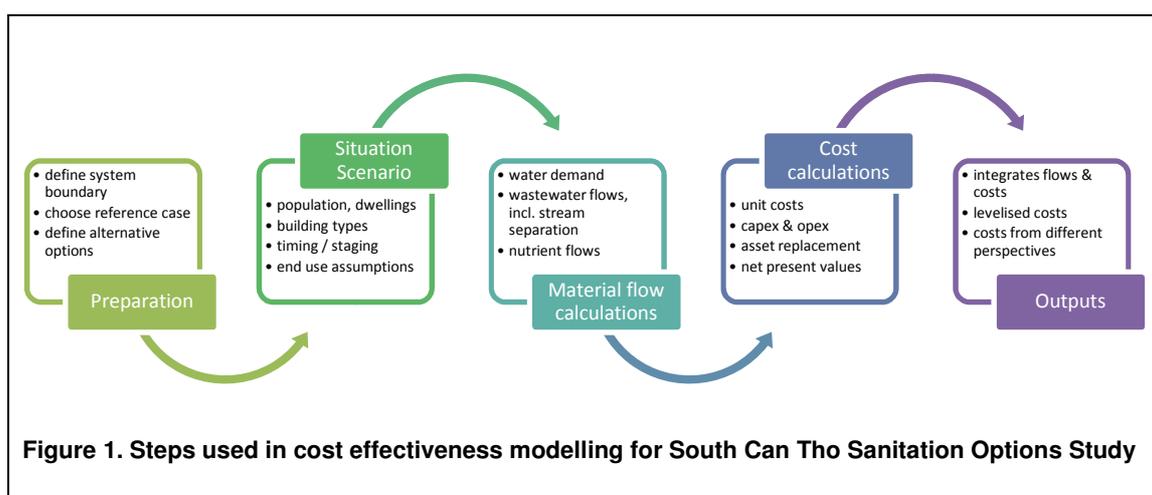
Model structure

The South Can Tho study was research based and the model was therefore built to support the research - investigating the cost-effectiveness of various centralised and decentralised sanitation options. However, the model was also designed so that it could be transferred to local stakeholders for future scenario modelling. Microsoft Excel was used as the modelling platform, due to the ease and flexibility of its use and the fact that the program is widely available. As the model was built with future users in mind, it was important to make the assumptions highly visible and easy to change. This was done by collecting the assumptions on several key pages and linking them through to the rest of the calculations. The broad steps used in developing the cost-effectiveness model for South Can Tho are illustrated in Figure 2. The major steps are preparation, developing the situation scenario, the material flow calculations, the cost calculations and the outputs. These major steps are described and discussed in the following sections of the paper.

Preparation

The key steps within the preparation phase were: defining the boundary of analysis, choosing a reference case and defining alternative options. The boundary of analysis refers to the physical boundary, which was shown by the study area boundary in Figure 1; the time frame of analysis, which was chosen to be 30 years; and the costing boundary, which was defined by which costs were included or excluded. Examples of costs that were included in the analysis were: capital costs, operating costs, asset renewal for pumps and revenue from sale of fertilizer. Examples of costs that were not included in the analysis were: land costs for treatment plant sites, external environmental monitoring costs and off-site sludge disposal. Land

costs were not estimated due to a lack of clarity regarding plant locations, land ownership and classification, and a lack of certainty in land prices into the future. The local team also considered them to be too variable to estimate adequately. The cost of transporting sludge off-site was included; however, the fees for disposal itself were unclear. The cost analysis aimed to be as inclusive as possible, and to show the costs from all possible perspectives, such as the utility, the customer, the government and so on. A more complete description of costs that were included or excluded from the analysis for South Can Tho can be found in Willetts et al. 2010b. The important issue with choosing a system boundary was ensuring consistency across all options. This consistency was of utmost importance to retain the validity and credibility of the analysis. Inadvertently choosing different system boundaries can generate significant errors and render option cost comparisons meaningless for decision makers. For more detailed discussion on costing boundaries, see Willetts et al. 2010 and Mitchell et al. 2007.



Cost-effectiveness analysis is based on the concept of comparing alternative options to a ‘base case’ or ‘reference case’, which represents a common centralised infrastructure option. In Can Tho, the reference case and alternative options were determined during workshops with stakeholders. Fortunately, significant planning information was available for the South Can Tho area, including the developers’ plans for the number and type of households. This spatial information helped in designing the overall options. For example, several options that were considered would use a centralised system for the more densely populated areas and decentralized systems for less dense areas which were further away from the centralised treatment plant. The four sanitation options that were chosen for comparative analysis for South Can Tho are described in Table 1. The reference case is represented by Option 1.

Option Concept	Option Description
Option 1 Centralised – connect to Wastewater Treatment Plant	Build sewer network to connect new developments in South Can Tho to centralised wastewater treatment plant (WWTP) which is currently under construction. Involves tripling the planned capacity of WWTP plant by adding a further 67,000m ³ /day.
Option 2 Decentralised – separate systems for each development area	Install decentralized wastewater treatment systems at all development lots, each with a flow rate of 500m ³ /day. This option involves building many small sewer networks to feed into these small wastewater treatment plants and disposal of treated effluent to nearby waterways.
Option 3 Combination of centralised and decentralised systems	Connect selected new developments (determined by spatial analysis) to the centralised WWTP. Involves increasing the currently planned capacity of the plant by 23,000m ³ /day. Provide decentralized wastewater treatment systems for remaining developments.

<p>Option 4 Combination of systems with separation of greywater, blackwater and urine for decentralised components</p>	<p>As in Option 3, connect selected new developments to the centralised WWTP. Provide decentralized wastewater treatment technologies for remaining developments, including urine separating toilets, collection systems and separate networks and treatment facilities for brownwater. Involves collecting and treating urine for agricultural reuse as fertilizer. This option builds on a pilot ecological sanitation project recently undertaken by Can Tho University.</p>
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Situation scenario

The situation scenario refers to the basic demographics and assumptions associated with the location. This included the staging for each of the development areas in South Can Tho. In a location with an existing population it would include a projection of population change over time. The staging for each development was estimated in workshops with CTWSSC and was based on the developers' plans and local knowledge regarding the progress of development. Ground-truthing during site visits also helped to establish which areas were already built and inhabited and which areas were at various stages of construction.

Aside from the demographics and development information, the end use assumptions were key to building up the projections of water demand and wastewater flows. For Can Tho, it was important to gain an understanding of how water is used and hence establish a picture of household end uses and likely wastewater streams. Consequently, a household end use survey was conducted by Can Tho University (CTU) researchers, where two hundred households were interviewed and the flow rate of their fixtures were measured. Once collated and analysed, this study provided valuable empirical data that was then used as the basis for modelling residential water demand and estimating wastewater flows, including greywater and blackwater. The benefit of having residential end use data in the model, with assumptions on the flow rate of showers, shower duration, toilet flushes and so on is that these assumptions can be changed to test the impact of efficiency measures, both on water demand and the costs of infrastructure. Efficiency measures may include tap or shower regulators or toilet displacement devices amongst others. In addition, when alternative sewerage systems such as pressure, vacuum or urine diverting systems are used, toilets connected to these systems require far less water and this can be accounted for by adjusting the toilet end use.

Efficiency measures can provide significant water savings and should be considered as part of any water and sanitation infrastructure project, as reducing the demand for water will reduce costs for the treatment and transport of both water and wastewater. Analysing efficiency measures was outside the scope of this project, but since the functionality is built into the model it will be possible for others to investigate efficiency options in the future.

Material flow calculations

The material flow calculations include the estimations for water demand, wastewater flows, nutrient flows and separated wastewater streams, such as urine, greywater, blackwater or brownwater (after a septic tank). Water demand for residential and non-residential areas was determined separately. Residential demand was estimated using the household end use data and the developers plans. Building up the calculations from end use, to a single house, to a cluster or development made it possible to consider treatment technologies and systems at different scales.

Water demand in non-residential buildings was estimated by calculating water use intensities for non-residential buildings in Can Tho and applying them to the proposed area of new buildings. Firstly, water usage data from a selection of non-residential buildings in Can Tho city were provided by the Can Tho Water Supply and Sewerage Company (CTWSSC) to represent each of the following non-residential categories: hotels, education, health, commercial, mixed use, office/administration and restaurant. Maps of the planned developments were examined to establish an average floor area for each non-residential building type and these floor areas were then used in conjunction with the average water consumption data to create water use intensities in metres cubed per metre squared (m^3/m^2). Several of these intensity figures were checked against non-residential building benchmarks from the tropical regions of Australia, namely for offices and commercial buildings. These intensity figures were similar to those calculated for Can Tho. Once established, the intensities were then applied to the floor areas proposed in the development plans to estimate the water use and wastewater flow from non-residential areas.

Nutrient flows from urine were determined as part of Option 4 in the Can Tho study, which included urine diverting toilets and urine collection for use as fertiliser in nearby agricultural areas. Nutrient flows were estimated using empirical data on the phosphorous (P) and nitrogen (N) content of urine in the Mekong Delta area (Wohlsager et al. 2009) and formulas from Jönsson and Vinnerås (2003). Calculations for potassium (K) loads in China were used as local information was not available. The availability of local data for P and N was helpful, as nutrient loads in urine differ geographically according to diet, however where local data was not available such as was the case for K loads in Can Tho, estimates can be based on research from comparable areas in terms of diet. The quantities of NPK were used in determining the sale value of the fertiliser and this benefit was included in the costs.

The residential and non-residential water use and wastewater flow estimates were aggregated to estimate the total flows from each development area and hence determine the required number of treatment plants for the decentralised options. Importantly, the timing of these flows were linked to the staging of infrastructure and form an integral component of calculating the costs. In South Can Tho, some of the development areas are already under construction, while others are more likely to be developed in 2020 or 2030. Linking the estimated flows with time allows flexibility in the approach to infrastructure, so that for example, smaller decentralized systems can be planned for construction when they are required, rather than building a large centralised system in the first year that has been sized to service a population that will finally eventuate 30 years later. Ultimately, the material flows and costs need to be linked to time so that the net present value (NPV) of both flows and costs can be determined and the cost can be calculated with reference to the service provided, for example, in dollars per kilolitre (\$/kL) for water supplied or dollars per household for sanitation services. Incorporating material flows into the costing model provided flexibility to work with options that had varied spatial configurations. In the future this model could be used to model any number of other variations in scale.

Costing calculations

The costing calculations are where the material flow calculations, design and costing information are combined to calculate net present values and levelised costs. The key background information that was required to develop the costing analysis included:

- Preliminary concept design for each option – including cluster size and technology choice
- Quotes for major infrastructure
- Unit costs and quantities for smaller infrastructure items – pipes, pumps, digging trenches
- Infrastructure lifetimes – including for plants, pumps etc.
- Ongoing costs such as maintenance, personnel, asset replacement

Some of the methods used in estimating or obtaining this data are discussed below.

Preparing preliminary concept designs with sufficient detail to calculate quantities for costing was the most challenging part of the modelling process as some detail is required for estimating costs, yet the scope of the project did not allow for comprehensive design and costing. As the South Can Tho area is made up of around 30 developments it was decided to estimate piping and pumping costs in three tiers – the backbone, within the development and between the development and backbone. Costs for a sewer system backbone had already been estimated by the water utility (CTWSSC) including pipes and pumps. To estimate network costs within each development, a typical development was chosen for a more detailed concept design. As the entire area of South Can Tho is extremely flat it was reasonable to assume a similar density of pumps and piping for other developments, so the length of pipe and number of pumps designed for the typical development was adapted for the other developments based on their expected number of dwellings and land area. Finally, to connect each development with the backbone an average pipe diameter was assumed. The number of pumps required was based on the length of pipe run and the number of dwellings connected. Pumps within each development were specified during the concept design and local costs were found to match these. For larger network pumps in South Can Tho, existing cost estimates prepared for the network being constructed in central Can Tho were used as the basis. This method of estimating network costs in three tiers and hence having disaggregated costs was useful as it simplified the collation of costs for different network options that were centralised, semi-centralised or decentralised.

Quotes for major infrastructure, such as the treatment facilities were obtained from various sources including the non-government agency BORDA Vietnam and local suppliers of pumps and construction materials. For the reference case (Option 1), the costs of the treatment plant augmentation were based on a scaling up of capacity for the planned treatment plant, for which costing was made available by KfW. The decentralised technologies that were chosen for inclusion in the study were the BORDA DEWATS package wastewater treatment plant for mixed wastewater (Options 2 and 3) and a recirculating sand filter for treating brownwater (separated from urine) (Option 4).

Due to the large size of the South Can Tho area, it would be possible to have many clusters with a range of sizes. In order to avoid unnecessary complexity in the modelling, it was decided to choose a flow rate for all decentralised treatment plants, in this case 500 m³/day and assume that all wastewater clusters would be of the same size. This size was chosen as it was the upper limit in treatment capacity for the DEWATS technology. This greatly helped to streamline the process, so that in the urine diversion and brownwater treatment option (Option 4), the same size and number of clusters was being compared, even though the technology differed.

Templates were set up to prepare costs for each of the options, such as the one shown in Figure 2. These templates were modular so that they could be easily added or deleted. Using a template was useful as it prompted the user to enter the same type of information for each option. The assumptions for each option were entered on an assumptions page and linked through to the template, which allowed changes to be made easily. Within each template, a time series of costs was developed, so that costs could be entered in the year in which they are expected to occur. This is where the costs are linked through to the staging information. For ongoing costs such as maintenance and personnel, a time series was developed to show those annual costs increasing over time with the cost of inflation.

Costing - Option 2										
Discount rate (%)										
Option 1										
		2011	2012	2013	2014	2015	2016	2017	2018	2019
Capital	NPV (mil VND)									
Pipes, trenches & pumps	VND 65,759	65758	0	0	0	0	80698	0	0	0
Distributed treatment plants	VND 194,510	194506	0	0	0	0	240848	0	0	0
Discharge pumps	VND 601	601	0	0	0	0	744	0	0	0
Discharge pipes	VND 3,779	3779	0	0	0	0	4680	0	0	0
	Sum Capex without disinf	VND 264,649	264644	0	0	0	326969	0	0	0
Disinfection	VND 12,014	12013	0	0	0	0	14876	0	0	0
	Sum Capex with disinf	VND 276,663	276657	0	0	0	341845	0	0	0
Operation & Maintenance	NPV (mil VND)									
Electricity costs per kWh	base cost (VND)	1020	1040.4	1061.208	1082.4322	1104.0808	1126.1624	1148.68567	1171.6594	1195.0926
Labour costs per day	base cost (VND)	105000	110250	115762.5	121550.63	127628.16	134009.56	140710.042	147745.54	155132.82
No. Small network pumps		6907	6907	6907	6907	6907	15459	15459	15459	15459
No. Decentralised treatment plants/discharge pumps		39	39	39	39	39	87	87	87	87
Network										
Energy - Local pumps	VND 427	0	3410	3478	3547	3618	8261	8426	8594	8766
Energy - Discharge pumps	VND 32	0	258	264	269	274	626	639	652	665
Labour - local pumps	VND 41	0	327	344	361	379	891	935	982	1031
Replacement - Local pumps	annualised costs	VND 881	0	7049	7049	7049	15777	15777	15777	15777
Replacement - Discharge pumps	annualised costs	VND 5	0	40	40	40	90	90	90	90
Decentralised treatment plant										
Energy	VND 0	0	0	0	0	0	0	0	0	0
Labour	VND 17	0	136	143	150	158	371	390	409	430
Equipment	VND 0	0	0	0	0	0	0	0	0	0
	Sum Opex	VND 1,404	0	11221	11317	11416	11518	26515	26504	26758
Disinfection O&M	VND 565	0	4522	4522	4522	4522	10122	10122	10122	10122
	Sum Opex with disinf	VND 1,970	0	15743	15839	15938	16040	36637	36625	36880
Total	NPV (mil VND)									
Total without disinfection	VND 266,054	264644	11221	11317	11416	11518	352984	26256	26504	26758
Total with disinfection	VND 278,633	276657	15743	15839	15938	16040	377982	36378	36625	36880
Metrics of service	NPV									
Wastewater volumes treated	NPV (m3/year)	7940981	7058502	7058502	7058502	7058502	15798720	15798720	15798720	15798720
Dwellings serviced	NPV (dwellings/year)	24870	22106	22106	22106	22106	43038	43038	43038	43038

Figure 2. Costing template showing capital, operating and maintenance costs

Source: Institute for Sustainable Futures

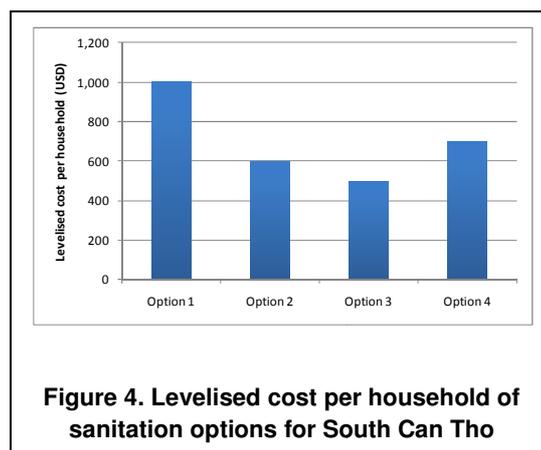
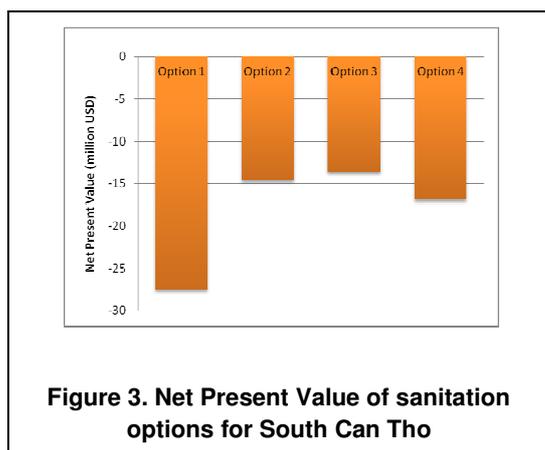
The unit costs for infrastructure were obtained from quotes and commercial suppliers. Other costs, including labour were gathered from government standards for salaries; these included jobs such as digging trenches and maintaining equipment. Asset replacement was included by determining the life of different components and the frequency of replacement and annualizing those costs. These costs could also be included by placing those costs at the year of replacement, but it would be necessary to consider the change in costs over time. Within the spectrum of costs it is highly important to ensure that costs borne by different parties, such as the utility and the customer are included and costs such as government subsidies are

recognised. Including these different cost perspectives provides a more holistic view of the total costs to society.

Uncertainty is always an issue and allowing for assumptions to be easily changed helped with the ongoing progress of the model. In the Can Tho study, the costing assumptions and staging information were particularly liable to change as the technologies chosen for analysis changed or as alternative population futures were considered. In this regard, it would have been useful to build in a range of situation scenarios that change several assumptions at once, such as different population and dwelling projections. Automating these changes would save work and help to minimise errors. Aside from being able to adjust assumptions, it was important to undertake some sensitivity analysis, such as testing the impact of changing key assumptions in order to understand the level of uncertainty in the model. Parameters that make a critical difference in the results may need to be reconsidered and estimated more carefully.

Outputs

The graphs displaying the net present values, levelised costs and various financial perspectives were developed in the outputs section of the model. The net present value of each option analysed in the South Can Tho project is shown in Figure 3 and the levelised cost of sanitation per household is shown in Figure 4, both in US dollars. Other outputs that are useful include the financial perspectives of the government, the water utility and the customer, the costs over time and the separate capital and operating costs. These graphs were produced for the South Can Tho study and were presented during a participatory sustainability workshop that brought together key stakeholders and rated the options based on the costing results and a range of sustainability criteria. Clear outputs were essential for communicating the results.



Recommendations

The key challenges during the modelling process were; undertaking sufficient design in order to enable costing estimates and structuring the model to allow maximum flexibility and transparency. In finding the right level of detail, it was useful to consider the depth of detail across the options. As the focus is on relative costs, it is a good idea to estimate costs across options in a similar way. For example, pipe and pump cost estimations should be similarly estimated in each option. Designing the options in too much detail would be time consuming and unnecessary, so it is important to avoid this. A broad concept design can be used to build up the costs based on local unit costs for materials, local labour costs, scaling costs of treatment facilities from other projects and so on. The model's flexibility to analyse a wide variety of situation scenarios and sanitation options was also a key issue. The options templates allowed flexibility to easily add or remove options and the use of assumptions pages provided the dual benefit of transparently communicating assumptions to future model users and allowing changes to be made readily. However, the front end of the model lacked flexibility as the initial population and dwelling projections were embedded in the calculations. In an improved version of the model, a more modular approach would be taken for the situation scenarios, so that the user could switch between population / dwelling scenarios and readily change the staging for the developments and infrastructure as these were key variables for stakeholders in Can Tho.

Other key recommendations for those undertaking cost-effectiveness modelling, are to:

- Ensure that the material flows are determined within the same model as the costing, so that changes to the situation scenario can be easily propagated through to the costs.
- Ensure costing boundaries are consistent, so that the same types of costs are included for each option.
- Build up flows and costs in an incremental way within the model so that it is possible to aggregate flows and costs for different cluster sizes and represent a wider array of options if necessary.
- Link material flows and costs so that the costs of an option can be evaluated relative to the service it provides, such as the number of people serviced or volume of water supplied
- Use local costs where available or use costs from neighbouring countries, where conditions might be similar and from where materials might be easily transported.
- Incorporate as many cost perspectives as possible to determine the ‘total cost to society’ and ensure these perspectives are included across each option. Excluding a cost perspective, such as a subsidy paid by the government or the income that can be received from fertiliser sales can change the outcome of the analysis significantly.

Importantly, cost effectiveness is not the only element for consideration when selecting infrastructure options. Stakeholders need to be consulted and other non-monetisable factors need to be assessed before selecting an option. The technical costing findings of this project formed part of a larger set of criteria including technical, environmental, financial, social and institutional aspects that were used to assess the relative merits of the sanitation options in a participatory sustainability assessment stakeholder workshop carried out in Can Tho (for results of this process see Willetts et al., 2010b).

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