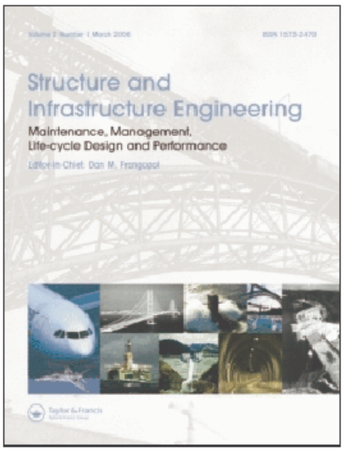

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A life-cycle capacity-based approach to allocating investments in municipal sanitation infrastructure

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A life-cycle capacity-based approach to allocating investments in municipal sanitation infrastructure

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The lack of access to water and sanitation services is a well-acknowledged problem that affects more than 40% of the world's people, who live in its poorest communities. Providing sustained access to infrastructure services in these communities requires approaches that build local capacity to acquire, build, and manage the systems that provide these services. This paper presents a pedagogical model that spans the lifecycle of sanitation infrastructure acquisition by communities with chronic inaccessibility to water and sanitation services. The pedagogy consists of community capacity assessment, service technology systems evaluation, and sequential allocation of capital investments to expand the capacity for water supply, wastewater and sewage treatment, and solid waste management infrastructure in affected communities. The allocation sequence covers a system lifecycle that allows the deficit in services in a community to be reduced to an acceptable minimum.

Keywords: Capacity assessment; Community capacity-building; Developing communities; Investment allocation; Integrated sanitation systems; Infrastructure management

1. Introduction

1.1 *Background*

The World Health Organization, in its Global Water Supply and Sanitation Assessment 2000 Report, notes that there are 1.1 billion people worldwide without access to improved water supply, and 2.4 billion without access to improved sanitation services (WHO/UNICEF 2000a). (The report does not provide comparable statistics for solid waste services.) The report goes on to note that Asia accounts for 63% of the population not served by improved drinking water supply, Africa for 28%, Latin America and the Caribbean (LAC) for 7% and Europe for 2%. In the case of sanitation, Asia accounts for 80% of those with no access to improved service, Africa for 13%, LAC for 5%, and Europe for the remaining 2%. The consequences of these deficiencies are higher rates of morbidity and mortality from sanitation-related diseases like cholera and diarrhea, and a vicious cycle of poverty, in which the inaccessibility of basic services constrains economic growth, which in turn limits the resources available for investment in basic sanitation services.

More than a decade after the end of the United Nations' International Drinking Water Supply and Sanitation Decade (1981 – 1990), its modest gains have been eroded. The percentage of the population in low-income countries (LIC) that were not served by improved water and sanitation services declined from 56% to 31%, and 54% to 44%, respectively, between 1980 and 1990. Moreover, from 1990 to 2000, the percentage of LIC population not served by improved water service declined from 31% to only 24%. In the case of improved sanitation services, it actually increased from 44% to 51%. Thus, the interventions of the UN's Water and Sanitation decade have not provided sustained access to service for the most affected populations. This is in part because they faced a moving target of ever-increasing population and demand for service.

In addition to the problem of a moving target, there are two other likely determinants that compromised the UN's

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interventions. The first determinant involves the treatment of water supply and sanitation (wastewater and sewage treatment) as independent services. These services are inherently interdependent and must be implemented in consort, in order to be sustainable. Furthermore, the interventions did not explicitly include solid waste management for improved service. In fact, drinking water supply, wastewater and sewage treatment, and municipal solid waste management are interdependent *services* that must be managed as components of an integrated municipal sanitation *system*.

The second determinant that contributed to the weakness of the UN's interventions is the lack of a comprehensive focus on capacity building over the lifecycle of the infrastructure for these services. By focusing its efforts on building service capacity, the immediate human resource, and institutional capacity necessary to provide the services, the UN cast its net too close to the *symptom* of the problem, rather than striking at all its *root causes*. This paper identifies eight capacity factors that must be addressed in order to provide sustained access to municipal sanitation infrastructure. These capacity factors are: institutional, human resource, technical, economic/financial, environmental/natural resource, energy, social/cultural, and service capacity (Bouabid 2004, Louis and Bouabid 2003). Furthermore, sustainable municipal sanitation infrastructure for low-income communities must be designed to evolve over a lifecycle that goes from community-based, labor-intensive systems to centralized, automated systems. This process of evolution will require a time horizon that is longer than the ten year limit imposed by the UN's original Water and Sanitation Decade, and the current International Decade for Action, Water for Life (2005 – 2015), which pursues the goal of halving by 2015 the proportion of people who are unable to reach or afford safe drinking water and who do not have access to basic sanitation.

1.2 *Integrated municipal sanitation systems*

Integrated municipal sanitation systems are the collective regional infrastructure, together with the engineering management and administrative system in which the services of drinking water supply (DWS), wastewater and sewage treatment (WST), and municipal solid waste management (MSW) are subcomponents. This is different from the prevalent current configuration, in which the services operate as independent administrative and management units. This difference is illustrated in figure 1.

A community is said to be deficient in a service if the annual built capacity of the service is less than 115% of the aggregated per capita demand for that service. The per capita demand is based on the minimum international standards for that service, established to protect human health. The standards for DWS, WST, and MSW are listed in table 1.

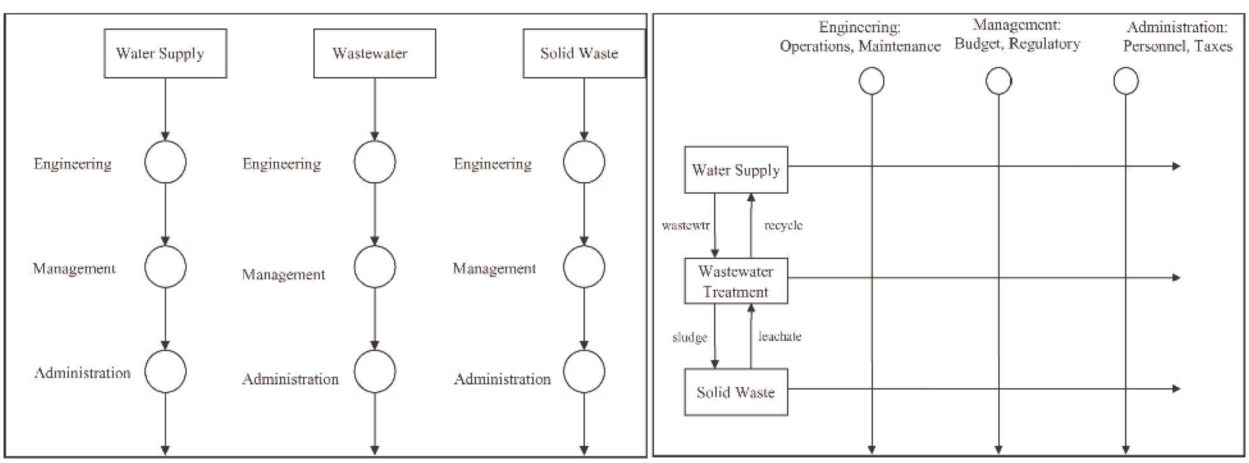

Figure 1. Independent services versus integrated municipal sanitation systems.

Table 1. International standards for municipal sanitation services.

Municipal sanitation service	Standard (units: per capita per day)
Water supply (DWS)	50 Liters/person day (WHO/UNICEF 2000)
Wastewater/sewage treatment (WST)	50 Liters/person day (Qasim 1999) [set to DWS level]
Municipal solid waste management (MSW)	0.6 kg/person day (UN 2001)

The overestimate of 15% is an allowance for losses in the distribution system for water service, for stormwater flow during heavy precipitation events in wastewater and sewage service, and for festivals or other special events in solid waste management services.

2. Research goal and objectives

The goal of this research is to provide sustained access to municipal sanitation services (MSS) to communities where those services are chronically deficient. These tend to be lower-income communities, where the median household income (MHI) is less than or equal to one standard deviation from the regional poverty baseline MHI (Louis and Magpili 2002a). The pedagogical objectives for achieving this goal are: (1) to assess the community's capacity to manage a municipal sanitation service, (2) to evaluate appropriate options for providing the service, and (3) to implement and manage the appropriate option over its lifecycle.

Community assessment is conducted by means of an inventory of the eight capacity factors that are necessary for sustainable municipal sanitation systems. The capacity assessment consists of measuring a list of requirements for providing the service in the community against a set of standards for this type of service provision established by the WHO or other relevant standards organizations. Based on the results of their assessment, communities are rated on an integral 5-point scale, with 1 representing the capacity to manage only the most basic technologies and systems for the desired service, and 5 representing the capacity to manage an advanced system. The score assigned to a community is called its technology management level (TML).

Options are evaluated by classifying technologies for providing each service using the eight capacity factors as criteria. Within each service, technologies are rated on an integral 5-point scale, with 1 being the most basic, labor intensive technologies, and 5 being the most advanced, centralized systems. The score assigned to a technology is called its capacity requirement level (CRL). For any given service, a community selects a technology that has a CRL that is equal to or less than its TML, confident that it will have the capacity to manage that technology for providing their required sanitation service. Louis and Ahmad (2004) and Ahmad (2004) developed the CRL model to facilitate the process of appropriate technology acquisition for municipal sanitation services in low-income communities.

The selected option is implemented in concert with other deficient sanitation services in the region. Resources are allocated to build the infrastructure for the MSS system, on the basis of the impacts (health, environmental, and economic) that deficits in each service have on the community. These allocation decisions are made sequentially each year over the planning horizon of the system. In the lifecycle approach to managing this infrastructure, provisions are made for capital improvements to upgrade the system to match the growing management capacity of the community.

3. Capacity assessment

3.1 *Capacity factors*

Capacity assessment involves the systematic measurement of deficiencies in the requirements for a known supply of a given municipal sanitation service. These requirements are defined for eight *capacity factors* (CF) that determine sustained access to the service in a community. These CF are: (1) the existing and desired level of *service*, (2) the *institutional* context for legislation, regulation, administration and management of the service, (3) available *human resources*, including professional, skilled, and unskilled labor, (4) *technical* considerations like the availability of spare parts, the supply chain for process materials, supporting services for maintenance and repair, (5) *economic/financial* mechanisms for securing private service provision, financing capital improvements and operating expenses, and options for collecting fees for service, (6) *energy* availability, cost, and reliability determine the types of technology that can be employed, (7) *environmental/natural resources* set constraints on the geography and manner of resource procurement, the rate of resource consumption, and the lifecycle impacts of supplying the service, and (8) *socio-cultural* capacity factors include such items as the prevalence of fixed housing units, the percentage of transient residents, the participation of women in decision-making, and the percentage of poor residents in the community (Louis and Magpili 2002b).

For a given service, each capacity factor consists of a set of requirements. For example, in the case of water supply, the human resources requirement includes engineers, certified water treatment operators, trained administrative staff, and general laborers. Assessment consists of measuring each requirement against the standard for requirement established by the WHO or other relevant standards organizations. For example, the safe administration of a 1,000 m^3 per day water supply may require ten community members trained to dose the supply with disinfectant. In the community assessment process the actual number of people in the community so trained would be compared to this standard. The ratio of actual trained people to the required number is recorded as a percentage. The community assessment procedure is illustrated by an example in table 3 later on in this paper.

3.2 *The capacity assessment model*

The community's TML is the outcome of the capacity assessment. Each requirement is recorded as a percentage of its corresponding international standard, and the score, f_i, of the parent capacity factor is derived from the weighted sum of its individual requirements (Triantaphyllou 2000) as shown in equation (1):

$$f_i = \sum_{j=1}^{n} C_{ij} w_j, \qquad (1)$$

where f_i is the score of the i-*th* capacity factor ($i = 1, \ldots, 8$), C_{ij} is the score of the j-*th* requirement of the i-*th* capacity factor, w_j is the weight of the requirement C_{ij} ($0 < w_j \leq 1$), and $\Sigma w_j = 1$ for $j = 1, \ldots, n$, and n is the number of requirements for the i-*th* capacity factor. The weight for each requirement is assigned by decision-makers in the community.

All eight capacity factors are assessed in this way. The community's TML is determined by the lowest scoring capacity factor, as shown in equation (2):

$$C_A = \text{Min}\,(f_i) \quad \text{for } i = 2, \ldots, 8, \qquad (2)$$

where C_A is the community capacity assessment, and f_i is the score of the i-*th* capacity factor. The score of the TML is then converted to a 5-point scale, which rates the community's capacity to manage the service. The conversion is summarized in table 2.

As previously explained, the community's TML allows it to select technologies for the given service that have a capacity requirement level (CRL) that is equal to or less than their TML. Thus, appropriate technologies may be selected by the community. The process is applied to each of the three sanitation services, water supply, wastewater/sewage treatment, and solid waste management. This approach is essentially conservative, since it limits the community to technology selections that match its lowest rated capacity factor. This conservatism increases the likelihood that the community will have the capacity to manage the acquired service system and its associated technology over the long term. Inherent in this conservative approach is the assumption that as the community's TML increases with practice in managing the selected system, it will acquire enhanced service delivery systems that match its new management capacity. Thus, community capacity assessment is an iterative process.

3.3 *Example*

Consider the case of a community that has a 1 MGD (million gallons per day) deficit for treated water (~4000 CMD (cubic meters per day)). Illustrating the human resources capacity factor for this case, with index $i = 3$. There are four requirements that comprise the human resources capacity factor. They are engineers ($j = 1$), certified operators ($j = 2$), administrative staff ($j = 3$), and general laborers ($j = 4$). Assessment of the human resource capacity factor for this community is compared to the staffing requirements for a 1 MGD water treatment plant according to the standards like those of the Florida Department of Environmental Protection for Treatment Plant Staffing (see website). Assume the results are as illustrated in table 3.

Table 2. Converting the CF score to a 5-point scale.

CF % score	Level	Notation	Explanation
1–20	1	High entropy	No coherent presence of the CF. No local capacity to manage the service.
21–40	2	Pre-community	Minimal organized evidence of the CF. Capacity to manage systems for small collections of residential units.
41–60	3	Community-based	The CF is evident and contributes to service access to at least 50% of units. Capacity to manage community-based systems.
61–80	4	Centralized	The CF is well established and the majority of units have access to service. Capacity to serve multiple communities from a centralized system.
81–100	5	Diversified	The CF approaches the standard value. The community has the capacity to manage a centralized system, along with individual service to more remote units.

Table 3. Illustrative assessment of the human resource capacity factor ($i = 3$) for a 1 MGD water deficit.

j	Description	Measured	AWWA standard	C_{3j} score (%)	w_{3j}
1	Hydro-engineers	1	2	50	0.40
2	Certified water treatment plant operators	1	4	25	0.30
3	Suitable administrative staff	6	12	50	0.20
4	Literate general labor	15	20	75	0.10
	SUMMATION		$\mathbf{f_3 = 50(0.4) + 25(0.3) + 50(0.2) + 75(0.1) = 45}$		

Thus the computation of the human resource capacity factor was obtained from equation (3), where the requirements, C_{ij}, of the CF have weights, w_j, as provided in table 3:

$$f_3 = \sum_{j=1}^{n} C_{3j} w_j. \quad (3)$$

In this example, $f_3 = 45$.

To complete the illustration, example scores for the other capacity factors are shown in table 4.

The community's TML is derived from equation (2). The lowest capacity factors score is chosen as the value for the overall capacity of the community as shown in equation (4):

$$C_A = \mathrm{Min}(f_i) = 18.50 \quad \text{for } i = 1, \ldots, 8. \quad (4)$$

Using the conversion in table 2, the C_A score is converted to a 5-point scale, corresponding to a TML of 1. The next step is to select water supply technologies with a capacity requirement level, CRL = 1 that match the TML of the community. As noted earlier, the CRL is discussed by Ahmad (2004) and Louis and Ahmad (2004).

4. Impact assessment

4.1 *Introduction*

Upon completion of the first two pedagogical steps of community capacity assessment, and technology evaluation for each of the three services, the community must take the final step of implementing and managing the integrated municipal sanitation system. This requires the coordinated expansion of the services to assure that lags in the access to any one service do not compromise gains achieved in the counterpart services. An impact-based, sequential investment allocation model is presented to make the appropriate proportional annual investment to each service in order to eliminate the deficit in all of the services over the planned lifecycle of the integrated sanitation system.

Table 4. Example of DWS capacity factors assessment.

CF #	Capacity factor	Example score
1	*Service*	80.00
2	*Institutional*	18.50
3	*Human Resources*	45.00
4	*Technical*	31.25
5	*Economic/financial*	25.50
6	*Energy*	32.00
7	*Environmental*	54.00
8	*Socio-cultural*	35.50

The first stage in this process is to determine the impact of deficits in each service. The three types of direct impact measured are, economic, social (as represented by human health), and environmental. The indirect impact of deficit in one service on the other two services is also estimated. Selected indicators are used as the metrics for each of these impacts, and measured in terms of their dollar value. The sum of the economic, social, environmental, and inter-service impacts is then computed for each service. Impact assessment is well established in the field of environmental impact assessment (EIA) and the estimation of impacts in this method is adapted from these earlier works (George 2000, Kirkpatrick 2000, Vanclay 2000).

The second stage in the process is to calculate the proportion of total impact attributed to each service. This is a simple ratio of the impact from each service over the sum of the impacts from the three services. The respective ratio determines the proportion of the total annual water and sanitation budget to be invested in each service (water, wastewater/sewage, and solid waste).

The third stage of the process computes the deficit in each service that remains after the respective capacity expansion purchased from its most recent budget allocation. These deficits serve as the basis for calculating the related impacts in the next year, and the subsequent proportional budget allocation. The process of impact assessment, proportional budget allocation, service expansion, and residual deficit measurement is repeated sequentially each year over the planning horizon of the integrated sanitation system. This planning horizon may be a fixed period, such as thirty or fifty years, or it may be defined by a target, such as a maximum residual deficit in any of the three services.

4.2 *Impact metrics*

The deficit in each sanitation service, i, is represented by the service gap, G_i, that is the difference between the total supply, S_i, and total demand, D_i, for the service at the start of the year in which the measurement is made. This is shown in equation (5):

$$G_i(t) = D_i(t) - S_i(t), \quad (5)$$

where i is the sanitation service (1 = DWS, 2 = WST, 3 = MSW), t is the time to the start of the year in which the budget allocation is to be made. The proportion of demand unserved for each service is called the non-service ratio, φ_i, and is calculated in equation (6):

$$\varphi_i(t) = G_i(t)/D_i(t). \quad (6)$$

Each service gap, G_i, has an associated set of impacts, ξ_{ij}, that represent the economic (j = 1), social, (j = 2), environmental (j = 3), and inter-service (j = 4) impacts from the lack of service. The total impact, T_i, of the deficit from each service is the sum of its economic, social, environmental, and inter-service impacts. This is shown in equation (7):

$$T_i(t) = \Sigma_j \xi_{ij}(t), \quad (7)$$

where j is the impact type (1 = economic, 2 social, 3 = environmental, 4 = inter-service). The proportion of impact from all services that is attributable to a single service is called the impact impression, ψ_I, and is calculated in equation (8):

$$\psi_i(t) = T_i(t)/\Sigma_i T_i(t). \quad (8)$$

4.3 *Example*

The evaluation of impacts may be illustrated in a case study of wastewater and sewage treatment (WST) service in Mombassa, Kenya undertaken by Constantinides for the Strategic Action for Sewage in East Africa (Constantinides 2000). Critical impacts for this service are listed and described in table 5.

Constantinides used both direct and indirect economic losses and gains to evaluate impacts across three main categories: (1) direct use value—changes in the productivity of activities that use environmental resources resulting from changes in environment conditions and quality, (2) indirect use value—changes in recreation, leisure and amenity opportunities, beach stability and quality offered to the public in and near coastal areas due to changes in environmental conditions and quality, and (3) non-use (existence) value—existence value of lost environmental quality and biodiversity.

Costs were associated with reduction in the use and non-use value of the environment, while benefits accrued from actions and investment that reduce or eliminate costs and improve environmental quality. The valuation approach helps in establishing the link between information on environmental changes/impacts and their socio-economic significance and the estimate of the positive or negative values of these changes expressed as costs or benefits (Constantinides 2000), as summarized in table 6. Finally,

Table 5. Critical impacts for Mombassa.

Perspective	Impact	Valuation
Environmental	Mangroves	Loss of mangrove trees for direct benefits such as firewood and indirect benefits such as nursery grounds for fish.
	Biodiversity	People's willingness-to-pay for maintaining marine and coastal biodiversity (quantitative and qualitative information from surveys).
Social	Health	Treatment costs, loss of work-days and loss of life due to environment-related diseases.
	Recreation	Number of people and cost of visiting clean and unspoiled coastal sites reflecting people's valuation of recreation opportunities.
Economic	Fisheries	Change in fisheries production and revenues and avoided losses.
	Tourism	Change in tourism revenues and avoided losses.
	Property	Increment/loss of property values.
Inter-service	Water supply	Treatment costs due to contamination.

Table 6. Estimated annual cost of impacts from WST deficit in Mombassa.

Impacts	Annual cost (million US$)	Class	Comments
1. Fisheries	0.5	Economic	Half of the reported production losses.
2. Tourism	15.0	Economic	Based on half of the revenue losses estimated for other countries (no relevant data available).
3. Property	26.7	Economic	Estimated loss of value due to proximity to polluted areas.
4. Health	2.4	Social	Diarrhea and skin diseases only.
	3.3		Child death; human capital valuation for loss of income only.
5. Recreation		Social	Qualitative benefits, not quantified.
6. Mangroves	0.1	Environmental	Tentative estimates of mangrove losses.
7. Biodiversity		Environmental	Qualitative benefits, not quantified.
8. Water supply	3.1	Inter-service	Clean-up cost.
Total	**51.1**		**Does not include unquantified costs and benefits.**

the proportional impacts or impact impression of each service is calculated. This is illustrated in table 7, with details for the wastewater service.

5. Sequential resource allocation

Once the proportion of total economic, social, environmental, and inter-service impact caused by each service is calculated, it is a simple matter to allocate the budget to each service based on its respective proportion of total impact. In the simplest case, the total budget, B(t), for the integrated sanitation system is known at the start of the year, and the product of this and the impact impression determines the amount to be spent on supply expansion for each service in that year. The process is shown in equation (9):

$$B_i(t) = \psi_i(t) * B(t), \tag{9}$$

where $B_i(t)$ is the budget invested in service i in year t, B(t) is the total sanitation infrastructure budget for year t, $\psi_i(t)$ is the impact impression for year t, and i is the sanitation service (1 = DWS, 2 = WST, 3 = MSW).

The investment in year t will purchase a capacity expansion, $E_i(t)$ for each service. Thus, at the end of the year, which is the start of the following budget year, the deficit in each service will be given by equation (10) as:

$$G_i(t+1) = G_i(t) - E_i(t) + d_i(t), \tag{10}$$

where $d_i(t)$ is the amount by which the demand for service has grown during the year t. The corresponding non-service ratio is shown in equation (11) as:

$$\varphi_i(t+1) = G_i(t+1)/D_i(t+1). \tag{11}$$

From this known deficit, new economic, social, environmental and inter-service impacts, T_i, may be calculated for each service, leading to an impact impression and budget allocation for the new year. Assuming that no other programs, such as public health or housing construction, have been adopted to mitigate the impacts from deficits in the sanitation services, the new impacts ξ_{ij} remain proportional to the non-service ratio. Thus, the total impact and the impact impression for each service, may be calculated from equations (12) and (13) respectively.

$$T_i(t+1) = T_i(t) * \varphi_i(t+1)/\varphi_i(t), \tag{12}$$

$$\psi_i(t+1) = T_i(t+1)/\Sigma_i T_i(t+1). \tag{13}$$

Of course, equation (13) is simply the application of equation (8) to the new budget period. Thus, from this point on the budget allocation may be updated sequentially by repeating equations (9) through to (13) each year until the end of the planning horizon is reached, or the maximum deficit remaining in any of the services reaches a preset value. Ideally, this value would be zero.

This simple sequential resource allocation model conveys the concept of coordinated expansion of the capacity of the three services in an integrated municipal sanitation system. However, the planning process is likely to be confounded by several factors that are particularly taxing for developing communities. Firstly, the total annual budget for the integrated sanitation system will not be known with certainty at the start of the year, nor is the full budget guaranteed to be appropriated to the services over the course of the year. Thus the amount of the annual investment available for each service is uncertain. Additionally, service expansions must be made in integral units. For example, water supply may only be added in 100 m^3 increments, because this may be the minimal size of water storage tank available. Thus the purchased expansions $E_i(t)$ may not be exactly proportional to the expected budget allocation $B_i(t)$, predicted by the model. The problems may be handled operationally by applying the model only to known budget allocations. In this method, the budget period may be shortened to six or even three months, depending on the schedule on which budget advances are made to the local authority. However, since construction of sanitation infrastructure may take months to complete, these shortened planning horizons may not be practical.

A second caveat about this model concerns the possibility of choosing an optimal allocation of funding. This may be defined as the allocation that achieves the minimal residual impact at the end of the budget year in the sense of

Table 7. Calculating the impact impression of sanitation services in Mombassa (in million US$).

	Impact					
Service	Environment	Economic	Social	Inter-service	Total T_i	Imp ψ_i
DWS	2	15	5	1	23	0.22
WST	0.1	0.5 + 15.0 + 26.7 = 42.2	2.4 + 3.3 = 5.7	3.1	51.1	51.1/106.1 = 0.48
MSW	5	15	10	2	32	0.30
Total	**7.1**	**72.2**	**20.7**	**6.1**	**106.1**	

a local optimum. A global optimum may be the sequence of allocations that results in the minimal residual impact over the lifecycle of the system or the shortest time to reduce the residual impacts in the system to zero. Since there are multiple options for expanding a service in any given year (remember there are multiple technology options with the same capacity requirement level), theoretically the planner should repeat the technology selection decision at the start of each budget year. The decision sequence in this case is amenable to analysis by a decision tree, however that case is beyond the scope of this paper, the goal of which is to introduce the basic impact-based allocation process.

6. Case study: Bacoor Municipality

Bacoor is the oldest, and for a long time, the only gateway from Metro Manila to the Province of Cavite. As such it has become an important link between the industrial and tourism areas of Cavite and Metro Manila. It also serves as one of the key residential catchments for Metro Manila and those employed by the industrial centers of the Province of Cavite, with as much as 84% of its land allocated to residential use. The impact assessment shown in table 8, expresses the state of the services at the beginning of period 1.

Projects considered for each of the sanitation services are shown in table 9 with details on costs and expected non-service ratio reductions for each option. For MSW, the projects are MSW1 (waste transfer), MSW2 (household composting), and MSW3 (composting facility). For DWS, the projects are DWS1 (development of two public wells), DWS2 (five public wells), and DWS3 (seven public wells). For WST, the projects are WST1 (construction of septic tanks), WST2 (construction of drying ponds), and WST3 (chemical treatment).

The objective is to select the set of projects for two planning periods, period 1 for 2003 and period 2 for 2004. The sanitation services budget for each period is $500,000 and $550,000 respectively. The budget allocation to each service, $B_i(1)$, for the year is proportional to the impact impression, $\psi_i(1)$, incurred at the beginning of the year. $B_i(1)$ is the upper limit allocation per service in the first budget period. This determines which projects are affordable during this period. The budget allocation for 2003, period 1, is detailed in table 10. The resulting non-service ratios and impact impressions from implementing the projects are shown in table 11.

The total budget for period 2, 2004, is $550,000. The budget allocation for each service is detailed in table 12. The resulting non-service ratios and impact impressions from implementing the projects are shown in table 13. Figure 2 shows the progression of non-service ratio.

Table 8. Impact assessment of Bacoor at the beginning of period 1.

Service	Non-service ratio $\varphi_i(1)$	Total impact (\$) $T_i(1)$	Impact impression $\psi_i(1)$
MSW	0.800	780,000	0.375
DWS	0.200	500,000	0.240
WST	0.500	800,000	0.385
Total	–	**2,080,000**	–

Source: Magpili 2003.

Table 9. Project cost and yield for each service option in Bacoor.

Service Options	Cost ($)	Expected Reduction ($\Delta\varphi_i$)
MSW Projects		
MSW1	75,000	0.050
MSW2	180,000	0.142
MSW3	220,000	0.316
DWS Projects		
DWS1	100,000	0.025
DWS2	120,000	0.050
DWS3	130,000	0.060
WST Projects		
WST1	185,000	0.050
WST2	190,000	0.175
WST3	200,000	0.300

Note: $\Delta\varphi$ (reduction in non-service ratio) includes adjustments for $E_i(t) + d_i(t)$.
Source: Magpili 2003.

7. Conclusions

Access to improved water, wastewater, and solid waste services at levels to support human health is chronically lacking for the world's poorest people. Finance, technology, and the availability of water and land resources are only three of eight factors that determine a community's sustained access to these services. Additional factors are: institutional, human resources, energy, socio-cultural, and the actual ratio of the service supply to demand. The prevailing practice for planning and managing sanitation infrastructure, treats water supply, wastewater treatment, and solid waste management as independent services, and plans for the expansion of service capacity in anticipation of demand, rather than from a position of a deficit in supply relative to demand. The prevailing practice also treats the budget for capital expenditures as deterministic. None of these assumptions are realistic in developing communities. In those communities, there is a chronic and often large gap between the demand for and supply of sanitations services, the interdependence between the services requires that expansions in capacity must be made in the three services

Table 10. Budget allocation for period 1, t = 1.

Service	Non-service $\varphi_i(1)$	Impact $\psi_i(1)$	Budget Allocation: B(1) = $500,000 $\psi_i(1) * B(1) = B_i(1)$	$B_i(1)$ in US$	Project selection Project	Cost (US$)
MSW	0.800	0.375	$500,000 * 0.375 =	187,500	MSW2	180,000
DWS	0.200	0.240	$500,000 * 0.240 =	120,192	DWS2	120,000
WST	0.500	0.385	$500,000 * 0.385 =	192,308	WST2	190,000
Total				**500,000**		**490,000**

Table 11. Resulting non-service ratio and impact impression for t = 2.

Service	Non-service ratio $\varphi_i(2)$	$T_i(1) * [\varphi_i(2)/\varphi_i(1)] = T_i(2)$	Total impact (US$) $T_i(2)$	Impact impression $\psi_i(2)$
MSW	0.658	$780,000 * [0.658/0.800] =	641,550	0.418
DWS	0.150	$500,000 * [0.150/0.200] =	375,000	0.244
WST	0.325	$800,000 * [0.325/0.500] =	520,000	0.338
Total			**1,536,550**	

Table 12. Budget allocation for period 2, t = 2.

Service	Non-service $\varphi_i(2)$	Impact $\psi_i(2)$	Budget allocation: B(2) = $550,000 $\psi_i(2) * B(2) = B_i(2)$	$B_i(2)$ in US$	Project selection Project	Cost (US$)
MSW	0.658	0.418	$600,000 * 0.418 =	229,639	MSW3	220,000
DWS	0.150	0.244	$600,000 * 0.244 =	134,229	DWS3	130,000
WST	0.325	0.338	$600,000 * 0.338 =	186,131	WST1	185,000
Total				**550,000**		**535,000**

Table 13. Resulting non-service ratio and impact impression for t = 3.

Service	Non-service ratio $\varphi_i(3)$	$T_i(2) * [\varphi_i(3)/\varphi_i(2)] = T_i(3)$	Total impact (US$) $T_i(3)$	Impact impression $\psi_i(3)$
MSW	0.342	$641,550 * [0.342/0.658] =	333,450	0.334
DWS	0.090	$375,000 * [0.090/0.150] =	225,000	0.225
WST	0.275	$520,000 * [0.275/0.325] =	440,000	0.441
Total			**998,450**	

simultaneously, and the annual budget for sanitation is highly probabilistic. Thus, specialized models are needed for the planning and management of sanitation infrastructure in developing communities. This paper presents an approach that adopts the pedagogy of risk analysis (Haimes 1999) to the life-cycle planning and management of sanitation infrastructure. It begins with the assessment of the capacity of the developing community to manage different integrated sanitation systems, which are composed of water supply, wastewater and sewage treatment, and solid waste management as inter-dependent services. It then moves to an evaluation of appropriate technology options to provide each service to the community. Finally, the approach uses a model for developing the required service capacity over the lifecycle of the integrated infrastructure system. The model explicitly accounts for the uncertainty in the annual budget for sanitation, and the need to allocate this budget to each of the three services in order to secure sustained incremental expansions in capacity over the lifecycle of the system. The combined economic, environmental, and social impacts of deficits in the services are used as the basis for the annual resource allocation decision. The model is illustrated in the case study of Bacoor Municipality in Metropolitan Manila, The Philippines.

The use of community capacity assessment, capacity-based acquisition of appropriate technology, and detailed impact-based allocation of investments to expand service capacity in an integrated system, is new to the literature on

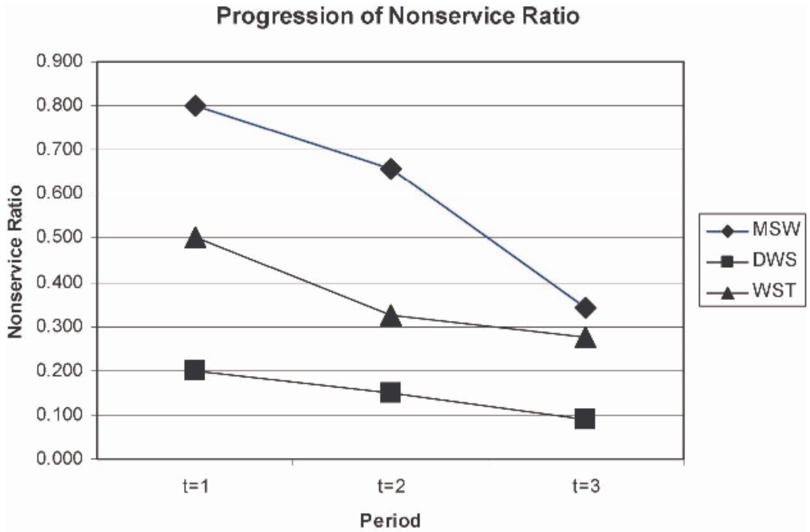

Figure 2. Expected non-service ratio for periods 1 to 3 (Yr2002 – Yr2004).

water and sanitation infrastructure management and planning. Yet it is exactly this pedagogy of community-oriented assessment, evaluation, and implementation that is necessary to ensure that the infrastructure built to provide access to water and sanitations services to the poor, will be appropriate to the capacity and preferences of the communities in which they are built, and will provide sustained access to these essential services over the full lifecycle of the infrastructure. Thus, this paper presents a detailed, inventory of capacity factors by which the capacity of a community to manage technologies for water and sanitation services may be assessed and evaluated. Such an assessment method is not available in existing literature. The paper makes the case for an integrated approach to service expansion, that coordinates the addition of water supply, wastewater and sewage, and solid waste management capacity to ensure that negative feedback from the interdependencies in the services is minimized. This explicit coordination of water, sewage, and solid waste in the approach to solving the 'water crisis' in poor communities is unprecedented in the literature, and thus a new contribution from this work. The paper presents a preliminary method for classifying technologies and management systems for providing water and sanitation services, so that communities may have a systematic method of selecting appropriate systems to meet their service needs. The scoring of community by their technology management level (TML), and technologies by their related capacity requirement level (CRL) as a basis for appropriate technology acquisition by communities, is a new contribution to technology selection in the field of sanitation infrastructure management. Finally, the paper presents a model for sequential, impact-based resource allocation that permits transparent, intuitive management of the investments required for the coordinated expansion of services in an integrated sanitation system. The model allows for the uncertainty in annual budget allocations that is common to developing communities, yet provides a disciplined but simple process for reducing persistent deficiencies in water and sanitation service capacity over a planned lifecycle of infrastructure growth. Thus, this work couples the methods of risk analysis to the programmed investments of decades of overseas development assistance to developing countries, to provide sustainable solutions to the problem of inadequate access to water and sanitation services.

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