Promote Canal Water Quality Improvement Using Decentralized Wastewater Management: Case Study Bangkok

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Abstract: A water quality improvement with financial model was developed to investigate total benefits over costs and relative competency of different wastewater management approaches for recovering pollution overloaded canals in the center of Bangkok, Thailand. Implementation of centralized and decentralized wastewater treatment systems was evaluated within five different scenarios. Three major improvement mechanisms for open-canal water quality were considered including removal of wastewater loads, dilution by reclaimed water, and self-purification. Percent improvement of water quality within each canal is ranging from 40-84\% if centralized system was implemented vs. 41-88\% if decentralized system was implemented. Estimated benefit/cost ratio from water improvement in centralized system, centralized with redistribution/reuse water system, and decentralized system are 2.28, 2.05, and 2.30 respectively. The results show that decentralized approach provides no significant difference in the benefit over cost ratio compared to centralized system, but offer slightly better in canal quality improvement. Therefore, decentralized wastewater management can be a promising alternative to promote sustainable uses of water and can work in help with centralized system. In the future, co-existing of large-scaled centralized and small-scaled decentralized systems may increasingly need to improve net efficiency of wastewater management where there are site specific problems with financial and political constraints.

Keywords: Benefit to Cost Ratio, Canal Water Quality, Decentralized Wastewater Management, Wastewater Dilution, Water Self-Purification

INTRODUCTION
Bangkok has extensive canal networks which are located within heart of the city. The canals have significant functional and historical values. Primary functions are transportation and flooding alleviation and prevention, while secondary function serves for sewage discharge. Major causes of fast water quality deterioration include dense population in the city, being at low level of land with high groundwater level, frequent floods, inefficient drainage and sewerage network, and lack of funding for a large-scaled public project. Bangkok Metropolitan Administration (BMA) has developed a master plan to construct centralized wastewater treatment plants since 1980. The original recommendation from Japanese Government was to construct 20 wastewater treatment plants within the next 30 years from the year 1980 (JICA, 1999). Until now, there are 7 centralized wastewater treatment plants with total treatment capacity of 992,000 m$^3$/day. Rate of water quality improvement has a slow progress and significant numbers of people are still in need for more wastewater treatment systems. After the construction of the centralized treatment plants completed, quantity of water in canals will be reduced and it can indirectly intensify quality of canal water. Moreover, overbuilding capacity of centralized system designed for future population requires high operation and maintenance, and has diseconomy of scale for piping network for large service areas. Current experience of centralized wastewater treatment plant operation do not run up to their full potential capacity which creates a huge lost of public project investment.

The risen question is whether Bangkok really needs more large-scaled centralized type of treatment plant or small-scaled, localized, near sources, distributed treatment plant with comparable...
treatment capacity could offer additional benefits. Decentralized system is a smaller scaled facility that collects, treats, and reuse or disposes of wastewater near sources of discharged (Crites and Tchobanoglous, 1998). The system could be as small as for installing in individual houses or in group of buildings clusters or as larger as in residential development, or in an integrated system. Technologies used for decentralized system tend to be simple and sustainable to operate and installed on-site of the polluters residential area or property (Bradley et al., 2002). The relative benefits and costs of different scale treatment systems depend very strongly on the specific nature of the situation and the available wastewater options (Friedler and Pisanty, 2006).

The decentralized wastewater management approach has been applied in different countries and found to improve water quality cost-effectively, especially in rural areas of developing countries (Bakir, 2001; Parkinson and Taylor, 2003; Engin and Demir 2006; Massoud et al., 2009). In developed countries, i.e. the United States, Canada, and Australia, decentralized systems are employed widely to avoid high cost of construction and operation of centralized systems (Wilder and Schreff, 2000; Tsagarakis et al.,2001). Moreover, decentralized systems allow for flexibility in management and planning and a series of processes, e.g. water recycling and reuse systems, can be customized to meet environmental and public health requirements.

The main objective of the study is to identify practical and cost-effective solution/strategy for improving canal water quality in Bangkok by (1) developing a model to compare management options and evaluate improvement of water conditions over the lifetime of centralized and decentralized wastewater treatment system, (2) evaluating costs and benefits between different potential management scenarios, and (3) identify a policy planning for improving canal water quality. The case study focuses on reusing reclaimed water to dilute canal water and improve its quality and quantity by locating at upstream of the canal.

METHODS

In this investigation, the decision-making model was developed to compare final water quality, total costs and benefits and all related competency in canal water quality improvement. Data was collected from Department of Drainage and Sewerage, Ministry of Environmental and Natural Resources, and private consulting companies in Thailand. Available information is area location of the proposed wastewater treatment project, map of canal network, boundary and characteristic of canals in Bangkok (length, width, depth, and elevation), canal water quality and flow conditions, canal maintenance plan, future plan for municipal wastewater management and for retrofitting a municipal wastewater collection system in Thailand, population data, and related price information. ‘Canal’ means ‘Klong’ in Thailand. The word ‘Klong’ will sometime use alternatively.

The proposed “Klong Toey Wastewater Treatment Project (WWTP)” was selected to be a case study (DDS BMA, 2001). The case study was divided into 5 scenarios, (1) baseline (no construction of treatment plant), (2) construction of a centralized wastewater treatment plant, (3) construction of wastewater treatment plant with water redistribution system (to carry reclaimed water upstream to improve canal water quality), (4) construction of decentralized wastewater treatment system with regular treatment technology (activated sludge), and (5) construction of decentralized wastewater treatment system with advanced treatment technology (membrane bioreactor).

Coverage area of Klong Toey WWTP including canals within the area is shown in Figure 1. Figure 1a shows a centralized zone with water redistribution system. While the decentralized system was divided into 3 smaller treatment zones, the 3 zones include Klong Toey, Klong Prakanong and Klong Bangna, as shown in Figure 1b. The coverage area size of the proposed zone was designed approximately based on canal locations and directions of water runoff. The location of decentralized treatment plants will be located at the upstream of canal. The proposed location of the centralized treatment system is at canal downstream near the outfall to Chao Praya River.
Figure 1: (a) Centralized with water distribution system and (b) Decentralized system

The model has 2 main elements: (1) water quality model and (2) cost model. The lifetime of the project is designed to be 20 years. Water quality model processes are summarized in Figure 2. In this study, water quality improvement is measured in term of BOD reduction. Three water improvement mechanisms are considered in the water quality model: (1) removal of wastewater loads by a wastewater treatment plant, (2) dilution of water in canal/waterway by reclaimed wastewater, and (3) self-purification of canal by biological degradation process during water travel. In the first step of improvement, BOD was removed by wastewater treatment. The remaining BOD in the canal is equal to BOD loads of background flow. In the second improvement process, dilution from treated wastewater will improve canal quality. New mixed water quality can be calculated using dilution factors. In case of centralized without redistribution/pumping system, the benefit from dilution does not exist. While traveling from canal upstream to the main outfall downstream, background concentration will be improved by microorganism activity. To estimate impacts from degradation, Streeter-Phelps equation is used. The model procedure of water quality for decentralized system is similar to that of the centralized system. The main difference is on the need to estimate water quality for each specific decentralized system (based on zoning) and the additional dilution benefits from connectivity of decentralized systems. The canal characteristics in each decentralized zone are summarized in Table 1.

Table 1: Characteristics of Canals

<table>
<thead>
<tr>
<th>Klong</th>
<th>Width (m)</th>
<th>Length (m)</th>
<th>MSL (m)</th>
<th>Average Calculated Flow (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klong Toey</td>
<td>14-55</td>
<td>3,150</td>
<td>-2.0</td>
<td>2.13</td>
</tr>
<tr>
<td>Klong Prakanong</td>
<td>22-44</td>
<td>8,650</td>
<td>-2.0</td>
<td>49.97</td>
</tr>
<tr>
<td>Klong Bangna</td>
<td>3-15</td>
<td>7,920</td>
<td>-2.5</td>
<td>4.12</td>
</tr>
</tbody>
</table>
Table 2: Calculated Treatment Capacity of Each Scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Capacity (m$^3$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized (2 and 3)</td>
<td>510,606</td>
</tr>
<tr>
<td>Decentralized (4 and 5)</td>
<td></td>
</tr>
<tr>
<td>Klong Toey</td>
<td>95,405</td>
</tr>
<tr>
<td>Klong Prakanong</td>
<td>295,483</td>
</tr>
<tr>
<td>Klong Bangna</td>
<td>119,718</td>
</tr>
</tbody>
</table>

In the cost model (Figure 3), the design capacity of treatment plants derived from future population, water consumption, rate of wastewater generation, rate of infiltration/inflow, and the designated life span. After chosen a coverage area of each decentralized zone, each decentralized system will have different population density which is used to estimate amount of wastewater generation from that municipal zone. The growth rate of population is used to forecast number of future population and the maximum flow of wastewater generation which plants need to design for. From the model estimation, total population within the proposed area in 2030 will be approximately 540,000 people. The designed treatment capacity of each scenario is presented in Table 2.

Total costs are estimated by summation of (1) capital cost (construction cost of plant, sewer pipe and pump system) and (2) operation and maintenance cost. Additional costs for centralized system include the cost of pipeline and pumping system necessary for carrying the reclaimed water back to the upstream to help diluting canals’ water. For a decentralized system, total costs can be calculated by summation total costs of each individual decentralized system. Treatment cost depends on technology chosen. In this study, technology for centralized system is activated sludge (AS). Decentralized system uses activated sludge (AS) and membrane bioreactor (MBR). Construction cost of wastewater treatment system is quantified as a function of the process size (design flow rate, volume) by adopting cost function developed by Tsagarakis et al. (2003). For MBR cost, data was collected from Japanese company. The cost function is included labor cost. Thai government manual suggested that annual cost for maintenance of wastewater treatment plant and sewer collection system is approximately 0.5 - 1% of construction cost. Annual cost for maintenance pump and electrical equipment is approximately up to 10% of equipment price. Cost of operation varies based on quantity and daily flow rate of wastewater. Operating cost is approximately 15% of system cost. The final total cost is calculated in net present value with a chosen internal rate of return at 7%. The cost of construction, operation and maintenance may also depend strongly on economic conditions of the country e.g. labor cost, equipment import, IRR, etc. Therefore, the cost/price chosen to be used for this study may not reflect situations in other country.

For the benefit estimation, benefits are calculated by multiplying amount of BOD reduction, % water level reduction, % energy saving, with marginal willingness to pay for water improvement of each beneficial category per person. Total benefits will be equal to amount of benefits per person multiplying by total amount of population. Since a lack of data for willingness to pay from Bangkok residents, the study adopted the willingness to pay value for water quality improvement of Teganuma basin in Japan to calculate the benefits. The calculated marginal willingness to pay for each category in Thai Baht is 503.17 Baht/year/capita for decreasing 1 mg/l BOD, -224.29 Baht/year/capita for 10% decrease in water quantity, and 97.14 Baht/year/capita for 10% decrease in life cycle energy consumption. This willingness to pay is calculated value by referring to the Japanese willingness to pay information (Otsuka et al., 2008) and adjusting by purchasing power parity from World Bank (2005). The result interpretation needs to be done carefully.
RESULTS AND DISCUSSION

Table 3 presents the summary of water quality in Klong Toey, Klong Prakanong, and Klong Bangna after inclusion of wastewater treatment, dilution and self-purification benefits for the centralized system with water pumping and decentralized systems, taking into account of population increase over 20 year period. After installing wastewater treatment system, average background concentration in each canal is estimated to be as the following: Klong Toey is 10.7 mg/l, Klong Prakanong is 7.3 mg/l and Klong Bangna is 15.8 mg/l. The final BOD at the end of canal can be calculated based on the Streeter-Phelps equation which dependent on the travel distance, flow rate, and degradation rate constant. In the case study, the travel distance was assumed to be equal to the length of each canal. The K (constant rate, base e) for degradation is used 1.3 day⁻¹ (Banjongproo and Wett, 2002). The calculated retention time is approximately 0.47 day for Klong Toey, 0.10 day for Klong Prakanong, and 0.34 day for Klong Bangna.

Based on the model result, percent improvement of water quality within each canal is ranging from 84%, 40%, and 66% for Klong Toey, Klong Prakanong and Klong Bangna, respectively. If the area upstream from
the case study that has connected canals also implements wastewater treatment, background concentration in the canal (located downstream) will be further improved.

**Table 3:** Summary of BOD Concentration in Each Canal within Different Scenarios

<table>
<thead>
<tr>
<th>Canal</th>
<th>Current WQ</th>
<th>With WWTP</th>
<th>With Self-Purification</th>
<th>Net BOD Improved</th>
<th>%WQ Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klong Toey</td>
<td>36.6</td>
<td>10.7</td>
<td>5.8</td>
<td>30.8</td>
<td>84</td>
</tr>
<tr>
<td>Klong Prakanong</td>
<td>10.6</td>
<td>7.3</td>
<td>6.4</td>
<td>4.2</td>
<td>40</td>
</tr>
<tr>
<td>Klong Bangna</td>
<td>30.0</td>
<td>15.8</td>
<td>10.2</td>
<td>19.8</td>
<td>66</td>
</tr>
</tbody>
</table>

**Table 4:** Costs and Benefits of Each Scenario

<table>
<thead>
<tr>
<th>Cost, Benefit System</th>
<th>Centralized without Pumping</th>
<th>Centralized with Pumping</th>
<th>Decentralized with Regular Technology</th>
<th>Decentralized with MBR Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (Mbaht)</td>
<td>7463</td>
<td>8693</td>
<td>7742</td>
<td>32649</td>
</tr>
<tr>
<td>Benefit (Mbaht)</td>
<td>17030</td>
<td>17815</td>
<td>17815</td>
<td>17815</td>
</tr>
<tr>
<td>Benefit/Cost</td>
<td>2.28</td>
<td>2.05</td>
<td>2.30</td>
<td>0.55</td>
</tr>
</tbody>
</table>

The model suggested that the decentralized system provides slightly higher percent improvement in canal water quality, compared with the centralized system without pumping system. Among the 3 zones, Klong Toey will receive the highest benefit of water quality improvement if the wastewater treatment plant were implemented. This is because Klong Toey is in small size and rather short canal and receives high wastewater loads from densely residential and business districts.

Table 4 summarized total costs and benefits estimated for each scenario. For cost comparison, the centralized system without pumping is the least expensive solution at 7,463 Mbaht (~$213M). Exchange rate is 35 baht/$US. The second least expensive system is the decentralized system with regular technology at 7,742 Mbaht (~$ 221M). It is clear that the decentralized system with advanced technology cost significantly higher at 32,649 Mbaht (~$ 933M) compared with other scenarios, and, therefore, is not a practical system for implementing at this time.

For benefit comparison, the decentralized system and the centralized with pumping system provide the highest amount of benefits at 17,815 Mbaht ($ 509M). Even though, providing the lowest cost, the centralized without pumping system yield less benefits compared to the other scenarios, at 17,030 Mbaht ($ 494.4M). Among the decentralized zones, total amount of benefits in Klong Prakanong is highest since the Klong Prakanong zone covers the largest area and number of people which therefore yields the highest total benefits. The cost of damage to the public, if there is no construction of a wastewater treatment system, is assumed to be equal to amount of benefit losses. In this case, the residents in the proposed area will lose approximately 17,030 – 17,815 Mbaht ($ 494.4 - 509M) of benefits for the delay of such construction.
For benefit/cost ratio comparison of water improvement, the decentralized system with regular technology offers highest ratio at 2.30. The centralized without pumping system has the 2nd highest ratio at 2.28 which is not significantly different from the decentralized system. The centralized system with pumping has the B/C ratio at 2.05. While the decentralized with advanced technology has the lowest ratio at 0.55. Based on the estimation, the results suggested that the decentralized system may require higher total costs but provide no significant difference in the benefit over cost ratio compared to the centralized system without pumping. Moreover, the decentralized system approach could offer slightly better in canal water improvement.

Amount of benefits per person for water quality improvement in each canal depends on ratio of original wastewater generation to total water passing through the canal system. The ratio of wastewater flow entering canal comparing with background flow in each zone is calculated in term percent reduction of amount flow rate, as follows: decrease in flow rate of water compared with original flow (1st-20th year): Klong Toey 48.8 - 54.0%, Klong Prakanong 6.7 - 7.9%, Klong Bangna 32.8 - 39.2%.

Obviously, Klong Toey has the highest ratio of wastewater discharge into canal. The benefits of the canal water quality improvement will be more significant as compared with the other zones. In addition, in the case of centralized system without pumping reclaimed water back to upstream, quantity of water in canal will reduce. If the pump station continues operating with the same flow, water level will become very low. Therefore, the operation should maintain level of original water level by reducing pumping rate. When the pumping rate is reduced, it will also create a cost-saving from pumping energy. However, it will also affect (reduce) the flow rate of the canal.

It is clear that the centralized without pumping system and the decentralized system with regular technology offer the best benefit/cost ratio. The centralized with pumping system offer equally as good benefits as the decentralized system with regular technology but at a higher cost due to the required additional pumping facilities and the energy requirement for pumping the treated water back to the canal system upstream.

The benefits considered in this section is solely on the quantifiable factors and do not include the other difficult-to-measure or intangible benefits. In addition to the quantitative benefits compared with the centralized system, the decentralized system can provide additional benefits in term of: shorten time for project execution and for overall water quality improvement, greater potential in future upgradability, flexibility for future advanced technology adoption, decreasing amount of total area required for wastewater treatment (therefore reducing community impacts), greater community involvement, better growth management (build as city/new community expand), learning for improvement on the reliability of networks of smaller system, reducing idling excess capacity and excess cost, less amount of capital investment required for construction, and lowering political debate over project execution and securing budgets for large public projects.

In this study, the model is developed based on systematic methodology for scenario planning process and data analysis to provide competence evidences to help the government on developing and making decision for an efficient wastewater management/implementation. The model framework provides an objective and systematic way of identifying a feasible, practical and most beneficial implementation option for wastewater facility in Bangkok city. Future works that could help better refine the modeling results include conducting a study for getting the willingness to pay for water quality improvement in the actual area/location, surveys for actual cost data for piping network and construction, land requirement and availability and price, exact field measurement on piping network and routes.

CONCLUSIONS

In conclusion, the difference in term of advantages and disadvantages between centralized and decentralized system approach is rather small. Decentralized system is not rather an expensive
treatment system as previously thought. To focus on canal water improvement, decentralized system can help promoting canal water quality as well as centralized system does, with similar benefit over cost ratio. However, levels of benefits from water quality and quantity improvement depend on proportion between the amount of wastewater discharged through canal system, canal sizes and canal flow rates. Decentralized wastewater treatment system, by locating upstream of the canals and treating wastewater near sources, yield higher net benefits when considering additional advantages from water reuse for dilution, amount of water increases in the canals, and cost reduction from piping system operation. Furthermore, the decentralized system offers implementation advantages in shortening time for water improvement project, reducing idle capacity and providing more flexibility for future expansion and advanced technology adoption. The results from the case study confirm that decentralized wastewater management approach can be a promising alternative to promote sustainable uses of water and can work in help with centralized system. Therefore, in the future, co-existing of large-scaled centralized and small-scaled decentralized systems may increasingly need to improve net efficiency of wastewater management for the future communities/cities.

ACKNOWLEDGEMENT

The researchers are thankful for financial supports by International Center for Environmental and Technology Transfer via PIER project 2008.

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