UNIVERSITY OF CALIFORNIA

Los Angeles

An Appropriate Wastewater Treatment System in Developing Countries: Thailand as a Case Study

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Civil Engineering

by

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2009

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2009

To my father, mother, brothers, sisters, nieces, nephews, and my ding.

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ACKNOWLEDGMENTS

I would like to express my gratitude to my advisor, Professor Michael K. Stenstrom, for his support, encouragement, and patience throughout my study at UCLA. His particular support on my scholarship extension was greatly appreciated. I would like to extend my gratitude to other committee members, Asst. Prof. Terri S. Hogue, Assoc. Prof. Jennifer A. Jay, and Assoc. Charles J. Corbett. I would also like to thank Assoc. Prof. Linwood H. Pendleton for his advice during the prospectus examination.

My most profound and deeply felt gratitude go to my great supporter, Assoc. Prof. Nopadon Sahachaisaeree who has been there for me since the beginning of my graduate education. I would not have achieved much without you giving me ideas, inspiration, encouragement, listening and discussing, sharing your knowledge, and last but not least your love and sense of humor. I can never thank you enough. I could not be successful as I am today, without you.

I wish to express my sincere gratitude to the Ministry of Science, Technology, and Environment for awarding me the Royal Thai Government Scholarship for pursuing Ph.D. in Environmental Engineering at UCLA. I would like to thank also the Office of Civil Service Commission; the Minister-Counselor (education) and staff of the Office of Educational Affair, Royal Thai Embassy in Washington D.C.; Mr. L.B. Tillakaratne at UCLA-the Office of International Students and Scholars; and Maida (department graduate student services) for their administrative support throughout my study.

I would especially like to express my gratitude to Thai experts, wastewater treatment plant operators, members of the Rom Klao and Fuen Nakorn Rom Klao communities, and local authority officials who participated in my surveys. Without whose participation and wisdom, this research would have been impossible. I also thank Thai students from King Mongkut's Institute of Technology Ladkrabang for their help with my questionnaire survey. Nong Ple, it was nice to work with you. Nong Jang, I really appreciated all your help with the mailing surveys.

I am very thankful to all my friends for their friendship, encouragement and moral support. I am grateful to my close friends, Tina Sanchez, Julie Ladel, Fatma Cakir, Sunny Li, Sim-lin Lau, Mi-Hyun Park, and Sunhyung Kim for always being there for me and for all joyful moments we shared together. I also would like to extend my thanks to the staff and faculty of the Civil and Environmental Department at UCLA. It has been the most wonderful time of my life to study here and have a chance to know all of you.

Finally, I am thankful to my dear family, my parents (Somchai and Ampon), sisters (Jum, Ja, Joy, and Jeab), and brothers (Sun and Jack) for their constant love and support. I am grateful to my cutest nieces and nephews (Mill, Anon, Smile, Smart, and New) who have kept me happy and made me smile throughout the tough time. Pa, I thank you for always believing in me. Mae, thanks for always being proud of me.

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ABSTRACT OF THE DISSERTATION

An Appropriate Wastewater Treatment System in Developing Countries:

Thailand as a Case Study

by

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Doctor of Philosophy in Civil Engineering

University of California, Los Angles, 2009

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Using appropriate technology suitable for local conditions is a key requirement to overcome operational failures of wastewater facilities in many developing countries. The term "appropriate" thus conveys the notions of feasibility and pragmatism for a specific circumstance. In *sustainable* terms, appropriateness also signifies the logic for meeting people's needs in the best possible way with two preconditions—the availability of local resources and the limitation of local conditions. Suitable option is, therefore, not only a system providing the best performance at least cost, but is also sustainable in terms of meeting local needs—socio-cultural acceptability, technological and institutional feasibility, economical affordability, and environmental acceptability. This study aims to

devise a comprehensive approach for selecting appropriate wastewater treatment systems in Thailand. Apart from the technical aspects of the treatment systems, the study integrated social, economic, and environmental aspects to develop a set of criteria and indicators (C&I) useful for evaluating appropriate systems. The study takes the C&I approach to develop the selection framework appropriate to the context of Thailand. The well-constructed set of C&I can be used to express what appropriate wastewater treatment systems mean for a specific location and can be incorporated within the selection process of wastewater treatment system for the community. A set of proposed criteria and indicators is used to assess the operating municipal wastewater treatment plants in Thailand.

The study provides a case study which is a systematic analysis of four wastewater treatment alternatives for Rom Klao and Fuen Nakorn Rom Klao communities. Assessment results obtained from the previous processes are used to develop a multi-criteria module for a decision support system. The study uses multi-criteria decision analysis (MCDA) techniques developed in the first part of the dissertation for comparing and rank ordering wastewater treatment technology alternatives against the identified technical, socio-economic, and environmental objectives. The proposed wastewater treatment options obtained from the MDCA are analyzed with the local needs, availability of resource, and constraints before the most locally appropriate system is selected.

CHAPTER 1

INTRODUCTION

1.1 STATEMENT OF PROBLEMS

Great efforts have been made at both international and local levels to promote and support water supply and sanitation programs in the developing world. Nevertheless, statistical data still shows that approximately two third of the World's population, or 4 billon people, are living without wastewater treatment (Mara, 2001). Most of them live in developing countries. Although the technologies for environmental remediation are available, it has proven difficult to implement them successfully, under the unique local conditions of developing countries. It is the most challenging issue for environmental engineers and decision makers to select and design locally appropriate wastewater treatment systems to meet the specific needs of people in developing countries.

Decision makers in these countries choose to apply conventional wastewater treatment techniques widely utilized in developed nations, and ignore the local context and constraints, particularly the affordability, skills, and political will of the relevant authorities. Such advanced wastewater treatment technologies are not only unaffordable, they are also too complicated to operate and maintain (Van Lier and Lettinga, 1999). As a result, a number of treatment plants constructed in developing countries had to be abandoned due to the failure to provide necessary operation and maintenance.

In recent years, studies concerning appropriate wastewater treatment technologies and the selection process in developing countries have become important issues, gaining recognition in the fields of environmental engineering and infrastructure planning as illustrated by Reid (1982), Ellis and Tang (1991), Eliman and Kohler (1997), Krovvidy (1998), Rodriguez-Roda et al (2000), Balkema et al. (2001). Many studies in the past centered on the traditional optimization approach by means of mathematical methods, focusing on the solution of systems with the highest performance and least cost (Mishra et al, 1974; Ellis and Tang, 1991). Nonetheless, researchers have begun to consider local factors, such as socio-economic, political, and institutional situations, which have been considered among the prime barriers preventing the success of implementing the selected technology (Ellis and Tang, 1991; Okubo et al, 1994; Loetscher and Keller, 2002).

Appropriate wastewater treatment technologies have also been recognized as part of *sustainable development strategies* in the Third World countries. The suitable option is, therefore, not only a system providing the best performance at least cost, but it should also be sustainable in terms of meeting the local needs—socio-cultural acceptability, technological and institutional feasibility, economical affordability, and environmental acceptability (Mara, 1996; Ujang and Buckley, 2002; Sarmento, 2001).

1.2 STATEMENT OF RESEARCH QUESTIONS

The study approaches the problems of wastewater management in developing countries by incorporating the issues of urban development with the aspect of environmental management. The study thus aims to answer the following research questions.

1. What are the factors governing the selection of appropriate technologies in communities located in urban area of developing countries?
2. With factors found in question 1, how can the most appropriate wastewater treatment systems be selected utilizing such factors? In other words, what would be the most appropriate procedure for selection?
3. Using communities in Bangkok as case studies, what are the appropriate wastewater treatment systems applicable for domestic sanitation?
4. How could Bangkok's example be applicable for the needs of sustainable wastewater treatment in communities typical of developing countries?

1.3 RESEARCH OBLECTIVES

The study incorporates the social research approach with that of environmental engineering discipline to bring about further insight to the remediation of technology selection failure. The main objectives of the research include the following:

1. Identify and analyze factors governing the selection of appropriate WWT technologies in developing countries;
2. With the findings from previous effort, develop a set of decision criteria and indicators (C&I) useful for the selection process;

3. Develop a framework for comparative assessment of alternative wastewater treatment technologies in Thailand by using the set of selected C&I;
4. Develop a decision support tool based on multi-criteria decision analysis (MCDA) methodology for assessing scenarios of Bangkok, Thailand and selecting appropriate wastewater treatment alternatives.

The finding from this research was expected to bring about a new line of thought, contributing to the development of decision-making and supporting systems in the field of environmental engineering. With contextual limitation, the results of the study can thus be generalized to the overall population in developing countries in a rather narrow fashion. The generalizations, nevertheless, could be safely made to other developing countries having similar context to Thailand in terms of urban characteristics, socio-economic, climatic and living conditions. Following this research, further study in developing countries elsewhere could refine the model to fit their respective local conditions.

1.4 RESEARCH APPROACH AND CONCEPTUAL FRAMEWORK

1.4.1 Sustainable Infrastructure Development

The research takes “Sustainable development” as the main approach to develop the basic framework of this study. Sustainable development has recently become one of the most important terms underpinning the wastewater management approach. Although the definition of sustainable development has been originally defined as “meeting the need of the present without compromising the ability of future generation to meet their own needs" (McCarney, 1994 referred to WCED 1987, p.8), a wide range of literature still interprets the term differently. Sustainability of cities concerns the development of systems to meet the needs of city dwellers (development goals) while keeping the minimum environmental costs passed to other people or other ecosystems (sustainable goals) (Hardoy et al, 1995)

Sustainability in the urban context especially within developing countries also addresses improved urban dwellers' survival strategy, who struggle to make ends meet in the city (McCarney, 1994 referred Wekwete, 1992). In those cities, the pressing needs, such as access to housing, water, sanitation, and a variety of services, are the priority concerns of the poor. Researchers thus attempted to relate such survival strategy to the consequence of urban environment and infrastructure development (McCarney, 1994).

The study of wastewater treatment strategies in developing countries will, therefore, consider poverty issues when trying to fulfill environmental sustainability. The technology to be applied to the urban poor should be sustainable and be chosen by considering the applicable alternatives that meet the needs of the local community, allowing localized operation and maintenance. All stakeholders, particularly from the local communities themselves, should be involved in the informed decision making process to reach the final policy.

1.4.2 Research Framework

The fundamental assumption of the framework postulates that local factors determine the selection of an appropriate treatment system in the Third World context—the extent of water pollution, socioeconomic factors, physical factors, and institutional and political factors (Figure 1.1).

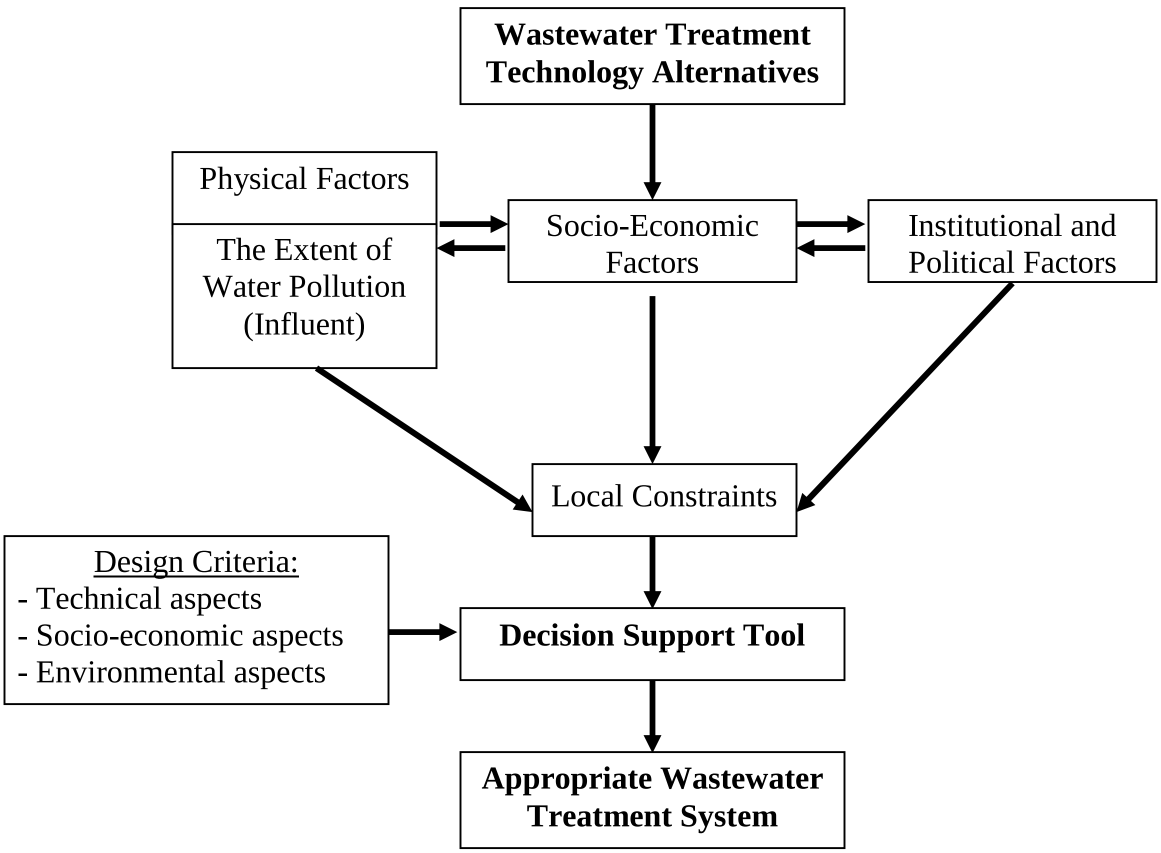


Figure 1.1 Research Framework

The problems of wastewater management in developing countries are closely related to a number of local conditions. Apart from the technical or engineering feasibility, the development of wastewater treatment systems needs to be considered hand in hand with the available infrastructure, institutions, human resources, and socio-economic conditions (Mara, 1996; Varis and Somlyódy, 1997; Pegram et al., 1999).

Household socio-economic status is among the factors determining the household wastewater characteristics. A study of household wastewater production in Brazil showed that amount of wastewater was significantly related to income level. The rate of wastewater production was 74 Liter/capita/day for the lowest income group vis-à-vis 210 Liter/capita/day for the highest income group (Campos and von Sperling, 1996). Income level is also a factor directly contributing to the legal and physical problems of the urban poor (Pegram et al., 1999). The urban poor usually earn insufficient and unstable income, which forces them to live in illegal settlements. The illegality further prevents them from obtaining access to services provided by government, which creates further deterioration of living conditions. A majority of the population in richer areas is able to access to wastewater treatment facilities provided by the city, while services in the poorer areas are virtually nonexistence (Tsagarakis et al., 2001).

The political and institutional structures are also constraints complicating the remedy of the existing problems. Examples of such barriers include complications as a result of governmental intervention in wastewater management plans and policies, legislation for controlling and enforcing the policies, institutional arrangements, financing mechanisms, and technical consultation (Pegram, 1999). Local ignorance and negligence in maintaining wastewater systems in communities are likely to be a consequence of governmental irresponsibility and inability to motivate the local civil society (Pegram, 1999).

The local conditions—demographic characteristics, community location, density, settlement conditions, local climate, and the availability of sewer systems and on-site treatment—are crucial determinants governing wastewater quality prior to treatment. In this light, the technical feasibility is another important factor in the selection process of an appropriate wastewater treatment system. Systems selected from a pool of existing treatment methods require cautious decision making to derive the most appropriate technology, applicable to the unique social, economic, political, and institutional environment. (See detailed rationale discussion in Chapter 2).

1.5 DISSERTATION ORGANIZATION

The dissertation is organized into five chapters. Chapter 1 presents the statement of wastewater treatment problems in developing countries leading to the major research questions and objectives. The approach of this study and the fundamental assumption of research framework are also defined in this introduction chapter. Chapter 2 summarizes an extensive literature review that includes three major sections. The first section focuses on wastewater treatment technologies and management approaches in the context of developing countries. The second section reviews different aspects of local conditions and selection criteria of appropriate wastewater treatment systems. The last section integrates approaches and methods for the technology selection. Chapter 3 specifies methodology for data collection. Results presented in Chapter 4 comprise 6 sections. The first section demonstrates the process of developing criteria and indicators for selecting appropriate wastewater treatment systems in Thailand. Results obtained from the expert survey are used to evaluate and select a final set of criteria and indicators applicable to local situation. Secondly, four wastewater treatment alternatives are identified to be used in the decision analysis process. In the third section, based on the selected criteria and indicators, a plant survey is developed to collect local information and evaluate the operating wastewater treatment systems in Thailand. The fourth section introduces the study area and case study communities. It also establishes a contextual background for the analysis of Rom Klao and Fuen Nakorn Ron Klao settlements. The following section describes the frameworks and principles of multi-criteria decision analysis technique. Findings and results obtained from the model are discussed in order to setup a framework of the decision support model applicable for local authorities and community organizations in the context of Thailand. The last result section elaborates the local socio-economic and technical circumstances, and constraints pertaining to the selection of treatment technology in different scenarios in Bangkok. Local factors determining the selection of locally appropriate technology are assessed before making the site-specific recommendation for the case studies. Chapter 5 presents overall conclusions and interesting topics for the future study.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In order to establish the theoretical rationale for research, this chapter contains three major sections of review. The first section reviews available treatment technologies for domestic wastewater and management approach in developing countries. The second section discusses methods and approaches for selecting appropriate technologies. The last section elaborates approaches and methods for wastewater technology selection in this study.

The first section focuses on wastewater treatment technologies and management approaches in the context of developing countries. This section investigates the key features, strength and weakness of the technologies and highlights the contextual difference between the developed and developing countries, which is the origin of the existing problems. Most policy makers adopt the conventional approaches from the developed countries and applied them in the Third World countries without considering the unique needs of the local communities, the suitability of local conditions, and the availability of resources. The following section reviews the conventional and non-conventional approaches to wastewater selection processes to reach the best solution for the existing sanitation problems and their impact on the urban residents, particularly the low-income communities in the developing countries. The last section touches on several different approaches, such as the optimization approach, the progressive approach, the non-mathematical method, the analytical hierarchy process, and the intelligent tools system. The final part of this section reviews the multi-criteria decision analysis as a basis for developing a model proposition in the study.

2.2 WASTEWATER TREATMENT TECHNOLOGY OPTIONS AND MANAGEMENT APPROACHES

2.2.1 Existing Wastewater Treatment Technologies

The following review in this section focuses on the existing domestic wastewater treatment technologies. The system typology is examined in two different dimensions—(1) the locational dimension; namely, the on-site and off-site systems, and (2) the technical dimension; namely, the aerobic, anaerobic and natural processes. The review attempts to investigate the conventional treatment systems which have been commonly used in the developed and developing countries.

2.2.1.1 Classification by Locational Dimensions

On-Site System: The on-site systems are mostly utilized separately, each for a single household. Wastewater from each household is channeled to the treatment unit and further to the subsequent wastewater disposal unit (if applicable). In small communities of the developed countries' remote rural areas, the commercially available prefabricated biological plants are popular. The system comprises a set of rather complicated components—a recirculating biological filter, a submerged aerated biological filter, an activated sludge package plants or a sequence batch reactors, and a bio-disc unit (Burkhard et al., 2000). The package functions as a self-contained unit for domestic utilization. Despite its effluent quality, the unit is relatively high in cost and requires professional installation and maintenance.

The low-cost on-site technology, in contrast, requires a relatively simple type of construction. There are two types of such technology. The single treatment unit includes a Ventilated Improved Pit (VIP) latrine pit, a pour-flush toilet, a septic tank, a double vault composting, and an aqua privy. The combined system is the integration of a treatment unit and an effluent disposal system such as soak away- or seepage-pit. Factors to be considered during the system selection process are usually the availability of water supply, collection of night soil, disposal facility, site appropriateness, costs, simplicity of construction, and requirements (Kalbermatten et al, 1982) (Table 2.1).

A septic tank is one of the low-cost on-site technologies and now the most well-know and commonly used system throughout the world. The system is able to perform the initial treatment well before the wastewater will be transferred and treated by a secondary off-site system. The additional benefit is very low investment cost and labor requirement, both of which are the major constraints in developing countries.

A large number of developed countries avoid using some on-site methods due to their low efficiency and high threat to ground and surface waters (Burkhard et al., 2000). In most cases, grey wastewater and all domestic wastewater, with the exception of toilet waste, is not treated by the on-site system. On the other hand, it is a common practice in

Table 2.1 Descriptive Comparison of On-Site Wastewater Treatment Systems

Technology	Rural application	Urban Application	Construction Cost	Operating cost	Ease of construction	Self-help potential	Water requirement	Required soil Conditions	Complementary off-site investment	Reuse potential	Health benefits	Institutional requirement
VIP latrines	Suitable	Suitable in Low/Medium -density areas	Low	Low	Very easy except in wet or rocky ground	High	None	Stable, permeable soil; groundwater at least 1 m. below surface	None	Low	Good	Low
Pour-flush toilet (PF)	Suitable	Suitable in Low/Medium -density areas	Low	Low	Easy	High	Water near toilet	Same as VIP latrines	None	Low	Very good	Low
Double vault composting (DVC) toilets	Suitable	Suitable in Low/Medium -density areas	Medium	Low	Very easy except in wet or rocky ground	High	None	None (can be built above ground)	None	High	Good	Low
Self-stopping aqua privy	Suitable	Suitable in Low/Medium -density areas	Medium	Low	Required some skilled labor	High	Water near toilet	Same as VIP latrines	Treatment facilities for sludge	Medium	Very good	Low
Septic Tank	Suitable	Suitable in Low/Medium -density areas	High	High	Required some skilled labor	Low	Water piped to house and toilet	Same as VIP latrines	Off-site treatment facilities for sludge	Medium	Very good	Low
Three-stage septic tanks	Suitable	Suitable in Low/Medium -density areas	Medium	Low	Required some skilled labor	High	Water near toilet	Same as VIP latrines	Treatment facilities for sludge	Medium	Very good	Low
Vault toilets and cartage	Not suitable	Suitable	Medium	High	Required some skilled labor	High (for vault constructi on)	Water near toilet	None (can be built above ground)	Treatment facilities for night soil	High	Very good	High
Sewered PF, septic tank, aqua privies	Not suitable	Suitable	High	Medium	Required skilled engineer/ builder	Low	Water piped to house and toilet	None	Sewers and treatment facilities	High	Very good	High

Source: Kalbermatten et al. (1982)

most developing countries, for such untreated wastewater to be discharged to the sewer system, if a system exists, or discharged directly to the nearby public water channels with or without legal permission. Due to its simplicity and low cost, the on-site system is still an acceptable pre-treatment alternative for low-income households in developing countries, where central sanitation services are often nonexistence.

Off-Site Systems: Off-site treatment systems are usually a decentralized wastewater treatment approach if they are small in scale or owned and operated by the community. The community systems for small clusters of houses are suitable for areas where each lot in the cluster is too small to take advantage of an individual on-site system, or where the soil and underlining strata are unsuitable for on-site systems (Metcalf and Eddy, 2003). Most off-site systems comprise (1) a collection system to convey the pretreated or raw wastewater away from each household; (2) some form of treatment at the end of the colletion system, and (3) an effluent disposal system, if necessary.

Table 2.2 summarizes the alternative technologies for off-site wastewater treatment systems. The table also describes the features of each system and compares their pros and cons.

Table 2.2 Overview of the Off-Site Wastewater Treatment Systems

Treatment systems	Description	Advantages	Disadvantages
Aerobic Processes			
Activated sludge: AS	- Providing treatment by bacteria fed on organic material and mechanically supplied oxygen	- Reliable - High degree of treatment - Low land requirement - Highly operational flexibility - Low production of odor, insects and worms - Extended aeration process: High resistance to variation in loads and toxics, and tolerates ranges of climate conditions	- High construction and O&M costs - Complicated process with many mechanical and electrical parts - High operation and maintenance requirements - Large amounts of sludge to be treated and disposed - Possible environmental problems with noise and aerosols - Conventional AS: Sensitive to toxic
Trickling (percolating) filters	- Passing wastewater down through a loose bed of stones with attached bacteria on the surface - Aerobic process with bacteria getting oxygen from the atmosphere	- No need for mechanical aeration - High efficiency in BOD removal - Small land required - Simple operation and maintenance with uncomplicated equipment	- High construction cost - Dependence on ambient temperature - Less flexibility in operation than AS - Sensitive to toxic contamination - Need of sludge treatment and disposal - Possible problems with flies
Rotating biological contractor (biodisk): RBC	- Series of thin vertical plates providing surface area for bacteria to grow - Providing treatment by conventional aerobic process.	- High removal efficiency	- Failure of many mechanical parts - High energy consumption

Table 2.2 Overview of the Off-Site Wastewater Treatment Systems (continue)

Treatment systems	Description	Advantages	Disadvantages
Aerobic Processes			
Oxidation ditch	- Oval-shaped channel with mechanical aeration	- Higher treatment power and less land requirements than waste stabilization ponds - Easier to control than AS	- Highs energy consumption
Waste-stabilization ponds (aerated lagoons and oxidation ponds): WSP	- Large surface area and shallow pond - Essential treatment by photosynthetic process from natural growing algae providing oxygen for microorganisms to oxidize the organic waste	- High efficiency in treating pathogenic material - Natural process with no power/oxygen requirement (except for aerated lagoon) - Low construction and O&M costs - Simple construction and O&M - Providing treated water of sufficient quality for irrigation - Satisfactory resistance to load variations - Suitability to hot and sunny climates	- Requires large flat areas - Dependent on climate conditions (temperature and solar radiation) - Possibility of odors with anaerobic and facultative ponds - Fair pollutant removal efficiency in a single facultative pond. - Evaporation of huge quantity of valuable water in arid regions, resulting in increased salt content - Inflexible in accommodating population growth
Upflow anaerobic stabilization blanket: UASB	- Anaerobic process using blanket of bacteria to degrade polluting load	- Little sludge production - No oxygen/power requirements - Very low land requirements - Low construction and O&M costs - Simple construction and O&M - Suitability to hot and sunny climates	- Poor effluent quality requiring additional post-treatment processes to meet the effluent criteria - Possibility of odors - Slow process startup - Sensitive to load variations

Table 2.2 Overview of the Off-Site Wastewater Treatment Systems (continue)

Treatment systems	Description	Advantages	Disadvantages
Anaerobic Processes			
Anaerobic filter	- Passing wastewater through a column filled with various types of solid media with anaerobic bacteria attached on the surface	- Similar advantages to UASB - Ability to treat low-strength wastes at ambient temperature - Adaptability to various types and concentrations of wastewater - Resistance to variations in effluent quality	- Similar disadvantages to UASB - Risk of clogging - Effluent contains high concentration of suspended solids - Restricted to treat influent with low suspended solids
Natural Treatment Processes			
Land treatment (solid aquifer treatment: SAT)	- Supplying sewage in controlled conditions to the soil - Usually used for effluent polishing	- High capacity soil matrix required - High efficiency in BOD and coliform removal - Simple construction and O&M - Low construction and O&M costs - Resistance to variations in effluent quality - No sludge production - Providing soil fertilizers - Ground water recharge	- Low removal efficiency for some pollutants, such as phosphorus - Requires large area - Possibility of odors, insects, and worms (but not the subsurface infiltration system) - Dependence on climate (but not the subsurface infiltration system) - Application interrupted or reduced in rainy periods - Dependence on soil characteristics - Risk of contamination to the soil and plants - Possibility of nitrate groundwater contamination - An overland flow system: greater dependence on ground slope

Table 2.2 Overview of the Off-Site Wastewater Treatment Systems (continue)

Treatment systems	Description	Advantages	Disadvantages
Natural Treatment Processes			
Constructed wetland	- Passing sewage through an area of reeds - Treatment by action of soil matrix and soil/root interface of plants - Reed-bed channels, an engineering version of constructed wetland	- No oxygenation requirement - Low-cost treatment systems - Requiring minimum levels of O&M - Robust on shock loadings - Equally pathogen removal efficiency as WSP with more flexible design criteria - Using harvested reeds as a good source for composing	- Dependence on climate conditions, i.e. cold climate negatively impacts system efficiency
Aquaculture	- Combining the wastewater treatment to aquaculture, the growth of fish and other aquatic organisms for the production of food - Providing treatment by keeping aerobic condition and maintaining low ammonia levels	- Harvested plants and fish for human consumption, animal food, and fertilizers - Very efficient in removing pollutants with the additional incentive income - Incorporated as the last (maturation) pond in a series of WSP.	- Need for large land areas - High construction and O&M costs in some types of systems - Possibility of health risk associated with consumption of fish or plants.

Note: The content of the table was compiled from several sources by means of analysis and synthesis. It attempts to illustrate the types and techniques of treatment systems to compare the pros and cons of each technique.

References: Metcalf and Eddy (2003); Pickford (1995); Von Sperling (1996); Van Lier and Lettinga (1999); Parr et al. (1999), Burkhard et al. (2000); Sundaravadivel and Vigneswaran (2001).

2.2.1.2 Classification by the Dimension of Treatment Techniques

From the perspective of treatment techniques, wastewater treatment systems can be classified into three types. They are aerobic, anaerobic, and natural treatment processes. This section examines the wastewater treatment processes within the domain of “off-site” or “secondary treatment” process, which are usually found in developing countries.

Aerobic Treatment: The conventional processes for treating domestic wastewater are mostly aerobic, which utilize bacteria to degrade waste products, particularly to remove the carbonaceous organic matter by adding oxygen to accelerate bacterial digestion. The four most frequently used aerobic systems in developing countries are (1) the activated sludge process, (2) aerated lagoons, (3) trickling (percolating) filters, and (4) rotating biological contractors (RBC) (Table 2.2).

The aerobic treatment process usually utilizes a large amount of energy to supply sufficient oxygen to bacteria in wastewater. As a result, a large volume of bacteria or sludge is produced and needs to be disposed and handled properly. The aerobic wastewater treatment system is thus a rather sophisticated process, with complicated mechanical and electrical parts. It requires well trained operators and very high construction and operation / maintenance costs (O&M). The prime reason of choosing this technique for central wastewater treatment in developing countries is its high efficiency, particularly the activated sludge process.

Anaerobic Treatment Process: A number of different anaerobic processes have been utilized in the past, mainly for the treatment of sludge and high strength organic waste. These techniques have been developed to treat domestic low-strength organic waste in both on-site and off-site treatment systems, and have been utilized in many developing countries, such as Brazil, Columbia, and India, to replace the costly activated sludge process (Van Lier and Lettinga, 1999). Septic tanks are the most well-known and commonly used on-site anaerobic treatment system for sewerage water. However, the popular off-site anaerobic systems in developing countries are (1) upflow anaerobic stabilization blanket (UASB) reactors, (2) anaerobic filters, and (3) anaerobic ponds. Table 2.2 was compiled from several sources to illustrate the types and techniques of treatment systems to compare their techniques and their advantages/disadvantages.

In principle, the anaerobic wastewater treatment system applies a mineralization process to decompose organic and inorganic matters without the need of oxygen. This process produces a number of by-products such as methane and carbon dioxide. The exclusion of oxygen has the advantage of making the operation and maintenance easier—using less energy and producing less sludge than other systems. The construction and O&M are thus cheaper and simpler. This process is more favorable in the warm tropical climates since high temperature tends to boost bacterial activities, which makes the maintenance much easier. Nonetheless, the process takes more time than that of the aerobic. This characteristic has been the major disadvantage of the anaerobic system..

Generally, the anaerobic treatment system is suitable for the removal of organic waste, but not for other important sort of pollutants, particularly nutrients and pathogens. The anaerobic system is often utilized in the pre-treatment phase, requiring some additional post-treatment process to meet effluent standards. After the anaerobic treatment phase, there is a variety of low-cost post-treatment anaerobic systems to choose from, for instance, bio-rotors, sand filtration, micro-aerobic ponds, bio-filters, soil infiltration, and the wetland systems (Van Lier and Lettinga, 1999).

The anaerobic process is far more attractive in many aspects when compared to conventional aerobic treatment processes. Anaerobic processes require relatively fewer resources in terms of investment costs, energy, and space. It also produces less excess sludge while retaining a higher loading capacity, (Van Lier and Lettinga, 1999). Moreover, anaerobic systems may also produce valuable energy in the form of methane biogas, which are renewable energy source.

Natural Treatment Process: The natural treatment systems apply the physical, chemical, and biological processes occurring naturally to provide wastewater treatment. The systems involves a number of natural mechanical principles found other treatment systems, such as sedimentation, filtration, adsorption, chemical precipitation, oxidation and reduction, biological conversion and degradation, and biological processes occurring naturally in most plants (i.e. photosynthesis, photooxidation, and plant uptake). To artificially trigger such natural process for wastewater treatment, mechanical devices can be added to accelerate the treatment rate with wastewater flows sequentially from one reactor tank to another (Metcalf and Eddy, 2003). As a result, energy input might be required as well. Examples of natural treatment systems commonly used in developing countries are land or soil aquifer treatment, constructed wetlands, and aquaculture (Table 2.2).

In most circumstances, natural treatment systems are capable of removing almost all the major constituents in wastewater which are considered pollutants—such as organic matter, nitrogen, phosphorus, trace elements, trace organic compounds, and microorganism (Metcalf and Eddy, 2003). The removal process could be either aerobic or anaerobic or the combination of both. Due to the simplicity in terms of operation and maintenance, natural treatment has become a popular approach in many developing countries. However, since the systems require a large portion of open space, they tend to be feasible only in the suburban areas or small cities, where land is not a major constraint. Nevertheless, with improper land treatment, the systems may have negative impacts on the public health conditions, which bring about public concerns when choosing the system. In very rare instances, there are also possibilities of groundwater contamination with bacteria and toxic chemicals, and the possibility of harmful disease transmission. There is also potential health risks associated with usage or consumption of crops irrigated by wastewater or grown in aquaculture systems.

In conclusion, there is currently an emergence of several urban wastewater treatment alternatives. Compared to the other treatment processes, the aerobic treatment systems are more complex in terms of operation and maintenance, and more expensive for construction and operation. Nevertheless, due to high degree of reliability and efficiency, aerobic treatment, particularly the activated sludge process, is widely selected for central wastewater treatment systems in developing countries. The anaerobic process, on the other hand, is relatively simpler and less expensive. Anaerobic systems produce poor effluent quality and require some additional post-treatment process to meet discharge standards. In many developing countries, although the natural treatment has become a popular approach, they require a large open space, which is a key constraint in urban areas. Choosing an appropriate technology for a community requires not only selecting the best performing wastewater treatment designs with highest efficiencies, but also matching the genuine needs of the community. Engineers and decision makers need to consider not only the advantages and disadvantages of wastewater treatment alternatives, but must also consider the local context and conditions affecting the success of wastewater treatment systems.

2.2.2 Wastewater Management Approaches in Developing Countries

Growth rate in many Third World cities is so large that provisions for basic urban infrastructure and housing services cannot catch up with the growing population. The main problem in these cities is attributed to the inability of the respective authorities to respond such demand in a timely fashion. In many cities, unplanned infrastructure was built hastily in order to cope with the rapid growth of urban population. As a result, most urban services tend to be substandard. A majority of urban residents cannot formally get access to basic essential urban sanitation, particularly clean running water, wastewater treatment, drainage, and solid waste disposal (Choguill, 1996). In this light, there are two main wastewater management approaches in most developing countries—the centralized management and decentralized (sustainable) management approaches—that will be discussed in this section.

2.2.2.1 Centralized Wastewater Management Approach

The traditional centralized model of infrastructure development has been widely accepted and has rarely been challenged by scholars in developing countries. The model mainly involves the provision of public infrastructure by central and local governments. The characteristics of the traditional system can be described as a top-down approach of management for the good of the community as a whole. The public sector invested in the facility and revenues are usually generated from all benefited users. Long term cost recovery is possible in the countries where per capita income is relatively high (Choguill, 1996). Therefore, applying such top-down management model in countries with a wide gap of incomes could hardly be successful (Choguill, 1996; Sarmento, 2001). Those who cannot afford would be discriminated from the services, and therefore, need to provide the services themselves without the initial subsidized investment.

Historically, the centralized wastewater treatment concept was developed from the Western countries, mainly to clean up the polluted and infectious water from urban areas. A large amount of discharged wastewater are collected by means of the sewerage network and transported from its originated areas to the treatment destination. Another large amount of clean water is utilized to help prevent clogging in the transportation process, resulting in the dilution of wastewater. The system designed for treatment of large amounts of diluted wastewater with high volumetric rates tends to be much more expensive and more energy consuming than those treating concentrated wastewater, which is discharged directly from the site. Moreover, from the engineer's point of view, treating concentrated wastewater is relatively easier to manage (Van Lier and Lettinga, 1999).

Large scale sewer networks also need extensive investment in constructing and maintaining the sewer and pumping stations. In many developing countries, where advance technologies are adopt from the developed nations, scarcity of high skilled technicians means failure of system maintenance over the long term implementation period, which further causes high losses of wastewater and environmental contaminations (Van Lier and Lettinga, 1999; Parr et al., 1999). Since the centralized systems in most developing countries are generally invested and operated by the government, they are highly dependent on the functioning bureaucracy—the availability of electrical supply, the stability of economic and political system. The operation of the system could be affected during crisis, such as economic crisis or in time of political change (Van Lier and Lettinga, 1999).

2.2.2.2 Decentralized and Sustainable Wastewater Management Approaches

During the past decades, environmental concerns gained recognition in both developed and developing world. The term "sustainable development" was brought to the attention of the world community in 1987 by the World Commission on Environment and Development (the Bruntland Commission). Although this definition of sustainable development has been recognized, there is a large and diverse literature on how to interpret this term (Hardoy et al., 1995).

Over the years, a great effort has been devoted to defining the meaning of the sustainable development concept and creating indicators to measure the relative sustainability of alternatives (Chen and Beck, 1997). People with urban ecological perspectives might define sustainability as the development of systems to meet the needs of city dwellers, while maintaining the amount of cities' wastes within the ecosystem's absorptive capacity of the particular realm (Hardoy et al., 1995; van Vliet 1996, quoted in Chen and Beck, 1997). However, there is still no specific solution on how wastewater should be managed to meet the sustainable need of developmental standard

The inapplicability of large-scale centralized wastewater treatment in the Third world cities' reality prompted decision makers to resort to the decentralized approach (Gawad and Butter, 1995; Van Lier and Lettinga, 1999; Lim et al., 2002). The basis of this approach is the focus on the utilization of technologies, which are able to treat the concentrated wastewater at the production site. In accordance with the Sustainable Environmental Protection concept, Van Lier and Lettinga (1999) integrated other criteria with the decentralized wastewater management to maximize efficiency of the treatment (Table 2.3).

Table 2.3 Criteria for Sustainable Environmental Protection Concepts

1.	No dilute of high strength residues (wastes) with (clean) waster
2.	Maximum of recovery and reuse of treated water and treatment by-product
3.	Application of efficient, robust, and reliable treatment/conversion technologies
4.	Low cost in construction, operation and maintenance
5.	Long lifetime and simple in operation and maintenance.
6.	Applicable at any scale, very small and very big as well.
7.	Leading to a high self-sufficiency in all respects.

Source: Van Lier and Lettinga (1999)

The decentralized approach is thus considered more sustainable and more efficient than the centralized approach in terms of the treatment competence and rate of resource recovery. The decentralized systems can supply treated water directly to the vicinity of the treatment plant, while the centralized systems need more investment on costly large scale distribution network (Van Lier and Lettinga, 1999; Lim et al., 2002). Although, the decentralized systems for urban wastewater treatment can significantly reduce the installation costs of the sewer network, the systems' performance is still questionable. In this light, policy makers still hesitate to utilize this alternative due to its "out-of-date" technology and the lack of capability to be flexibly adapted to the urban area. The decentralize system tends to be small in scale. The inability to take advantage of the economy of scale is the prime reason that increases the cost of the decentralized system. Nevertheless, the concept of economy of scale depends much upon the characteristics of the treatment system on how the system generates other financial benefits. For example, the recovery of valuable recyclable resources, such as clean water in arid area, is able to compensate the lost of economy of scale (Van Lier and Lettinga, 1999).

It can be concluded from the above discussion that most decisions made by authorities in developing countries relies largely on the conservative centralized approach and dominated by the overseas consultant companies and contractors. This approach is obviously driven by the supply side of the service, and generally relies on engineers or planners to assess the local needs and to choose the type of service (UNEP/GPA, 2002). The demand-driven approach of decentralized systems, on the contrary, pays more attention to the end-users' needs and focuses on using the appropriate technologies to local conditions and preferences, and their ability to pay for the services (Sarmento, 2001; UNEP/GPA, 2002).

2.2.3 Development of Urban Wastewater Treatment Infrastructure

2.2.3.1 Urban Contexts of Developing and Developed Countries

To select an appropriate wastewater treatment technology for developing countries, one needs to understand the current local contexts since the technology that work effectively in one city of industrialized country, might not be successful in another developing country's city.

Table 2.4 illustrates some typical contextual differences of the urban settings between the developing and developed countries. Usually, the urban environmental management policy in developing countries carries a strong top-down approach determined by the governmental authorities. Most developing country governments possess an assertive political power to allocate and utilize national resources. With the centralized administrative systems, governmental policy, legislation and enforcement can not be efficiently implemented locally. Political will and the power structure are important factors, yet lacking in the development of infrastructure (Pegram et al., 1999). The decentralized policy in mostly developed countries, in contrast, empowers the local community to allocate and manage their own resources.

In most cities of developing countries, the high population density and imperfect land use planning has become an obstacle to the urban infrastructure management. Local authorities are unable to respond adequately to the rapid rate of urbanization. As a result, the local communities, especially most low-income settlements, perpetually run short of basic infrastructure and services.

Table 2.4 Differences in Urban Contexts of Developing and Developed Countries

Urban contexts	Developing countries	Developed countries
Government policy	Centralized and top-down approach	Decentralized and bottom-up approach
Spatial organization	High population density Poorly managed	Low population density Well managed
Infrastructure allocation	Inadequate	Adequate
Land availability	Very limited	Available/Limited
Socio-economic levels	Low	High
Labor system	Formal and informal sectors (dual system)	Formal sector
Land tenure	Legal and illegal holding	Legal holding

Note: The content of the table was compiled from several sources. It attempts to illustrate some typical contextual differences on the urban settings between the developing and developed countries

References: Douglass and Zoghlin (1994); Sahachaisaeree (1995); Choguill (1996); Drakakis (1996); Van Lier and Lettinga (1999); Sarmento (2001)

People in the developing world have much lower income comparing to those in the developed countries. The growing disparity in education and income between the rich and the poor within the Third World itself are the factors determining disparity of opportunity and affordability to get access to infrastructure and services. Most low-income residents in these countries work in the informal sector, and thus have unstable and insufficient earning. The balance between their income and expenditure is on a day-to-day basis (Drakakis. 1996). The poors' inability to compete for land in the market allocates them to live in the spontaneous settlements, where basic life sustaining services are virtually nonexistence (Douglass and Zoghlin. 1994). Such urban milieu eventually brings about deterioration and unpleasant environment in their communities and the adjacent areas.

2.2.3.2 Wastewater Management Problems in Developing Countries

The failure of the Third World's urban environmental management, especially on urban sanitation, infrastructure, and services, result from two major factors—the shortage of resources and the deficiency of the delivery systems, particularly to the low-income settlements (McCarney, 1994). Urban infrastructure and services are essential life-sustaining amenities as part of people's basic needs in the cities. Such amenities also attribute to the urban environmental health in helping reduce the locally generated pollution in the urban areas. Therefore, the inadequacy of basic infrastructure and services in a particular area can cause unhygienic and deteriorating living conditions.

Like the rest of physical infrastructure, wastewater treatment in developing countries has adopted the traditional model of central-driven development from the western nations. Experiences from developing countries show that such adoption rarely provides adequate universal wastewater treatment services (Choguill, 1996; Sarmento, 2001). Choguill (1996) argues that the adoption of western model divides the service into two distinctive delivery systems—a "Town system" and an "On-site system". Inner-city residences who can afford the service are subsidized through formal service provided by the town system. Communities located outside the town systems' service areas resorted to any self-built on-site systems in accordance with the income and affordability, although these systems can hardly meet the hygienic standard.

The section that follows will explain and give some real life comparison between the situation of wastewater treatment system in developed and developing countries.

City dwellers in the developed world can access services provided by the central or local sanitation systems. The inner-city areas are usually the places for business and commercial activities. Some deteriorated areas of the city likely belong to the low-income strata, where land values decreases due to the concentration of such groups and the inability to develop the area. People in the high income strata, who can compete for land in an alternate locale, choose to commute and reside in a better environment of the suburban areas. For the relatively remote suburban areas, any expensive on-site household wastewater treatment system would be acceptable, provided that the central services are not accessible. Most of these self-sufficient wastewater treatment systems not only enhance the dwellers' quality of life, but also comply with the city's regulatory requirement.

The Third World's inner city, on the contrary, still maintains its high land value, which make it unaffordable for the urban poor to reside. Large cities, such as Bangkok, tend to expand geographically, and its population is growing virtually without limit. By the year 2025, there will be 486 mega-cities, with population as large as 10 million, in the developing world (Choguill, 1996 referring to the United Nations' projection). Mega-cities will become significant centers of development and accumulation, which attracts cheap labor from the poorer peripheries and rural areas (Amstrong, W. and McGee, T.G., 1985). A large number of migrants have already moved into big cities expecting better economic opportunities and employment.

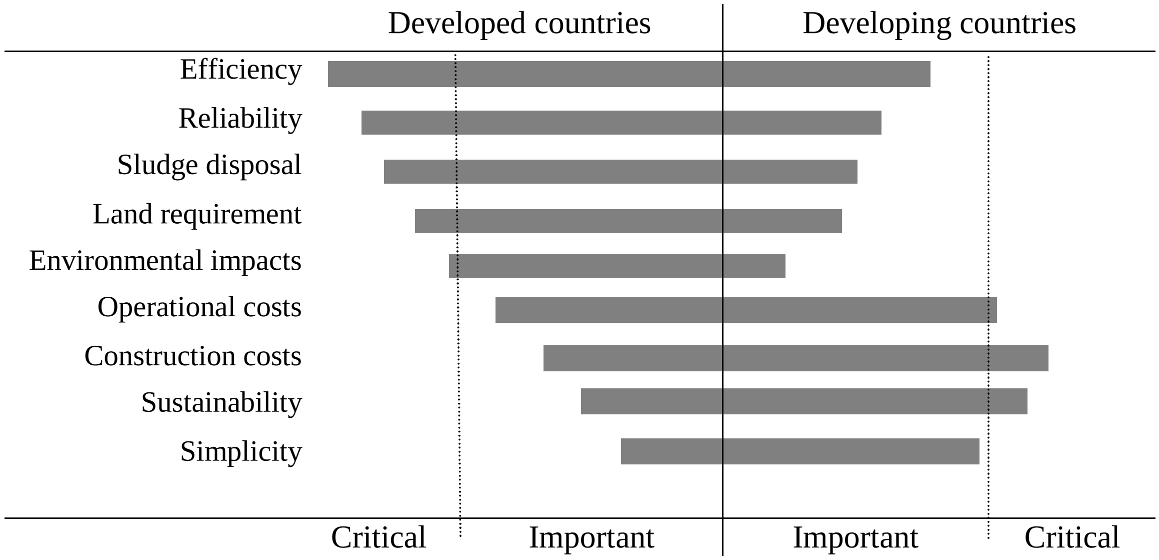
In cities like Bangkok, different forms of land allocation reflect the varying degrees of tenure security, which virtually determines the differentiating physical conditions of the settlements (Sahachaisaeree, 1995). Low-income people, who can not get access to the formal housing market, squat in spontaneous settlements. In the suburban areas of Third World cities, even though there are the concentrations of both medium-to high-income settlements, the suburb is still an affordable place for the low-income poor due to the low land value. Most suburban low-income settlements often lack wastewater system, since they are located outside the service area of central wastewater treatment facilities, yet the communities cannot afford to build their own system.

Some suburban areas encounter serious wastewater management problems. A study regarding peri-urban settlements in South Africa shows that both the suburban formal and informal residential areas are have limited waste management and are becoming significant non-point sources of pollution to water resources (Pegram et al, 1999). Due to the residents' limited resources to access services, and the authority's limited capability and resources, the suburban informal / low-income settlements in South Africa are often associated with severe water contamination (Pegram et al., 1999).

In conclusion, the top-down approach for urban wastewater management has been applied in both developed and developing countries, despite the contextual differences in their culture and economics. It is evident from the experiences in many developing countries that adopting such a conventional approach from the Western countries will adequately provide services for all (Choguill, 1996; Sarmento, 2001). The low-income settlements suffer discrimination from the formal systems and are forced to live without proper wastewater management.

2.3 SELECTION CRITERIA FOR APPROPRIATE WASTEWATER TREATMENT SYSTEMS

von Sperling (1996) asserted nine elements for determining the selection of a locally appropriate wastewater treatment system in both developing and developed countries. They were efficiency, reliability, sustainability, sludge disposal, land requirement, environmental impacts, construction and operational costs, and simplicity. A critical comparison showed that criteria for selecting an appropriate system for developing and developed countries were quite different (see Figure 2.1). Since the limitation of local resources was the prime issue in most developing countries, costs and simplicity were among the foremost factors. The rest of the items, such as efficiency, reliability, and environmental impact, seemed to be less critical for present circumstances. In contrast, the developed countries' most critical items were system efficiency, reliability, and land requirement, while costs, sustainability and simplicity were considered less important compared to the developing countries' perspective. To select an appropriate wastewater treatment technology for developing countries, one needs to understand the current, local contextual situations.



Source: von Sperling (1996)

Figure 2.1 Important Aspects in the Selection of Wastewater Treatment Systems.

2.3.1 Different Aspects of Local Conditions and Resource Availabilities

There are five groups of local parameters that should be considered when choosing a wastewater treatment technology—socio-economic, physical, institutional and political, and environmental. This section discusses each of the factors with regards to how and why there are important.

2.3.1.1 Socio-Economic Factors

The socio-economic conditions of the local settlements are generally the underlying cause of its physical problems (Pegram et al., 1999). The urban poor usually earn insufficient and unstable income which bars them from accessing legal settlements. Illegality of housing also prevents them from accessing necessary formal services and has bought about deteriorated living conditions. The extent of water pollution is generally determined by the extent of household activities, which are governed by their own socio-economic status. Although the poor communities generate relatively less wastewater than wealthy ones, the content is more concentrated than that from the high-income residences. Wastewater contamination tends to decrease with increasing affluence due to higher levels of functioning services (Pegram et al, 1999).

The availability of skilled labors is not only determined by the existing number of technical training programs or academic institutes, but it is also a function of people's socio-economic status. The opportunities to be educated and employed are important and interrelated to the income and households' ability-to-pay. Nevertheless, in countries where unskilled labor is cheap and available, the reduction of construction cost can be achieved by the use of self-help labor (Choguill, 1996). Moreover, the community's involvement in construction could have some psychological advantages (Kalbermatten et al., 1982). A sense of belonging within the community is created through self-built projects (Douglass and Zoghlin, 1994). The sense of belonging is, in other words, the sense of owning something and wanting to maintain it in good condition. The treatment systems, which could be built together, should be simple enough to be maintained by workers with local skill level.

Some behavior patterns including lifestyle, social values, and religious or traditional inhibition can affect hygienic practice and the applicable technology (Pickford, 1995; Kalbermatten et al, 1982). Wastewater streams from households in agrarian communities, for instance, can be contaminated with pesticides or herbicides (Tsagarakis et al, 2001).

In some particular cultures, the gender issue may affect the choice of technology, particularly on-site systems. Women in some societies are not allowed to use the same tiolets as men (Pickford, 1995). Some religious principles also govern the way wastewater should be treated. The Muslim tradition, for instance, forbits defecation facing Mecca or with their back against the holy city, Therefore, the recommened on-site system should colnform to local traditions (Pickford, 1995).

Some knowledge and attitudes to environmental issues can also influent perceptions of people, their awareness and susceptibility to any development projects (Kalbermatten et al, 1982). Individuals might have the “out of sight, out of mind” attitutde (Burkhard et al, 2000) and be careless about benefits from a community system. Social acceptance can depend on people’s experiences, social background, and secular knowledge. The review of wastewater treatment technologies and public awareness in Europe showed that some ecological systems, such as constructed wetlands and aquaculture, are likely to be acceptable because of its potential for amentity enhancement (Burkhard et al, 2000). In addition, people may be concern as much about environmental nuisances (Tsagarakis et al, 2001). By-products of the system, such as noise, odor, insects, visual and landscape impairments should be considered, particularly for systems located near resident areas, schools, and religious buildings.

Community participation is also one of the social functions which shoud be considered. People might not be motivated to participate in matters that will have no direct impact on their everyday life (Burkhard et al, 2000). Nevertheless, this assumption could not explian fully the lack of public participation in the context of developing countries. Most urban poor are typically undereducated, and thus have little knowleage regarding the danger derived from their own lifestyles. Formal decision-making processes often limit their access to participation, particularly people living in illegal settlements. Most participation processes still do not contribute enough time and resources to educate participants to the extent that they can make the right decision.

2.3.1.2 Physical Factors

Settlement characteristics of the poor; such as socio-economic status, can affect the settlement location and its settings. Most of the urban poor are allocated in spontaneous settlements, which are densely populated with substandard housing and insufficient urban services. Housing types, occupancy rate, and tenure patterns should then be considered carefully. In addition, location of settlements and their site layouts tend to determine the residences' daily activities and social interactions, which are key factors affecting design and the delivery system (Pegram et al, 1999). Accessibility of vehicles to buildings and the communal areas needs to be planned ahead, if the treatment system needs to transport sludge from each household or from the communal system in large quantities. Housing or living density is likely to affect the project's *economy of scale*. For scattered suburban housing, a central treatment system may not be economical, due to the high cost of piping network investment.

Location of the settlement is an important factor determining the price and availability of land for the system. Availability of land is also one of the most important factors to be considered when choosing technology. Some systems may demand a large plot of land, which might not be appropriate for high density areas in the inner city. In addition, the location of the settlement also indicates the extent of accessibility to the service area. For instance, suburb residential areas, usually located outside the service networks, depend on self-built community system or some other types of informal services.

Geo-morphology, such as topography, soil conditions, and level of groundwater, determine the technicality of construction and operation of the systems (Kalbermatten et al., 1982; Tsagarakis et al., 2001). Soil conditions are an important element for most types of wastewater treatment. For subsurface treatment or effluent disposal process, one must take into account the hydro-geologic conditions, which include soil permeability, seasonal water table fluctuations, soil stability, and vulnerability to flooding (Kalbermatten et al., 1982; Tsagarakis et al., 2001). In some cases, the local topographic characteristics should also be considered in the site selection process. In Greece, for instance, land in hilly and mountainous terrains is relatively cheaper than elsewhere, but a large amount of extra costs might be required due to the extensive volume of earthwork (Tsagarakis et al, 2001).

Local climatic conditions can influent reliability and efficiency of the treatment processes. Temperature is one of the most important parameters in many processes (Tsagarakis et al, 2001). For example, the winter temperature usually affects performance of treatment ponds, digesters, and biogas units. Usually the biochemical reaction rate will drop as much as half each time the temperature decreases 10 ºC (Kalbermatten et al, 1982). In an arid area, hot and dry climate may benefit the effluent disposal technology that involves evaporating processes. In most large cities in developing countries such as those in the Southeast Asia, where their climatic characteristics are hot and humid, the most important climatic factor is the amount of rainfall, which can be measured in terms of volume, number of rainy days, and rainfall intensity (Silverira, 2002).

2.3.1.3 Institutional and Political Factors

The institutional structure affects its ability to management wastewater treatment facilities. As mentioned earlier regarding the case in Thailand, the existence of design standards or the adoption of advanced technology did not guarantee the success of an urban wastewater system, if there is no institutional mechanism to ensure proper implementation.

The local politics could interfere with the decision-making process regarding site and technology selection as well. Political intervention may involve in the arrangement of operating agencies and funding allocation during the designing and construction process. Ignorance and lack of political will are likely to be the result of governmental irresponsibility and incapability (Pegram, 1999). The foresight of decision makers, politicians and governmental authorities, are very important, which govern the distribution of resources. Many authorities do not prioritize the problems of wastewater management because it is perceived as less important and not an urgent matter.

In conclusion, this section discusses a number of factors determining the success of the wastewater treatment system—socio-economic, physical, institutional and political, and environmental. Given that there are many contextual differences between the developed and developing countries, the approaches taken by the developing country to select an appropriate wastewater system should be differed from that of the developed countries. Decision makers should take into account local needs and conditions discussed in this section. Solving wastewater management problems in developing countries not only deal with the searching of technical solutions, but also deal with the intertwining socio-economic, institutional and political issues as well.

2.3.2 Concept and Scope of an Appropriate Wastewater Treatment System

A large body of literature has already listed the important factors, which must be considered when evaluating and selecting wastewater treatment technologies. Traditionally, the process of evaluation and selection is one of the most challenging phases of treatment plant design. The process should achieve the most appropriate treatment system, capable of meeting standards and requirements. These factors are then reformulated into criteria, which are associated with the engineering rules in designing, constructing, and operating the system i.e. influent wastewater characteristics (flow and quality), efficiency, land requirement, and process reliability (Melcalf and Eddy, 2003). While the economic, social, and institutional factors are still constraints in the system design, other attributes, such as simplicity, social acceptability and sustainability, should also be considered in choosing the treatment technologies for developing countries.

In this study, appropriate technology suitable for local conditions has been one of the key solutions to overcome operational failures of wastewater facility management in many developing countries. The term "*appropriate*" thus conveys the notions of feasibility and pragmatism for a specific circumstance. In *sustainable* terms, appropriateness also signifies the logic for meeting people's needs in the best possible way with two preconditions—the availability of local resources and the limitation of local conditions. The suitable option is, therefore, not only a system providing the best performance at least cost, but is also sustainable in terms of meeting local needs—socio-cultural acceptability, technological and institutional feasibility, economical affordability, and environmental acceptability (Mara, 1996; Ujang and Buckley, 2002; Sarmento, 2001). The selection of appropriate wastewater treatment systems, therefore, should take the comprehensive approach, which incorporates local aspects of social, cultural, economic, institutional, and environmental conditions, into the consideration.

The following section summarizes seven important elements, which are intended to summarize the technical, socio-economic, and environmental aspects of the appropriate systems (Figure 2.2). These elements included reliability, simplicity, efficiency, land requirement, affordability, social acceptability, and sustainability.

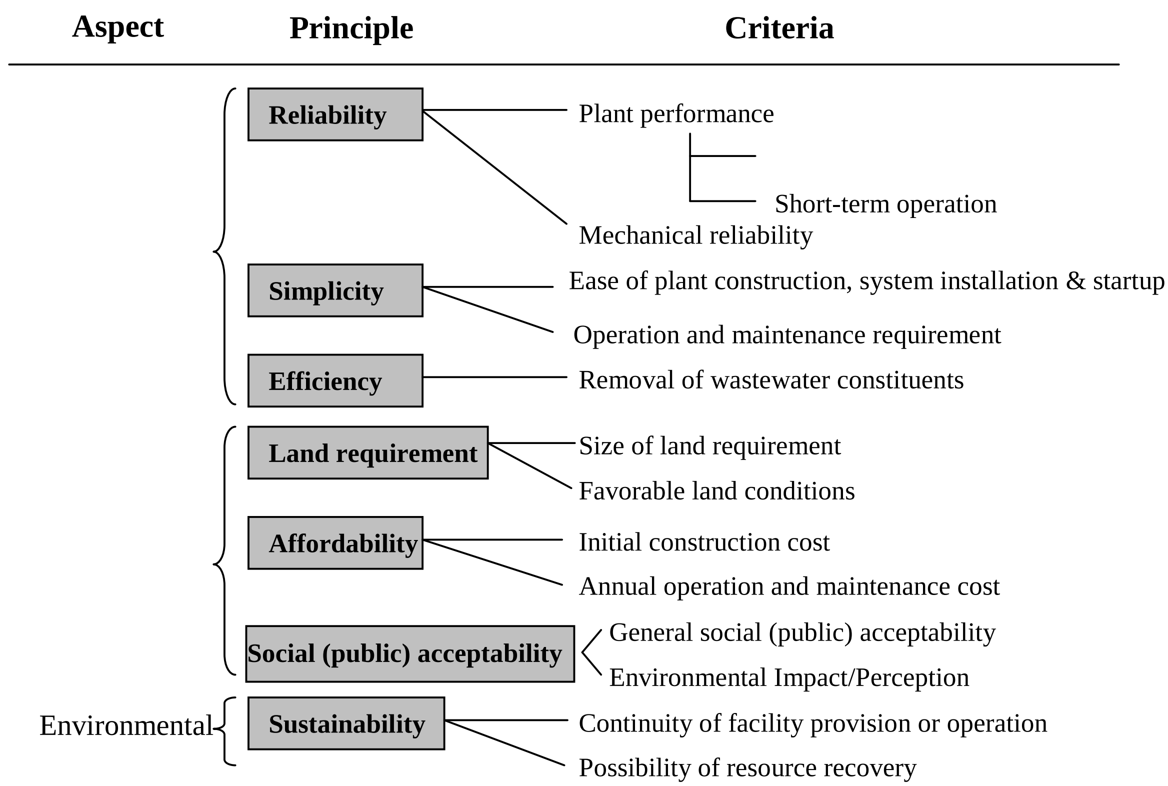


Figure 2.2 Conceptual Variables Determining the Selection of Appropriate Wastewater Treatment Systems for Developing Countries.

2.3.2.1 Technical Aspects

Reliability: Reliability of the system is defined as the possibility of achieving adequate performance for a specific period of time under specific of conditions (von Sperling and Oliveira, 2007). This study considers two major aspects of reliability for the wastewater treatment process—plant performance and mechanical reliability. Reliability of the treatment system can be assessed by means of: (1) the variability of treatment effectiveness under normal and emergency operation, (2) the probability of mechanical failures, and (3) the impacts of failures upon effluent quality (Eisenberg et al, 2001). Measuring the variation of product quality reflects the robustness and the way the process responds to changes in wastewater characteristics (Metcalf and Eddy, 2003; von Sperling, 1996; Eisenberg et al, 2001).

Simplicity: Simplicity of wastewater treatment is one of the most crucial attributes in the selection process of the treatment systems, particularly for developing countries. In countries where unskilled labor is cheap and available, the reduced construction cost can be achieved with self-help labor (Choguill, 1996). However, lack of skilled workers presents a major constraint when decision makers choose a sophisticated treatment system in remote areas. Operational and maintenance simplicity should be a prime concern, since simplicity could determine the long-term operating success of the system.

Efficiency: Wastewater must be treated to the extent that the final water quality will comply with the regulatory standard or requirements. Most conventional wastewater treatment processes have been designed primarily to remove the suspended and dissolved organic constituents (Parr et al., 1999). The organic matter in wastewater, is usually measured in terms of biochemical oxygen demand (BOD), and is one of the most important parameters determining the effluent quality. Another important objective of wastewater treatment is to reduce the pathogenic microorganisms from wastewater. Contamination with infectious microorganisms such as those from human waste can cause acute localized impacts on public health. Nutrients, mainly nitrogen and phosphorus, can cause eutrophication through accumulation in regional surface water, while nitrate can cause health threatening ground water contamination (Pegram et al, 1999).

2.3.2.2 Socio-Economic Aspects

Land requirement: The availability of the land is another major constraint determining the choice of wastewater treatment systems. In most cases, space sufficiency means not only the space to accommodate the size of the present facilities, but also the possibility for future expansion. Since most wastewater treatment systems are located outdoors, it may cause negative environmental impacts, such as noise and odor, on the surrounding residences. Therefore, system site and plot size should be sufficient to provide a buffer to minimize the visual, odor and noise impacts. Under this criterion, land properties or geo-morphology e.g., topography, soil conditions, and level of groundwater, are also important factors determining the technical feasibility of construction and operation of a particular system.

Affordability: The financial aspect considers not only the initial cost for construction and installation, but also the ability of the local community to pay for the continuing operation and maintenance costs. System design with "affordability" in mind must include the selection of a technology that users are able-to-pay for. Treatment cost must reflect the level of household income and expenses (Sarmento, 2001). In the developing countries' context, the ability-to-pay is an important issue, reflecting the reasonable amount of payment that the user is able to pay for, which is, in turn, determined by the type of wastewater treatment.

Social (public) acceptability*:* Social norms and traditions are also important in the designing of treatment system, which aims to meet the local needs and be sustainable. Some knowledge and attitudes to environmental issues can also influence perceptions of people, their awareness and susceptibility to any development project (Kalbermatten et al, 1982). Social acceptance will depend on people's experiences, social background, and secular knowledge (Pickford, 1995). In addition, people may also have concern about environmental nuisances (Tsagarakis et al, 2001). Systems located close to the community and sensitive ecosystems should have minimal noise, odor, and visual impacts.

2.3.2.3 Environmental Aspects

Sustainability: The study considers two aspects of sustainability—(1) the continuity of operation and (2) the environmental sustainability. For the continuity of the project, it needs to be financially and operationally self-sufficient (Pybus and Schoeman, 2001). The treatment system should be affordable, meet the needs of the local community, and be maintainable by locals. The latter aspect of environmental sustainability involves the survival of the environment itself. The selected technology applicable for the treatment system must have the least adverse environmental effects and should be able to recover renewable resources from the treatment systems, such as being able to reuse treated wastewater for irrigation, recharge groundwater, produce biogas, and recycle organic matter. In developing countries, treated wastewater and products from the treatment processes are considered as resources. The water with nutrient content, in particular, is very useful for agriculture activities provided that the effluent is treated properly (Kalbermatten et al, 1982; Pickford, 1995; Parr et al.,1999). Recycled material such as biosolids can be utilized as crop fertilizer or soil conditioners for non-agricultural land.

In conclusion, the problems of wastewater management in developing countries are closely related to a number of local conditions. Apart from the technical or engineering feasibility, the development of wastewater treatment systems need to be considered hand in hand with the available infrastructure, institutions, human resources, and socio-economic conditions (Mara, 1996; Varis and Somlyódy, 1997; Pegram et al., 1999). This study devises a comprehensive approach for selecting appropriate wastewater treatment systems in developing countries. Instead of focusing merely on the technical dimension, the study integrates the social, economic, and environmental concerns to develop a set of criteria and indicators (C&I) useful for appropriate system alternatives (see detail in Chapter 4).

2.4 APPROACHES AND METHODS FOR TECHNOLOGY SELECTION

This section aims to find an alternate approach for appropriate wastewater treatment systems selection, which considers local needs and is able to incorporate the crucial local factors of developing countries into the selection process. This section begins with two parts of review, firstly on the conventional optimization approaches in wastewater treatment system design and selection, and secondly on the novel non-conventional approaches of wastewater management and technology selection in developing countries.

2.4.1 Conventional Optimization Approaches

The optimization approach in wastewater treatment system design and selection was originated in the Western countries. The main efforts were to find the best available technology and to optimize the design to make it cost effective. The optimization approaches have then been utilized in preliminary design of treatment systems to reduce / manage the overwhelming number of design possibilities, derived from a combination of the processes and their operating efficiencies (Elimam and Kohler, 1997 refers to Adam and Panagoitakopoulos, 1977). The ultimate goals of the optimization procedure, however, are to maximize the efficiency and minimize the cost.

The optimization approaches in designing and selecting the wastewater treatment systems comprises three major groups of applications (Mishra, 1974). The first group is called *unit process designs.* It refers to the design of the individual process units such as the primary clarifier, or the aeration vessel of an activated sludge. The second group is called *process subsystem designs.* It includes design of more than one process unit in conjunction with each other, to form a series of stages in the total treatment process. For example, the second stage of activated sludge system consists of an aeration vessel and a secondary clarifier. The last group, *system designs,* refers to the design of more than one subsystem in conjunction with each other. The conventional modeling of treatment performance is evaluated according to the BOD removal efficiency.

A variety of optimization approaches emerged during the past three decades—linear programming (Lynn et al, 1962), dynamic programming (Everson et al, 1969; Shih and Krisman, 1969; Shih and Defilippi, 1970), geometric programming (Ecker and McNamara, 1971; Tyteca and Smeers, 1981), nonlinear search techniques (Berthuex and Polkowski, 1970; Mishra et al., 1973; Narbaitz and Adam, 1980), and network algorithm (Adam and Panagoitakopoulos, 1977). Table 2.5 has been compiled from several sources to compare the techniques and functions of different optimization approaches. Recently, two lines of academic inquiries on wastewater treatment optimization have been manifested—(1) the attempt to develop and demonstrate the usage of power and sophistication of the optimization techniques, while neglecting the modeling phase and (2) the attempt to focus on the accurate mathematical model of plant operations, while using rough or simplified optimization techniques (see reviews in Mishra et al, 1974; Tyteca et al., 1977; Tyteca, 1981).

The first trend had been criticized for using over-simplified mathematical models and focusing on the demonstration and application of specific optimization techniques. These efforts were meaningful but were seldom put into practice by design engineers (Mishra et al., 1974). It have also been criticized that such a general optimization study can not be conducted without the aid of mathematical models which explain and rationalize the physical, chemical, and biological characteristic of the wastewater (Tyteca et al., 1977). However, advanced mathematical models will likely be too complicated to be understood by lay persons such as local end users, planners, community leaders, and decision makers in developing countries. As a result, technology and modeling that relied on the decisions of engineers and overseas consultants, and those which have been copied from the Western countries frequently failed to succeed in most developing countries (UNEP/GPA, 2002; Van Lier and Lettinga, 1999).

2.4.1.1 Single- and Multi-Objective Approaches

Traditionally, most mathematical models have a mere objective—to minimize costs (Table 2.5). Even though the least cost solution of the optimization model provides important information with respect to the cost of treatment system, that solution may be non-optimal when other factors are considered (Chang and Liaw, 1985).

Some recent optimization programming started to incorporate more than one objective function beside system costs, such as non-linear programming optimizations developed by Berthoux and Polkowski (1970), Rossman, (1980) and Narbaitz and Adams (1980). Chang and Liaw (1985) used the optimization methods from the field of planning, namely, modeling-to-generate-alternative methods (generating and screening (G&S) and efficient random generation (ERG) methods. It takes into account the multi-objective function values of total annual costs, energy requirement, and land requirement. Chen and Beck (1997) employed the same methods to obtain a possibility to combine alternatives from a number of wastewater treatment unit operations and processes. Even though these more recent optimization models include more than one objective function, there are still some additional important objectives that can not be quantified and, thus, can not be included in the models. Consequently, most water treatment models deal only with quantitative or numeric information.

Table 2.5 Approaches and Methods for Selecting an Appropriate Wastewater Technology

Author	Year	Integrates wastewater and sludge treatment	Includes multiple pollutants	Includes multiple objective functions	Considers qualitative factors	Solution technique	Comments
Lynn, et al.	1962	No	No	No	No	Linear programming	- Pioneering application of optimization techniques - Uses the operations research/system analysis to select an optimal process train for wastewater treatment plant
Everson et al.	1969	No	No	No	No	Dynamic programming	- Uses a fixed unit cost to account for sludge disposal
Shih and Krisman	1969	No	No	No	No	Dynamic programming	
Shih and DeFilippi	1970						
Ecker and McNamara	1971	No	No	No	No	Geometric Programming	
Berthuex and Polkowski	1970	Yes	Yes	Yes	No	Nonlinear programming	- Considers variance in BOD removal as a second design criteria
Mishra et al.	1973	No	Yes	No	No	Nonlinear programming	- Optimizes recycle arrangements and parallel treatment schemes
CIRIA	1973	Yes	Yes	No	No	Nonlinear programming	- Considers recycle of side streams from sludge treatment
U.S. Army Corps of Engrs.	1976	Yes	Yes	No	No	Complete Enumeration	- Does not consider recycle of side streams
Patterson	1976	No	No	No	No	Dynamic programming	- Refinement of earlier dynamic programming model
Adam and Panagiotakopou - los	1977	Yes	Yes	No	No	Network algorithm	- Integrates cost burden to sludge producing processes - Solves the industrial wastewater treatment problem

Table 2.5 Approaches and Methods for Selecting an Appropriate Wastewater Technology (continue)

Author	Year	Integrates wastewater and sludge treatment	Includes multiple pollutants	Includes multiple objective functions	Considers qualitative factors	Solution technique	Comments
Efstathiadis	1977					Dynamic programming	- Extends the Shih and Krishman work to optimize wastewater (liquid phase) with respect to BOD and analyses many sludge treatment alternatives
Rossman L.A.	1980	Yes	Yes	Yes	No	Nonlinear mixed integer programming (with nonzero one decision variables)	- Incorporates a heuristic optimization algorithm which could also select the cost-optimal processes and rank alternatives with respect to multi-objective functions - AS and Trickling filter as a 2nd treatment process
Narbaitz R.M. and B.J. Adams	1980	Yes	Yes	Yes	No	Nonlinear programming	- Preliminary design - 76 alternatives of treatment process stream were generated. - The liquid and sludge treatment processes are optimized simultaneously, differentiating between sludge of different origins.
Tyteca D.; Tyteca and Smeers	1981 1981	Yes	Yes	No	No	Geometric programming	- Develops both of the aspects (accurate mathematical model and powerful optimization technique) in any analysis of the optimal design of WWTP
Reid G.W.	1982	Yes	Coliform and SS	Yes	Yes	Predictive model (weighting scales and index)	- Reduces raw data through weighting process to calculate different socio-technology indexes and resource capacity categories

Table 2.5 Approaches and Methods for Selecting an Appropriate Wastewater Technology (continue)

Author	Year	Integrates wastewater and sludge treatment	Includes multiple pollutants	Includes multiple objective functions	Considers qualitative factors	Solution technique	Comments
Hasit Y., D.L. Siman and R.I. Dick	1983	Yes	Yes	Yes	No	OSMP (Optimal sludge management program); Sequential unconstrained minimization technique	- A program computer developed by Dick et al.(1978) for simulating and optimizing the operation and preliminary design of a plants - Focused on the effect of primary sedimentation size changes on other processes designs and costs
Chang S-Y and S.L. Liaw	1985	Yes	Yes	Yes	No	Nonlinear integer programming; Modeling-to-generate-alternative methods (MGA)	- Extends the EXEC/OP method proposed by Rossman (1980) - Focuses on the generation of various good and different designs - Nonlinear integer programming to create the possible alternatives - MGA used to evaluate the alternatives and make a decision
Tang C-C et al.	1987	Yes		No	No	Nonlinear and geometric programming algorithm	- The design of unit process with specific treatment train - Considers more in a liquid and sludge subsystems effecting wastewater/sludge characteristics
Ellis K.V. and S.L. Tang	1991 1994 1997	Yes Sludge treatment included in 1997	Yes	Yes	Yes	Analytical Hierarchy Process (AHP)	- Considers combination of unit processes - Including subjective factors into the model - (1994)Testing the model sensitivity in predicting changes to an appropriate technology selected as socioeconomic parameter change with time.

Table 2.5 Approaches and Methods for Selecting an Appropriate Wastewater Technology (continue)

Author	Year	Integrates wastewater and sludge treatment	Includes multiple pollutants	Includes multiple objective functions	Considers qualitative factors	Solution technique	Comments
Uber J.G. et al.	1991	Yes	Yes			Extending nonlinear optimization model	- The approach integrates a standard nonlinear optimization and system sensitivity analysis technique
Eliman A.A. and Kohler D.	1997	No	Yes	No	No	Integer linear programming model	- Gets optimum sequence of wastewater treatment processes - Acyclic directed network - Kuwait facilities
Chen J. and M.B. Beck	1997	Yes	Yes	Yes	Yes	G&S for generating the alternatives; Screening analysis	- Sustainability concept - Using of Monte Carlo simulation to generate candidate combinations and to account for the uncertainties attaching to the performance of each individual unit
Okubo T. et al.	1994	Yes (not specific process)	Yes	Yes	Yes	Decision support system (Advisory system) and AHP	- Includes the using of existing natural processes
Srinivas Krovvidy	1998		Yes	No	No	Intelligent tools	Three intelligent tools 1. Learning system 2. Optimization algorithm 3. Case-based retrieving system
Rodriguez-Roda I. et al	2000	Yes	Yes	Yes		Decision support system (DSS)	- Conceptual design - Knowledge based design system: a prototype to keep design history

Table 2.5 Approaches and Methods for Selecting an Appropriate Wastewater Technology (continue)

Author	Year	Integrates wastewater and sludge treatment	Includes multiple pollutants	Includes multiple objective functions	Considers qualitative factors	Solution technique	Comments
Balkema A.J. et al	2001		Yes	Yes	Yes	A model based decision support tool; Integer programming to optimize the sustainable option	- Defines the multi-disciplinary set of sustainability indicators, including technical, economic, environmental and socio-cultural - Uses a life-cycle analysis to assess the sustainability - Pareto-optimization solutions used to optimize all sustainability indicators.
Nuria Vidal et al	2002		Yes	Yes		DSS tools "DRAMA" and simulator "GPX-X)	- Extended the work of Rodriguez-Roda, 2000 - Combines a hierarchical decision process w/ the math modeling of WWTP

Note: The content of the table was compiled from several sources by means of analysis and synthesis. It attempts to compare the techniques and functions of different optimization approaches. Information before 1980 is reviewed by Rossman, A.W. (1979).
References: Narbaitz and Adam (1980); Tyteca (1981); Reid (1982), Hasit et al. (1983); Chang and Liaw (1985); Tang et al. (1987); Ellis and Tang (1991, 1994, 1997); Uber et al. (1991); Okubo et al. (1994); Eliman and Kohler (1997); Chen and Beck (1997); Krovvidy, S. (1998); Rodriguez-Roda et al. (2000); Balkema et al. (2001); Vidal et al. (2002)

2.4.2 Technology Selection Approaches for Developing Countries

As mentioned earlier, the conventional models of optimization will not be an appropriate wastewater management approach for developing countries. The following section presents non-conventional approaches of wastewater management in developing countries that can be used as an alternative to replace the traditional approach. The review includes practical applications proposed for developing countries.

The particular social, economic, and environment conditions of the local society, which the treatment system serves, are crucial factors. The suitable selection method, therefore, should be able to incorporate all important objective function values beside system costs and also handle both quantitative data and qualitative variables. Apart form the mathematical optimization approaches, there are other methods ranging from non-mathematical and simple approach, such as a simple flow chart, to intelligent tools and the computerized decision support system which has yet been tested.

4.2.2.1 Non-Mathematical and Simple Approaches

Beside the conventional mathematical models, there are still other types of selection models without complicated mathematical formula. These models, such as the technology selection algorithm (Kalbermatten, 1982; Mara, 1996), and the predictive model (Reid, 1982) were developed for selecting treatment systems in developing countries. These selection procedures aims to help local authorities and communities with limited resources and skills to evaluate and select the most appropriate wastewater treatment systems to match their own situations.

Technology selection algorithm: The technology selection procedures can be a decision algorithm comprising a set of sequential questions and preconditions. The selection of technology can be made with a yes-no route of decision tree (Kalbermatten, 1982; Mara, 1996). This method showed the selecting example of sanitation technology algorithm, which mainly choose from a variety of low-cost on-site treatment systems and a few of off-site treatment and sewerage systems. Even though this selection algorithm is basically a simple procedure to help make the decision, it could be used as an initial starting point for other selection process as well. With this process, users can appraise the selected technology with regarding to both the local physical conditions and the socio-cultural applicability to make the final selected treatment method economically appropriate and financially affordable (Mara, 1996).

The predictive model: This model was developed by Reid (1982) as a tool to help planers select a suitable supply-water and wastewater treatment methods, which are compatible with available materials and human resource capabilities of a particular country at a point in time. Several treatment processes are combined and evaluated vis-à-vis the operating constraints, such as limitation of manpower and material requirements. Two categories of information are compiled—socio-economic conditions and indigenous resources. Information regarding the socio-technology levels and resource capacities are then indexed by means of weighting process, in order to make it calculable for the final decision making. These indices are then put into a matrix against the constraint dimension, in order to be compared and screened to reach the most acceptable alternative at the end of the decision making process.

The model still has limitations due to the incompleteness of fiscal and population data in the developing countries, where administrative data at the sub-district and village level are virtually non-existence. Most policy makers have no choice but utilize the National Year Book data to establish policies at the local level, which deeds have become the prime cause of administrative chaos. The basic assumption of this model is to decide in accordance with the specificity of the local needs. First hand data from the local level are crucial inputs for the decision making process.

4.2.2.2 Analytical Hierarchy Process (AHP)

The AHP is a system analysis technique introduced by T.L. Saaty (1977). Decision makers utilize this method to model complicated problems in conceptual wastewater treatment design by associating with the Decision Support Systems (DSS) (Okubo et al, 1994; Vidal et al, 2002).

Ellis and Tang (1991) and Tang et al (1997) used AHP in the treatment system selection process, due to its capability to include subjective factors including environmental, social, and cultural concepts in to the model. The process employed the systematic comparison method to sort out the most appropriate system for the specific user community. In the modeling process, sets of treatment alternatives were formulated in a hierarchical order. The model aimed to prioritize a set of weighting variables, such as alternative treatment technology, so that the optimal one can be selected from the priority list of the rankings. Pairwise comparisons were used to assess the relative importance weight for each pair of treatment alternatives. Although the AHP can provide a systematic procedure for technology comparison, it was found unsuitable in case of complicated problems, dealing with a large number of pairs, such as the selection of sanitation system (Loetscher and Keller, 2002).

4.2.2.3 Intelligent Tools and Decision Support System

Apart from the sophisticated mathematical models, many studies in recent years have experimented with the intelligent tools in developing *decision support systems* (DSS) such as *expert systems* (ES) or *knowledge-based systems*. The tools utilize an interactive or computer-based approach to design and select an appropriate wastewater treatment system (Okubo et al, 1994; Krovvidy, 1998; Rodriguez-Roda et al, 2000; Balkema et al, 2001; Loetscher and Keller, 2002).

Expert systems, sometime referred to as *knowledge-based systems*, are computer programs, which provide expert advice, decisions, and recommended solution for a given situation. They are designed to capture the non-numeric factors and their reasoning logic, which could not be represented in traditional computing approaches, through a set of rules or decision trees. (Lukasheh et al, 2001).

Loetscher and Keller (2002) developed a multi-criteria decision model based on the *Multi Utility Technique* (MAUT) to rate the desirability of the alternatives by means of the 'sustainability' and 'implementability' indices. To help planners and the user communities assess the suitability of alternatives, a computer-based *decision support system*, SANEX^{TM} was developed to deal with the complicated conditions in developing countries, where inhomogeneous socio-economic circumstances has an impact on the extent of success of the selected system. The proposed SANEX^{TM} system analyzed a number of existing wastewater treatment systems, focusing only on the on-site systems plus a few off-site treatment and sewerage systems. Other innovative treatment technologies still have not been tested by the system.

As aforementioned, the existing mathematical optimization models, such as linear, dynamic, and nonlinear models, are unable to deal with the non-numerical data which are crucial factors in the decision making process, i.e. the socio-culture, institution, and environmental factors. The multi-criteria decision approaches either utilizing intelligent tools or *DSS* have been recently developed and tested in a number of Third World countries to substitute the backdrop of the modeling approach and to sort out an alternative that can meet the local conditions more appropriately.

The previous sections touch on several different approaches. The review of existing literature in those sections asserts that the wastewater design could not be successful unless the local factors are incorporated in the system selection process. Based on the findings from the literature review, the main approach of technology selection for this study will be based on the following assumption:

- Selection method must be able to handle both quantitative data and qualitative variables;
- The important characteristics of local conditions can be incorporated into the selected method.

- The most appropriate options can be obtained by considering all important criteria beside system costs.

Based on these preconditions, the study applies a multi-criteria decision analysis (MCDA) approach to meet the main purpose of the study. The MCDA has been proved to be a promising approach to deal with the problem with conflicting objectives and criteria. The MCDA methods provide subjective and implicit decision making that can be made objective and transparent in a simple evaluation model. Either quantitative or qualitative data can be considered in the same model.

2.4.3 Multi-Criteria Decision Analysis: A Framework for Selection of Appropriate Wastewater Treatment Technologies.

Decision-making processes in environmental projects often involve impacts from various aspects: social, political, economic and environmental impacts. It is typically a complex and confusing practice, characterized by tradeoffs between those impacts. A large number of researches in the area of MCDA have proposed available practical methods for applying scientific decision and theoretical approaches to multi-criteria problems. This section reviews concepts and application of MCDA in environmental problems/projects. Based on the review, the study develops a decision analytical framework and decision support model specially tailored to deal with decision making for the selection of appropriate wastewater treatment technologies.

2.4.3.1 Basic Concepts and Decision with Multiple Criteria

Multi-criteria decision techniques are tools developed in the field of decision theory to aid in problem solving. The multi-criteria approach examines how all the relevant aspects of a problem are assessed and traded off by decision makers. The technique basically employs data on the performance of competing options against the decision maker's stated objectives and develops the composite utility functions for each option (Wilson, 2001). Considering both quantitative and qualitative data in the same model, the techniques assist the structuring and trading-off of disparity criteria, which are basic conflicts in a complex decision.

The relative preference for alternative options can be judged by quantifying their performance against a set of relevant objectives, attributes, or dimensions, which describe the option's "values" to the decision maker (Wilson, 2001 in reference to Miller, 1985). In practice, each option demonstrates advantages and disadvantages. It is unlikely that any one option will be found that will be best against all objectives and can be clearly preferred. The complex problem for the decision maker is how to describe the balance between objectives and to identify the preferred option. The techniques of trade-off between objectives or substitution ratio is then used to determine how much can be surrendered in order to achieve another. If the comparisons are simple and involve only a few objectives, the trade-off can be done intuitively.

Multi-criteria decision making (MCDM) problems can be divided into two major classes based on their formal statement. In the first class of problems called discrete MCDM problems or *multi-criteria analysis problems*, a finite number of alternatives are presented in a tabular form. The second class, continuous MCDM problems or *multi-criteria optimization problems*, a finite number of explicitly set constraints in the form of an infinite number of feasible alternatives (Vassilev et al., 2005).

2.4.3.2 Multi-Criteria Decision Methods and Tools

Multi-criteria techniques comprise a large number of methods and different approaches. They range from simple rating systems to highly sophisticated techniques. Some techniques rank options; some identify a single optimal alternative; some provide an incomplete ranking; and others differentiate between acceptable and unacceptable alternatives (Linkov et al, 2004). In this section, multi-criteria methods are divided into five major groups: scoring/rating methods, value/utility theory, analytical hierarchical process, outranking methods, and mathematical programming. The common purpose of these methods is to evaluate and choose alternatives based on multiple criteria using systematic analysis that overcomes the observed limitations of decision makers (Linkov et al, 2004). Table 2.6 highlights the comparative strengths and weaknesses of these methods.

1) *Scoring/Rating methods*: alternatives are compared on several criteria by assigning simple scores (e.g., from 1 to 10). The more complex and most commonly used approach is developed from the first Kepner-Tregoe method (1965) called *Score Matrix method.* A simple matrix presents the criteria for each goal/objective, the estimate values for the alternative on the different criteria, the weights for each criterion, and the total score for each alternative.

The best alternative could be selected among the high-scoring options (Nguyen, 2003).

2) *Multi-Attribute Utility/Value Theory* developed by Keeney and Raiffa (1976): This approach enables an individual decision maker to define a separate utility function for each criterion (attribute), to weigh the criteria and then to aggregate the weighted criterion into a single function (more detail in the following section). Based on an *additive value model*, a simplified subset of value theory, the overall value of an alternative is considered to be the weighted sum of the values assigned to different attributes (criteria). The decision maker will choose the alternative with the highest overall (accumulative) value. There are three well known techniques based on this approach including SMART (Simple Multi-Attribute Rating Technique), SWING (SMART with Swing weighting), and SMARTER (SMART with Rank weights) (Nguyen, 2003; Ashley et al, 2001).

3) *Analytical hierarchy process (AHP)* developed by Saaty in the early 1970s: the main idea of this method is to find the attribute trade-off weights through pair-wise comparisons of attributes. The approach used by the AHP is to have the decision maker compare every pair of attributes, using informed judgement, and determine the relative preference of one over the other using some standard numerical scale. It is mathematically more rigorous version of the scoring method, providing a logical framework to determine benefit of each alternative (Nguyen, 2003).

Table 2.6 Comparisons of the Multi-Criteria Decision Analysis Methods

Method	Key Elements	Strengths/Advantages	Weaknesses/Disadvantages
Score/Rating	- The assessments of individual criteria are typically based on subjective information expressed as values on a numerical scale.	- Flexible and simple - Ability to incorporate many different concerns (criteria) - Ability to combine subjective judgements with objective assessments - Easy to understand a priority-setting output.	- Lack of two key elements of decision analysis techniques: 1. accounting for interdependence between criteria 2. establishing distance measure among alternatives on every criterion
Multi-Attribute Utility/Value Theory (MAUT/MAVT)	- Express overall performance of an alternative in a single, non-monetary number representing the utility of that alternative -Criteria weights often obtained by directly surveying stakeholders	- Formal, scientific, and transparent technique - Preferential technique to decision makers - Easier to compare alternatives whose overall scores are expressed as single number. - Independent of the alternatives (changing the number of considered alternatives will not affect the decision scores of the original alternative)	- Requires the verifying assumptions and construction of the individual value functions - Maximization of utility may not be important to decision makers. - Criteria weights obtained from less rigorous stakeholder survey may not accurately reflect stakeholders' true preference. - Rigorous stakeholder preference elicitations are expensive.
Analytical Hierarchical Process (AHP)	- Criteria weights and scores a re based on pair-wise comparisons of criteria and alternatives, respectively	- Mathematically proven - Systematic procedure - Provides a profound insight in the complex decision making - Encouraging participants to express their knowledge and expertise	- Time consuming process of pairwise comparison - Likely to obtain inconsistencies among the decision maker's responses to the pairwise comparison question. - Unsuitable to complicated problems with a large number of pairs (attributes) - Rank reversal problem caused by the addition or deletion of alternatives

Table 2.6 Comparisons of the Multi-Criteria Decision Analysis Methods (continue)

Method	Key Elements	Strengths/Advantages	Weaknesses/Disadvantages
Outranking: ELECTRÉ and PROMETHEE	- One option outranks another if: 1. it outperforms the other on enough criteria of sufficient importance (as reflected by the sum of criteria weights) 2. it is not outperformed by the other in the sense of recording a significantly inferior performance on any one criterion - allows options to be classified as "incomparable"	- Provides academic rigor in the decision analysis - Widely applied in environmental management problems, providing many studies of a similar nature - Does not require the reduction of all criteria to a single unit.	- Uses complex algorithms - Difficult to fully understand by non-expert decision makers - Requires many non-intuitive inputs (i.e. the preference functions of PROMETHEE) - Requires the support of decision analysis experts and software specialists
Mathematical programming	- Aims to maximize an objective function with explicit consideration of the constraints.	- The most advanced methodology for priority setting	- Seldom used - Very complicate - Inaccessible to many people i.e. lay people

Note: The content of the table is compiled from several sources by means of analysis and synthesis. It illustrates the comparative strengths and weaknesses of multi-criteria decision analysis methods.

References: Linkov et al. (2004; 2007); Nguyen (2003); Loetscher and Keller (2002); Ashley et al (2001)

4) *Outranking methods*: a decision maker gives ranks on information aiming to find outranking relations between alternatives. The result will lead to one dominating alternative. The outranking approaches differ from the value-function approaches in that there is no underlying aggregative value function (Nguyen, 2003). The output of an analysis is not a value for each alternative, but an outranking relation on the set of alternatives. There are two most promising outranking approaches:

   a. ELECTRÉ (ELimination Et Choix TRaduisant la Realité) introduced by Roy in the early 1900s: this method aims to incorporate fuzzy and vague nature of decision making and uses an outranking approach based on pair-wise comparisons. The main concept of this outranking method is that an alternative can be eliminated if it is dominated by other alternatives. The concepts of outranking may be appropriate where the alternatives remain uncertain or where imprecise data exist (Ashley et al, 2001).

   b. PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) developed by Bran et al. in the mid 1980s: this method starts with the same procedure as ELECTRÉ, it begins with an evaluation matrix containing an evaluation of the criteria on the alternative. For PROMETHEE, the decision maker must specify a preference function for each criterion. Six possible shapes of preference functions (usual, U-shape, V-shape, level, linear, and Gaussian) are suggested and used to compute the degree of preference associated with the best action in case of pair-wise comparisons. The two versions of PROMETHEE (I and II) differ from ELECTRÉ by providing either a partial or total pre-order of the alternatives.

5) *Mathematical programming methods*: these methods aim to maximize an objective function, which is the contribution of alternatives to set of weighted criteria. The best alternatives are selected basing on the predefined criteria weights under some restriction on resource availability. These methods consider explicitly the constraints under which the objective function is being maximized. The other methods, on the contrary, do not consider the constraints but assume that alternatives with high scores/values have priority or implementation over alternatives with lower scores/values (Nguyen, 2003).

The last three methods in Table 2.8 represent the highly mathematical and more advanced methodologies for decision making analysis. They, nevertheless, require extensive support of decision analysis experts and software specialists. The complexity of the approaches makes them inaccessible to non-experts and in particular the decision makers and stakeholders in developing countries. The first two approaches, on the contrary, are more easily applied in developing countries requiring less special knowledge. The scoring/rating methods are more useful for initial attempts at priority setting conducted at lower levels. The methods nevertheless, can not carry out the rigorous sensitivity analysis (Nguyen, 2003). For any rigorous method, a sensitivity analysis is necessary. In this light, MAUT/MAVT can be suitable presenting a complete ranking or a range of feasible alternatives rather than the best solution.

This study uses the Value/Utility theory approach for the selection of appropriate wastewater treatment system because of its simplicity and ability to take into account the technical, social, economic, and environmental aspects. The following section elaborates in more detail of the value/utility theory and available techniques using for the decision analysis. The techniques that will be chosen and used for developing a decision support model in this study should be easy to apply and be implemented by non-expert decision makers such as local authority or community organization.

2.4.3.3 Multi-Attribute Utility/Value Theory (MAUT/MAVT)

MAUT/MAVT developed by Keeney and Raifa (1976) in the mid 1970s, aims to find a simple expression for the net benefits of a decision. Through the use of utility or value functions, the methods transform diverse criteria into one common scale of utility or value in order to represent decision maker's preference structure, and provide assistance in choosing between a range of options (Linkov et al, 2007; Ashley et al, 2001). It presents a range of feasible alternatives, as an outcome, rather than one best solution.

MAUT/MAVT is also considered as a part of "compensatory methods" because the low scores on criteria can be compensated by high scores on other criteria. Decision makers are assumed to be rational, choosing the alternative with the highest utility/value and having perfect knowledge. The approach also relies on the assumptions that preferences are transitive but do not change (Linkov et al, 2004). The goal of decision makers in this process is to maximize the utility or value (Linkov et al, 2007).

MAUT and MAVT methods are often mentioned together in the MCDA literature and not always seen as fundamentally different (von Winterfeldt and Edward, 1986). Although, both methods use the aggregated value functions to present the performance of alternatives based on the preference of decision makers, they are differentiated on the basis of certainty. MAVT provide a value that is focused approach to decision making problems with no uncertainty (Keeney and Raiffa, 1976). A value function used to represent the outcome of deterministic alternatives. In MAUT on the contrary, the uncertainty in decision outcomes and the risk attitude of decision maker are taking into account. MAUT uses a utility function, which is based on the expected utility of each alternative (Keeney and Raiffa, 1976). MAUT can be used in cases where uncertainty can be modeled using probability distributions (von Winterfeldt and Edward, 1986; Bolton and Stewart, 2002). MAUT is considered strong decision making when compared to MAVT. Nevertheless, MAUT has been very difficult to apply and no real applications are known (Herwijnen, 2007). To select an appropriate technology, the study only takes the approach of deterministic model so that decisions under uncertainty are not taken into consideration. The following review provides on a brief overview of MAVT and illustrates the software application of MAVT to develop a decision model in the study.

Multi-Attribute Value Theory (MAVT)

The main objective of MAVT is to model and represent the decision maker's preferential system into a value functions $v(x)$.

$$v(x) = f\,(v_1(x_1),\ldots, v_n(x_n))$$

In this process, decision makers aim to identify the alternative x that maximizes the overall value of $v(x)$. An additive model is the most widely used form of function $f(\ )$. The general form of additive value function for an alternative x is

$$v(x) = \sum_{i=1}^{n} w_i\, v_i\,(x_i)$$

where:

x_i = consequence of an alternative x for attribute (criterion) i

$v_i\,(x)$ = the rating of an alternative x with respect to an attribute (criterion) i

n = the number of attributes (criteria),

i = attribute (criterion) of interest, i=1,…, n.

w_i = the relative importance of an attribute (criterion) i, $w_i>0$, $\sum_{i=1}^{n} w_i = 1$

The sum of weights is normalized to one, and the component value function $v_i(\cdot)$ has values between 0 and 1.

The overall value of an alternative is considered to be weighted sum of the values assigned to the different attributes (criteria) (Nguyen, 2003). In this light, the compensation between attributes is possible. A large gain in a lesser important attribute will eventually compensate for a small loss in a more important attributes, no matter how low one attribute is (Herwijnen, 2007).

Criteria (Attribute) Weighting:

MAVT (also MAUT) has been criticized based upon its practical implementation because it is difficult to elicit judgments from decision makers and develop realistic assumptions. These issues lead to the development of the Simple Multi Attribute Rating Technique (SMART) by Edwards and Newman in the early 1980s (Ashley et al, 2001; Linkov et al, 2004). The weights of the attributes can be, nevertheless, given directly, or by some other sophisticated methods e.g., SWING (von Winterfeldt and Edward, 1986) or SMARTER (Edward and Barron, 1994). As an alternative, values can be given directly or used in value functions to transform the ratings of the alternatives into values (Mustajoki, 1999).

1) *Direct weighting*: the decision maker directly allocates numbers to each attribute to reflect their importance. The decision maker is asked, for example, to divide 100 points among the attribute (Nguyen, 2003) or directly asked to give values between 0 and 1.
2) *SMART*: The weights are defined in two steps:
    a. Attribute changes from worst attribute level to the best level are ranked in the order of their importance.
    b. Ratio estimates of the relative importance of each attribute relative to one are ranked lowest in importance. Usually, the least importance attribute change is assigned 10 points. The relative importance of the other attributes is then evaluated by giving then points from 10 upward (Mustajoki, 1999; Nguyen, 2003).

After all the ratios are given, the points are normalized to get the weights associated with the attributes. The point scale in SMART is actually continuous. The decision maker can use the whole scale of real number to define the points (Mustajoki, 1999).

3) *SMARTER*: the local weights are based only on the ranks of the attributes. The weights are calculated with the rank order centroid method (Mustajoki, 1999). The weight of an attribute ranked the k^{th} is

$$w_k = \frac{1}{N} \sum_{i=k}^{N} \frac{1}{i},$$

where N is the number of attributes. The attributes having the same ranks also have the same weights.

4) *SWING*: this procedure is similar to SMART, but weighting starts from the most important attribute. In SWING, all attributes are hypothetically at their worst level. The decision maker is asked to move (swing) one attribute to its best level and assign 100 points to this attribute. The decision maker, then, assign points less than 100 to the other attributes based on the relative importance of swinging them in respect to the most importance attribute (Mustajoki, 1999; Nguyen, 2003).

2.4.3.4 Software System

The state of multi-criteria decision support systems has been reviewed and discussed by Weistroffer and Narula (1997) and Vassilev et al. (2005). The software systems developed to support the solution of MCA problems can be categorized in any of three groups: (1) commercial software packages; (2) software packages developed primarily for research/teaching purposes; and (3) programs written for experimental purposes and testing new techniques (Vassilev et al., 2005). Some research or learning software systems demonstrate very success implementation. Developers are also offering the software systems free of charge, for non-commercial purposes. Due to the proliferation and advancement of the internet, many web-based software packages have been developed to support MCDA. The web-based software also provides techniques for multimedia communication, interactive distributed modelling and preference elicitation, and the exchange of the results (Mustajoki 2004).

In this study, we apply the Web-HIPRE (HIeararchical PREference) software for MCDA. Web-HIPRE (released in 1998) located on http://www.hipre.hut.fi, which is a web-version of the earlier HIPRE 3+ software (developed by Hämäläinen, R.P. and Lauri, H. in the mid 1900s). It provides tools for decision analytic problem structuring, preference elicitation, multi-criteria evaluation, privatization, and sharing results on the internet (Nguyen, 2003; Mustajoki 2004). Web-HIPRE is one of a few general purpose decision analytical software systems programmed with Java-language, which enables the use via internet. Web-HIPRE supports two MCDA methods; multi-attribute value theory (MAVT) and the analytical hierarchy process (AHP). These approaches develop a hierarchical model of objectives related to the problem and the stakeholders' preferences. This computer-support system provides the visual construction and weighting of the value trees, and the computation and graphical analysis of the results (Mustajoki, 1999).

In MAVT, the decision making problem is structured in the form of *a value tree*, which is a hierarchical structured consisting of a goal to be achieved, attributes (criteria) affecting the decision and alternatives to be chosen from. The attributes are weighted according to their importance, and the alternatives are evaluated in respect to each attribute (criterion).

Sensitivity Analysis

The sensitivity analysis is aimed to investigate the influence of modified input data on the calculated results and stability of an obtained solution. The software WEB-HIPRE provides a graphical sensitivity analysis based on the net preference flows. The results from this analysis are expected to provide:

- The sensitivity of a ranking to changes in the data of all alternatives of certain criteria;
- The influence of changes in the scores of a specific alternative of certain criteria;
- The minimum modification of the weights required, making a specific alternative ranked first.

In MAVT, the sensitivity analysis can used to demonstrate the sensitivity in the changes of overall value with respect to the local weights of some criteria (or value of some alternative) varying (Nguyen, 2003).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The main objectives of the research are to identify and analyze the relevant factors determining the success of wastewater treatment systems, and develop a set of decision criteria and indicators useful for selecting appropriate treatment systems. To propose a decision-support model for selecting an appropriate treatment plants in developing countries, the research collected data from experts, reviewed actual practices and experiences from wastewater treatment plants, and assessed local needs and constraints. The research, therefore, comprises of 3 major tasks: the expert survey, the plant survey, and the community survey. Three tasks are designed to gather empirical data to establish the waste water treatment alternatives and selection approaches.

3.1 DEFINING RESEARCH VARIABLES

The previous literature review chapter contributes to two main purposes in designing the research methodology. Firstly, the review aims to establish relevant factors, which determine the success of wastewater treatment systems in developing countries, and to discuss the interrelationship among these factors. Secondly, the review of previous studies provides alternative approaches of methods and measurements for analysis that can be the basis of this research.

Figure 3.1 presents the conceptual framework of the relevant variables and their interrelationships to be investigated in the research. The research relates seven treatment plant attributes, which determine the success of the treatment systems, and therefore must be put into consideration in the evaluating and selecting process of wastewater treatment technologies. The seven characteristics include system reliability, simplicity, land requirement, affordability, efficiency, social acceptability, and sustainability. Local conditions and resource availability are also important factors affecting the suitability of the wastewater treatment system for a particular situation. These factors are socio-economic, physical, institutional and political condition, and the extent of water pollution factors.

The study extends the aforementioned conceptual variables by converting them into operational variables and indicators for data collection in the field study, after which, research tools, such as questionnaire, interview and observation checklist, are created and tested before the collection of data.

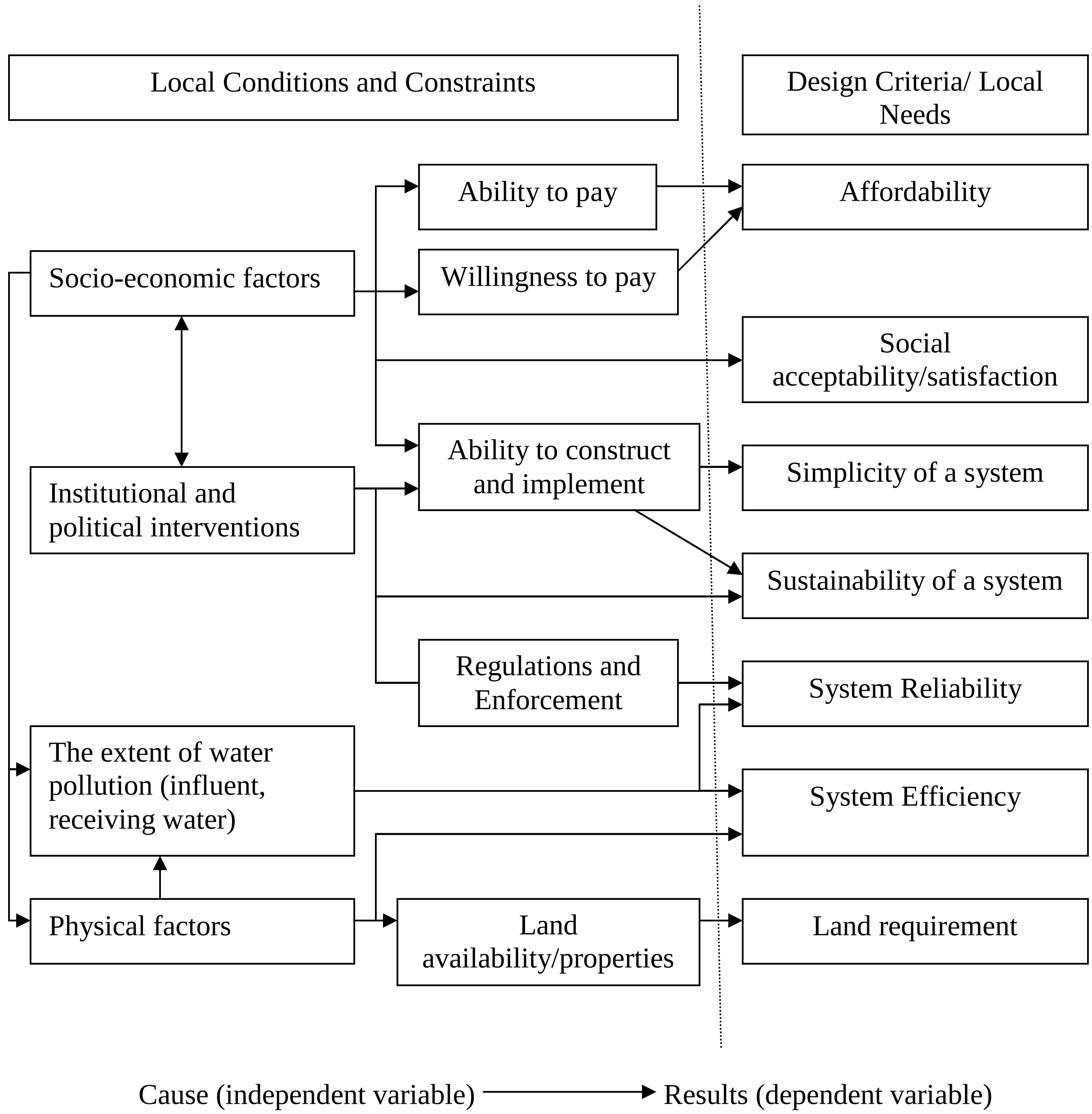


Figure 3.1 Hypothetical Framework of the Relevant Parameters and Their Interrelationship

3.2 DATA COLLECTION

Survey methods comprise 3 major tasks (see Figure 3.2).

Task 1 *Expert Survey: To assess the criteria and indicators for appropriate wastewater treatment systems*

The survey aims to identify and select the criteria and indicators useful for evaluating and selecting appropriate WWT systems. The study used a structured questionnaire to obtain information from Thai experts representing academicians, consultants/plant designers (private sector), and government officials, who have been working in the field of wastewater treatment and management in Thailand. The 153 experts were all mailed a survey form and a cover letter explaining the purpose of the survey. The participating experts were requested to return the form by prepaid mail. The schedule was conducted from September, 2006 to March 2007. A total of 33 experts participated in the survey.

Task 2 *Plant Survey: Collecting data from the existing municipal WWT plants in Thailand*

This portion of the study aims to acquire information regarding the characteristics of municipal WWT plants operated in Thailand and to use the collected information as database to develop a decision-support model. The study applies a set of criteria and indicators as measures to examine municipal wastewater treatment plants through the formal questionnaire. Along with *Task I*, a mailed-in questionnaire survey was conducted with operators of 63 municipal WWT plants during the months of February and June, 2007. A total of 32 wastewater treatment plant operators were participated in the survey.

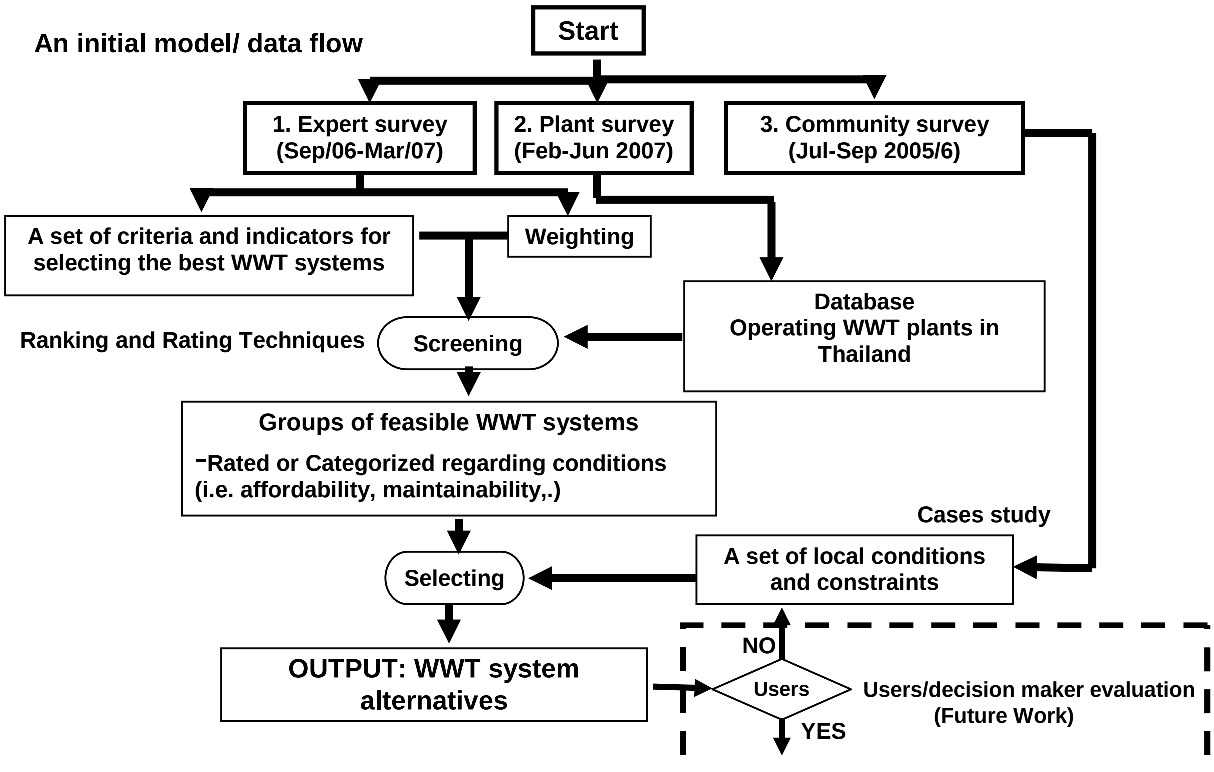


Figure 3.2 Overview of the Research Design

Task 3 *Community Survey: Scenario study*

The purpose of the last survey is to explore the local socio-economic and technical circumstances and constraints affecting the treatment technology selection in different sanitation scenarios in Bangkok. Inquiry for this section comprises a formal questionnaire together with a non-structured interview for gathering of socio-economic, physical, and other local information. The Rom Klao (RK) and Feun Nakorn Rom Klao (FNRK) Housing Projects at the eastern segment of Bangkok Metropolis were used as case studies. The study collected information by means of a questionnaire survey from 339 households in 10 communities during the months of July and September in 2005/2006.

3.3 SAMPLING CRITERIA

Both non-probability and probability sampling techniques were used to draw samples for the research survey.

Non-probability sampling methods provide samples basing on the judgment of the surveyor or on the needs of the survey. It is usually adequate for survey of specific groups as the purpose of the survey in Task I (expert survey) and Task II (plant survey). In addition, the non-probability samples will be appropriate for the tasks due to the difficulties in obtaining cooperation or capability for answering the questions among the potential respondents.

Probability sampling methods: In these methods, all members of the target population have the same chance to be selected, providing a statistic basis to make the sample a representative part of the target population (Sarmento, 2001). In this research, the survey in Task III (community survey) employed the *Systematic sampling*, one of the methods applied for probability sampling.

Residents of RK and FNRK communities were formally interviewed by dividing the population into 11 groups according to their current types of wastewater treatment facilities, houses, and locations. A random sampling was done within each group. The number of respondents selected in each group was proportional to its relative population size. Every n^{th} member of population was selected after a random start (n = total population/ number of target samples). The selected householders were individually interviewed by the local graduate students. If the selected householders were not available at the time of survey, the previous or the following household in the sequence was selected.

Data obtained from the expert survey are used to assess the proposed set of criteria and indicators (section 4.1). The results from this assessment are used to quantify the set of indicators and evaluate the technical, socioeconomic, and environmental criteria of wastewater treatment alternatives based on the plant survey (section 4.3). Using data obtained from the community survey and informal interview with local authorities, the study examines different aspects of local factors, which determine the extent of long-term success of a community-scale wastewater treatment system in the case studies (section 4.6).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 DEVELOPMENT OF CRITERIA AND INDICATORS FOR SELECTING APPROPRIATE WASTEWATER TREATMENT SYSTEMS IN THAILAND

4.1.1 Approach to Developing Selection Criteria

This study presents a comprehensive approach with factors to select appropriate wastewater treatment systems in developing countries in general and Thailand in particular. Instead of focusing merely on the technical dimension, the study integrates the social, economic, and environmental concerns to develop a set of criteria and indicators (C&I) useful for evaluating appropriate system alternatives. This Chapter describes the process of developing a set of locally appropriate selection criteria and discusses the results from expert survey used to assess the initial set of C&I. With the assessment in the preceding section, the final set of C&I is identified and used to evaluate wastewater treatment systems, and to incorporate into the decision support model in the next Chapter.

The study takes the criteria and indicator approach to develop a technology selection framework appropriate to the context of Thailand. This approach is based on a hierarchical structure, aiming to create a strong links between the upper-level ideas (Principles) and the dimension of interests (Criteria) down to the measurable components (Indicators) so that the final set of C&I will be meaningful, coherent and comprehensive (Mendoza, G.A. and Prabhu, R., 2000; Mendoza, G.A., 1999). The well constructed set of C&I can be used to express what appropriate wastewater treatment system means for the local, to assess performance of the existing treatment systems, and to incorporate within the selection process of wastewater treatment system for a community.

The study applies processes of conceptualization and operationalization, which are commonly used in the social sciences as part of the scientific research method. Conceptualization is the process by which a term of concept in the research is clarified (conceptual definition). The succeeding operationalization procedure involves taking these specific conceptualized constructs and translating them into specific measures or indicators (operational variables) that can be used to collect data (Babbie, 2005). The study employs both objective and subjective approaches to create questions or specific measures. The developing process of criteria and indicators involves the following steps:

1) Specify the conceptual definition of "appropriate wastewater treatment system", and the conceptual variables;
2) Identify the dimension of interests in each conceptual variable;
3) Operationalize the conceptual variables into specific measures and indicators (operational variables);
4) Organize all relevant variables (conceptual and operational) into three hierarchical elements; namely, principles, criteria, and indicators;
    - *Principles*, which are broadly defined, refer to the main ideas or concepts of appropriate wastewater treatment systems for developing countries.
    - *Criteria* demonstrate the dimension of interests in each principle needing to be assessed; however, they still have conceptual characteristic.

A Criterion can, therefore, be seen as a 'second order' Principle, one that adds meaning and operationality to a principle without itself being a direct measure of performance. Criteria are the intermediate points to which the information provided by indicators can be integrated.

- *Indicators* are the components or variables that indicate the state or conditions required by each criterion. These are real information that can be measured in some way.

The conceptual definitions of appropriate wastewater treatment systems are identified and widely discussed in Section 2.3. The criterion framework aims to encapsulate the socio-economic and environmental principles of appropriate technology, together with technical criteria, which relate primarily to the performance of wastewater treatment system. The study assumes seven important elements, which determine a particular appropriate system. These elements include *reliability, simplicity, land requirement, affordability, efficiency, social acceptability, and sustainability* (see Figure 2.2). The set of conceptual and operational variables is organized into three hierarchical elements, namely; principles, criteria, and indicators to be evaluated in the expert survey. The lists of hierarchical elements are summarized in Table B.1 (Appendix B).

4.1.2 Criteria and Indicator Assessment

The initial set of generated C&I assessed by means of a multiple criteria analysis (MCA) method is used as a basis toward the selection of final C&I which are applicable to the final wastewater system selection model (Mendoza, G.A. and Prabhu, R., 2000; Mendoza, G.A., 1999). Two MCA approaches, ranking and rating, are used to evaluate and select the C&I set. An interdisciplinary expert group is asked to evaluate and rank the relative importance of each component in relation to the upper-level element and to the overall selection process of appropriate domestic wastewater treatment systems for Thailand. The steps of criteria and indicator assessment can be summarized as follows:

1) Apply ranking and rating methods to develop a questionnaire for assessing the initial set of C&I;
2) Conduct a survey to inquire information from a diverse group of experts;
3) Assess the initial set of C&I, basing on the results obtained from step 2).
    - Prioritize the Principles, Criteria, and Indicators according to their relative importance;
    - Eliminate those Principles, Criteria, and Indicators with significantly low weights, if possible.
4) Select the final set of C&I with the consideration of local situations.

4.1.3 Data Assembly and Assessment

4.1.3.1 Data Collection: Expert Survey

In order to validate C&I, the study utilizes a structured questionnaire to obtain information from experts--academicians, practitioner (consultants/plant designers), and government officials--who have been working in the field of wastewater treatment and management in Thailand to assess a list of C&I. The survey was conducted by mail from January to March, 2007. A total of 33 experts have participated in the questionnaire survey and assessment (Figure 4.1).

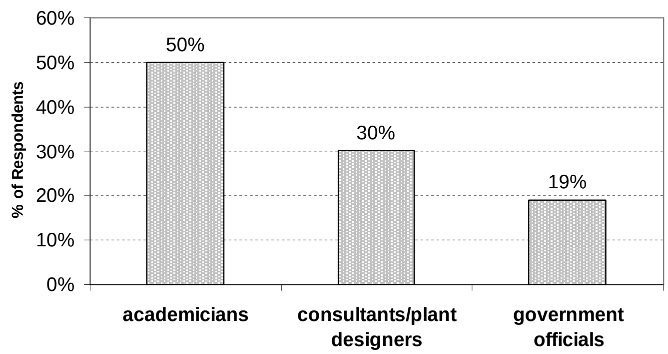


Figure 4.1 Respondents in the Expert Survey

The questionnaire was designed to evaluate three levels of information--criteria analyses, indicator suggestions, and principles propositions, starting with the analysis at the lower levels which were less conceptual, and based more on quantitative measurements and observations. This sequence provided the respondents the opportunity to review and advocate a C&I hierarchy (Mendoza, G.A. and Prabhu, R., 2000; Mendoza, G.A., 1999).A sample questionnaire from the expert survey is showed in Appendix C.

4.1.3.2 Data Analysis

MCA is a decision-making tool pertinent to solving complex multi-criteria problems which include qualitative and/or quantitative aspects of decision-making process. It is able to help evaluate the relative importance of all criteria involved, and then apply them to the final decision-making process. In this light, the ‘criteria’ mentioned earlier are also known as *decision elements*, which refer to the involving components in the complex decisions making process. In this study, C&I are elements representing Principles, Criteria or Indicators which can be systematically evaluated by means of the MCA method.

Ranking and Rating are two simplest MCA techniques, with minimal relative comparisons, that can be used in a C&I assessment.

The Regular Ranking Method analyzes each element by assigning a rank depending on the perceived importance. Ranks are assigned according to a nine-point scale (1, weakly important; 3, less important; 5, moderate; 7, more important; 9, extremely important).

The Rating Method is similar to ranking, where decision elements are assigned ‘scores’ ranging from 0 to 100, and the total score for all the elements must add up to 100. The relative weight of each element thus plays an importance role against the rest of the other elements. Such scoring method is therefore able to differentiate the extent of significance among the entire set of composite elements.

Calculation of Relative Weight is done by means of assembling the ranks and rates from the experts’ responses, where generalization of relative importance for each decision making element can be accomplished basing on a pattern found among the responses. The relative weighting can be calculated by dividing the actual weight of a particular element by the sum of all weights and multiplied by 100. The resultant of element weighting is then utilized as basis for C&I formation.

For ranking, the relative weight can be calculated as follows:

$$w_{ji} = \sum_{k} r_{ji} \,/\, \sum_{j}\sum_{j} r_{jki} \qquad (1)$$

Where; j is a criterion with *m* indicators described as C_j ε (I_{j1}, I_{j2}…, I_{jm});

k is the ranking (r) given by a participant/expert to respective indicators of criterion *j* as r_{jk1}, r_{jk2}…, r_{jkm}; and

w_i is the relative weight, for indicator *i* (*i* =1,2,…m)

For Rating, since weight of decision elements are assigned explicitly summing to 100 points (the sum of weights). The weights of all elements can therefore be described using the following logical formula:

$$0 \le w_{ji} \le 100; \text{ and } \Sigma w_{ji} = 100 \text{ for all i}$$

Calculation of Composite Weight:

1) Calculate the sum of the expert's votes for each decision element for both ranking and rating techniques. This shows the total weight allocated to each elements by the two different techniques.
2) Calculate relative weight of each decision element for ranking and rating techniques and compare the results from both techniques.

3) Calculate the composite weight for each decision element by averaging the relative weights obtained from ranking and rating techniques.

4.1.4 Results and Discussion

Ranking and rating methods are used as screening tools for deciding whether a particular C&I should be included, which composite weights could be the ultimate measure for the final justification explained in the final selection.

1. Principle Level:

The principle level comprised 7 major system attributes, which govern the selection of treatment technologies, comprises three crucial aspects: technical, socio-economic, and environmental aspects. Table 4.1 and Figure 4.2 show the composite weights at the principle level derived from groups of expert respondents. The result shows, based on the overall weight summation, that 'efficiency', 'reliability', and 'affordability' are among the most important elements, followed by 'sustainability' and 'social acceptability'. On the contrary, 'simplicity' and 'land requirement' were low in priority, indicated by their relatively lower weights. The low weighting of 'simplicity' might be attributed to the perception that it is not as important as 'reliability' and 'affordability'. The finding may be a partial reason for the current operational failure of treatment facilities in Thailand, which neglects the simplicity of systems and the limitation of local skill and resources in the system selection process. In the case of 'Land requirement', it may be considered low priority because most of municipal wastewater treatment projects were situated on publicly owned land.

Table 4.1 Relative Weights of Principles Calculated by Ranking and Rating Method

Principle	Average		SD		Relative Weights (All votes)		
	Ranking	Rating	Ranking	Rating	Ranking	Rating	Combined
P1.Reliability	7.6	19.6	1.4	15.9	15.8	15.7	16.0
P2. Simplicity/ Complexity	6.1	13.2	2.1	16.1	12.0	9.1	11.8
P3. Efficiency	7.6	19.9	1.2	15.4	16.9	18.6	16.2
P4. Land Requirement	6.1	14.0	1.8	15.7	14.4	18.9	12.2
P5. Affordability	7.2	18.8	1.9	16.7	11.6	10.8	15.3
P6. Social Acceptability	7.1	16.2	1.7	15.9	14.5	14.6	14.1
P7. Sustainability	7.4	16.0	1.6	15.5	14.9	12.3	14.3

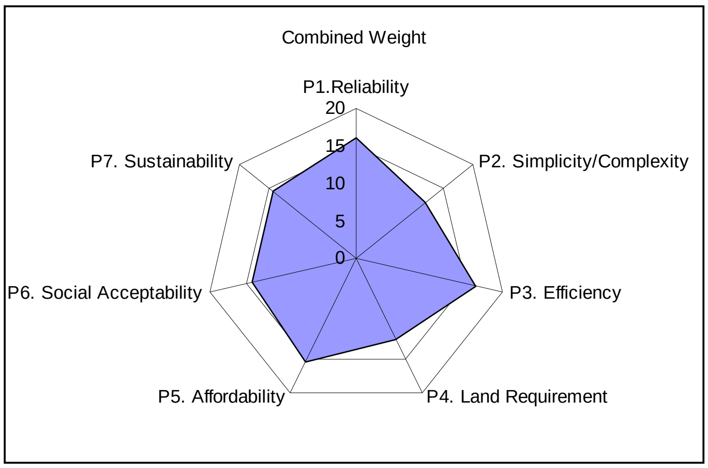


Figure 4.2 Combined Weights of the Principles

Figure 4.3 shows the combined weights from different groups of experts. Consultants/plant designers and government official agreed closely. These practitioners are mostly involved in hands-on operations, and showed slightly higher weights for Simplicity, Land Requirement, and Sustainability when compared to the other groups' values. The academic experts, on the other hand, expressed higher priorities for the Efficiency and Affordability of the system.

At this level, the overall composite weights show slight differences among principles. It is therefore difficult to judge whether the lower weighted principles (i.e. Simplicity and Land Requirement) are sufficiently low to be eliminated from the list.

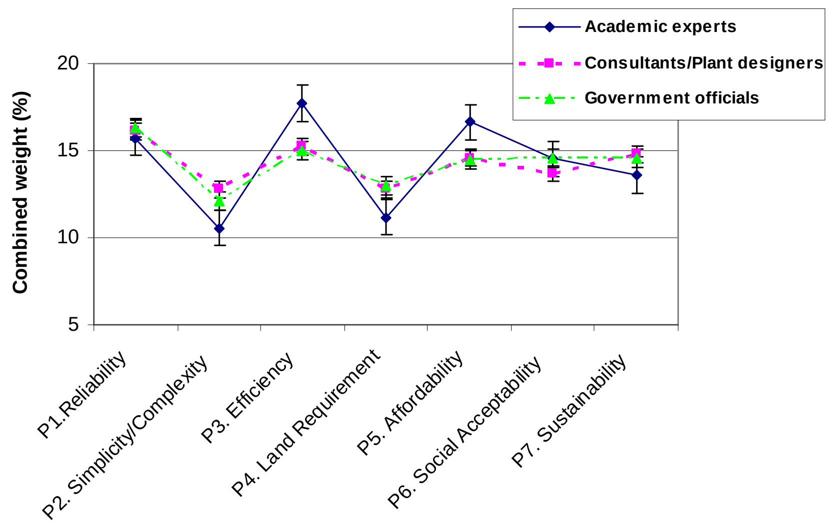


Figure 4.3 Combined Weights of the Principles from Different Groups of Experts

2. Criteria level

The second stage of assessment identifies the respective criteria for each of the aforementioned principles. The objective of this process is to denote the meaning and conditions of each principle, by which 14 criteria are identified and operationalized via 64 indicators for the succeeding stage. The relative importance of the entire set of criteria is shown in Figure 4.4, with the exception of 'Efficiency' in the third Principle, since it has only one criterion. Figure 4.4 reflects the following pattern:

1) All criteria under principles P1 (Reliability) and P6 (Social acceptability) are relatively important. None of them had significantly low weight.

2) The ranking and rating for the criteria in the P1 (Reliability), P5 (Affordability), and P6 (Social acceptability) categories are in accordance with the response and consistency among experts, where principles P2 (Simplicity), P4 (Land requirement), and P7 (Sustainability) exhibited the highest inconsistency (Table A.2 in Appendix A). In particular, criteria C2.1, C2.2, C4.1, 4.2, and C7.2 show very high variance in both ranking and rating among experts.

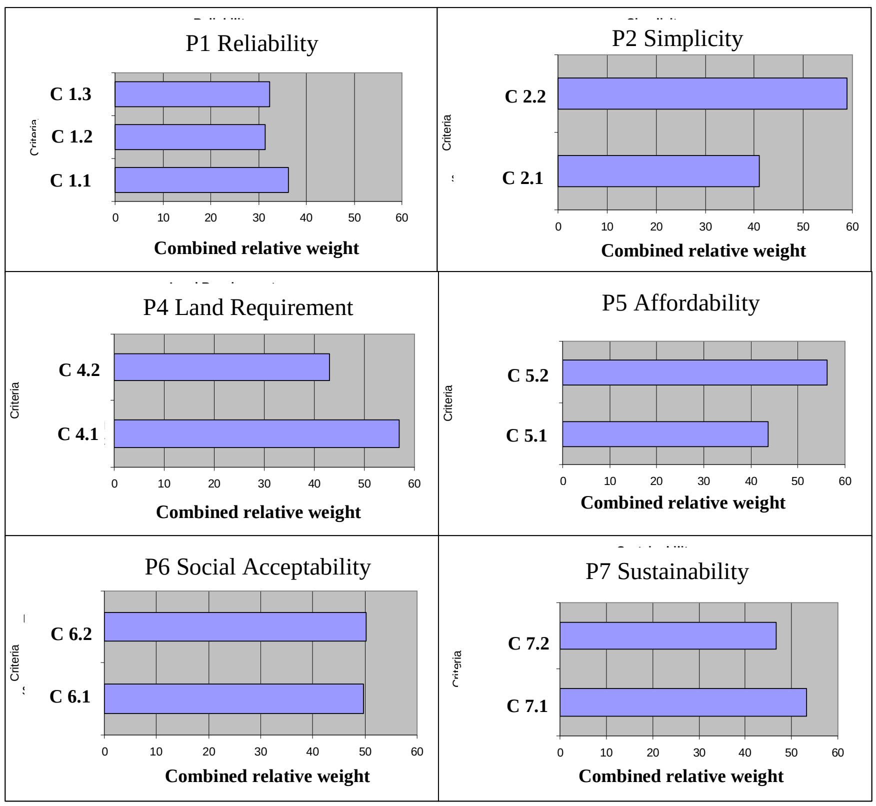


Figure 4.4 Combined Weights of the Criteria

3) Thai experts rated criteria C2.2 (Operational and maintenance requirement), C4.1 (Size of land requirement), C5.2 (Annual operation and maintenance cost), and C7.1 (Continuity of system provision/operation) the most important criteria under their respective principles.
4) None of the criteria will be eliminated from the list until the indicator level has been analyzed. Some criteria such as C2.1, C4.2, and C5.1 might need close attention due to their low relative weights.

3. Indicator level

In this stage, a total of 64 indicators are identified in relation to criteria in the preceding state. The assessment at this level is crucial to developing a set of measurable variables. Ranking and rating methods are utilized for the screening and selection of indicators from a pool of them. Indicators with significantly low weights are deemed to be eliminated with care, since some of them were local or site specific. Different local/community scenario and resource availability are also taken into account in the final selection process.

Figure 4.5 shows the composite weight of indicators for all criteria with the exception of C1.3, 4.1, and 7.1. Indicators under these criteria show the equally importance or composite weight for each category. The resultant composite weight clearly differentiates and prioritizes indicators for each criterion, from which the following postulations are deduced:

1) Basing on the composite weighting, indicators I1.2.7, I2.1.4, I2.1.5, I2.2.4, I2.2.5, I5.2.5, I6.2.6, I6.2.7, I7.2.5, and I7.2.6 exhibit relatively low weight and deem to be eliminated.
2) Thai experts express very low ranking and rating for indicator I1.2.7 (the effect of weather variation on system performance) with an average rank of merely 4 and a mean rating of 6.97. Since fluctuations of seasonal temperature are usually low in Thailand, most experts do not expect any seasonal impact on the performance of wastewater treatment. Thailand, nonetheless, located within the tropical monsoon zone with almost 6 months of heavy rain shower, large amount of rain water could dilute the influence and eventually affect the plant performance, particularly the system with biological treatment processes. The study thus retains the indicator at this stage considering only the effect of rain water discarding the impact of temperature.
3) Under criterion C2.1, indicators I2.1.4 and I2.1.5, representing the time requirement for construction and system installation, reflect the lowest composite weight. Experts might not imply the equivalent of time requirement with construction simplicity. On the contrary, indicator I2.1.6, time required for start-up a system, receives the highest rating in terms of importance. The study thus retains all indicators in the C2.1 category, which included the ‘time requirement’ indicators on the list.

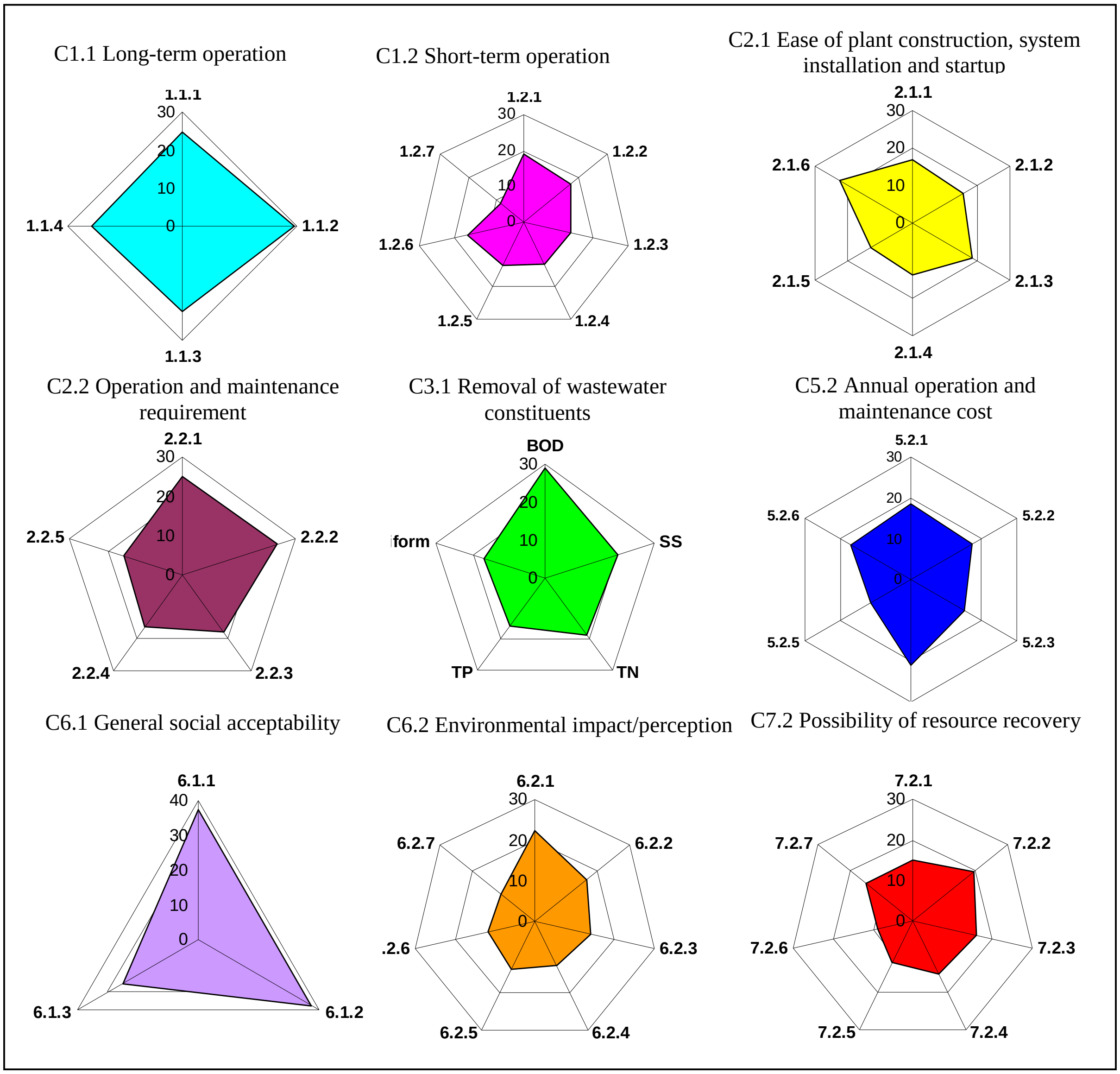


Figure 4.5 Relative Importance of Indicators (Combined Weights)

4) Indicators I2.2.4, I5.2.5, and I6.2.7 are eliminated with the following reasons. Indicator I2.2.4 (special O&M requirements) is eliminated due to its similarity to I2.2.1 (skill and personnel requirement), while indicator I5.2.5 (administration cost) only partially represented the amount of O&M cost. Wastewater treatment

plant operation, on the other hand, has very little impact on indicator I6.2.7 (traffic impact).

5) The study retains the rest of low weight indicators including I2.2.5 (special manufactured/imported equipment), I6.2.6 (landscape/visual impact), I7.2.5 (irrigation of food crop), and I7.2.6 (groundwater recharge). As site specific issues, these indicators might be of interest in specific circumstances. Indicator I7.2.5, for instance, would be important in the area surrounded by agricultural production.

4.1.5 Selection of Final Criteria and Indicators

In addition to the assessment in the preceding section, the selection of final C&I is also based on the following guidance criteria:

1. The four major aspects of appropriate wastewater treatment systems including technological, social, economic, and environmental aspects be considered collectively.
2. Be simple to allow understanding, interpreting, and presenting by specialists as well as lay persons (i.e. local authorities and community organizations)
3. Be applicable across the range of all the wastewater treatment options under consideration.
4. Be sufficiently practical to obtain numerical data or qualitative information

As stated before, different aspects of local/community conditions and resource availabilities are taken into consideration before selecting the final list. The above selection criteria provide an initial guidance in the choice of C&I. The proposed set of C&I were applied in practice by conducting the plant survey in Thailand. This survey helped to further assess the applicability of the proposed set.

The plant survey results suggest a difficulty in evaluating the effects and values of some indicators and eliminate the from the list, for example the effect of toxic contaminations (I1.2.4), which have not been analyzed during a routine operation; the time requirement for startup (I2.1.6), which most plant operators considered this phase as a part of installation; the time requirement for training (I2.2.3), which most plants did not have plan for operator training. Indicators I6.2.5 (groundwater impact), I6.2.6 (landscaping/visual impact) and I4.1.2 (plant foot print) are also omitted.

Indicators I5.1.3 (Cost subsidy), I6.1.2 (Public support for wastewater fee collection), and I6.1.3 (Public participation) are incorporated in the evaluation of the community capacity (in Section 4.6)

The results above demonstrate the potential for using the two methods as screening tools. The composite weights derived from the ranking and rating methods can sufficiently explain and justify the final selection measures of C&I. The C&I approach from this study would be a useful process for the development of variables and measurements inquiring data in the local level. In the following section, the final sets of C&I are summarized in tables providing the linkages among principle, criterion and indicator levels with respective variables.

In conclusion, the study produces a set of selection criteria covering technical, socio-economic, and environmental aspects and applicable to evaluate appropriate wastewater treatment alternatives for Thailand. The final set of C&I is derived from seven principles including reliability, simplicity, efficiency, land requirement, affordability, social acceptability, and sustainability. Based on these principles, a set of 14 criteria and 54 indicators are developed and used to assess the operating wastewater treatment systems in Thailand (in Section 4.2). The set of criteria selected will determine the outcome of the decision being made as well as the method of comparison (decision support process).

4.2 WASTEWATER TREATMENT ALTERNATIVES

4.2.1 The State of Wastewater Treatment in Thailand

In Thailand, most of wastewater treatment plants (WWTP) provide only services within the municipal or urban areas, due to the availability of budget and other resources. There are 95 wastewater treatment projects (including seven plants in Bangkok Metropolitan area) with the total capacity of 3.0 Million m^3/d, equivalent to approximately 20% of wastewater generated (Table 4.2). Central government agencies (i.e. the former Public Works Department (PWD) of the Ministry of Interior and the former Ministry of Science, Technology, and Environment (MOSTE)) were primarily responsible for the planning, financing, and constructing municipal WWTP Local Government Authorities in each area are responsible for operation and maintenance with managerial and financial supports from Pollution Control Department (PCD) and Wastewater Management Authority. During 1994-1999, PWD and MOSTE allocated tremendous budget to construct WWTP projects in many municipal areas throughout the country.

Table 4.2 Central Wastewater Treatment Plants in Thailand

Area/Region	In Service	Refurbished (Delayed)	Under Construction	Total	Capacity m^3/d (MGD)
Bangkok	7	-	-	7	992,000 (262)
Central	19	1 (1)	-	21	812,100 (215)
East	12	2	1	15	293,900 (78)
North	11	4	2	17	256,378 (68)
Northeast	9	2	7	18	285,082 (75)
South	12	-	5	17	358,320 (95)
Total	70	10	15	95	2,997,780 (791)

Source: Pollution Control Department (PCD) Thailand, 2006

Data used to evaluate the wastewater treatment alternatives in the next section are based on the questionnaire survey from 32 municipal WWTP in Thailand. Utilizing secondary data collected by PCD in 2003, design capacities, construction costs, and O&M costs of the other 26 plants are used to analyze the economic criteria.

Figure 4.6 and 4.7 show types and size distribution of 53 municipal WWTP used in the study. From the figures, waste stabilization ponds have been the most frequently used treatment process in the provincial area due to their simplicity and the availability of land. Activated sludge systems, on the other hand, are rarely used due to high energy requirement and complexity on operation and maintenance. Most of treatment plants are in the medium size categories with the design capacities of 2,000-10,000 m^3/d (33%) and 10,000-25,000 (38%) m^3/d (38%).

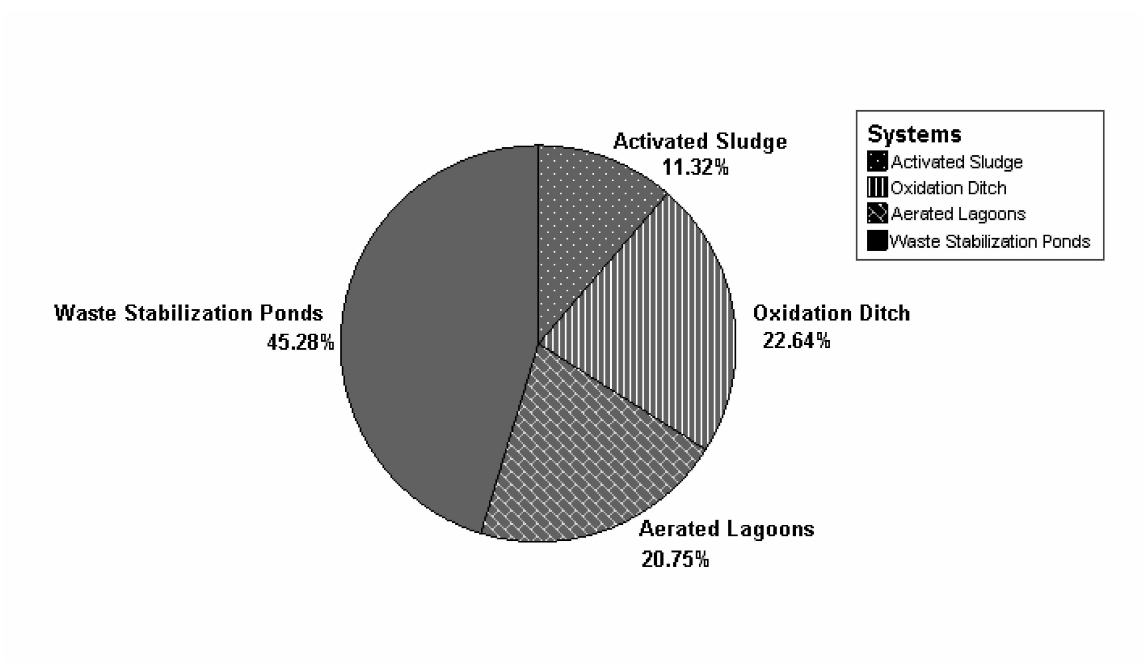


Figure 4.6 Types of Municipal Wastewater Treatment Plants in Thailand

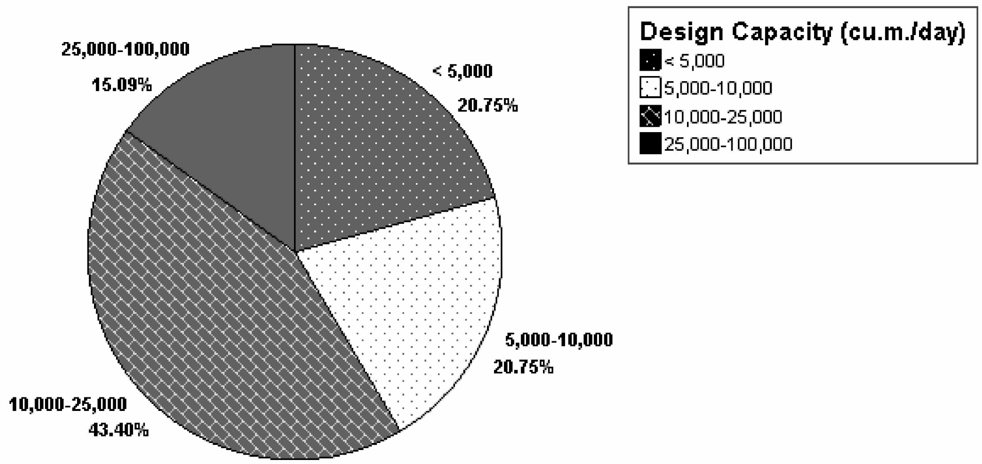


Figure 4.7 Size Distributions of Municipal Wastewater Treatment Plants in Thailand

4.2.2 Overview of Identified Wastewater Treatment Alternatives

In most circumstances, the treated wastewater in Thailand is discharged to nearby inland water such as canal or river where maintaining an adequate dissolved oxygen (DO) concentration is necessary. In this light, secondary treatment is required because primary treatment alone is insufficient to treat the wastewater to the target quality. Among the various wastewater treatment processes qualifying for consideration (details in Chapter 2), four types of secondary wastewater treatment alternatives that are widely used to treat domestic wastewater in Thailand are considered in the study:

Alternative 1: Conventional Activated Sludge (AS)

Alternative 2: Oxidation Ditch (OD)

Alternative 3: Aerated Lagoons (AL)

Alternative 4: Waste Stabilization Ponds (WSP)

All alternatives are aerobic biological processes. The first two processes are some forms of high-rate and aerobic suspended-growth biological treatment. The other two processes are types of lagoon or pond systems and considered low-rate biological wastewater treatment processes. Before quantifying relevant indicators for these alternatives, this following part elaborates the main characteristics of the four alternative treatment processes.

Alternative1: Activated Sludge (AS)

Among the aerobic biological processes, the activated sludge process is widely used in waste treatment in developed countries and big cities of developing countries. Various modifications of the process have been used to treat domestic wastewater in Thailand, such as oxidation ditches, rotating disks, contact stabilization process, and sequencing batch reactors. In this study, activated sludge represents the conventional activated sludge process. The treatment process basically utilizes a large amount of energy to mechanically supply sufficient oxygen to bacteria in wastewater. As a result, a large volume of bacteria or sludge is produced and needs to be disposed and handled properly. It requires well trained operators with very high construction and operation / maintenance costs (O&M). Besides its complex operation, the activated sludge process requires relatively expensive mechanical components and electric equipment that would need to be imported.

Arceivala (1981) notes that activated sludge is likely to be unfavorable for developing countries, except perhaps for very large applications. In these situations, activated sludge could be the most appropriate technology where land is expensive and unavailable, and where skilled personnel and good operational facilities are available. This explains why the process has often been selected for large-scale central wastewater treatment systems in developing countries, and in cases were skilled operators are available, provides a high degree of reliability and efficiency. Figure 4.8 shows the flowchart of the conventional activated sludge process. Another advantage of activated sludge over the other processes is relatively low land requirement. From the survey, the activated sludge systems in Thailand are mostly situated in the busiest cities with blooming tourism businesses such as Pataya and Phuket, where available land is very limited and expensive.

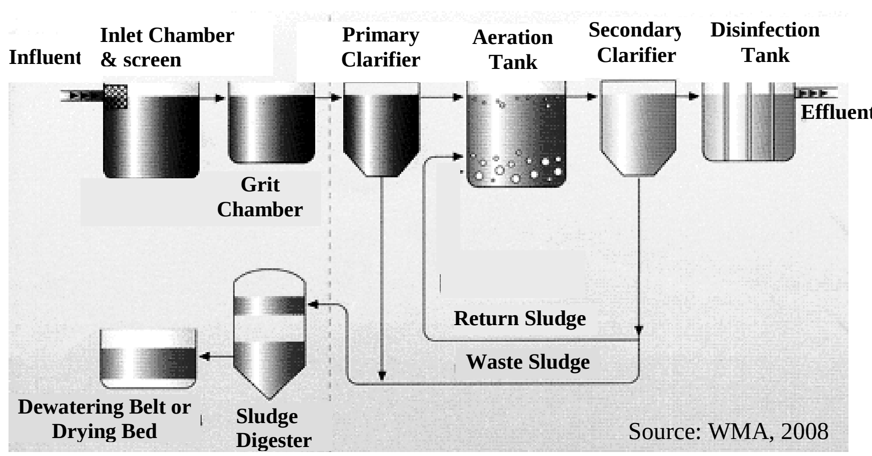
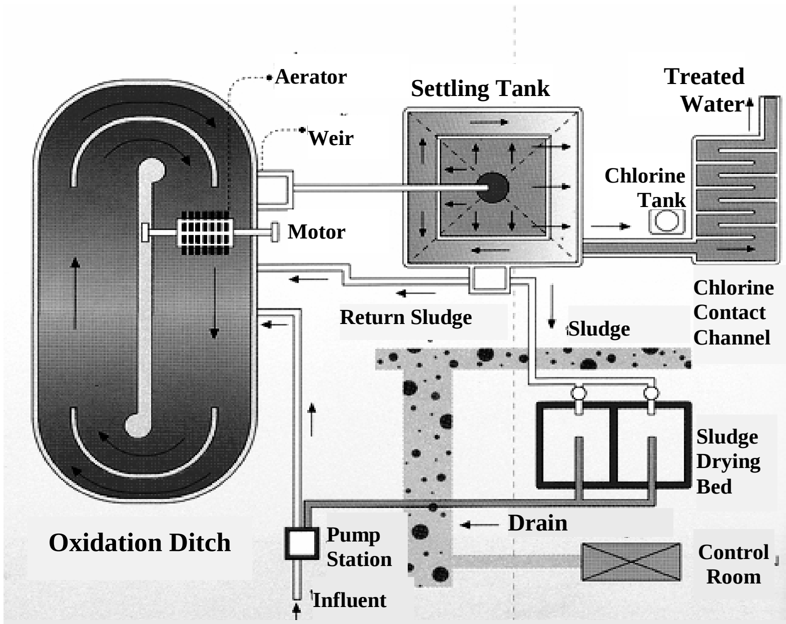


Figure 4.8 Typical Activated Sludge Treatment System in Thailand

Alternative 2: Oxidation Ditch (OD)

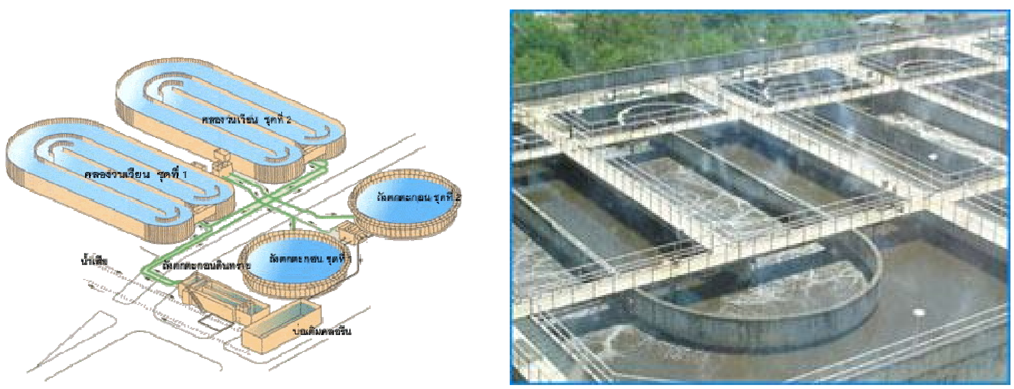
The oxidation ditch is a modification of the complete-mixed extended aeration activated sludge process using a continuous channel or loop reactor (Crites and Tchobanoglous, 1998). An elongated oval race track in the shape of channel is widely used in Thailand, although a number of different configurations have been developed. Figure 4.9 and 4.10 show the typical oxidation ditch processes in Thailand. This process removes BOD at very high efficiency (95-98%). The effluent is also fully nitrified (WEF and ASCE, 1992). Because of the long detention times, high mixed-liquor suspended solids (large mass of organisms), and efficient aeration, the oxidation ditch can achieve nitrogen removal (nitrification and denitrification). The oxidation ditch has been very effective in the treatment for organic shock loadings because the system contains large mass organisms (Crites and Tchobanoglous, 1998; WEF and ASCE, 1992).

The oxidation ditch process is simpler to construct and operate than the conventional activated sludge. The costs for construction are also generally lower than those conventional plants. Nevertheless, because it operates in the extended aeartion mode, the process requires more power. The oxidation ditch also requires a large amount of land area. It may not suitable for large scale plants where land is costly and unavaliable.



Source: Wastewater Management Authority, 2008

Figure 4.9 Layout of Typical Oxidation Ditch System in Thailand



Source: Pollution Control Department, 2008

Figure 4.10 Views of Oxidation Ditch Plants in Thailand

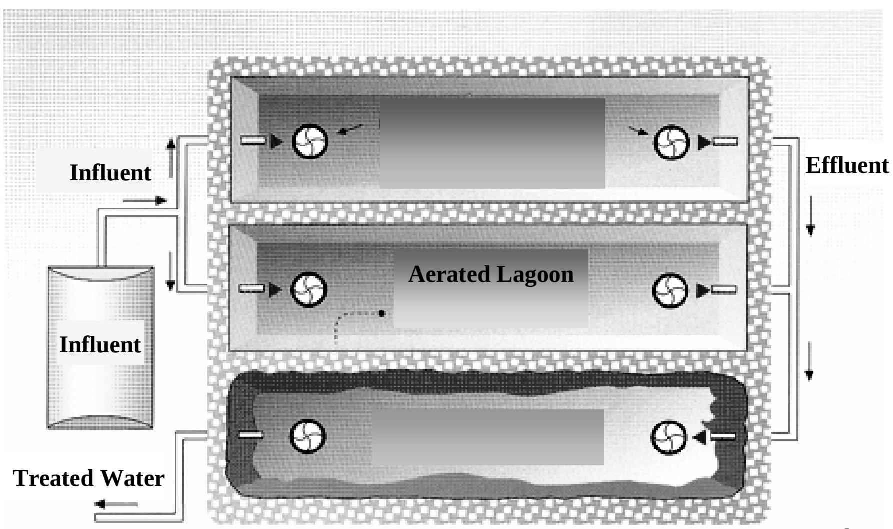
Alternative 3: Aerated Lagoons

Lagoons or pond systems can be classified into four main types based on the presence and source of oxygen; aerobic (oxidation), facultative, partial-mixed, and anaerobic lagoons (Crites and Tchobanoglous, 1998). Using this classification, these four types also have different depth and biological reactions that occur in the lagoons. The study considers two systems that utilize the concepts of lagoon or pond systems: aerated lagoons and waste stabilization ponds (will be described in the following part).

Aerated lagoons are considered partially mixed. The lagoons typically use earthen basins and are relative deeper than the others types of lagoons. Thus, oxygen is mechanically supplied by floating aerators and sometimes by diffused aeration. The partially-mixed aerated lagoons that are also referred to as aerated facultative lagoons are the most widely used in Thailand. This system has the advantage of facultative lagoons or oxidation ponds used for waste stabilization ponds, where the biological reaction can be partly aerobic at the surface layer and partly anaerobic at the bottom. Sludge generation and handling, thus, are reduced to the minimal level because of the anaerobic composition at the bottom of the lagoon. Since the oxygen in the aerated lagoons is supplied by mechanical aeration as opposed to an algal photosynthesis in waste stabilization ponds, the stabilization rate is somewhat faster. Therefore the detention times are less which results in less land area than other lagoon systems.

The main disadvantage of the aerated lagoons is that they are not efficient in removing suspended solids concentrations and faecal bacteria (Mara, 2004). High algae content in effluent that could be problematic for surface discharge is also commonly observed (Arceivala, 1981). A series of maturation ponds or a sedimentation pond are often needed to treat the effluent from the aerated lagoons in order to achieve the required water quality standards.

In Thailand, the typical aerated lagoons consist of a series of one and more partially mixed aerated facultative lagoons followed by a series of shallow maturation ponds or polishing ponds. The maturation ponds aim to reduce suspended solid and pathogens (Mara, 2004). The treated effluent is chlorinated before being discharged to the environment (Figure 4.11 and 4.12).



Source: Wastewater Management Authority, 2008

Figure 4.11 Layout of Typical Aerated Lagoons in Thailand

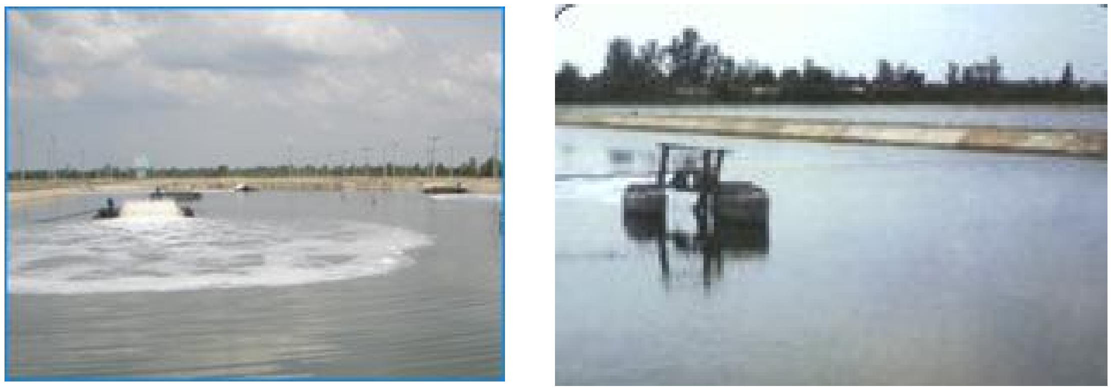


Figure 4.12 Views of Aerated Lagoons in Thailand

Alternative 4: Waste Stabilization Ponds

The waste stabilization pond system typically comprises three main types of ponds: *anaerobic*, *facultative*, and *maturation ponds*. These ponds are designed to operate singly, in series, or in parallel. According to biological activities occurring in the ponds, anaerobic and facultative ponds are designed for BOD removal and maturation for pathogen removal, although some BOD removal occurs in maturation ponds and some pathogen removal occurs in anaerobic and facultative ponds (Mara, 1996). In waste stabilization ponds, the numbers of disease-causing microorganisms can be reduced significantly, because of the long detention time (Gloyna, 1971).

There are, nevertheless, several configurations of waste stabilization ponds. A series-connected system might include anaerobic, facultative, and maturation ponds or the latter two types only. In Thailand, some series-connected systems include the relatively shallow *oxidation (aerobic) ponds*, in which photosynthetic oxygen and wind-aided surface aeration allow bacteria to degrade organics aerobically during the daylight hours.

In most waste stabilization pond systems, the facultative or oxidation ponds are the main units. The biological treatment processes naturally occur in the ponds and involve both algae and bacteria. The oxidation rate is rather slow because oxygen is provided by natural surface aeration (wind) and photosynthesis.

Waste stabilization ponds are normally large shallow basins enclosed by earthen embankments. The design and construction are very simple. The system practically requires no mechanical equipment, no energy consumption, and minimal operational requirements. Construction cost is the least compared to the other treatment methods. With the highest land requirement, land cost could be the crucial factor affecting the overall investment. The cost per capita for small pond systems, however, does not increase rapidly with decreasing size, as they do with other treatment systems (Gloyna, 1971). The waste stabilization ponds system is the most suitable for locations where land is available and relatively inexpensive, organic loadings fluctuate, and there is a lack of trained operating personnel (Gloyna, 1971).

In Thailand, due to the favorable temperature for operation, waste stabilization ponds systems have been the most frequently used treatment process in the provincial area where sufficient land is available. The waste stabilization ponds are found in a wide range of design capacity from 1,000 to 70,000 m^3 /d. Figure 4.13 and 4.14 show an example configuration and views of waste stabilization ponds in Thailand.

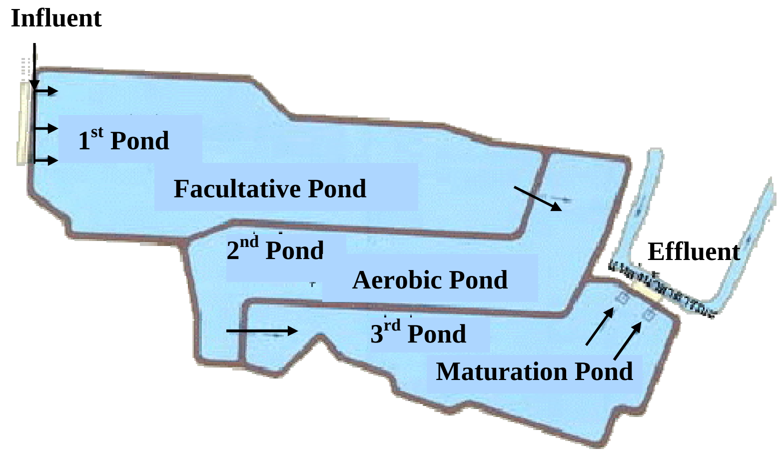


Figure 4.13 Layout of Waste Stabilization Ponds in Nakorn Pathom Municipality

Figure 4-15 Views of Waste Stabilization Ponds used in Thailand

4.3 CALCULATION OF INDICATORS FOR APPROPRIATE WASTEWATER TREATMENT SYSTEMS

The proposed framework to evaluate wastewater treatment processes consists of seven principles including reliability, simplicity, land requirement, affordability, efficiency, social acceptability, and sustainability (in Section 4.1). Fourteen criteria are defined to evaluate each principle. Table 4.3 summarizes the main objectives of each criterion. A set of indicators are developed to thoroughly assess the applicability of each wastewater treatment technology for given socio-economic and physical environments. Different assessment methodologies are used to quantifying the indicators.

In this section, data used to quantify the set of indicators and evaluate the technical and environmental criteria of wastewater treatment alternatives are based on the questionnaire survey from 32 Thai municipal WWTP (see Chapter 3 for the methodology description). To analyze the economic aspects of alternatives, the study utilizes capacity, construction cost, and O&M cost data of an additional 21 plants from government maintained database (PCD, 2003). A total of 53 WWTP are used to analyze economic criteria. With regard to land requirement and affordability categories, total area and construction and O&M cost values are calculated from surveyed results and secondary data. For others categories, the scores (1 to 5) are designed for each indicators based on a set of defined expectations related to an item being assessed.

Table 4.3 The Main Objectives of Each Criterion

Principle	Criterion	Objective
P1 Reliability	C1.1 Long-term operation (events occurring over the lifetime of treatment plant) C1.2 Short-term operation (events occurring during annual operation)	Evaluate the probability of attaining a performance level and the variability of treatment effectiveness under normal and emergency operation
	C1.3 Mechanical reliability	Evaluate the probability of mechanical failures and the impacts of failures upon effluent quality
P2 Simplicity	C2.1 Ease of plant construction, system installation and startup	Evaluate the level of expertise and time requirements for the construction, installation, and startup phases
	C2.2 Operation and maintenance requirements	Evaluate to what extent a given technology requires skilled personnel for operation and maintenance
P3 Efficiency	C3.1 Removal of wastewater constituents	Evaluate the removal efficiency of wastewater constituents (BOD, Suspended solids, Total Nitrogen, Total Phosphorus, and pathogens).
P4 Land requirement	C4.1 Size of land requirement	Evaluate to the size of area space required
	C4.2 Favorable land conditions	Evaluate to what extent land conditions could impact the technical feasibility of construction and operation of a given technology
P5 Affordability	C5.1 Initial construction cost	Evaluate the initial construction cost of the system and the subsidy from government
	C5.2 Annual operation and maintenance costs	Evaluate the annual O&M costs (operation, maintenance, personnel, energy, and administration costs), including potential revenue source)
P6. Social (public) Acceptability	C6.1 General social (public) acceptability	Evaluate to what extent the operation of a given technology is acceptable to local communities.
	C6.2 Environmental Impact/Perception	Evaluate the level of nuisance produced by odor, noise, insects, by-products, etc.
P7. Sustainability	C7.1 Continuity of system provision or operation	Evaluate the continuity of system operation in terms of its life expectancy and the likelihood of plant upgrading to accommodate future development.
	C7.2 Possibility of resource recovery	Evaluate the possibility of recovering treated wastewater (for cleaning, plant watering, irrigation, ground water recharge), and by-products (organic matter or fertilizer)

4.3.1 Technical Aspects

4.3.1.1 System Reliability (P1)

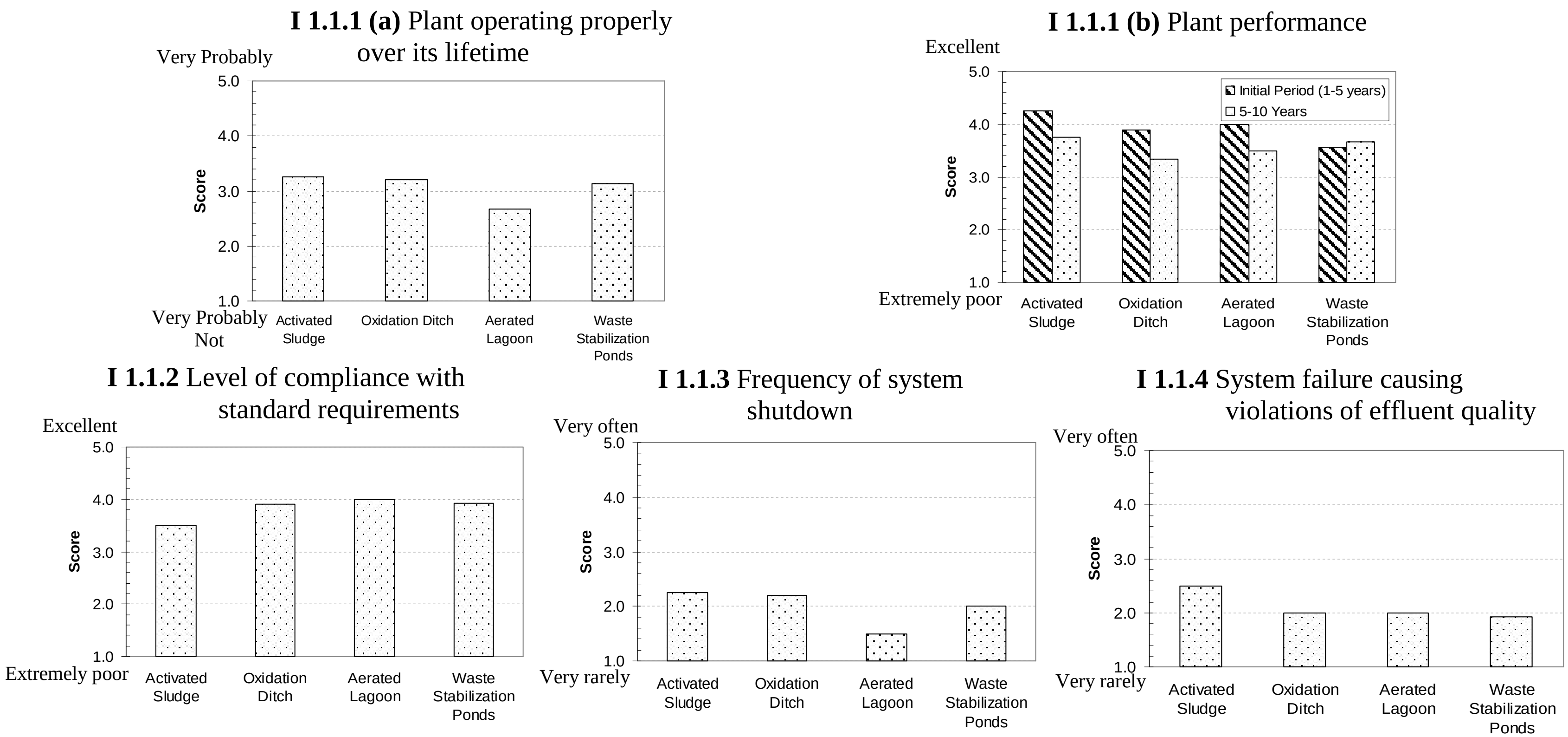
This study considers two major aspects of reliability for the wastewater treatment process—plant performance and mechanical reliability. Performance of the system is evaluated into two following scenarios: long-term operation and short-term operation. The indicators and variables in used to characterize system reliability during long and short term operation are presented in Table 4.4. Values of indicators from the survey are summarized in Figure 4.15- 4.17.

Table 4.4 List of Selected Indicators to Evaluate System Reliability (P1)

Indicator	Units	Description
Criterion 1.1 Long-term operation		
I1.1.1 Plant operating properly over its lifetime	1=very probably not; 5=very probably	a. Possibility that the plant will operate "properly" over its lifetime
	1=extremely poor; 5=excellent	b. Level of overall plant performance • during the first 5 years of operation • after 5 years of operation
I1.1.2 Level of compliance with standard requirements	1=extremely poor; 5=excellent	Level of compliance with standard requirements
I1.1.3 Frequency of system shutdown due to hardware or process problems	1=very rarely (0-1 time/year); 5=very often (>3 times/month)	Frequency of system shutdown
I1.1.4 System failure causing violations of effluent quality		Frequency of system failure to meet required conditions due to treatment process malfunction

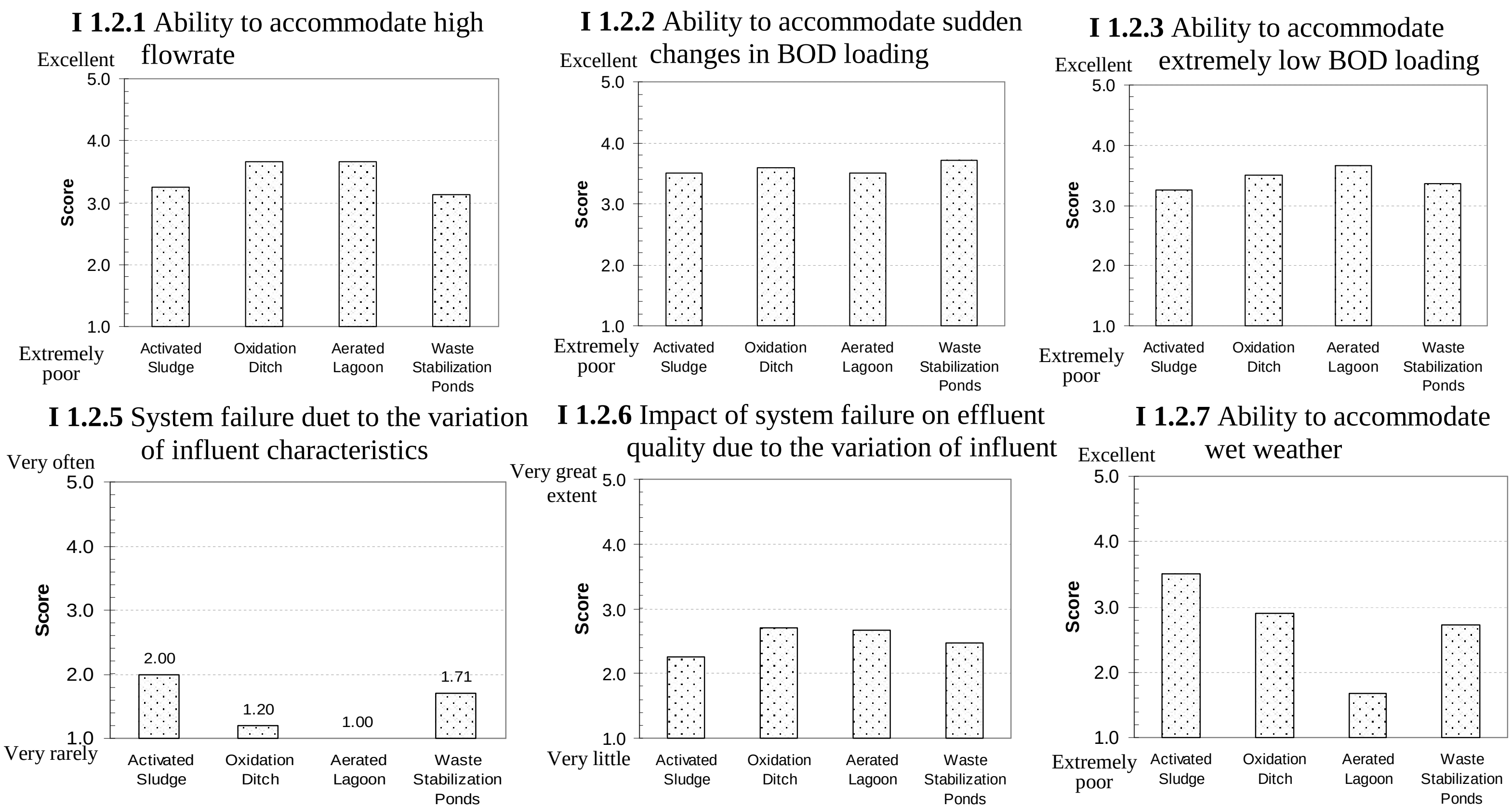
Table 4.4 List of Selected Indicators to Evaluate System Reliability (P1) (continue)

Indicator	Units	Description
Criterion 1.2 Short-term operation		
The process responses to the variation of: I1.2.1 High flow rate	1=extremely poor; 5=excellent	Ability to accommodate high flow rate; sudden changes in BOD loading; and extremely low BOD loading
I1.2.2 Periodic shock BOD loading		
I1.2.3 Extremely low BOD loading		
I1.2.5 System failure duet to the variation of influent characteristics	1=very rarely (0-1 time/year); 5= very often (>3 times/month)	Number of failure to meet required conditions due to the variation of influent characteristics
I1.2.6 Impact of system failure on effluent quality due to the variation of influent	1=very little; 5=very great extent	Impact of system failure on effluent quality, occurring due to the variation of influent
I1.2.7 Ability to accommodate wet weather	1=extremely poor; 5=excellent	Ability to accommodate wet weather
Criterion 1.3 Mechanical reliability		
I1.3.1 Frequency of unplanned maintenance due to mechanical (component) failures	1=very rarely (0-1 time/year); 5= very often (>3 times/month)	Number of unplanned maintenance events per year
I1.3.2 Impact of mechanical (component) failures on effluent quality	1=very little; 5=very great extent	Impact of mechanical failure on effluent quality



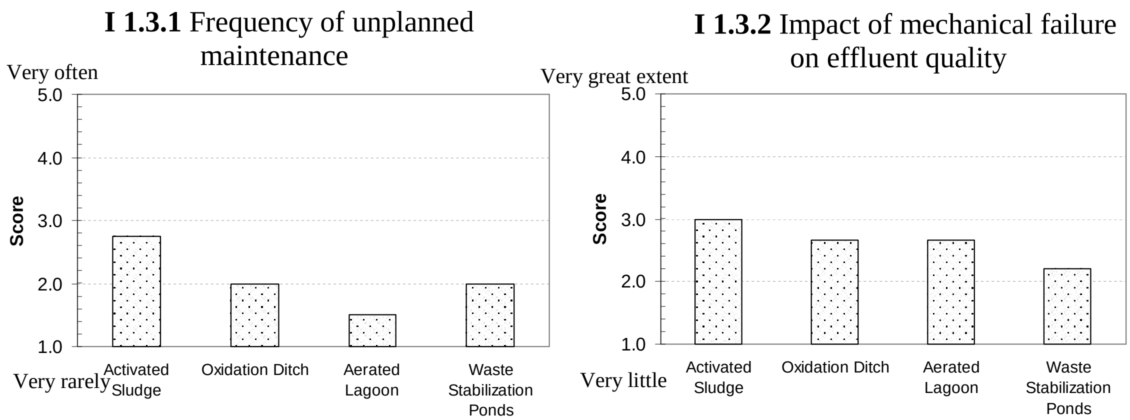
System	Average Score (Standard Derivation)						N
	I1.1.1 (a)	I1.1.1 (b) Plant performance		I1.1.2	I1.1.3	I1.1.4	
		Initial period	5-10 years				
Activated Sludge	4.25 (0.96)	3.75 (0.50)	3.25 (1.26)	3.75 (0.50)	2.25 (0.96)	2.50 (0.58)	4
Oxidation Ditch	3.90 (0.88)	3.33 (0.50)	3.20 (0.78)	3.33 (0.50)	2.20 (0.92)	2.00 (1.05)	10
Aerated Lagoon	4.00 (1.00)	3.50 (0.71)	2.67 (1.53)	3.50 (0.71)	1.50 (0.71)	2.00 (1.00)	3
Waste Stabilization Ponds	3.57 (0.76)	3.67 (0.89)	3.13 (1.13)	3.67 (0.89)	2.00 (1.11)	1.93 (0.92)	15

Figure 4.15 Summarized Values of Plant Performance Indicators (Long-Term Operation)



System	Average Score (Standard Derivation)						N
	I1.2.1	I1.2.2	I1.2.3	I1.2.5	I2.2.6	I2.2.7	
Activated Sludge	3.25 (0.05)	3.50 (0.58)	3.25 (0.96)	2.00 (0.82)	2.25 (0.96)	3.50 (0.58)	4
Oxidation Ditch	3.67 (0.71)	3.60 (0.52)	3.50 (0.53)	1.20 (0.42)	2.70 (1.42)	2.90 (1.45)	10
Aerated Lagoon	3.67 (0.58)	3.50 (0.71)	3.67 (0.58)	1.00 (0.00)	2.67 (0.58)	1.67 (0.58)	3
Waste Stabilization Ponds	3.13 (0.92)	3.71 (0.73)	3.36 (0.63)	1.71 (1.14)	2.47 (0.74)	2.73 (1.33)	15

Figure 4.16 Summarized Values of Plant Performance Indicators (Short-Term Operation)



System	Average Score (Standard Derivation)		N
	I1.3.1	I1.3.2	
Activated Sludge	2.75 (0.96)	3.00 (0.82)	4
Oxidation Ditch	2.0 (1.05)	3.00 (1.33)	10
Aerated Lagoon	1.50 (0.71)	2.67 (0.58)	3
Waste Stabilization Ponds	2.00 (0.93)	2.20 (0.94)	15

Figure 4.17 Summarized Values of Mechanical reliability Indicators

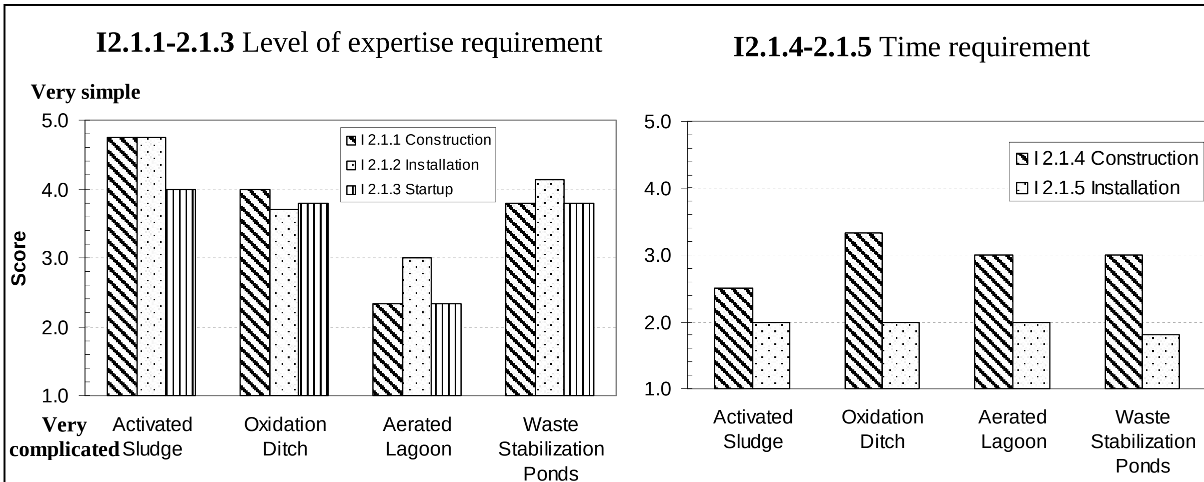
4.3.1.2 Simplicity (P2)

The simplicity of system construction, operation, and maintenance are the major concerns determining the success of project development and long-term system operation. Implementation of each technology requires a certain level of expertise for installation and operation. The study evaluates the simplicity and expertise requirements during both construction and O&M phases. Indicators and variables are presented in Table 4.5. The calculated values of indicators from the survey are summarized in Figure 4-.18 and 4.19). The survey plant operators assessed each technology and gave a score (1-5) based on its simplicity in different stages of construction and O&M. Lower scores correspond to less complex technology. The overall complexity of O&M (I2.2.1) is calculated by using data from I2.2.2 (Skill and personnel requirement) (Figure 4.19).

Table 4.5 List of Selected Indicators to Evaluate Simplicity (P2)

Indicator	Units	Description
Criterion 2.1 Ease of plant construction, system installation and startup		
Overall complexity of : I2.1.1 plant construction	1=not at all (0%); 5= almost always needs (>80% of the processes)	Level of expertise requirements (engineer/consultant) for the construction, installation, and startup. Percentage of professional work required
I2.1.2 system installation		
I2.1.3 system startup		
Time requirement for: I2.1.4 plant construction	1=very simple (<6months) 5= very complicated (>36months)	How much time is needed for plant construction, system installation, and startup?
I2.1.5 system installation		
Criterion 2.2 Operation and maintenance requirements		
I2.2.1 Overall complexity of operation and maintenance	1=very simple; 5=very complicated	The complexity of the overall system operation and maintenance
I2.2.2 Skill and personnel requirement	1=seldom needed; 2=on call-one day response; 3=half-day shift; 4= present 8-hour shift; 5=24-hour a day presence	Level of expertise requirements (i.e. civil/ environmental engineering, instrumentation specialist, chemist, mechanic, electrician)
I2.2.5 Special manufactured or imported equipment and spare parts	1=not at all (0%); 5= most of the equipment or instruments (>80%)	An amount of special manufactured or imported equipment and spare parts

The survey shows a wide range of time requirements for system construction, installation, and startup. The amount of time needed depends upon several key factors including process type, size, budget, site conditions, and contractors. Activated sludge systems require less time for construction than the other processes with similar sizes, and ranges from six months to two years. The larger plants tend to need more time for construction. In some cases, the problems with budget and contracting can slow the construction process. The study found that it was difficult to identify the time for process installation and startup from the time required for construction. Plant operators usually estimated time required for these phases as parts of construction period.

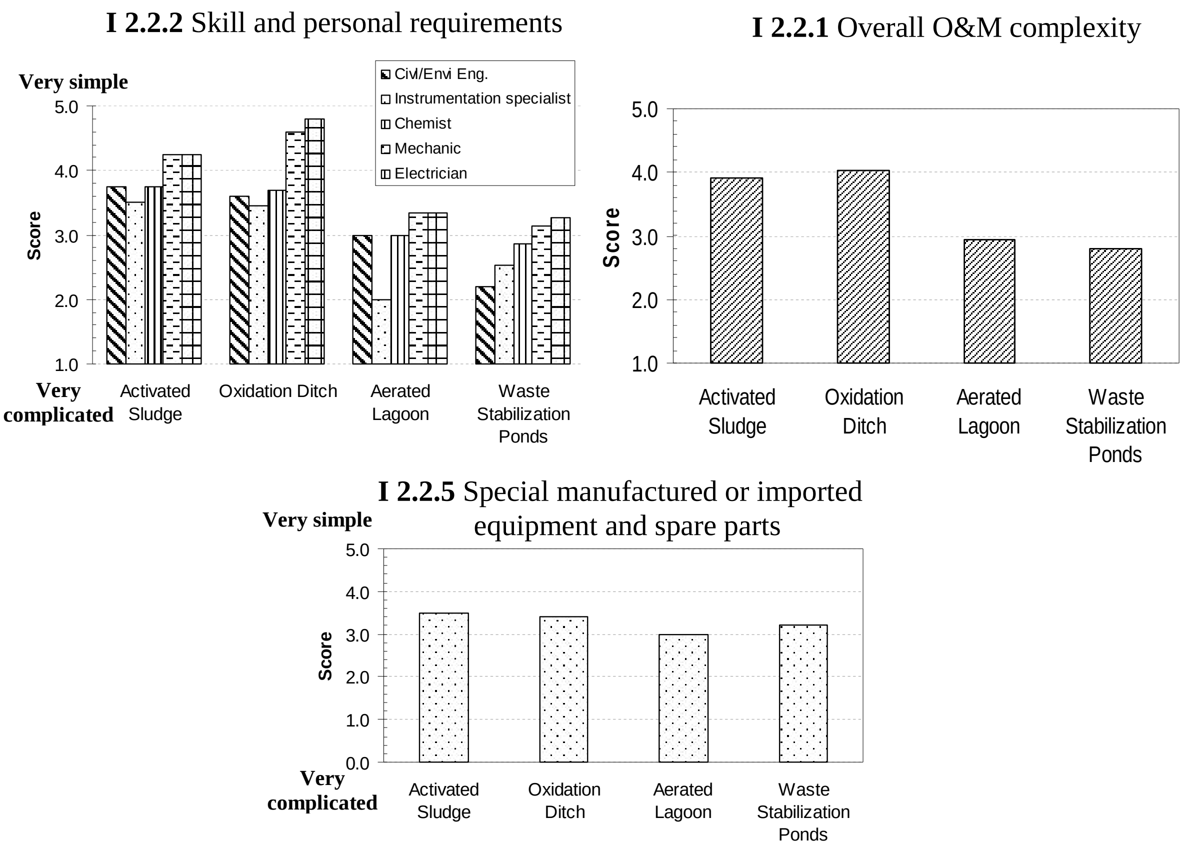


System	Average Score (Standard Derivation)					N
	Level of expertise requirement			Time requirement		
	I2.1.1	I2.1.2	I2.1.3	I2.1.4	I2.1.5	
Activated Sludge	4.75 (0.50)	4.75 (0.50)	4.00 (0.82)	2.5 (0.58)	2.0 (0.82)	4
Oxidation Ditch	4.00 (1.05)	3.70 (1.06)	3.80 (1.23)	3.33 (1.12)	2.00 (0.0)	10
Aerated Lagoon	2.33 (1.15)	3.00 (0.00)	2.33 (1.15)	3.00 (1.41)	2.00* (n/a)	3
Waste Stabilization Ponds	3.79 (1.53)	4.14 (1.16)	3.79 (1.48)	3.00 (1.55)	1.8 (1.03)	15

*Less than 3 plants were used

Figure 4.18 Summarized Values of Simplicity of System Construction, Installation and Startup

Major factors influencing the number of personnel required for operating and maintaining WWTP include the degree of plant automation, plant size, and type of treatment process. For larger facilities with more advanced processes (i.e. AS and OD), the continuous processes requires the presence of an engineer or a certified operator 24 hours a day. Smaller, less complex facilities such as AL and WSP will likely not require the continuous 24-hour-a-day presence of a certified operator. Operating personnel for Thai municipal WWTP are normally provided by local authorities with basic skill in mechanical and electrical maintenances. In case that the required expertise is not locally available, it may be gained by importing and training. Some municipalities have subcontracted the operation and maintenance work to private companies.



System	Average Score (Standard Derivation)							N
	I2.2.2 Skilled and personnel requirements					I2.2.1 Overall	I2.2.5	
	Civil/Envi. engineer	Instrumental specialist	Chemist	Mechanic	Electrician			
Activated Sludge	3.75 (0.50)	3.50 (1.00)	3.75 (0.50)	4.25 (0.50)	4.25 (0.05)	3.90	3.5 (0.58)	4
Oxidation Ditch	3.60 (1.50)	3.44 (1.33)	3.70 (1.16)	4.60 (0.70)	4.80 (0.42)	4.03	3.4 (0.84)	10
Aerated Lagoon	3.00 (1.73)	2.00 (1.73)	3.00 (1.73)	3.33 (1.15)	3.33 (1.15)	2.93	3.00 (1.00)	3
Waste Stabilization Ponds	2.20 (1.08)	2.53 (1.24)	2.86 (1.24)	3.13 (1.36)	3.27 (1.10)	2.80	3.20 (1.21)	15

Figure 4.19 Summarized Values of Simplicity (P2)

4.3.1.3 Efficiency (P3)

The study considers the convention water quality constituents associated with wastewater treatment including BOD, SS, phosphorus, nitrogen, and coliforms (Table 4.6). There are some major differences in removal efficiencies of each treatment. The study uses information from literature research to assess the efficiency of technology alternatives (Table 4.7 and Figure 4.20) (von Sperling, 1996). The scores 1 to 5 are assigned to each technology based on the percent removal of wastewater constituents (Figure 4.21).

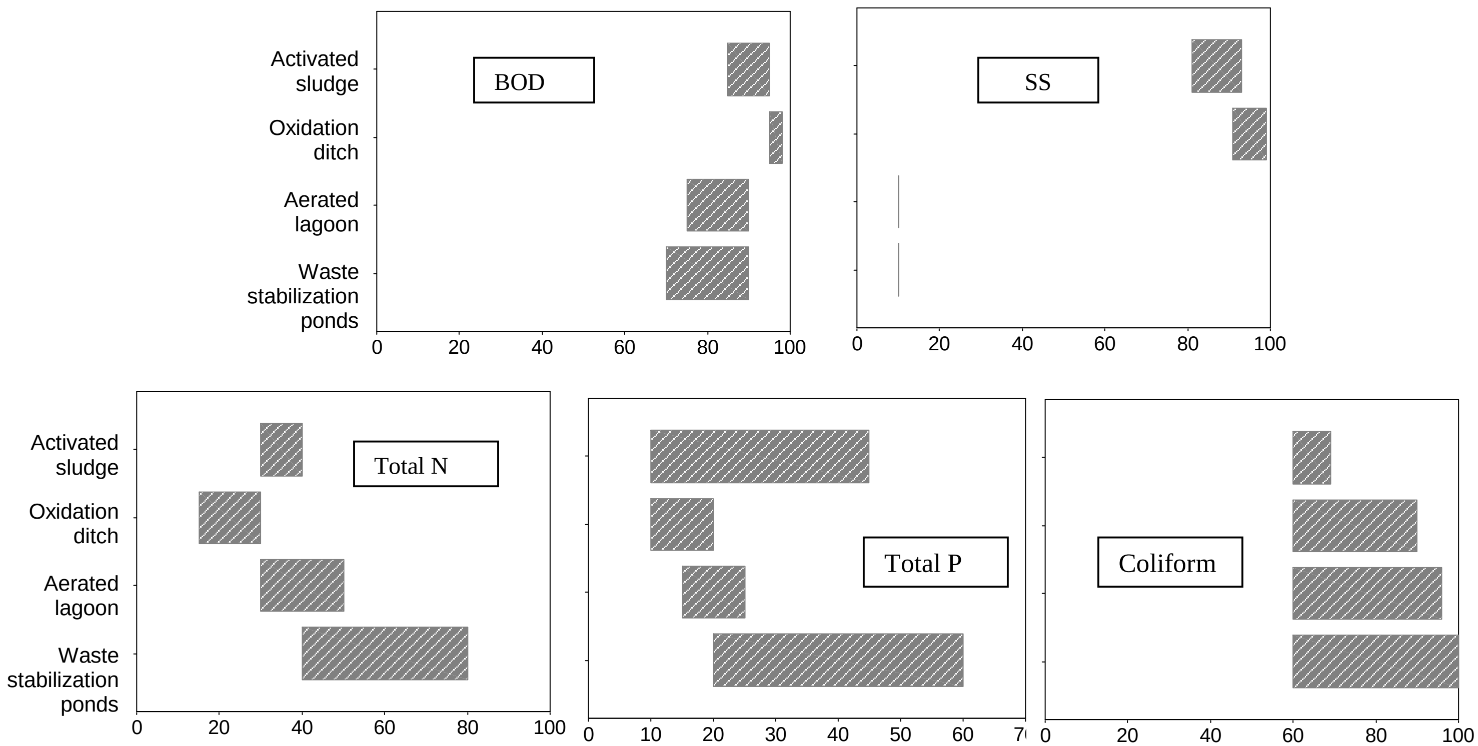
Table 4.6 List of Selected Indicators to Evaluate Efficiency (P3)

Principle 3: Efficiency		
C3.1 Removal of wastewater constituents		
Removal efficiency of: I3.1.1 BOD	Percent removal	The removal efficiency of wastewater constituents (BOD, Suspended solids, Total Nitrogen, Total Phosphorus, and pathogens (coliform)).
I3.1.2 Suspended Solids		
I3.1.3 Total Nitrogen		
I3.1.4 Total Phosphorus		
I3.1.5 Pathogens		

Table 4.7 Comparative Removal of Water Quality Constituents by Alternative Technologies

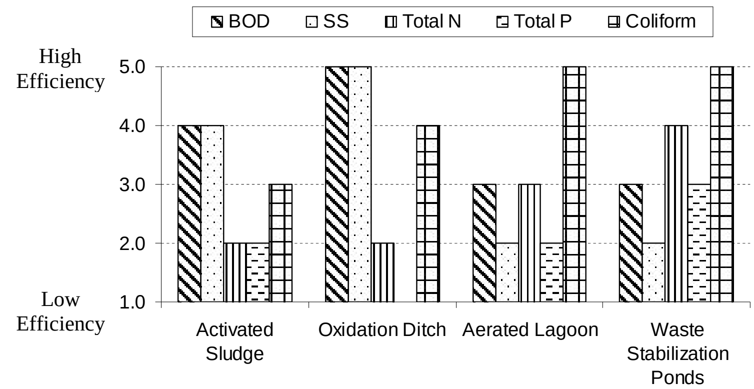
System	Removal efficiency (%)				
	BOD	SS	Total N	Total P	Coliform
Activated Sludge	85-95	81-93	30-40*	10-45	60-69
Oxidation Ditch	95-98	91-99	15-30*	10-20*	60-90
Aerated Lagoon	75-90	Low	30-50	15-25*	60-96
Waste Stabilization Ponds	70-90	Low	40-80**	20-60	60-99.9

References: Arceivala, 1981; von Sperling, 1996; Metcaff&Eddy, 2003; USEPA, 2000; Hannah et al., 1986; WEF and ASCE, 1992; Mara, 2004
Note: * An additional nutrient removal can be achieved through modifications in the process
**With maturation pond (s) in the series of ponds.



Source: von Sperling, 1996

Figure 4.20 Comparative removal of water quality constituents by alternative technologies



System	Removal efficiency (P3)				
	I3.1.1 BOD	I3.1.2 SS	I3.1.3 Total N	I3.1.4 Total P	I3.1.5 Coliform
Activated Sludge	4	4	2	2	3
Oxidation Ditch	5	5	2	1	4
Aerated Lagoon	3	2	3	2	5
Waste Stabilization Ponds	3	2	4	3	5

von Sperling, 1996

Figure 4.21 Summarized Values of Efficiency (P3)

4.3.2. Socio-Economic Aspects

By incorporating data from the plant survey and the secondary data from the Pollution Control Department (PCD, 2003), three principles under the socio-economic aspects: *land requirements (P4), affordability (P5), and social acceptability (P6)* are evaluated.

4.3.2.1 Land Requirement (P4)

The size and availability of land are the primary criteria determining the choice of wastewater treatment process. The area needed for a municipal system usually depends on the level of treatment, types of treatment systems and processes, and the size of a treatment plant (Tsagarakis et al, 2003). In this study, the area required for a given alternative process is estimated by using surveyed data from the existing municipal wastewater treatment installations. Table 4.8 summarizes all indicators in land requirement category.

Table 4.8 List of Selected Indicators to Evaluate Land Requirement (P4)

Indicator	Units	Description
C4.1 Size of land requirement		
I4.1.1 Total area	m^2/design capacity (m^3/d)	Total land area required by the wastewater treatment facility
I4.1.3 Buffer zone around the plant facility	meters from the property line	Buffer zone recommended to provide landscaping to minimize visual and other impacts
C4.2 Favorable land conditions		
I4.2.1 Groundwater level	1=very little; 5=very great extent	Impact of groundwater level, soil type (i.e. infiltration effect), and flooding on the system operation
I4.2.2 Soil type		
I4.2.3 Flooding risk		

Total area of plant facility (I4.1.1)

Using the regression method of the statistical analysis, land usage of wastewater treatment plants are expressed in the form of exponential equations (2):

$$y = a.x^{b} \qquad (2)$$

where *a* and *b* are calculated coefficients; and *x* is design capacity (flow).

Figure 4.22 presents average values of land requirements per design flow (m^3/d) for different processes. These data represent the entire area of the facilities including plant footprints, pathways, offices, etc. The overall data show, as expected, that more advanced processes such as AS and OD require less area than the natural treatment systems. WSP requires the most space per m^3 of daily design flow. This process needs about 10 times more area than the space required by AS and OD. Figure 4.22 also shows the average area required per m^3 of daily design flow for plants ranging in size from less than 5,000 m^3 to 100,000 $m^{3.}$ There is a presumption that larger plants generally require less land per unit served due to an economy of scale. The graphs clearly show a strong economy-of-scale trend in WSP process, for which the amount of land required per m^3 of design flow decreases as the size of treatment plant increases.

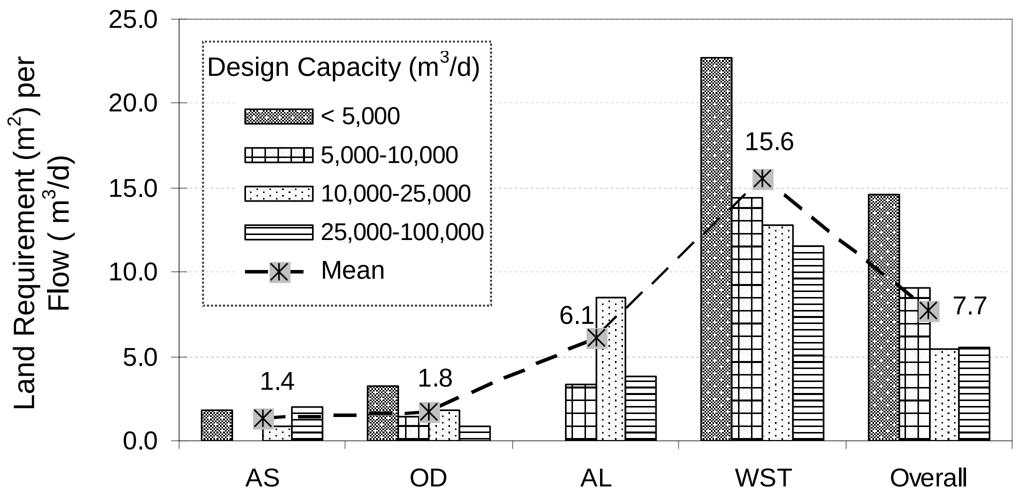


Figure 4.22 Land Requirements for Different Processes and Design Capacities

In Figure 4.23, the values of land requirements in m^2 for the four processes are graphically presented as a function of design capacity (m^3/d). Models for land requirements give a good fit to the data of all processes except for OD. With very high R^2 values, area requirements for AS and WSP can be well explained by their design capacities. Nevertheless, the moderately high R^2 of 0.64 for AL and 0.60 for OD models could indicate an acceptable goodness of fit between the design capacity and land area requirement variables, suggesting a fairly strong predictive potential for the models.

Based on graphical data in Figure 3, the equations produced to express the land requirements are summarized in the form of $L = a.Q^b$ (Table 4.9). The results from this section will be used to estimate land usage for identified wastewater treatment alternatives in different scenarios.

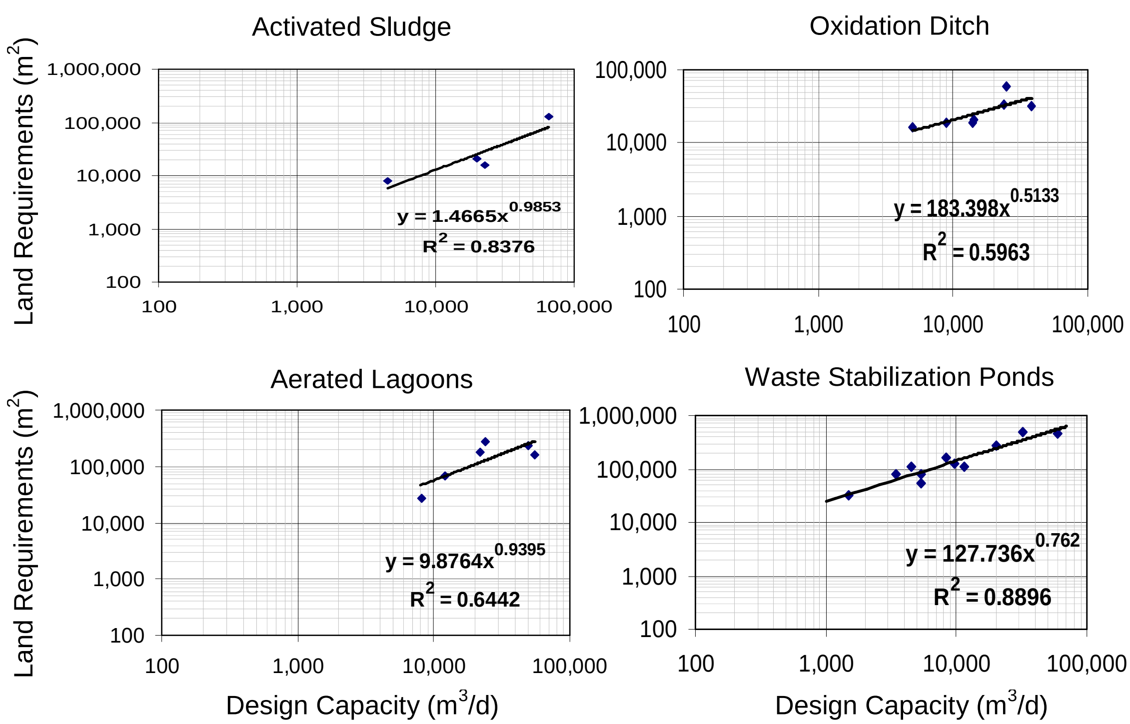


Figure 4.23 Land Requirements for Identified Wastewater Treatment Alternatives

Table 4.9 Land Requirements for Wastewater Treatment Alternatives in Relation to Design Capacities (m^3/d)

System	N	$y = a.x^b$				
		a	*b*	R^2	Sig.	Model
Activated Sludge	4	1.467	0.985	0.838	p=0.08	$L = 1.467.Q^{0.985}$ *(3)*
Oxidation Ditch	7	183.398	0.513	0.596	p=0.04	$L = 183.398.Q^{0.513}$ *(4)*
Aerated Lagoon	6	9.876	0.940	0.644	p=0.05	$L = 9.876.Q^{0.940}$ *(5)*
Waste Stabilization Ponds	11	127.736	0.762	0.890	p<0.01	$L = 127.736.Q^{0.762}$ *(6)*

L = Land Requirement (m^2); Q = Design Capacity in m^3/d

Provisions for buffer zones are very important in the design of wastewater treatment plants. To minimize the visibility, odor, noise, and other adverse environmental impacts on the surrounding area, a strip of land around the facility is needed to avoid complaints from neighborhoods and prevent encroachment into the facility. The buffer area can be used for roads, drain reserves, agricultural purposes, or beautification zone (i.e. planting of a ring of trees). The size of buffer zone depends upon the form of adjacent existing land uses (i.e. residential or industrial areas) and the type of treatment processes.

A number of treatment plants surveyed (43%) indicated that there is no specific recommendation for buffer zone size. The study uses the following recommendation as a guideline for buffer zones for different wastewater treatment plants (Ludwig, 2005 refers to Bradley, 1987) (Table 4.10).

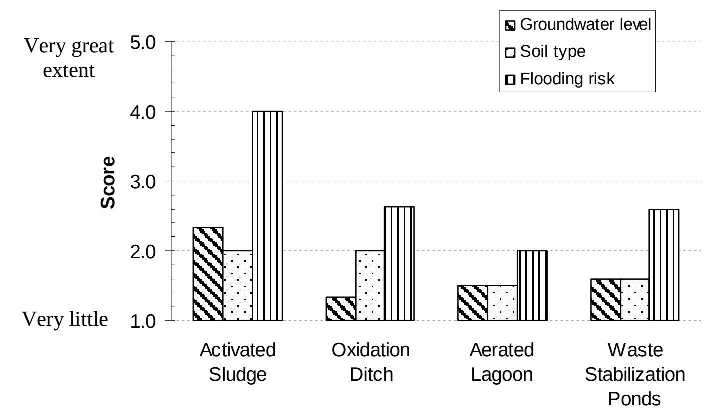
Table 4.10 Buffer Zones for Different Wastewater Treatment Plants

System	The buffer distance from the boundary (m.)
	Residential/ commercial plot boundary
Ponds	
- Low loaded facultative	150
- High loaded facultative	300
- Anaerobic	500
Activated Sludge	75

Source: (Ludwig, 2005 refers to Bradley, 1987).

Favorable land conditions (I 4.2.1-4.2.3)

The favorable land condition criteria (C4.2) evaluates the compatibility of each technology with local land condition parameters: groundwater, soil type, and flooding risk. The survey plant operators assessed each technology and gave a score (1-5) based on its compatibility and risk to be impacted by each parameter (Figure 4.24). A lower score indicates that the treatment system is more prone to be impacted by groundwater level, soil types, and flooding risk. The highest score indicates that these local conditions have no bearing on the operation of the wastewater treatment system.



System	Average Score (Standard Derivation)			N
	I4.2.1Groundwater	I4.2.2 Soil type	I4.2.3Flooding risk	
Activated Sludge	2.33 (1.15)	2.00 (1.00)	4.00 (1.41)	4
Oxidation Ditch	1.33 (0.52)	2.00 (1.10)	2.63 (1.19)	10
Aerated Lagoon	1.50 (0.71)*	1.50 (0.71)*	2.00 (1.00)	3
Waste Stabilization Ponds	1.60 (0.91)	1.60 (0.91)	2.60 (1.24)	15

*Less than 3 plants were used

Figure 4.24 Favorable Land Conditions

4.3.2.2. Affordability (P5)

Cost functions of wastewater treatment plants are also expressed in the form of $y = a.x^b$ where *a* and *b* are calculated coefficients; and *x* is design capacity (flow). The following results and equations of construction cost values are produced for specific systems and presented with respect to the design flow (m^3/d). Meanwhile, O&M cost is presented in relation to an actual flow of each plant and can be modeled using linear regression (*y*=*a*+*bx*). The results from this section will be used to estimate construction and O&M cost for identified wastewater treatment alternatives in different scenarios. Respective indicators and variables in this principle (Affordability) are presented in Table 4.11.

Table 4.11 List of Selected Indicators to Evaluate Affordability (P5)

Indicator	Units	Description
C5.1 Initial construction cost		
I5.1.1 Construction cost (excluding land cost)	US$ per design capacity (m^3/d)	Present value of the construction costs
I5.1.2 Land cost		Present value of the land cost
C5.2 Overall annual operation and maintenance cost		
I5.2.1 Operational cost	US$ per design capacity (m^3/d)	The overall annual O&M costs including operation, maintenance, personnel, energy, and administration costs
I5.2.2 Maintenance cost (materials and equipment)		
I5.2.3 Personnel cost		
I5.2.4 Energy cost		
I 5.2.5 Administration cost		

Construction cost (I5.1.1)

The costs of construction mainly depend on the capacity of the installation, which is expressed either by design flow or by served population size; the quality of raw sewage to be treated; and the level of wastewater treatment required (Tsagarakis et al, 2003; Friedler and Pisanty, 2006). This study uses cost information from the survey and documented data (PCD, 2003) to develop predictive equations. Construction costs and corresponding design flows of 53 municipal wastewater treatment plants throughout Thailand are evaluated.

Since the treatment plants were built and operated during different time periods, the construction cost (in Thai Baht) of each plant is adjusted to give the present value in the year 2007 (see more data in Appendix A). The present value (*PV*) of the historical cost (*HC*) is calculated by using Equation (7):

$$PV_t = HC_t \times \left(1 + f_t\right)^{t\text{-}1} \qquad (7)$$

Where, f_t is inflation at different time *t.*

The present values of construction costs are converted to US dollar according to the official exchange rate in 2007 (1US$=34.5 Baht) (Bank of Thailand, 2008).

Figure 4.25 shows the effect of design capacities on construction costs in different processes and sizes. Data of AL and WSP show that construction costs per m^3/d decreases with increasing plant size, due to an economy of scale. Because of a small number of AS and OD plants, the result in small size categories shows very little economy of scale for these processes. AS shows the highest construction cost per volume compared to other processes except in the 10,000-25,000 m^3/d category. For this group, AS and WSP data show comparable high construction costs per m^3 treated.

The construction cost functions of wastewater treatment plants are expressed in the form of $C_C = a.Q^b$, where C_C is construction cost; Q is design flow (m^3/d); and *a* and *b* are calculated coefficients. Within the flow range of 1,000-78,000 m^3/d, Figure 4.26 and Table 4.12 give best fit equations for estimating construction costs for AS, OD, AL, and WSP processes. These power regression equations are statistically significant ($p \leq 0.02$) with acceptably high R^2, indicating that the proportional construction cost is greatly determined by the plant size.

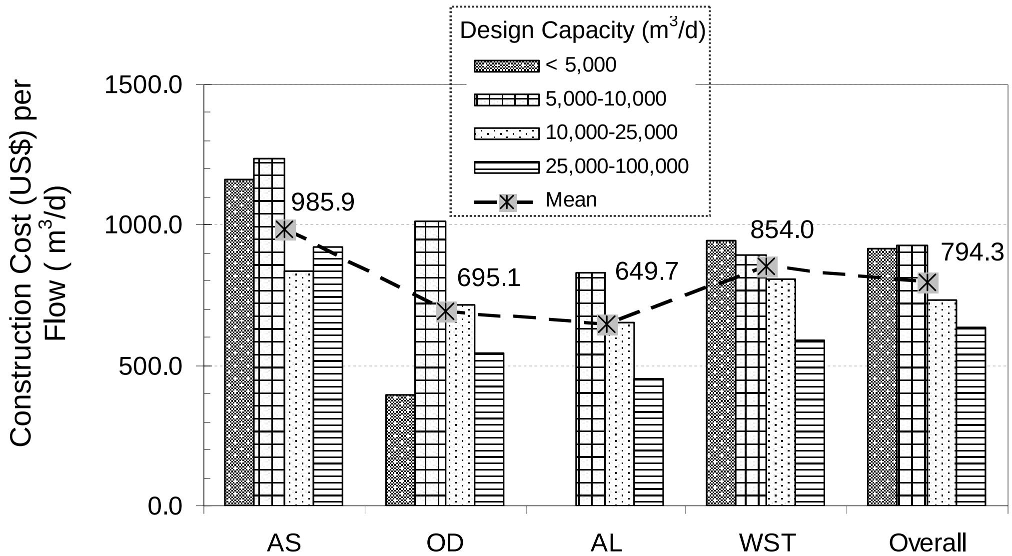


Figure 4.25 Construction Costs for Different Processes and Design Capacities

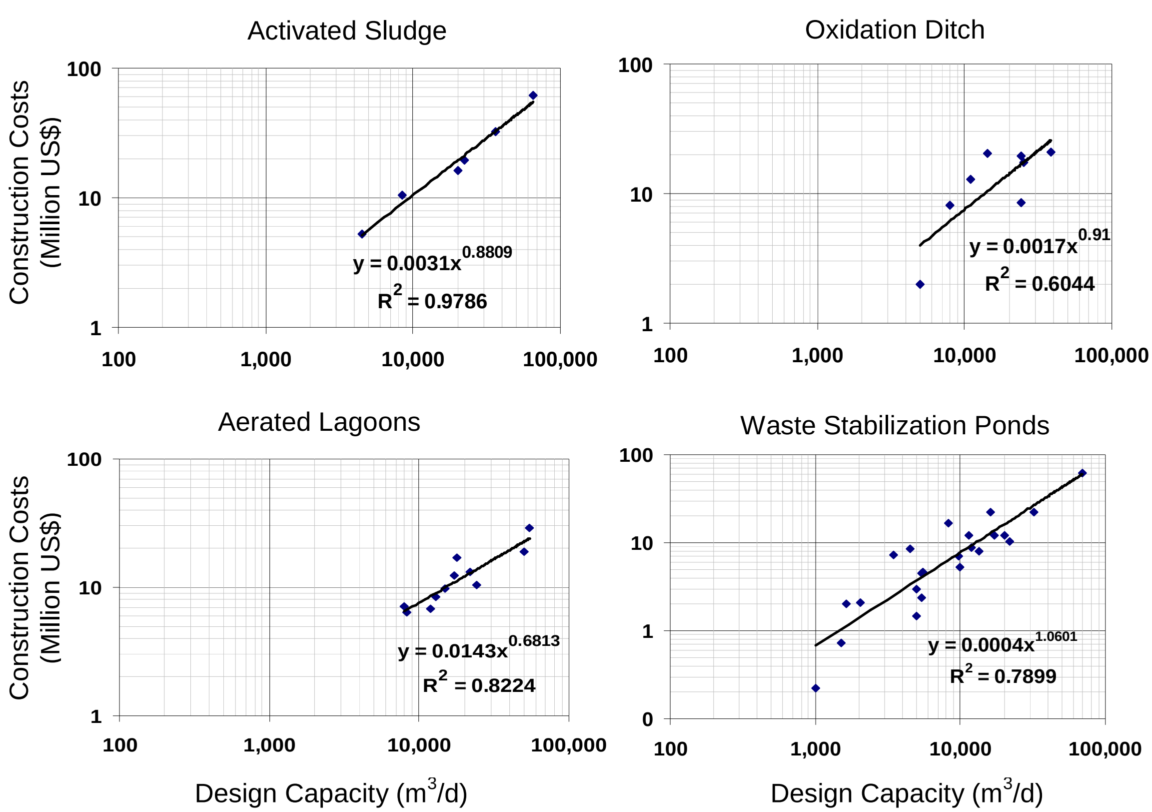


Figure 4.26 Construction Costs for Identified Wastewater Treatment Alternatives

Table 4.12 Construction Costs for Wastewater Treatment Alternatives in Relation to Design Capacities (m^3/d)

System	N	$y = a.x^b$				
		a	*b*	R^2	Sig.	Model
Activated Sludge	6	0.0031	0.881	0.979	p<0.01	$C_c = 0.0031.Q^{0.881}$ *(8)*
Oxidation Ditch	8	0.0017	0.910	0.604	P=0.02	$C_c = 0.0017.Q^{0.910}$ *(9)*
Aerated Lagoon	11	0.0143	0.681	0.822	p<0.01	$C_c = 0.0143.Q^{0.681}$ *(10)*
Waste Stabilization Ponds	23	0.0004	1.060	0.790	p<0.01	$C_c = 0.0004.Q^{1.060}$ *(11)*

C_c = Construction Cost (Million US$); Q = Design Capacity in m^3/d

Operation and Maintenance (O&M) Cost (I5.2.1-5.2.5)

The annual O&M costs include the total cost of four major components: personnel, energy, equipment & chemical, and maintenance costs. The major factors influencing the O&M costs include the treatment processes and target effluent qualities to meet standard requirements. The study considers the past year’s O&M costs for wastewater treatment plants that are in operable condition with similar effluent quality requirements. Plants in very poor condition and subjected to major overhaul or shut down during the survey are not considered in the analysis. The O&M costs are related to the actual flow rather than design capacity.

Figure 4.27 shows the overall annual O&M costs per actual unit of flow (m^3/d) for different treatment processes and sizes. The general trend of economy of scale is observed in the figure as the actual flows to the plants increase. Natural processes like WSP require 55-70% lower O&M costs per volume of wastewater than the more advanced and energy intensive processes, i.e. AS and OD. In the small flow category (<5,000 m^3/d), data show the highest O&M costs in OD process followed by AL and

WSP systems. The O&M costs of medium-sized AS and OD processes are somewhat comparable.

The results of regression analysis are shown in Figure 4.28 and Table 4.15. Data show that the linear regression models give the best fit for estimating O&M costs for all considered treatment processes. From Table 4.15, the linear regression equations are statistically significant ($p<0.01$) with high R^2. The annual O&M costs are considerably affected by the volume of wastewater being treated.

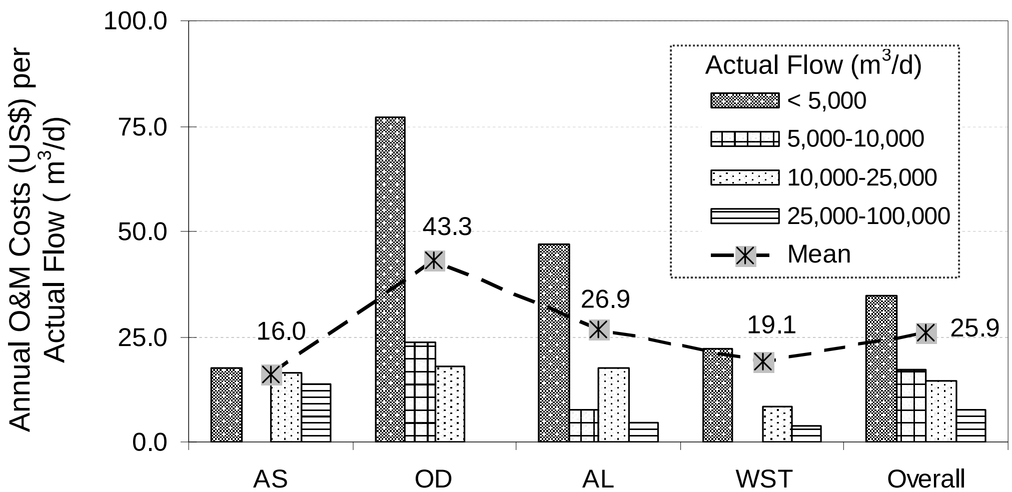


Figure 4.27 Overall Annual O&M Costs for Different Processes and Actual Flows

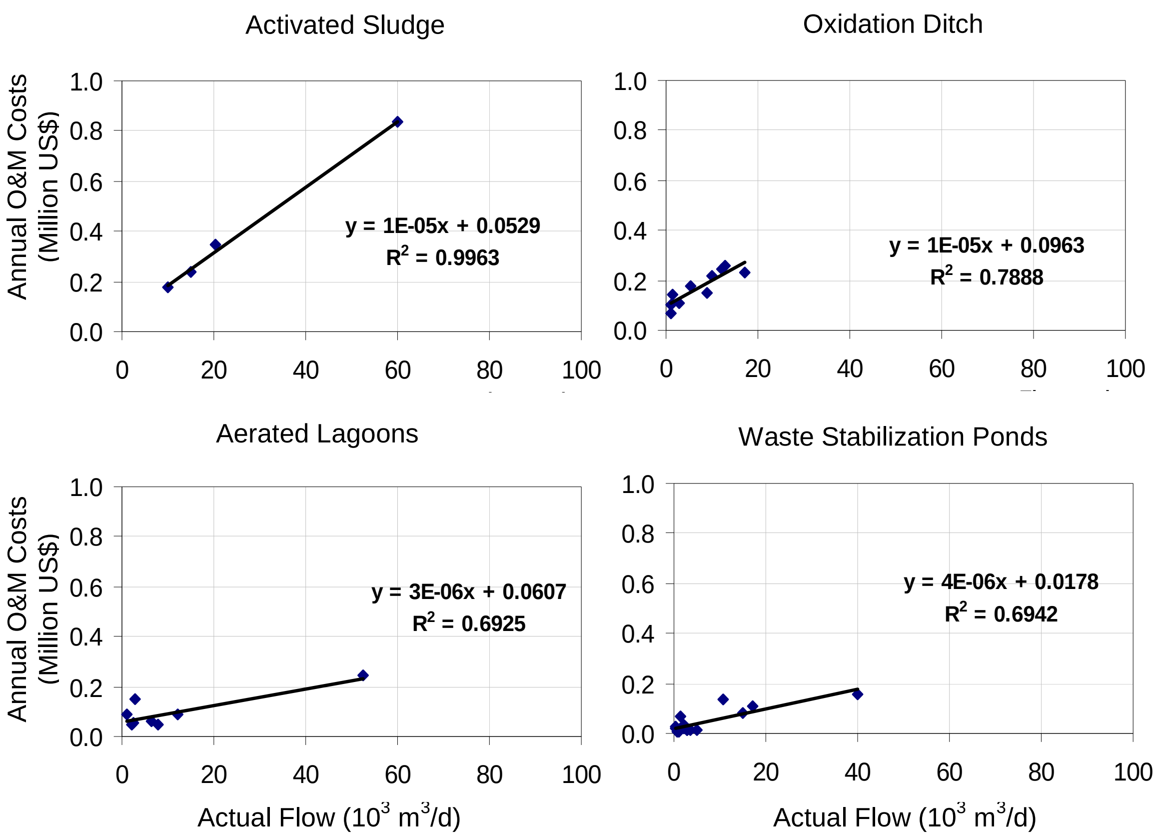


Figure 4.28 Annual O&M Costs for Identified Wastewater Treatment Alternatives

Table 4.13 Annual O&M Costs for Wastewater Treatment Alternatives in Relation to Actual Flows (m^3/d)

System	N	$y = a+bx$		
		Model	R^2	Sig.
Activated Sludge	4	$C_{O\&M} = 0.0529 + 1.31 \times 10^{-5}.F$ *(12)*	0.996	p<0.01
Oxidation Ditch	10	$C_{O\&M} = 0.0963 + 1.02 \times 10^{-5}.F$ *(13)*	0.789	p<0.01
Aerated Lagoon	8	$C_{O\&M} = 0.0607 + 3.31 \times 10^{-6}.F$ *(14)*	0.693	p<0.01
Waste Stabilization Ponds	19	$C_{O\&M} = 0.0178 + 4.03 \times 10^{-6}.F$ *(15)*	0.694	p<0.01

$C_{O\&M}$ = Annual Operation and Maintenance Cost (Million US$)

F = Actual Flow in m^3/d

4.3.2.3 Estimate of Economic Indicators

Using 200 L/cap/day of average wastewater production for developing countries, approximately 70% or 140 L/cap/day of water consumption will be discharged to collecting sewers (if available) or to receiving water (Ludwig, 2005; PCD, 1996). Considering flow variations, the study estimates the total design flow generated from residential unit by using the rate of 210 L/cap/day or about 1.5 times the average sewage flow (140 L/cap/day). The economic indicators for the four wastewater treatment alternatives are compared in Figure 4.29.

The cost of land is also one of key parameters influencing the choice of treatment process. In Thailand, most of municipal wastewater treatment plants are built on state properties or land owned by government. The government allocated land to local sewage authorities at no financial cost. The given land, however, has economic value and cost that should be considered. This cost can be obtained from recent sales of land in the area (Mara, 1996; Tsagarakis et al, 2003). To calculate the land purchase cost for the case studies, the data of land valuation are obtained from the Treasury Department report in 2008. The values of land are US$ 24.6 and 94.2 per m^2 (1US$ = 34.5 Baht) for low-income neighborhoods and higher-income residential areas, respectively.

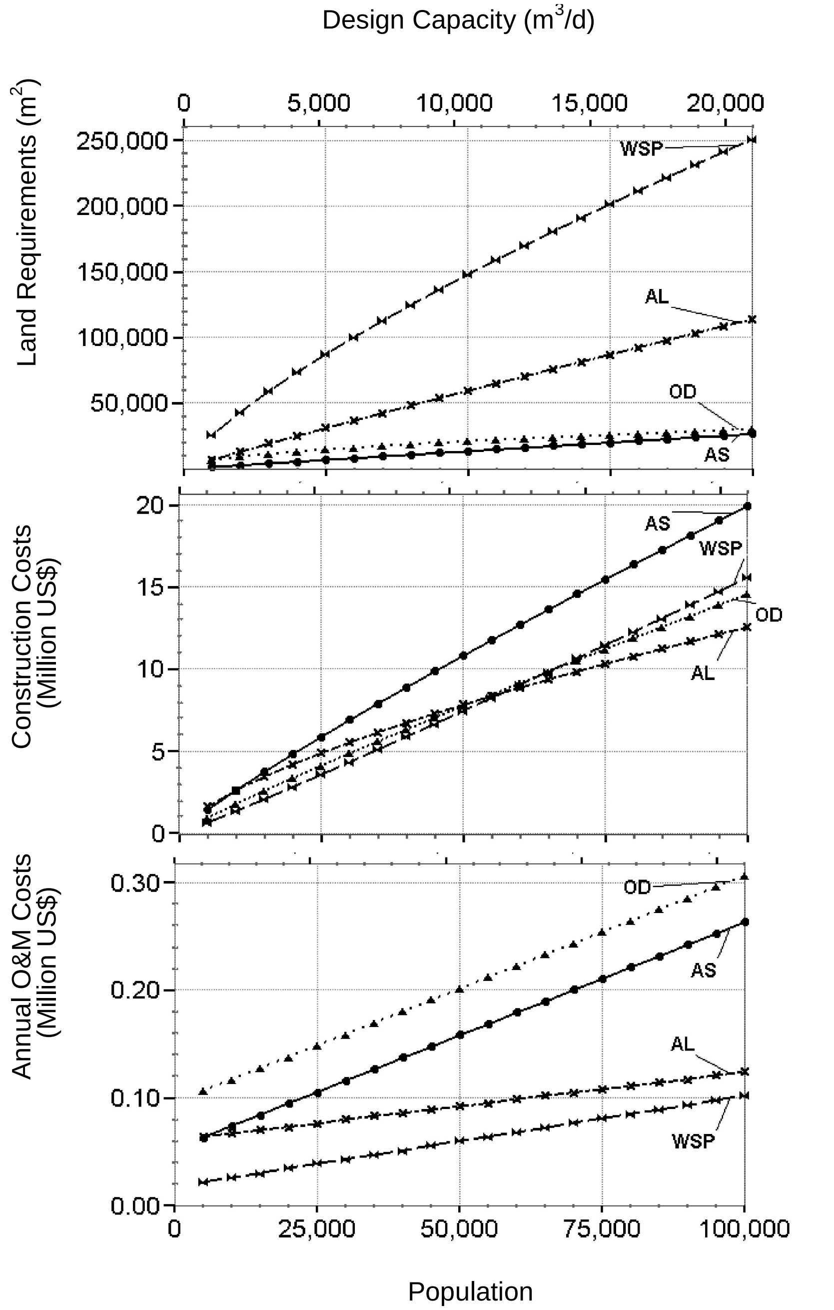


Figure 4.29 Economic Indicators for Wastewater Treatment Alternatives

Using the equations *(3)* to *(6)* and these land values, the cost of land can be calculated and presented in Table 4.9. The costs for construction and O&M for four wastewater treatment alternatives, namely activated sludge, oxidation ditch, aerated lagoons, and waste stabilization ponds; are calculated by using the equations (8) to (15). The computation results calculated from existing conditions of four case studies and the treatment alternatives are presented in Table 4.14 and Figure 4.30.

Table 4.14 Estimates of Land Requirements, Construction Costs, and Annual O&M Costs for Wastewater Treatment Alternatives in the Case Studies

Case Study	Pop	Flow (m^3/d)	System	Land Requirement		Land Cost (Million US$)	Construction Cost (Million US$)	Annual O&M Costs (Million US$)
				Land Area (m^2)	Land Value* (US$/$m^2$)			
RK 1	23,024	4,835	AS	6,245	94.2	0.59	5.46	0.10
			OD	14,239		1.34	3.83	0.14
			AL	28,702		2.70	4.62	0.08
			WSP	82,005		7.72	3.27	0.04
RK 2	8,925	1,874	AS	2,456	94.2	0.23	2.37	0.07
			OD	8,757		0.82	1.62	0.12
			AL	11,777		1.11	2.42	0.07
			WSP	39,831		3.75	1.20	0.03
FNRK 1	5,700	1,197	AS	1,579	24.6	0.04	1.60	0.06
			OD	6,958		0.17	1.08	0.11
			AL	7,727		0.19	1.78	0.06
			WSP	28,303		0.70	0.74	0.02
FNRK 2	10,550	2,216	AS	2,895	24.6	0.07	2.75	0.08
			OD	9,542		0.23	1.88	0.12
			AL	13,782		0.34	2.71	0.07
			WSP	45,246		1.11	1.43	0.03

Wastewater generation = 210 L/cap/day; 5 capita per housing unit
1USD = 34.5 Baht
*Data Source: The Treasury Department (2008). Summary of Land Valuation in the Bangkok Metropolitan Area.

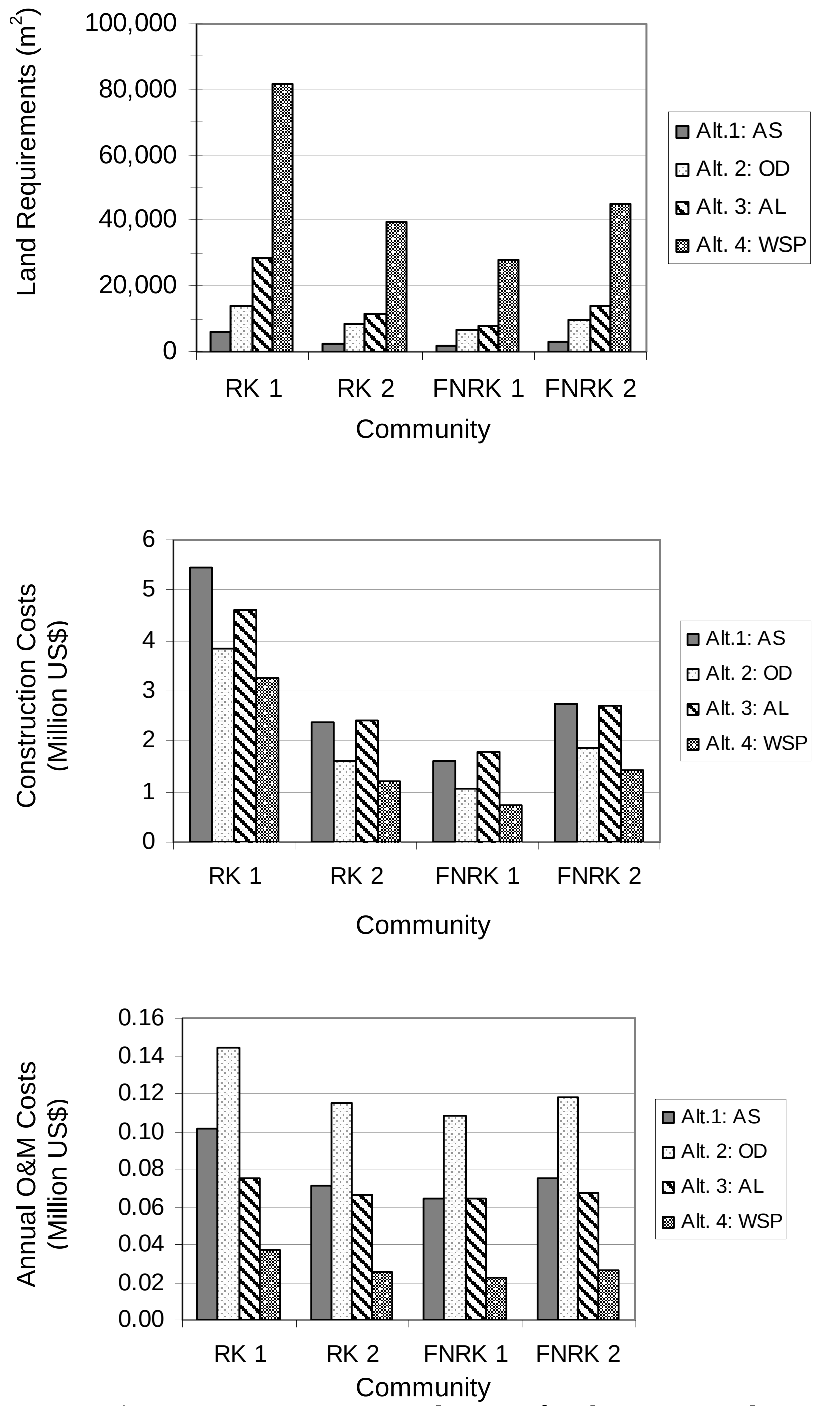


Figure 4.30 Economic Indicators for the Case Studies

4.3.3.4 Social (public) Acceptability (P6)

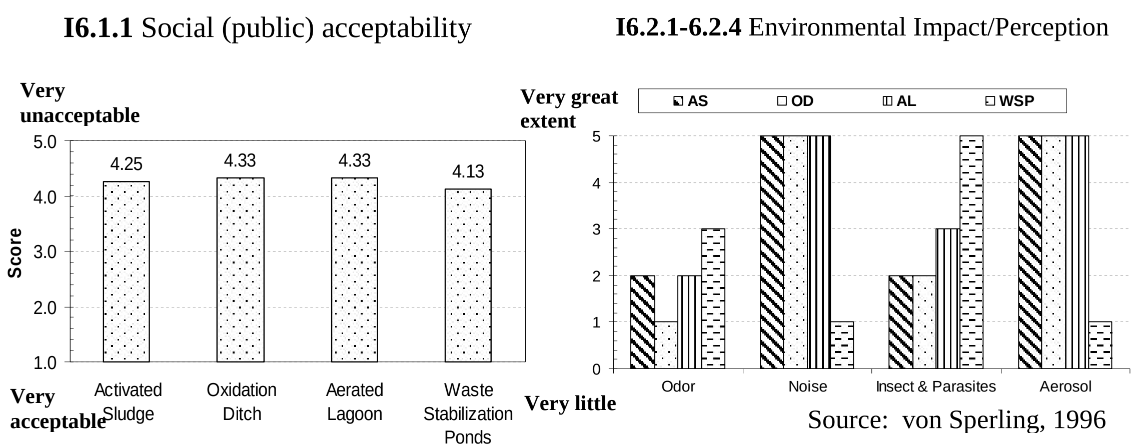
The successful implementation of the treatment system also depends upon the acceptance from the served communities or users. Indicators in this category are intended to evaluate how neighboring people accept or against the operation of the existing system. The list of indicators and variables are presented in Table 4.15.

Table 4.15 List of Selected Indicators to Evaluate Social (Public) Acceptability (P6)

Indicator	Units	Description
C6.1 General social (public) acceptability		
I6.1.1 Public acceptability of the system operation	1=very unacceptable (local protest against); 5=very acceptable (gaining local support, no complaint)	Level of public acceptability to a given technology
C6.2 Environmental impact/perception		
I6.2.1 Odor production	1=very little; 5=very great extent	Level of nuisances and impacts produced from operating the system
I6.2.2 Noise impact		
I6.2.3 Insects & parasites		
I6.2.4 Aerosol production		
I6.2.5 Groundwater quality		
I6.2.6 Landscape/visual		

Figure 4.31 shows that the overall result shows comparable levels of social acceptability in all treatment systems. Almost 90 percent of the systems surveyed indicate the high level of social acceptance with a very low potential complaint frequency. However, WSP systems receive relatively lowest score. Due to the high visibility of WSP projects, the systems that were not properly operated and adequately maintained would cause unpleasant nuisances: odor, insect, etc.

The study assesses the presence of nuisances: odors, noise, insects/parasites, and aerosols based on their qualitative comparisons. The scoring is relative to each nuisance impact and not general to all categories (von Sperling, 1996) (Figure 4.31).



System	Average Score (Standard Derivation)					N
	I6.1.1	I6.2.1*	I6.2.2*	I6.2.3*	I6.2.4*	
Activated Sludge	4.25 (0.50)	2	5	2	5	4
Oxidation Ditch	4.33 (0.71)	1	5	2	5	10
Aerated Lagoon	4.33 (0.58)	2	5	3	5	3
Waste Stabilization Ponds	4.13 (0.92)	3	1	5	1	15

Note: * von Sperling, 1996

Figure 4.31 Summarized Values of Social Acceptability and Environmental Impact/Perception

4.3.3 Environmental Aspects

4.3.3.1 Sustainability (P7)

The study considers two aspects of sustainability: the continuity of operation and the environmental sustainability. The complete list of indicators in this principle is summarized in Table 4.16.

Table 4.16 List of Selected Indicators to Evaluate Sustainability (P7)

Indicator	Units	Description
C7.1 Continuity of system provision or operation		
I7.1.1 Life expectancy of the system	Years	Life expectancy of the system, given routine maintenance
I7.1.2 Possibility to upgrade or extend the operation	1=no; 2= yes	Possibility for upgrading or extending to accommodate future changes
I7.1.3 Limitation factors for the upgrading or extension	1=very little; 5=very great extent	Extents to which the system upgrade or extension would be limited by budget deficit; land limitation; technological availability
C7.2 Possibility of resource recovery		
I7.2.1 By-product (biogas)	1=very probably not; 5= very probably	Possibility to use the system by-product
Reuse treated wastewater for: I7.2.2 General purposes		Possibility to reuse treated wastewater for general purposes (cleaning, plant watering); for non-contact activities; for non-food crops; for food crops; for groundwater recharge;
I7.2.3 Non-contact activities		
I7.2.4 Irrigation of non-food crops		
I7.2.5 Irrigation of food crops		
I7.2.6 Groundwater recharge		
I7.2.7 Recycling of organic matter or fertilizer		Possibility to recycle organic matter

Life expectancy of the system (I7.1.1)

Durability of the system is normally expressed by the expected lifetime. The service life of plant is not only dependent to the types of technologies, but also the development trend of a given area. Some area would be connected to the sewer network of central wastewater treatment plants in the future. However, the study considers life expectancy of the system based on the length of time that a particular technology must operate in the absence of a sewer connection. The identified wastewater technology alternatives in the study have showed a long expected lifetime greater than 20 years if they are adequately maintained and upgraded (Graae et al, 1998; Heathcote, 2000). The 20-year lifespan indicates an acceptable operational duration that could sustain the community's wastewater treatment needs.

Possibility of upgrading or expansion (I7.1.2)

This indicator evaluates the technology's ability to make future changes to the system such as an increase and decrease in capacity. The study qualitatively assesses the possibility of expanding and upgrading by integrating information from the survey and knowledge from literatures. This category is rated binaries: no (1) and yes (2), indicating whether or not the technology is easily expandable. Based on the following information, each technology receives a score of 2 indicating that, all technologies have comparable adaptability to future changes under any given constraints. The following indicator evaluates local factors constrained the possibility to extend or upgrade the system.

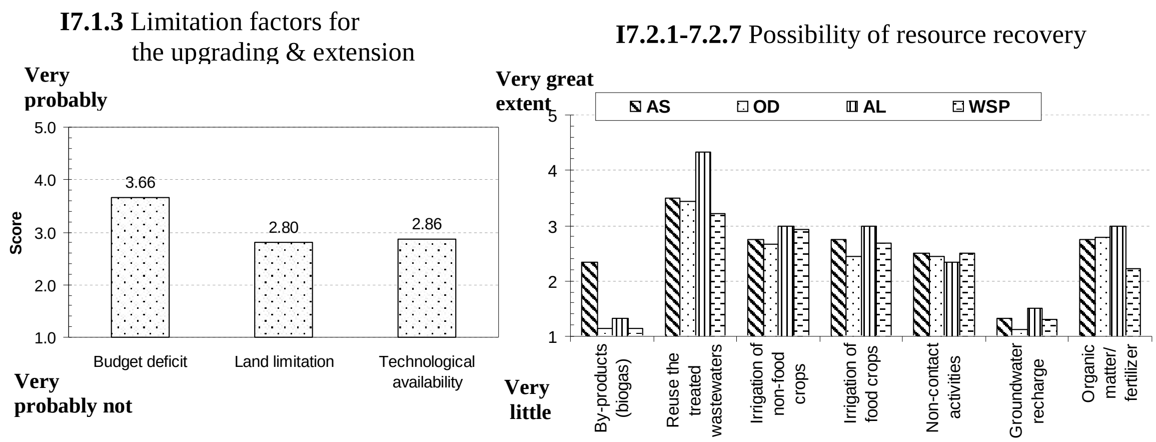
For AL and WSP, it is relatively simple to upgrade existing ponds or lagoons by adding more addition series of ponds/lagoons, adding anaerobic ponds or maturation ponds to improve the effluent quality, and alternating size and configuration i.e. combining two ponds to create a larger pond. However, cost of construction and the integrity of the buffering zone must be considered. On the other hand, AS and OD processes, which are typically designed with standardized units are highly modular, can be expanded by adding new sub units in each treatment stage. In cases where no additional land is available, process expansion using deep or taller processes and equipment will be required.

Limitation factors for the upgrading or extension (I7.1.3)

The study also analyzes the extents to which the system upgrade or extension would be limited by budget deficit; land limitation; technological availability. Figure 4.32 shows the overall effects of each limitation factors in expanding or upgrading the domestic wastewater treatment facilities in Thailand.

Possibility of resource recovery (I7.2.1-I7.2.7)

The possibilities for resource recovery are considered. The systems that could provide the benefits from reused wastewater and recovered by-products in each category would receive a higher score. After adequate treatment, wastewater from all systems may be recycled for irrigation, groundwater recharge, and general-purpose uses. Domestic wastewater effluents, which normally contain high concentrations of nitrogen and phosphorus, may be especially useful for irrigation. However, the organic and microbiologic pollutants must be reduced to levels compatible with the reuse purposes. For landscape, non-food crops and non-contact (recreation) activities, the effluent quality restriction is less important. As for food-crop irrigation and aquifer recharge, many pollutants common in domestic wastewater such as biological and heavy metal contaminations must be removed. The methane can be recovered as an alternative energy sources (biogas).



System	Average Score (Standard Derivation)										N
	I7.1.3			Possibility of resource recovery							
	Budget	Land	Tech.	I7.2.1	I7.2.2	I7.2.3	I7.2.4	I7.2.5	I7.2.6	I7.2.7	
AS	3.66 (1.73)	2.80 (1.29)	2.86 (1.29)	2.33 (1.53)	3.50 (1.29)	2.75 (0.96)	2.75 (0.96)	2.50 (1.00)	1.33 (0.58)	2.75 (1.50)	4
OD	3.66 (1.23)	2.80 (1.73)	2.86 (0.78)	1.14 (0.38)	3.44 (0.88)	2.67 (1.41)	2.44 (1.42)	2.44 (1.42)	1.13 (0.35)	2.78 (1.39)	10
AL	3.66 (1.00)	2.80 (0.58)	2.86 (1.15)	1.33 (0.58)	4.33 (0.58)	3.00 (1.00)	3.00 (1.00)	2.33 (1.53)	1.50 (0.70)	3.00 (1.00)	3
WSP	3.66 (1.03)	2.80 (0.98)	2.86 (0.79)	1.14 (0.36)	3.21 (1.19)	2.92 (1.26)	2.69 (1.25)	2.50 (1.34)	1.31 (0.48)	2.21 (1.31)	15

Figure 4.32 Summarized Values of Limitation Factors for the Upgrading & Extension and the Possibility of Resource Recovery

4.4 CASE STUDIES

The previous chapter develops a technology selection framework that employs a set of technical, socio-economic, and environmental criteria to select wastewater alternatives for communities in Thailand. In this section, the study uses this framework to identify an appropriate wastewater treatment system for four settlements located at the eastern sub-urban Bangkok.

4.4.1 Introduction to Study Area

The study collected information from ten communities in Rom Klao (RK) and Feun Nakorn Rom Klao (FNRK) Housing Projects which are located at the eastern segment of Bangkok Metropolis (Figure 4.33). Since 1970s, such projects located in the east of Bangkok's suburban area have been established as a part of the national low-income housing policy by National Housing Authority (NHA). The overall area consists of more than 9,600 housing units and approximately 48,000 residents.

The RK Housing Projects were established on the area of 2,201 rai (870 acres) during the national housing plans (1979-1982). By adopting the World Bank concept "sites and services", NHA constructed the first RK project (Phase 1) with the main purpose of providing vacant land plots with basics infrastructure and services to 3,830 households. Residents were required to build the rest of the houses by themselves. In 1992 and 1993, NHA had constructed 2,366 completed house units for the following projects, the RK Phases 2/1, 2/2 and 2/3, respectively (Figure 4.34).

In the adjacent area of the RK projects, the 36-hectare FNRK low-income housing projects consisted of six zones (communities) with approximately 3,250 households. During the years of 1985-1994, NHA had developed these projects with an aim to relocate slums from the inner-city area to the suburbs and give security of tenure for the squatter people by offering an affordable plot of land (72-108 square meters) with basic services. Land recipients had to build houses by themselves with all available resources they had. Since most of land occupants were very poor, it was commonly found that within the FNRK communities, people built their home from substandard materials and had to live in the uncompleted houses (Figure 4.34).

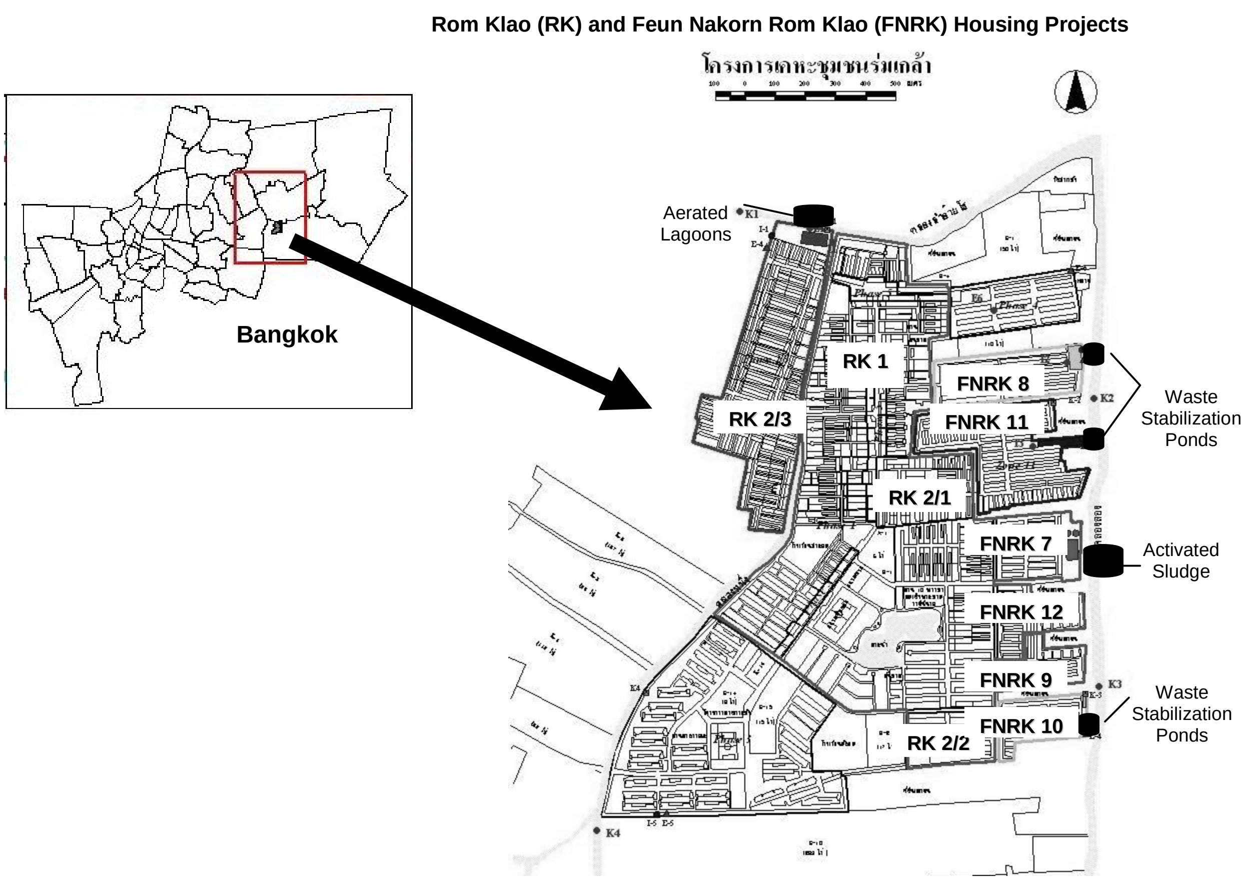


Figure 4.33 Location of Study Site

4.4.2 Site Characteristics

The study area is situated on flat low land in the southern part of the Lower Central Plain of the country. Due to its low-lying topography and close proximity to local canals, the area is subject to flooding during the rainy season. The housing project area has to rely on flood protection systems to prevent inundation in the monsoon season.

Settlement conditions

Table 4.17 summarizes the settlement conditions and shows the different construction phases (RK) and zones (FNRK), and the wastewater treatment systems in the different areas. The RK projects were basically targeting lower middle-income people. Their communities are in good locations close to transportation and social services. Communities in the RK phases 1, 2/1, and 2/2 share most of their infrastructure and services. The overall living conditions in the RK phases are good with relatively low housing density. Due to its better developed physical and social infrastructure, the property values in the RK projects are relatively high compared to the FNRK area. People live in these projects tend to have higher socio-economic status than those who live in FNRK communities.

The six low-income communities of FNRK are located along a canal (Klong Song canal) providing less convenient accesses to main streets and local service areas. The living density in this area is very high. The FNRK area is on a plain bordering a canal and is subject to seasonal flooding. The existence of a substandard sewer system and inoperative wastewater treatment facilities in these communities compounded the problems of rundown dwellings.

For land and housing status, the majority (70%) of the surveyed households were the owners of their land and house. The remaining houses were rented (23%) and leased (7%.)

The differences in environmental conditions between these two areas have created disparities in social and economic conditions, as reflected by income, employment, educational levels, and accessibility to the basic infrastructure. The differences in physical characteristics of the settlements influence the accessibility to infrastructure services, especially sewage collection and wastewater treatment (Table 4.17).

Table 4.17.The Settlement Conditions of the Study Area

Type of Community (Housing Type)	Community	Total Area (ha)	No. Houses (Unit area)	No. Residents (5cap/house)	Density		Wastewater Treatment System	Plant Condition
					Houses /ha	Capita /ha		
Low medium-income community (Single/Town houses; good conditions)	**RK 1** (Phases 1, 2/1-2)	114.9	4,605 (84-200 m2/unit)	23,024	40	200	Activated Sludge	Well operated by DDS
	RK 2 (Phase 2/3)	22.59	1,785 (72-162 m2/unit)	8,925	79	395	Aerated Lagoons	Poorly operated by NHA
Low-income community (Self-built house; poor conditions)	**FNRK 1** (Zones 7,9,12)	12.51	1,140 (78 m2/unit)	5,700	88	438	Sharing the service of AS in RK 1	Well operated by DDS
	FNRK 2 (Zones 8,10,11)	23.50	2,110 (78 m2/unit)	10,550	90	449	Three waste stabilization ponds	Inoperative

Note: DDS: The Department of Drainage and Sewerage, Bangkok Metropolitan Administration (Local Authority)
NHA: The National Housing Authority of Thailand (Land Developer)
RK: Rom Klao housing projects; FNRK: Fuen Nakorn Rom Klao slum relocation projects

Physical infrastructure

Water supply in the study area has mostly been obtained from groundwater extraction, due to its locations on the suburban area (away from the main water distribution systems). The NHA constructed a community-managed water supply system for their residential units. However, it was found that some newly established residential projects and business units have connected to the metropolitan water networks. Upon the completion of the seventh Bangkok water supply improvement project (2006-2009), the Metropolitan Waterworks Authority will have enough capacity to accommodate the expanding water needs of the nearby Suvarnabhumi International Airport and to replace the use of underground water in this eastern sector of Bangkok (MWA, 2008).

Pour-flush toilets are commonly used in Thailand and the study area. A simpler on-site unit comprising one or two pits is used to toilet discharge. The pit(s) serve both as a septic tank and as a leaching system.

Five wastewater treatment facilities were planned and constructed by the NHA across the entire study area to treat wastewater from different phases and zones. Three types of wastewater treatment systems including an activated sludge system, aerated lagoons, and waste stabilization ponds are operated by three different agencies.

Activated sludge: Wastewater from RK phases 1, 2.1, and 2/2 are collected by combined sewage system to an extended aeration activated sludge plant. Except for the RK phase 2/3, this off-site treatment facility is serving most people in RK projects and those who live in three FNRK communities adjacent to the facility. The plant was constructed in 1985 and operated by the office of RK housing projects, NHA. In 1997, the treatment facility was transferred to the responsibility of the Bangkok Metropolitan Administration (BMA). The BMA as a local authority that has provided skilled labors and funds for operation and maintenance. The facility has been performing well with acceptable quality effluent.

Aerated lagoon: This treatment facility is located in the RK phase 2/3. Using simply subsurface aerators, the single 50 x 100 m^2 aerated lagoon has been operated by the office of RK housing projects, NHA. The study found that this office lacked skill and knowledge to properly operate and maintain the treatment plants. As a result, the poorly operated lagoon can rarely provide the effluent quality to meet the required standards.

Waste stabilization ponds: Three waste stabilization ponds were designed and constructed by the NHA for treating wastewater from FNRK Zones 8, 10, and 11. Due to lack of financial support and the capability to operate the systems, these plants have never been properly operated since they were built. The ponds have been practically abandoned without regular maintenance.

Socio-economic conditions

Table 4.18 summarizes household characteristics of the case studies. The survey shows that the average length of residency for the households is from 7 to 12 years. Of the households surveyed approximately 70% indicated the length of residency from 10-25 years. The length of time a person has been living in a community provides a good indication of the stability of that particular community and its potential for future development.

Data from the survey showed the high variation of total household income ranging in each settlement. Households in RK phases show relatively higher income than the residents live in FNRK communities. Most households were single families with 2-6 members per household (86.1%) and 1-2 income earners per family (70%). The majority of households (48%) received only compulsory education up to primary level (6 years). Thirty percent received 9-12 years of education in secondary schools.

Table 4.18 Socio-Economic Conditions in the Study Area

Type of Community (Housing Type)	Community	Length of residency (yr)	Household income (Baht/month)	Family size (Capita/household)	Education level (yr.)
Low medium-income community	**RK1**	11.82 (7.24)	23,617.95 (16,751.50)	3.90 (1.58)	9.23 (4.00)
	RK2	6.88 (4.11)	23,102.56 (13,939.80)	4.10 (1.38)	7.59 (3.00)
Low-income community	**FNRK 1**	11.91 (4.05)	19,864.30 (16,430.710	4.64 (2.29)	8.20 (3.59)
	FNRK 2	9.50 (5.35)	20,158.40 (22,833.27)	4.49 (2.04)	8.96 (4.06)
Overall		10.55 (5.67)	21,612.94 (18,044.65)	4.28 (1.93)	8.66 (3.82)

Note: ( ) standard derivation; (38 Baht=1$US at the time of survey)

Figure 4-34 Settlement conditions of case studies

4.5 MULTI-CRITERIA DECISION ANALYSIS

The study carries out a systematic analysis of four wastewater treatment alternatives for the case studies. The previous section demonstrates an overview of how wastewater treatment is provided in the suburban communities of Bangkok. Due to the lack of proper wastewater treatment system in *RK2* and *FNRK2*, the study selected these two community groups as case studies for decision process analysis in this section. The quantified indicators obtained from section 4.3 are used to develop a multi-criteria module for a decision support system. The study uses multi-criteria decision analysis (MCDA) techniques for comparing and rank ordering wastewater treatment technology alternatives against the identified technical, socio-economic, and environmental objectives.

The Web-HIPRE (HIearарchical PREference) software is used for this comparative analysis. It is used to make complex decision where there are tradeoffs among competing objectives. The theoretical background of the tool is the multi-attribute value theory (MAVT). This approach develops a hierarchical model of the objectives related to the problem and the decision makers' preferences. In Web-HIPRE, an additive value function can be used to aggregate the component values. The overall value of an alternative x is evaluated as

$$v(x) = \sum_{i=1}^{n} w_i \, v_i(x_i) \qquad (16)$$

where:

x_i = consequence of an alternative *x* for attribute (criterion) *i*

$v_i(x)$ = the rating of an alternative *x* with respect to an attribute (criterion) *i*

n = the number of attributes (criteria),

i = attribute (criterion) of interest, *i*=1,…, *n*.

w_i = the relative importance of an attribute (criterion) *i*, $w_i>0$, $\sum_{i=1}^{n} w_i = 1$

The sum of weights is normalized to one, and the component value function $v_i(\cdot)$ has values between 0 and 1.

The steps for constructing the model include:

1. *Problem structuring*
2. *Rating alternatives with respect to each indicator*
3. *Preference elicitation*
4. *Rank ordering the wastewater treatment alternatives*

Step 1 Problem structuring: Goal and objective are clarified. The complete set of relevant criteria and indicators identified in Section 4.1 is used to structure a multi-attribute value tree or a hierarchy of criteria and objectives (Figure 4.35). In this tree the overall goal or objective is divided hierarchically into lower level criteria and measurable attributes, on the lowest level. From the figure, the model consists of five layers, beginning with the selecting goal of the most appropriate wastewater treatment technology for suburban communities in Bangkok.

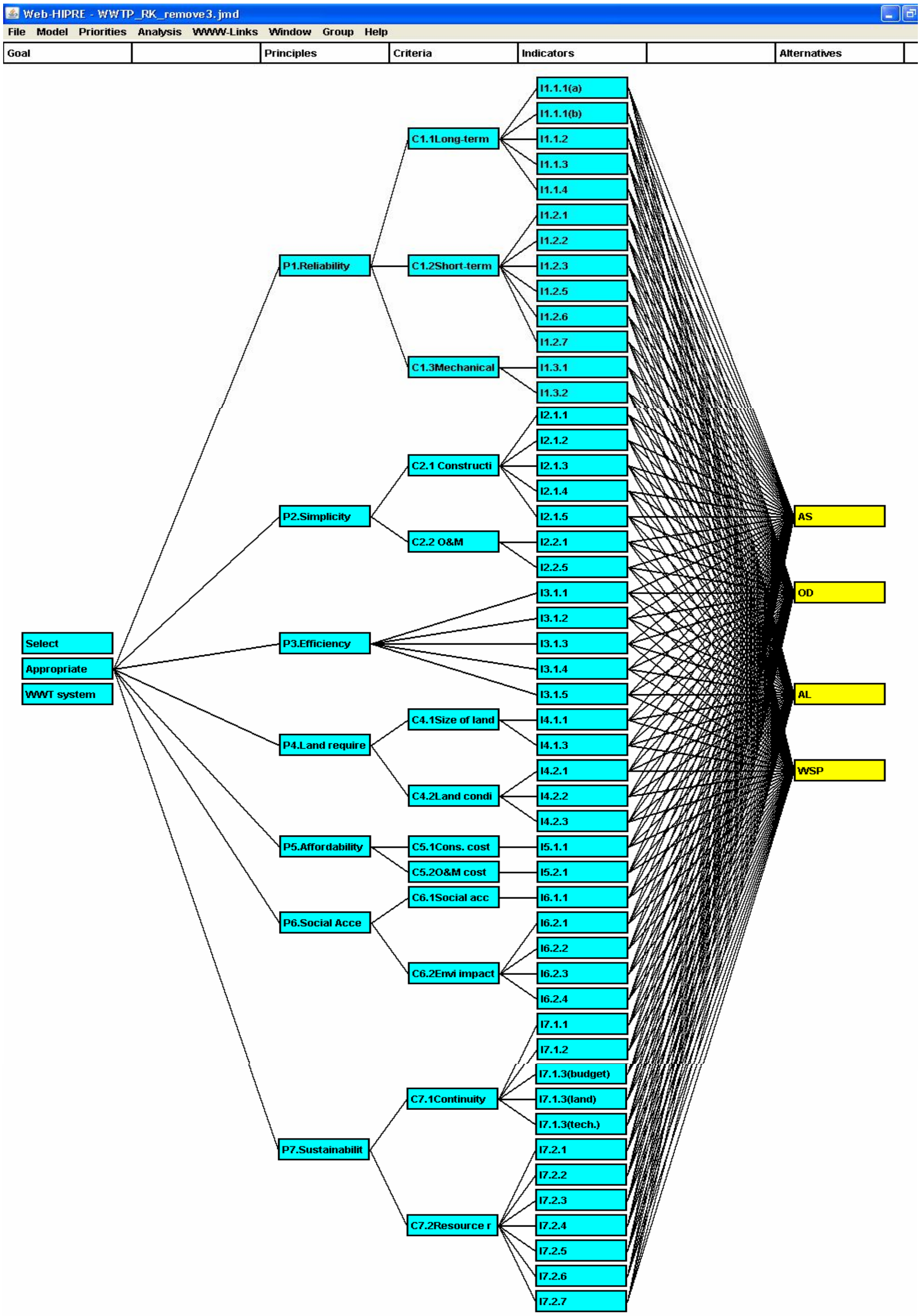


Figure 4.35 Hierarchical of Criteria (Values Tree)

The following layers are decision criteria hierarchically structured from primary decision criteria to lower level subcriteria. The primary level includes seven principles: Reliability, Simplicity, Efficiency, Land requirement, Affordability, Social acceptability, and Sustainability. The secondary criteria consist of 14 elements. The third level includes all indicators providing further details to the criteria. Finally, the lowest level (the rightmost) elements of the values tree are treated as alternatives which include the four potential wastewater treatment systems: Alternative1 Conventional Activated Sludge (AS); Alternative 2 Oxidation Ditch (OD); Alternative 3 Aerated Lagoons (AL); Alternative 4 Waste Stabilization Ponds (WSP).

Step 2 Rating alternatives with respect to each indicator: The set of final indicators were quantified in Section 4.3 and used as *ratings* of alternatives. The summary of the ratings are complied in Table A.6 (Appendix A). Ratings of alternatives are entered into a *Rating*-dialog or in a form of alternative-indicator matrix (see example in Figure 4.36). A linear function is used for each individual attribute. Subsequently, the value functions are used to transform the ratings of the alternatives into values (see example in Figure 4.37) according to the following objectives:

- maximize system reliability
- maximize simplicity
- maximize removal efficiency
- minimize land requirement
- minimize costs
- maximize social acceptability
- maximize sustainability

Figure 4.36 Example of a *Rating*-dialog (alternative-indicator matrix) of Criteria 1.1

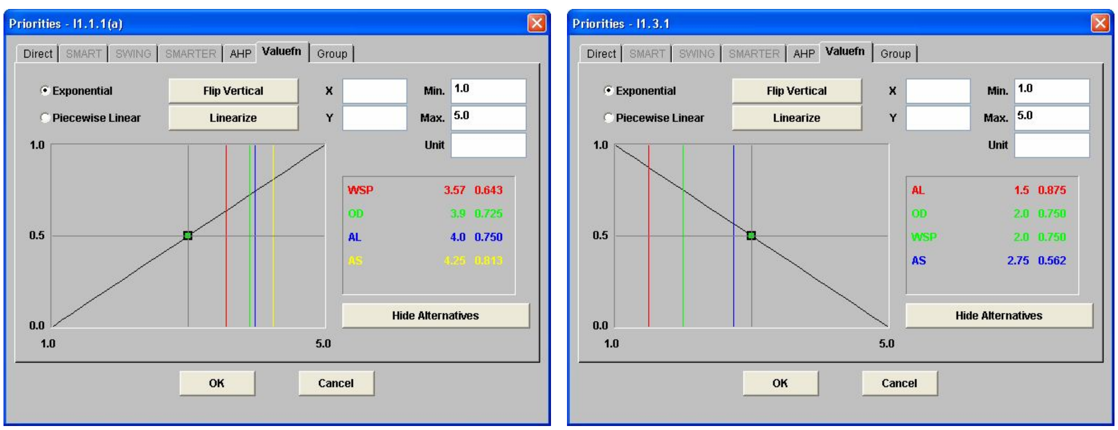


Figure 4.37 Examples of a Value Function Map of I1.1.1 (A) and 1.1.3

Step 3 Preference elicitation: The weighting of criteria on the attribute tree is carried out by using the relative weights from the expert survey in Section 4.1 (criteria and indicator assessment). These preference weights are complied in Table A.1 (Appendix A) were elicited from the expert survey using direct weighting technique. The experts directly allocated number to each attribute by dividing 100 points among the attributes.

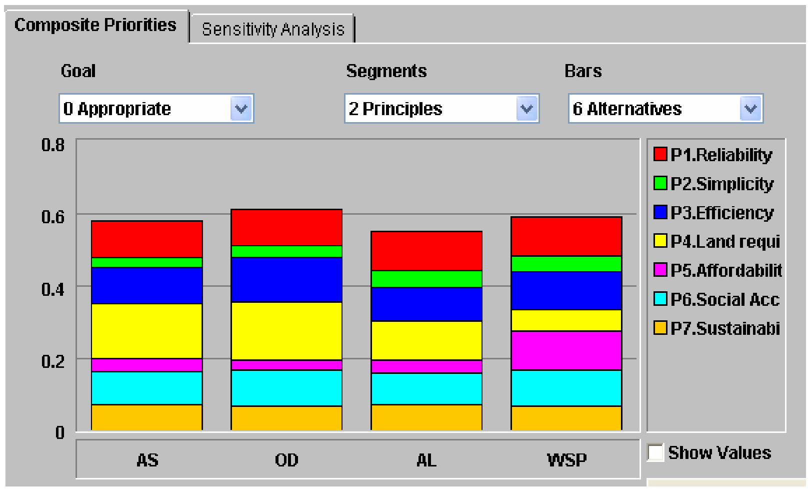
Step 4 Rank ordering the wastewater treatment alternatives: Following the preference elicitation, the composite priorities are calculated

4.5.1 Analyzing the Results

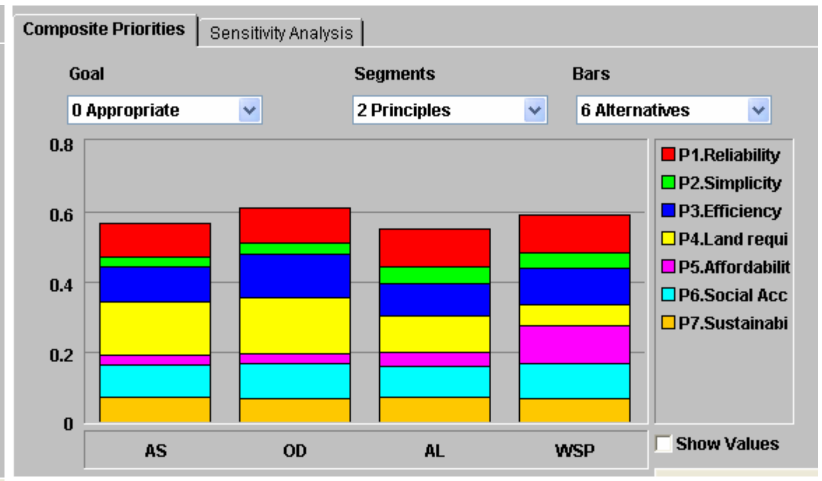
The composite priorities or the overall value scores for the alternatives are calculated and graphically presented in Figures 4.38 - 4.40. In a preliminary model, the study considers all seven important attributes of wastewater treatment systems (namely, reliability, simplicity, efficiency, land requirement, affordability, social acceptability, and sustainability) based on the results from the plant survey. In addition, three indicators: size of land, construction cost, and O&M cost of each alternative were calculated by integrating the local conditions of the case studies: *RK2* and *FNRK2* communities (Table A.6).

In Figure 4.38, the impacts of different attributes (Principles) are analyzed and presented in stacked bar graphs. Each bar represents the overall value scores of each alternative and the sizes of stack bars also show the relative contributions of the attributes on an alternative's score. Basing on the overall composite priorities, OD is the most preferred system for both RK2 and FNRK2 cases with the priorities of 0.61, followed by WSP and AS (Figure 4.38). AL is ranked the last with slightly lower score of 0.55. The graphs also show that "P4 land requirement" attribute provides a large contribution to the good overall scores of OD and AS, while "P5 affordability" is the important factor in favoring WSP over AL.

RK 2



FNRK 2



RK 2 Composite Priorities

	AS	OD	AL	WSP
P1.Reliability	0.097	0.102	0.108	0.106
P2.Simplicilty	0.028	0.030	0.050	0.043
P3.Efficiecy	0.101	0.126	0.092	0.108
P4.Land requirement	0.152	0.159	0.105	0.059
P5.Affordaability	0.038	0.029	0.036	0.108
P6.Social acceptability	0.091	0.100	0.089	0.101
P7.Sustainainability	0.071	0.067	0.073	0.067
Overall	**0.578**	**0.612**	**0.553**	**0.590**

FNRK2 Composite Priorities

	AS	OD	AL	WSP
P1.Reliability	0.097	0.102	0.108	0.106
P2.Simplicity	0.028	0.030	0.050	0.043
P3.Efficiecy	0.101	0.126	0.092	0.108
P4.Land requirement	0.152	0.160	0.104	0.059
P5.Affordability	0.029	0.029	0.037	0.108
P6.Social acceptability	0.091	0.100	0.089	0.101
P7.Sustainability	0.071	0.067	0.073	0.067
Overall	**0.569**	**0.613**	**0.554**	**0.590**

Figure 4.38 Overall Values of Alternatives

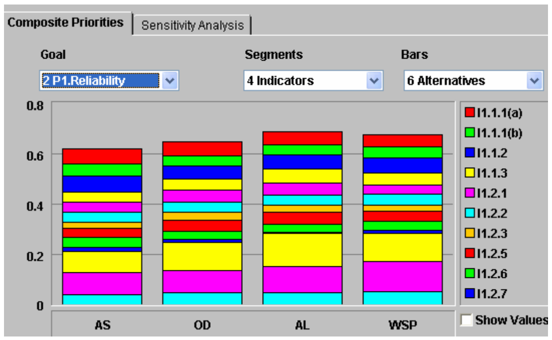
Due to the tradeoffs between the seven different objectives, the overall value scores of the four alternatives are, to some extent, comparable. In the following part, the study analyzes the value scores of each principle with respect to its lower criteria.

Figure 4.39 and 4.40 demonstrate the effects of each criterion on the composites priorities of alternatives. The analysis found that OD as the most preferred alternative turns out to be among the lowest priorities when maximize simplicity (P2) and minimize costs (P5) are the main objectives. The system simplicity and costs have also the similar effect on the AS process. On the other hand, WSP shows relatively high scores in all attributes except for "P4 land requirement". Figure 4.40 shows that the land area required for WSP creates an enormous effect on its overall value score. It is also interesting to observe that AL, which scores the least when multiple objectives are considered, becomes the best alternative in terms of simplicity, especially for the operation and maintenance.

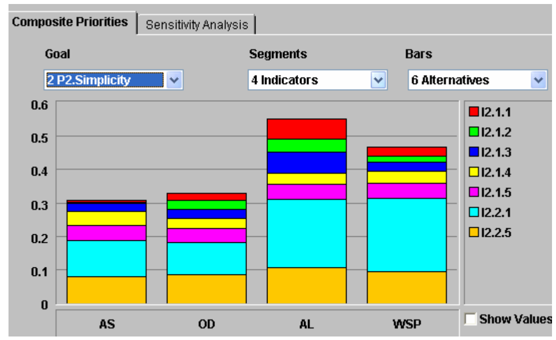
4.5.2 Sensitivity Analysis

An analytical procedure is applied to study the effects of changes in the attribute weights and in the component values of the alternatives. Figure 4.41 illustrates the sensitivities of the weights on "P4 land requirement" and "P5 affordability" to its values and hence deriving the rank order of alternatives. Sensitivities of remaining principles are presented in Appendix D.

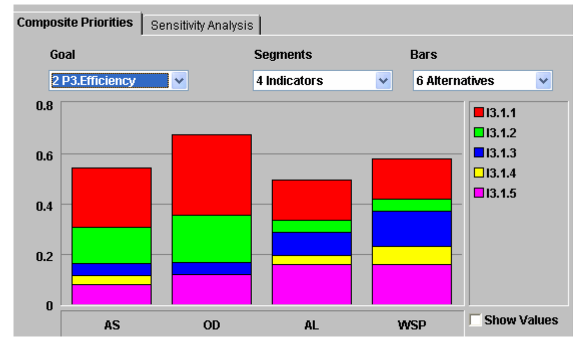
P1 Reliability



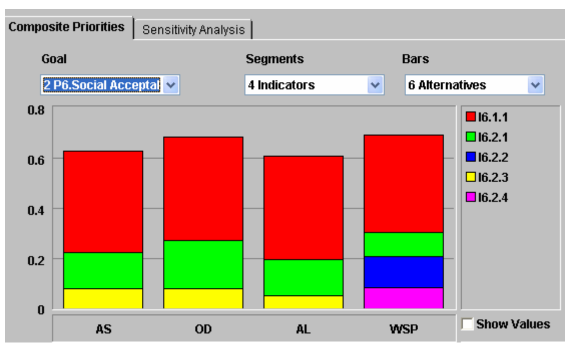
P2 Simplicity



P3 Efficiency



P6 Social acceptability



P7 Sustainability

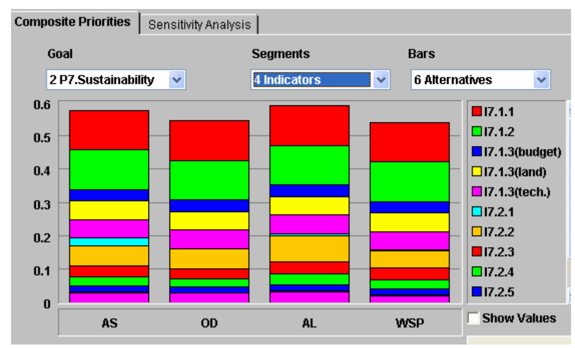
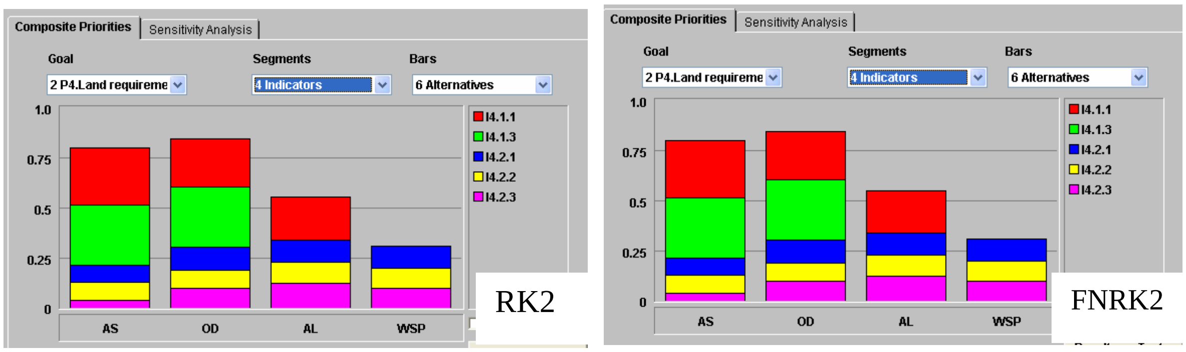


Figure 4.39 Composite Priorities based On Reliability, Simplicity, Efficiency, Social Acceptability and Sustainability

P4 Land requirement



P5 Affordability

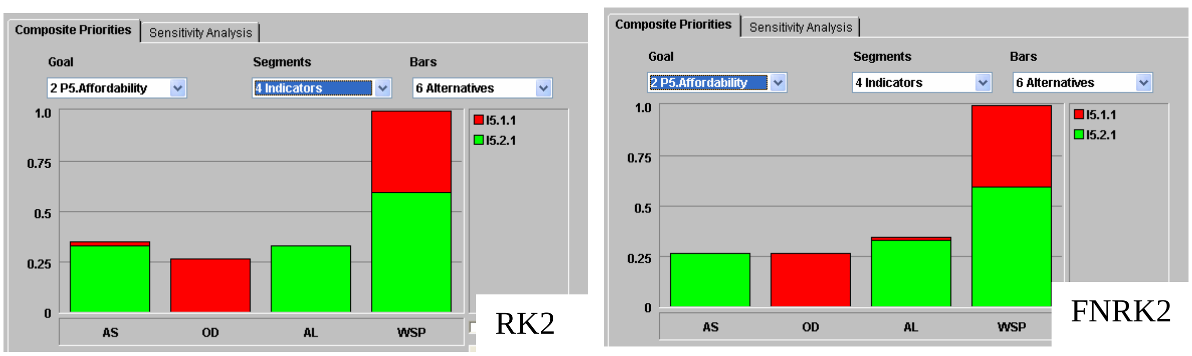


Figure 4.40 Composite Priorities based on Land Requirement and Affordability

P4 Land requirement **P5 Affordability**

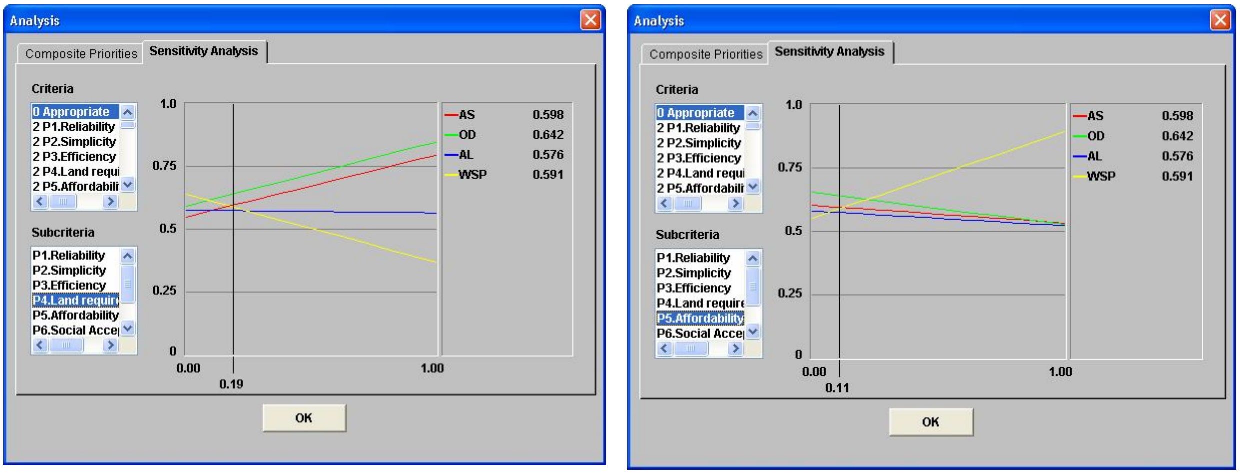


Figure 4.41 Sensitivity Analyses for Land Requirement and Affordability

The sensitivity analysis on “P4 land requirement” allows the examination of the robustness of the choice of an alternative in relation to the changes of the weights assigned to “land requirement”, which is represented by the black vertical line in the graph (Figure 4.41). As seen from the graph, OD and AS have positive effects on the function values with respect to weight. Meanwhile, the WSP has an opposite impact; and the AL remains approximately the same. The graph also shows that OD and AS remain the most preferred element if the weight on “P4 land requirement” is increased. Nevertheless, for a further reduction of weight, WSP turns out to be the best choice.

Figure 4.41 presents also the sensitivity for “P5 affordability”. The graph shows that only WSP has a positive effect and remains the most preferred element with the increasing weight. On the contrary, OD, AS and AL have opposite effects. The graph also indicates that OD will be ranked the best if the weight is decreased toward 0.

In conclusion, the resultant of the research presented in this section demonstrates that the development of multi-criteria decision analysis model provides a comprehensive information to support the decision making process, by ranking the various wastewater treatment alternatives against the multi-disciplinary objectives (i.e. technical, socio-economic, and environmental aspects). Most of the multiple criteria methodologies typically aim to obtain a final score per alternative to identify the best performance. However, in the study, the value scores and the rank ordering of alternatives are not the ultimate solution to the wastewater technology selection for developing countries. The purpose of this multi-criteria framework is to facilitate discussion and analysis during the decision making process, by using the scores and rank ordering as the decision-support tool. Decision makers can compare local needs and conditions with the preferred options to find the most suitable alternative for their community context. In this light, (local) community factors will be analyzed in the following section before making the site-specific recommendation for the case studies.

4.6 LOCAL FACTORS INFLUENCING THE SELECTION OF COMMUNITY SYSTEM

The previous sections provide the analysis of wastewater treatment options and the selection of preferred alternative(s). To select the locally appropriate system, this section analyzes the possible wastewater treatment options with the local needs, availability of resource, and constraints. Using data obtained from the community survey (see Chapter 3 methodology description) and informal interview with local authorities, the study examines different aspects of local factors, which determine the extent of long-term success of a community-scale wastewater treatment system in the two case studies: *RK2* and *FRNK2.* Those factors include technical, socio-economic, environmental, institutional aspects.

4.6.1 Technical Factors

The quality of the personnel employed in wastewater treatment plants plays a key role in its proper operation. One of the major problems of effective wastewater treatment in Thailand is the lack of operational skill and knowledge among plant operators. It is difficult to find good engineers with good experience and awareness of the technologies; especially the more advanced processes like AS and OD.

Data from the community survey show that educational levels in both case studies are quite low. The majority of residents received only primary and secondary education levels (Table 4.18). It is thus possible to employ unskilled labors for construction and basic mechanical work. In this sense, WSP and AL are good choices for both communities.

In terms of system efficiency, AS and OD can provides higher removal efficiencies for BOD and SS as opposed to those of AL and WSP. With respect to the standard for treatment plant effluent in Thailand, , the maximum permitted values of BOD (30mg/L) and SS (40 mg/L) for housing estate (>500 units) will possibly be satisfactory using the WSP and AL systems. In Bangkok, recycling wastewater from a system for irrigation or groundwater recharge could be considered low priorities at the present. The area is located in high rainfall region and capable to obtain water supplies from existing watershed. Therefore, wastewater treatment can be optimized to the extent that the discharge water will not harm aquatic livings or deteriorate the quality of receiving water. In this sense, the highly efficient treatment processes might not be necessarily.

4.6.2 Amount of Land Requirement

The survey information from Section 4.3 showed that the living density in low-income *FNRK2* area is extremely high. The total area available for wastewater treatment facility is thus very limited. There are three abandon ponds located in three separate land spaces. Based on the land area estimation, these three spaces can not satisfy the land area required for WSP unless the additional land is provided. There are privately owned and vacant lots next to the community zones 8 and 11. Due to the low land values, it might be possible for *FNRK* community and local authority to purchase such unused land;

otherwise the more expensive processes and less land required would be more suitable. In this case, further cost analysis is needed.

For *RK2*, land availability is not a constraint. There is plenty of vacant area available around the existing lagoon. To improve the current AL process, additional lagoons need to be added in series or parallel to the existing single lagoon. To upgrade the treatment process for the community, OD system could be possible, provided the extensive costs for construction and O&M are available.

4.6.3 Affordability

Information from interviews with community leaders showed that it is impossible for the current community organizations to financial support the construction of any wastewater treatment system. Without strong organization and leaders, these communities could by no means motivate their residents to either participate in their own development project or negotiate with the authority for financial support. However, since these housing projects are developed by the National Housing Authority of Thailand, the investment cost could be subsided by the government or other state agencies.

For O&M cost, the estimated O&M expenditure for each process was presented in Table 4-15. Based on these estimates, one can approximate the amount of payment per household, if community members have to pay for their service without any subsidy by the government. Based on such calculation in Table 4.14, the possible monthly O&M cost per household is presented in Table 4.19.

Table 4.19 O&M Cost per Household

Community	O&M cost/household (Baht/month)			
	AS	OD	AL	WSP
RK2	114	196	114	49
FNRK2	110	165	97	40

Note: 1 $US = 35 Thai Baht

In addition, data from the community survey are used to evaluate the reasonable amount of payment that users are able to pay for the wastewater treatment service. In the survey questionnaire, the respondents were asked to state the amount that they were able to pay per month for the service. To avoid the excessive amount, the choice from which respondents would select was ranging from less than 50 to 200 Baht. The results show that the ability to pay declines considerably from the first category (<50 Baht/month) to the second category (50-100 Baht/month). Nevertheless, approximately 20 percent of residents in both groups of communities expressed that the WWT service should be available free of charge. Respondents living in different types of communities significantly demonstrate the differences in ability to pay for the community service. It is very interesting to find that those who are living in the better settlements (RK projects) and being served by well-operated WWT system stated a lower average of amount. On the other hand, people in FNRK low-income communities express relatively higher amount of ability to pay (Table 4.20). The overall ability to pay for the service is 40.02 baht/month. The results show that without the subsidy from government and local authority, the fee collection from *RK2 and FNRK 2* residents could cover the monthly O&M cost for WSP process.

Table 4.20 Ability to Pay for the Wastewater Treatment Service

Community	Ability to Pay for WWT service (Baht/month)
RK1	39.09
RK2	29.29
FNRK 1	41.00
FNRK 2	44.87
TOTAL	**40.02**

4.6.4 Acceptability of Wastewater Treatment Service Charge

In the study area, the specific fee for the wastewater treatment service has never been directly collected from the users. The plants were constructed and still maintained by the NHA as a land developer. The highly operational and maintenance costs for the systems can hardly be covered merely by the NHA' revenues. Without the external source of financial supports nor any collection of service charge from the community members, these systems could by no means establish any proper and effective decentralized wastewater treatment systems.

The main objective of the community's self-management approach is to stimulate the community's involvement to provide its own services with only minor intervention from government. Different forms of local activities such as regular meetings or cleaning projects could be initiated to improve public awareness and to reinforce community participation. To provide the financially sustainability, all stakeholders, particularly the community members, should be allowed to participate in the *informed decision making process* of the service charge and billing systems. The majority of respondents suggest that wastewater treatment service charge should vary according to the volume of household water consumption. More than 60 percent prefer a separate fee collection system. The others prefer the fee to be included in water bill or garbage collection charge. Most respondents prefer the BMA as being the local authority who is responsible for fee collecting. Nevertheless, most of the respondents who are living in low-income communities (comprising 20 percent of all respondents) agree that the community organizations should play a key role of fee collection.

CHAPTER 5

CONCLUSIONS

The appropriate selection of wastewater treatment technologies has been recognized as a part of the sustainable development strategies in the Third World countries. Local context, such as socio-economic, political, and institutional situations are considered the prime barriers to the success of technology implementation. The ultimate goal of this study is to advocate a comprehensive approach toward the wastewater technology selection in developing countries, where technical solution alone can hardly provide an appropriate resolution to the wastewater problems. This chapter summarizes the main findings and methodological framework leading towards the development of criteria and indicators for system selection; multi-criteria decision analyses of wastewater treatment alternatives; and an assessment of the applicable decision support model basing on case studies from developing countries. Some policy recommendation and relevant topics for future study are also presented at the end of this chapter.

5.1 FINDINGS OF THE STUDY

The study approaches the problems of wastewater management in developing countries and identifies the following research questions regarding to the selection of appropriate wastewater technology in developing countries:

1) What are the factors governing the selection of appropriate technologies for communities in developing counties?

2) What would be the most appropriate procedure of selection?

3) What are the appropriate wastewater treatment systems applicable for domestic sanitation in Bangkok suburban area?

4) How could Bangkok's example be applicable for the needs of wastewater treatment in communities typical of developing countries?

The research objectives are set forth by the research questions to identify and analyze the relevant factors determining the success of wastewater treatment systems, and develop a set of decision making criteria and indicators useful for technology selection process. The research, therefore, comprises of 3 major tasks of inquiry: the expert survey, the plant survey, and the community survey. These tasks were designed to gather empirical data to identified wastewater treatment alternatives and establish selection approaches for Thailand.

The study devises a comprehensive approach for selecting appropriate wastewater treatment systems in the case of Thailand. Apart from a technical aspect of technologies, the study integrated the social, economic, and environmental aspects toward the development of criteria and indicators (C&I) useful for evaluating appropriate systems. The study takes the C&I approach to develop the selection framework appropriate to the context of Thailand. It first conducted the expert survey to obtain information from Thai experts to evaluate the initial set of C&I. The established C&I can further be used to express the meanings of appropriate wastewater treatment systems for each specific location; and the process can be incorporated within the selection process of wastewater treatment system at the communal level in the later stage.

A set of C&I derived from seven principles—*reliability, simplicity, efficiency, land requirement, affordability, social acceptability, and sustainability*—is proposed to be used to evaluate the applicability of each wastewater treatment technology for the given socio-economic and physical environments in Thailand. The study provides a systematic analysis of four wastewater treatment alternatives (i.e. *activated sludge, oxidation ditches, aerated lagoon, and wastes stabilization ponds*) for two selected case studies: *RK2* and *FNRK2.*

The study uses a multi-criteria decision analysis (MCDA) technique for comparing and rank ordering wastewater treatment alternatives against the identified technical, socio-economic, and environmental objectives. The Web-HIPRE (HIeararchical PREference) software is used for the comparative analyses of multiple objective problems in wastewater technology selection process. The MCDA comprise four major steps:

5. Problem structuring
6. Rating alternatives with respect to each indicator
7. Preference elicitation
8. Rank ordering the wastewater treatment alternatives

In the Web-HIPRE analysis process, the decision problem is visually structured in a form of objectives/attributes value tree. The composites priorities and ranks ordering of the alternatives are then graphically presented. These features are proved to be very helpful for lay persons (i.e. local authorities and community organizations) to understand and to use the information from the model for further discussion and decision making. The models derived from the study demonstrate that the development of multi-criteria decision analysis method could provides a comprehensive information to support the decision making process.

Since the study's main objective is to develop a decision support tool for assessing different scenarios in Bangkok's suburban communities and selecting appropriate wastewater treatment alternatives; the final part of the study analyzed the possibility of wastewater treatment options with the local needs, resource availability, and constraints in mind. Using data obtained from the community survey, the study examined different aspects of local factors, which determine the long-term success or failure of wastewater treatment at the community level. Two of the case studies are: *RK2* and *FRNK2*. The local contextual factors crucial to the selection of the most suitable wastewater treatment technology for the community are technical, socio-economic, environmental, and institutional aspects which are needed to be analyzed and explicated.

The study demonstrates that four key factors are important to evaluate the local technology suitability, namely, the technical factors, land area requirement, local affordability, and acceptability and support from the community members. The lessons learned from the case studies demonstrate that simplicity of the system, land area requirement, and especially affordability during the operational phase are the most important factors and needed to be considered thoroughly in the decision making process. The implementation of wastewater treatment plant at the community level could not be successful without the acceptance and support from the community members themselves.

It seems impossible for the low-income communities which located outside the service areas to provide the service by themselves. With constraints as such in most developing countries—technological, financial, institutional, and political constraints are included—the self-provision of treatment systems seems to be out of reached if not improbable for low-income communities. In order to overcome these constraints particularly in the low-income neighborhoods, the concept of "self-help" can be applied to motivate the community involvement in its own development project with minimal intervention from the governmental agencies and NGOs. An appropriate wastewater treatment technology utilized in this self-help system must be self-maintainable and be affordable by the local communities. Apart from technological aspects, encouraging *community participation* is among the most important principle to help low-income communities start their development and management strategies that can lead a successful community self-managed wastewater system.

5.2 SUGGESTIONS AND FUTURE STUDY

Comminity participation is one of the key social functions which shoud be considered within the development process of wastewater treament system. People might not be motivated to participate in activities that will have no direct impact on their own everyday life. Nevertheless, this assumption could not explian fully the lack of public participation in the context of developing countries. Most urban poors are typically undereducated, and thus have little knowleadge regarding the danger derived from their very own lifestyle. Formal decision-making processes often limited their access to participate, particularly people living in illegal/spontaneous settlements. Most participation initiatives still do not invest enough time and resource to educate participants to the extent that they can make the right or well-informed decision. In this light, different forms of local activities such as regular meetings or community cleaning projects could be instigated to improve public awareness and reinforce community participation. To provide the financially sustainable wastewater treatment system, all stakeholders, particularly the user communities, should be allowed to participate in the informed decision making of the service charge and billing systems.

In the study area, the specific fee for the wastewater treatment service has never been directly collected from the users. The highly operational and maintenance costs for the systems can hardly be covered by the community organization. Without the other source of financial supports and a collection of service charge, these systems could by no means establish any proper and effective decentralized wastewater treatment systems.

The main objective of the community's self-management approach is to stimulate the community involvement to provide its own services with only minor intervention from government. In the planning process of a community wastewater treatment system, the future study could focus on the socio-economic and settlement-related factors determining the potential of building public participation, and enhancing community capacity and support. The possibility and policy implication for integrating the community's self-management approach into the urban wastewater management planning and policy should also be extensively studied.

Suggestions and preconditions for applying the model include:

1. The purpose of the listing C&I is to give the user/decision maker a set of indicators from which most appropriate technology to the local situation can be selected.
2. Indicators can be used as a tool for monitoring or evaluating the performance of existing wastewater treatment systems in the future.
3. The proposed decision model and results are not the absolute manual for the wastewater technology selection. They, however, can be very useful approach for supporting the decision making process, provided some adjustment should be made elsewhere to fit the different context and time.
4. The proposed list of C&I and decision analysis module are very flexible. Other users can use it as a guideline and should also be able to develop more alternatives and new indicators to suite the local circumstances.
5. The study aims that the proposed set of C&I and the multi-criteria decision model will be useful to those who are interested in using them as a decision-making tool for the assessment, evaluation and selection of wastewater treatment technology alternatives. Prospect users might include: local/central government officials, funding agencies, community organizations, and NGOs.

As stated earlier, the finding from this research is due to bring about a new line of thought, contributing to the development of decision-making and supporting systems in the field of environmental engineering. The generalizations, nevertheless, could be limited to developing countries which share similar contextual characteristics with Thailand—in term of urban fabric, socio-economic, climatic and living conditions. Following this research, further study in developing countries elsewhere could refine the model to fit their respective local conditions.

APPENDIX A

DATA AND STATISTICS

A.1 Criteria and Indicator Assessment

Descriptive Statistical Data for Relative Weights of Principles Calculated by Ranking and Rating

Principle	Relative Weights			Average		Standard Derivation		Variance	
	Ranking	Rating	Combined	Ranking	Rating	Ranking	Rating	Ranking	Rating
P1.Reliability	15.8	15.7	16.0	7.58	19.56	1.41	15.86	2.00	251.61
P2. Simplicity/	12.0	9.1	11.8	6.09	13.22	2.10	16.07	4.40	258.31
P3. Efficiency	16.9	18.6	16.2	7.64	19.86	1.22	15.37	1.49	236.28
P4. Land Requirement	14.4	18.9	12.2	6.12	14.03	1.78	15.72	3.17	247.18
P5. Affordability	11.6	10.8	15.3	7.21	18.77	1.95	16.65	3.80	277.14
P6. Social Acceptability	14.5	14.6	14.1	7.12	16.22	1.75	15.91	3.05	253.00
P7. Sustainability	14.9	12.3	14.3	7.36	16.00	1.60	15.50	2.55	240.31

Descriptive Statistical Data for Relative Weights of Criteria Calculated by Ranking and Rating

Principle	Criteria*	Relative Weights			Average		Standard Derivation		Variance	
		Ranking	Rating	Combined	Ranking	Rating	Ranking	Rating	Ranking	Rating
1.Reliability	1.1 Long-term operation	35.62	36.87	36.25	7.24	39.06	1.94	16.77	3.75	281.35
	1.2 Short-term operation	32.04	30.68	31.36	6.52	32.50	1.46	16.66	2.13	277.42
	1.3 Mechanical reliability	32.34	32.45	32.39	6.58	34.38	1.60	15.38	2.56	236.69
2.Simplicity	2.1 Ease of plant construction, system installation and startup	43.44	38.74	41.09	5.52	37.34	2.33	19.67	5.45	387.07
	2.2 Operation and maintenance requirement	56.56	61.26	58.91	7.18	59.06	2.52	21.83	6.34	476.51
3.Efficiency	3.1 Removal of wastewater constituents	-	-	-	-	-	-	-	-	-
4. Land Requirement	4.1 Size of land requirement	55.45	58.63	57.04	6.94	56.25	1.84	21.55	3.37	464.52
	4.2 Favorable land conditions	44.55	41.37	42.96	5.58	39.69	2.50	19.88	6.25	395.06
5.Affordability	5.1 Initial construction cost	47.16	40.27	43.72	6.79	41.41	1.67	16.52	2.80	272.96
	5.2 Annual operation and maintenance cost	52.84	59.73	56.28	7.61	61.41	1.82	14.66	3.31	214.89
6.Social Acceptability	6.1 General social (public) acceptability	50.20	49.38	49.79	7.64	50.97	1.34	13.93	1.80	194.03
	6.2 Environmental Impact/Perception	49.80	50.63	50.21	7.58	52.26	1.70	13.77	2.88	189.73
7.Sustainability	7.1 Continuity of system provision or operation	52.34	54.34	53.34	7.12	55.78	1.47	18.50	2.17	342.11
	7.2 Possibility of resource recovery	47.66	45.66	46.66	6.48	46.88	2.11	19.50	4.45	380.24

Note: * The relative importance of the entire set of criteria is shown in table, with the exception of 'Efficiency' in the third Principle, since it had only one criterion.

Descriptive Statistical Data for Relative Weights of Indicators Calculated by Ranking and Rating

Criteria	Indicators	Relative Weights			Average		Standard Derivation		Variance	
		Ranking	Rating	Combined	Ranking	Rating	Ranking	Rating	Ranking	Rating
C 1.1	I 1.1.1	24.3	25.2	24.7	6.70	25.17	2.11	9.96	4.47	99.17
	I 1.1.2	27.4	31.2	29.3	7.55	31.21	1.80	11.17	3.26	124.72
	I 1.1.3	23.4	21.3	22.3	6.45	21.26	2.08	7.63	4.32	58.17
	I 1.1.4	24.9	22.4	23.6	6.85	22.36	1.68	7.93	2.82	62.95
C 1.2	I 1.2.1	17.3	20.4	18.9	7.03	20.42	1.96	8.53	3.84	72.69
	I 1.2.2	16.1	17.3	16.7	6.55	17.33	1.35	6.99	1.82	48.90
	I 1.2.3	13.9	13.3	13.6	5.64	13.30	2.00	6.25	3.99	39.02
	I 1.2.4	13.6	12.6	13.1	5.52	12.60	1.60	5.10	2.57	26.02
	I 1.2.5	13.6	13.2	13.4	5.69	13.25	1.73	5.76	3.00	33.16
	I 1.2.6	15.8	16.1	16.0	6.42	16.13	1.50	9.49	2.25	90.06
	I 1.2.7	9.8	7.0	8.4	4.00	6.97	2.05	4.34	4.19	18.86
C1.3	I 1.3.1	47.9	46.7	47.3	6.58	46.72	1.60	11.47	2.56	131.63
	I 1.3.2	52.1	53.3	52.7	7.15	53.28	1.33	11.47	1.76	131.63
C2.1	I 2.1.1	17.0	17.0	17.0	6.00	16.99	1.95	10.27	3.81	105.41
	I 2.1.2	16.4	14.8	15.6	5.78	14.83	1.83	5.98	3.34	35.80
	I 2.1.3	18.1	18.2	18.2	6.41	18.21	1.98	8.68	3.93	75.39
	I 2.1.4	15.0	12.8	13.9	5.28	12.85	1.67	5.55	2.79	30.75
	I 2.1.5	14.4	11.1	12.8	5.09	11.14	1.69	4.29	2.86	18.36
	I 2.1.6	19.1	26.0	22.5	6.75	25.98	1.68	17.59	2.84	309.24
C2.2	I 2.2.1	24.0	26.3	25.1	7.38	26.30	2.06	10.46	4.24	109.44
	I 2.2.2	23.6	27.3	25.4	7.25	27.27	1.72	12.42	2.97	154.21
	I 2.2.3	18.6	17.3	18.0	5.72	17.33	1.87	7.76	3.50	60.15
	I 2.2.4	17.5	14.6	16.1	5.38	14.65	1.72	5.16	2.95	26.65
	I 2.2.5	16.4	14.4	15.4	5.03	14.45	2.13	6.32	4.55	39.88

Descriptive Statistical Data for Relative Weights of Indicators Calculated by Ranking and Rating (Continue)

Criteria	Indicators	Relative Weights			Average		Standard Derivation		Variance	
		Ranking	Rating	Combined	Ranking	Rating	Ranking	Rating	Ranking	Rating
C 3.1	I 3.1.1	26.34	31.82	29.08	8.18	35.16	1.07	17.94	1.15	321.75
	I 3.1.2	20.78	19.15	19.97	6.45	21.16	2.02	13.27	4.07	176.01
	I 3.1.3	19.02	18.39	18.71	5.91	20.31	2.02	14.42	4.09	207.96
	I 3.1.4	16.49	14.63	15.56	5.12	16.16	2.18	14.34	4.73	205.68
	I 3.1.5	17.37	16.01	16.69	5.39	17.69	2.28	14.69	5.18	215.71
C4.1	I 4.1.1	32.7	33.1	32.9	6.61	33.11	1.87	11.70	3.50	136.86
	I 4.1.2	33.3	31.8	32.6	6.73	31.77	1.92	10.62	3.70	112.86
	I 4.1.3	33.9	35.1	34.5	6.85	35.12	1.46	15.93	2.13	253.61
C4.2	I 4.2.1	31.7	31.0	31.3	6.52	30.95	1.50	9.08	2.26	82.37
	I 4.2.2	31.1	28.3	29.7	6.39	28.30	1.60	8.83	2.56	77.90
	I 4.2.3	37.3	40.7	39.0	7.67	40.75	1.55	11.69	2.42	136.70
C5.1	I 5.1.1	35.5	34.6	35.1	7.64	34.62	1.19	10.95	1.43	119.95
	I 5.1.2	31.5	29.0	30.2	6.76	28.98	1.70	6.72	2.88	45.12
	I 5.1.3	33.0	36.4	34.7	7.09	36.40	1.94	13.00	3.77	168.91
C5.2	I 5.2.1	18.1	18.8	18.5	7.36	18.83	1.58	9.60	2.49	92.11
	I 5.2.2	17.2	17.4	17.3	6.97	17.41	1.55	6.19	2.41	38.32
	I 5.2.3	16.0	14.3	15.1	6.48	14.26	1.64	5.28	2.70	27.84
	I 5.2.4	19.0	23.0	21.0	7.73	22.96	1.42	10.12	2.02	102.41
	I 5.2.5	12.3	9.9	11.1	5.16	9.87	1.95	4.04	3.81	16.29
	I 5.2.6	17.3	16.7	17.0	7.03	16.67	1.55	8.52	2.41	72.61
C6.1	I 6.1.1	37.2	37.3	37.2	7.70	37.27	1.33	12.97	1.78	168.23
	I 6.1.2	35.3	40.0	37.6	7.30	39.99	2.02	16.02	4.09	256.58
	I 6.1.3	27.5	22.7	25.1	5.70	22.74	2.30	10.07	5.28	101.48

Descriptive Statistical Data for Relative Weights of Indicators Calculated by Ranking and Rating (Continue)

Criteria	Indicators	Relative Weights			Average		Standard Derivation		Variance	
		Ranking	Rating	Combined	Ranking	Rating	Ranking	Rating	Ranking	Rating
C 6.2	I 6.2.1	18.7	25.7	22.2	7.97	25.74	1.33	13.61	1.77	185.28
	I 6.2.2	16.1	16.3	16.2	6.88	16.30	1.90	5.16	3.60	26.65
	I 6.2.3	14.2	14.0	14.1	6.06	13.97	2.17	6.33	4.71	40.02
	I 6.2.4	13.1	11.4	12.3	5.59	11.40	2.08	4.89	4.31	23.92
	I 6.2.5	13.7	12.4	13.0	5.84	12.37	2.22	6.20	4.91	38.49
	I 6.2.6	12.7	10.7	11.7	5.41	10.71	2.11	4.81	4.44	23.10
	I 6.2.7	11.5	9.5	10.5	4.91	9.50	2.22	3.53	4.93	12.49
C7.1	I 7.1.1	34.0	34.7	34.4	7.32	34.73	1.38	9.02	1.89	81.32
	I 7.1.2	34.0	35.3	34.7	7.32	35.29	1.49	10.24	2.23	104.92
	I 7.1.3	31.9	30.0	31.0	6.87	29.98	1.54	8.84	2.38	78.21
C7.2	I 7.2.1	14.7	15.5	15.1	5.81	15.45	2.13	10.53	4.54	110.79
	I 7.2.2	17.4	20.8	19.1	6.91	20.83	1.86	9.63	3.44	92.74
	I 7.2.3	15.6	16.2	15.9	6.19	16.15	1.80	5.34	3.25	28.48
	I 7.2.4	15.1	14.1	14.6	6.00	14.12	1.95	4.61	3.81	21.21
	I 7.2.5	11.8	11.3	11.5	4.69	11.28	2.31	6.62	5.32	43.82
	I 7.2.6	10.2	7.8	9.0	4.06	7.79	2.05	4.12	4.19	17.00
	I 7.2.7	15.1	14.4	14.8	6.00	14.38	2.09	5.65	4.39	31.94

A.2 Summary of regression results for land requirements

Power regression:

$$y = ax^b$$

where: y = dependent variable (L; land requirements in m^2)
x = independent variable (Q: design capacity in m^3/day)
a = calculated coefficient
b = regression coefficient

Alt.1: Activated Sludge: $L = 1.467.Q^{0.985}$

```
Dependent variable.. AS_AREA           Method.. POWER

Multiple R           .91522
R Square             .83762
Adjusted R Square    .75643
Standard Error       .58352

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        3.5128608        3.5128608
Residuals      2         .6809855         .3404928

F =      10.31699       Signif F =  .0848

-------------------- Variables in the Equation --------------------

Variable                    B        SE B       Beta          T  Sig T

AS_CAPAC              .985280     .306749    .915217      3.212  .0848
(Constant)           1.466509    4.453731                  .329  .7732
```

Alt.2: Oxidation Ditch: $L = 183.398.Q^{0.513}$

```
Dependent variable.. OD_AREA           Method.. POWER

Multiple R           .77218
R Square             .59626
Adjusted R Square    .51552
Standard Error       .31836

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        .74840177        .74840177
Residuals      5        .50675109        .10135022

F =       7.38431       Signif F =  .0419

-------------------- Variables in the Equation --------------------

Variable                  B        SE B       Beta         T  Sig T

OD_CAPAC            .513319     .188900    .772181     2.717  .0419
(Constant)       183.397644  334.814883                 .548  .6074
```

Alt.3: Aerated Lagoons: $L = 9.876.Q^{0.940}$

```
Dependent variable.. AL_AREA           Method.. POWER

Multiple R           .80265
R Square             .64425
Adjusted R Square    .55531
Standard Error       .58967

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        2.5187416        2.5187416
Residuals      4        1.3908348         .3477087

F =       7.24383       Signif F =  .0546

-------------------- Variables in the Equation --------------------

Variable                  B        SE B       Beta         T  Sig T

AL_CAPAC            .939489     .349066    .802651     2.691  .0546
(Constant)         9.876397   34.685465                 .285  .7900
```

Alt.4: Waste Stabilization Ponds: $L = 127.735.Q^{0.762}$

```
Dependent variable.. WSP_AREA          Method.. POWER

Multiple R            .94320
R Square              .88962
Adjusted R Square     .87736
Standard Error        .29712

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        6.4036567        6.4036567
Residuals      9         .7945350         .0882817 ]\32

F =      72.53666       Signif F =  .0000

-------------------- Variables in the Equation --------------------

Variable                     B        SE B       Beta         T  Sig T

WASP_CAP               .761961     .089465    .943197     8.517  .0000
(Constant)          127.735613  104.398879                1.224  .2522
```

A-3 Summary of regression results for construction costs

Power regression:

$$y = ax^b$$

where: y = dependent variable (C_c : construction cost in million US$)
x = independent variable (Q: design capacity in m^3/day)
a = calculated coefficient
b = regression coefficient

Alt.1: Activated Sludge: $C_c = 0.0031.Q^{0.881}$

```
Dependent variable.. AS_CCOST          Method.. POWER


Multiple R           .98925
R Square             .97861
Adjusted R Square    .97326
Standard Error       .14074

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        3.6242827        3.6242827
Residuals      4         .0792274         .0198069

F =     182.98121       Signif F =  .0002

-------------------- Variables in the Equation --------------------

Variable                    B        SE B       Beta          T  Sig T

AS_CAPAC              .880948     .065125    .989246    13.527  .0002
(Constant)            .003137     .002016                1.556  .1946
```

Alt.2: Oxidation Ditch: $C_C = 0.0017.Q^{0.910}$

```
Dependent variable.. OD_CCOST          Method.. POWER

Multiple R           .77745
R Square             .60442
Adjusted R Square    .53850
Standard Error       .54437

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        2.7167868        2.7167868
Residuals      6        1.7780450         .2963408

F =       9.16778       Signif F =  .0232

-------------------- Variables in the Equation --------------------

Variable                    B         SE B       Beta          T  Sig T

OD_CAPAC              .910024     .300553    .777447     3.028  .0232
(Constant)            .001726     .005019                 .344  .7427
```

Alt.3: Aerated Lagoons: $C_C = 0.0143.Q^{0.681}$

```
Dependent variable.. AL_CCOST          Method.. POWER

Multiple R           .90682
R Square             .82232
Adjusted R Square    .80258
Standard Error       .21105

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        1.8554230        1.8554230
Residuals      9         .4008969         .0445441

F =      41.65362       Signif F =  .0001

-------------------- Variables in the Equation --------------------

Variable                    B         SE B       Beta          T  Sig T

AL_CAPAC              .681316     .105566    .906820     6.454  .0001
(Constant)            .014252     .014775                 .965  .3600
```

Alt.4: Waste Stabilization Ponds: $C_c = 0.0004.Q^{1.060}$

```
Dependent variable.. WSPCCOST          Method.. POWER

Multiple R           .88878
R Square             .78992
Adjusted R Square    .77992
Standard Error       .57721

            Analysis of Variance:

               DF   Sum of Squares      Mean Square

Regression      1        26.308811        26.308811
Residuals      21         6.996698          .333176

F =      78.96368       Signif F =  .0000

-------------------- Variables in the Equation --------------------

Variable                   B         SE B       Beta          T  Sig T

WASP_CAP            1.060117      .119300    .888777      8.886  .0000
(Constant)           .000444      .000476                  .934  .3610
```

A.4 Summary of regression results for operation and maintenance costs

Linear regression:

$$y = a + bx$$

where: y = dependent variable ($C_{O\&M}$: operation and maintenance cost in million US$)
x = independent variable (F: design capacity in m^3/day)
a = constant
b = regression coefficient

Alt.1: Activated Sludge: $C_{O\&M} = 0.0529 + 1.31 \times 10^{-5}.F$

```
Dependent variable.. AS_OM             Method.. LINEAR

Multiple R           .99813
R Square             .99625
Adjusted R Square    .99438
Standard Error       .02247

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        .26846297        .26846297
Residuals      2        .00100955        .00050477

F =     531.84915       Signif F =  .0019

-------------------- Variables in the Equation --------------------

Variable                  B        SE B       Beta         T  Sig T

AS_RFLOW     1.31042673E-05  5.6822E-07    .998125    23.062  .0019
(Constant)          .052909     .018723               2.826  .1057
```

Alt.2: Oxidation Ditch: $C_{O\&M} = 0.0963 + 1.02 \times 10^{-5}.F$

```
Dependent variable.. OD_OM             Method.. LINEAR

Multiple R           .88814
R Square             .78879
Adjusted R Square    .76239
Standard Error       .03197

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        .03054381        .03054381
Residuals      8        .00817857        .00102232

F =      29.87693       Signif F =  .0006

-------------------- Variables in the Equation --------------------

Variable                    B         SE B       Beta          T  Sig T

OD_RFLOW     1.01629664E-05  1.8593E-06    .888138     5.466  .0006
(Constant)           .096347     .016880                5.708  .0005
```

Alt.3: Aerated Lagoons: $C_{O\&M} = 0.0607 + 3.31 \times 10^{-6}.F$

```
Dependent variable.. AL_OM             Method.. LINEAR

Multiple R           .83218
R Square             .69252
Adjusted R Square    .64128
Standard Error       .04092

            Analysis of Variance:

              DF   Sum of Squares      Mean Square

Regression     1        .02262501        .02262501
Residuals      6        .01004544        .00167424

F =      13.51360       Signif F =  .0104

-------------------- Variables in the Equation --------------------

Variable                    B         SE B       Beta          T  Sig T

AL_RFLOW     3.30937321E-06  9.0024E-07    .832179     3.676  .0104
(Constant)           .060651     .017511                3.464  .0134
```

Alt.4: Waste Stabilization Ponds: $C_{O\&M} = 0.0178 + 4.03 \times 10^{-6}.F$

```
Dependent variable.. WAP_OM            Method.. LINEAR

Multiple R           .83320
R Square             .69421
Adjusted R Square    .67623
Standard Error       .02614

            Analysis of Variance:

               DF   Sum of Squares      Mean Square

Regression      1        .02636395        .02636395
Residuals      17        .01161274        .00068310

F =      38.59444       Signif F =  .0000

-------------------- Variables in the Equation --------------------

Variable                    B        SE B       Beta         T  Sig T

WS_RFLOW     4.03396931E-06  6.4934E-07    .833195     6.212  .0000
(Constant)          .017824     .007175                2.484  .0237
```

A.5 Data Analysis Results for Economic Indicators

System	Treatment Plant	Start operation year	Design Capacity (m^3/d)	Actual Flow (m^3/d)	Land Requirement (m^2)	Construction Costs (Million Baht)	Present Value at Year 2007 (Million Baht)	Present Value at Year 2007 (Million US$)	Annual O&M (Million US$)
Activated Sludge	Ayuthaya_phrain	1999	4,500	1,900	8,000	148.30	180.28	5.23	
	Chonburi	2001	22,500	10,315	16,000	565.00	665.27	19.28	0.17
	Chonburi Pataya-Nakue	2000	65,000	50,000	128,000	1,786.88	2,138.93	62.00	0.83
	Chonburi Soi Wat	1994	20,000	6,000	20,800	359.11	559.57	16.22	0.24
	Phuket	1998	36,000	20,443		912.00	1,112.06	32.23	0.35
	Prachup_Hua Hin2	2002	8,500			310.00	362.70	10.51	
Oxidation Ditches	Ayuthaya_City	1998	25,000	1,500		496.92	605.93	17.56	0.22
	Chachoengsao	1998	24,000	3,000	33,600	240.00	292.65	8.48	0.26
	Chonburi_Lamchabang	1999	25,000	1,450	59,200	179.60	218.33	6.33	0.07
	Chonburi_Sansuk1	1995	14,000		19,000				
	Chonburi_Sansuk2	1995	9,000		19,200				
	Chonburi_Sriracha	1997	18,000	1,444		115.52	152.24	4.41	0.17
	Kanchanaburi	2001	24,000	12,000		574.25	676.16	19.60	0.15
	Nonthaburi	2001	38,500	20,000	32,000	616.00	725.32	21.02	0.23
	Pathumthani	1997	11,000			340.00	448.08	12.99	0.14
	Phuket_Patong	1989	14,250	7,000	20,800	360.19	710.19	20.59	0.24
	Rajaburi_Potharam	1998	5,000	2,500	16,000	55.92	68.19	1.98	0.11
	Rayong_Banpa	1999	8,000	941		230.00	279.59	8.10	0.11
Aerated Lagoons	Angthong	1998	8,200	900	27,200	179.00	218.27	6.33	0.09
	Burirum	2001	13,000	6,500		249.30	293.54	8.51	0.06
	Chaengmai	1997	55,000	15,000	160,000	760.09	1,001.72	29.04	
	Khonkaen_Thungsang	2002	50,000	50,000	233,600	533.00	648.48	18.80	0.24
	Petchaburi_Chaum	2001	17,000	2,306		359.50	423.30	12.27	0.04
	Pichit	1997	12,000	3,000	68,800	180.00	237.22	6.88	0.15
	Prachupkirikhan	1998	8,000	2,480		200.00	243.87	7.07	0.06
	Rayong_Maptaput	2001	15,000			286.70	337.58	9.78	
	Songkhla	2000	35,000	5,000	281,600	298.70	357.55	10.36	
	Trang	1998	17,700	8,000		480.80	586.27	16.99	0.05
	Ubon Rajathani	1998	22,000	5,500	176,000	370.00	451.17	13.08	0.09

(Continue)

System	Treatment Plant	Start operation year	Design Capacity (m^3/d)	Actual Flow (m^3/d)	Land Requirement (m^2)	Construction Costs (Million Baht)	Present Value at Year 2007 (Million Baht)	Present Value at Year 2007 (Million US$)	Annual O&M (Million US$)
Waste Stabilization Ponds	Chainart	1998	3,469	2,500	80,000	203.80	248.51	7.20	0.02
	Chanthaburi	1996	17,000	2,591		300.00	417.44	12.10	0.02
	Chonburi_Panat	1992	5,000	2,000		30.00	50.74	1.47	0.02
	Chumsang_ Nakorn Sawan	1997	1,650	487		52.42	69.08	2.00	0.02
	Kampaengpetch	1999	13,500	2,500		230.00	279.59	8.10	0.02
	Krung Chanthaburi	2000	5,400	2,591	54,400	128.24	153.51	4.45	0.02
	Lopburi_Banmi	1993	1,000	600		4.68	7.66	0.22	0.00
	Mahasarakham	2002	1,500	600	32,000	21.39	25.03	0.73	0.03
	Nakorn Pathom	1994	60,000	15,000	456,000	219.16	341.50	9.90	0.08
	Nakorn Rajasrima	2002	32,000	50,884	492,800	655.00	766.34	22.21	
	Nan	2000	8,259	1,400	161,600	478.33	572.57	16.60	0.07
	Pakchong_Narorn Rajasima	2002	1,500	2,000		255.66	299.12	8.67	0.04
	Petchaburi	1994	10,000	3,500		117.60	183.25	5.31	
	Phayao	1998	9,700	3,598	126,400	200.00	243.87	7.07	0.02
	Rachaburi_Banpong	1998	5,000	5,000		82.74	100.89	2.92	0.01
	Rajaburi	2001	20,000	17,000	272,000	359.00	422.71	12.25	0.11
	Sakon Nakorn	1998	16,000	7,295		630.00	768.20	22.27	0.14
	Sakon Nakorn_Tharae	2000	2,054	952		60.76	72.73	2.11	0.01
	Singburi	2002	4,500	1,900	107,200	249.50	291.91	8.46	
	Songkha_Hatyai	1999	69,000	60,000		1,784.38	2,169.13	62.87	0.16
	Suphaburi_Uthong	2001	5,500	3,500		135.51	159.56	4.62	0.01
	Suphanburi	2003	11,400	2,000	112,000	363.21	417.43	12.10	
	Tak	1999	5,400	2,903	80,000	66.40	80.72	2.34	
	Ubon_Warinchamrub	2002	22,000	2,896		309.00	361.53	10.48	0.01

1USD = 34.5 Baht [a] Exclude identified outlier(s) from the model(s)

Thailand Inflation Rate (average consumer prices)

Year	Inflation, average consumer prices	Year	Inflation, average consumer prices
1983	3.700	1996	5.871
1984	0.900	1997	5.583
1985	2.400	1998	8.080
1986	1.800	1999	0.308
1987	2.490	2000	1.554
1988	3.800	2001	1.661
1989	5.370	2002	0.639
1990	5.890	2003	1.801
1991	5.702	2004	2.768
1992	4.154	2005	4.542
1993	3.295	2006	4.642
1994	5.081	2007	2.229
1995	5.773		

Source: International Monetary Fund- 2008 World Economic Outlook

Computations of Indicators (Input Values) for Each Alternative (Continue)

Technology Alternatives	Reliability (P1)												
	I1.1.1(a)	I1.1.1 (b)	I1.1.2	I1.1.3	I1.1.4	I1.2.1	I1.2.2	I1.2.3	I1.2.5	I2.2.6	I2.2.7	I1.3.1	I1.3.2
AS	4.25	3.50	3.75	2.25	2.50	3.25	3.50	3.25	2.00	2.25	3.50	2.75	3.00
OD	3.90	3.27	3.33	2.20	2.00	3.67	3.60	3.50	1.20	2.70	2.90	2.00	3.00
AL	4.00	3.09	3.50	1.50	2.00	3.67	3.50	3.67	1.00	2.67	1.67	1.50	2.67
WSP	3.57	3.40	3.67	2.00	1.93	3.13	3.71	3.36	1.71	2.47	2.73	2.00	2.20

Technology Alternatives	Simplicity (P2)							Removal efficiency (P3)					Land requirements (P4)			
	I2.1.1	I2.1.2	I2.1.3	I2.1.4	I2.1.5	I2.2.2	I2.2.5	I3.1.1	I3.1.2	I3.1.3	I3.1.4	I3.1.5	I4.1.3 (m.)	I4.2.1	I4.2.2	I4.2.3
AS	4.75	4.75	4.00	2.50	2.00	3.90	3.50	4.00	4.00	2.00	2.00	3.00	75	2.33	2.00	4.00
OD	4.00	3.70	3.80	3.33	2.00	4.03	3.40	5.00	5.00	2.00	1.00	4.00	75	1.33	2.00	2.63
AL	2.33	3.00	2.33	3.00	2.00	2.93	3.00	3.00	2.00	3.00	2.00	5.00	300	1.50	1.50	2.00
WSP	3.79	4.14	3.79	3.00	1.80	2.80	3.20	3.00	2.00	4.00	3.00	5.00	300	1.60	1.60	2.60

Computations of Indicators (Input Values) for Each Alternative (Continue)

Technology Alternatives	Social Acceptability (P6)					Sustainability (P7)											
	I6.1.1	I6.2.1	I6.2.2	I6.2.3	I6.2.4	I7.1.1 (yr.)	I7.1.2	I7.1.3 (budget)	I7.1.3 (land)	I7.1.3 (tech.)	I7.2.1	I7.2.2	I7.2.3	I7.2.4	I7.2.5	I7.2.6	I7.2.7
AS	4.25	2.00	5.00	2.00	5.00	20	2	3.66	2.80	2.86	2.33	3.50	2.75	2.75	2.50	1.33	2.75
OD	4.33	1.00	5.00	2.00	5.00	20	2	3.66	2.80	2.86	1.14	3.44	2.67	2.44	2.44	1.13	2.78
AL	4.33	2.00	5.00	3.00	5.00	20	2	3.66	2.80	2.86	1.33	4.33	3.00	3.00	2.33	1.50	3.00
WSP	4.13	3.00	1.00	5.00	1.00	20	2	3.66	2.80	2.86	1.14	3.21	2.92	2.69	2.50	1.31	2.21

Case Study	Pop	Flow (m^3/d)	System	Land Requirements (P4)		Affordability (P5)		
				4.1.1 Land Area (m^2)	Land Value* (US$/$m^2$)	I5.1.2 Land Cost (Million US$)	I5.1.1 Construction Cost (Million US$)	I5.1.3 Annual O&M Costs (Million US$)
RK 2	8,925	1,874	AS	2,456	94.2	0.23	2.37	0.07
			OD	8,757		0.82	1.62	0.12
			AL	11,777		1.11	2.42	0.07
			WSP	39,831		3.75	1.20	0.03
FNRK 2	10,550	2,216	AS	2,895	24.6	0.07	2.75	0.08
			OD	9,542		0.23	1.88	0.12
			AL	13,782		0.34	2.71	0.07
			WSP	45,246		1.11	1.43	0.03

Wastewater generation = 210 L/cap/day; 5 capita per housing unit; 1USD = 34.5 Baht

*Data Source: The Treasury Department (2008). Summary of Land Valuation in the Bangkok Metropolitan Area.

APPENDIX B

LIST OF INDICATORS

Summary of Principles, Criteria, and Indicators

Concepts (Principles)	Dimension of Interest (Criteria)	Specific questions or Measures (Indicators)
Technical Aspects		
P1.Reliability	C1.1 Long-term operation (events occurring over the lifetime of the system)	I1.1.1 What is the possibility that the plant will operate "properly" over its life expectancy?
		I1.1.2 What is the possibility that the effluent will consistently meet the requirements?
		I1.1.3 How often could shutdowns occur due to hardware or process problems?
		I1.1.4 What is the possibility that system failures can cause violations of effluent quality?
	C1.2 Short-term operation (events occurring during annual operation)	How well can the process respond to the variation of the following influent characteristics? I1.2.1 High flow rate
		I1.2.2 Periodic shock BOD loading
		I1.2.3 Extremely low BOD loading
		I1.2.4 Toxic contaminations (Pesticides, Heavy metal, etc.)
		I1.2.5 How often will the process be upset due to the variation of influent characteristics?
		I1.2.6 How do such occurrences (system upset) affect the quality of the effluent?
		I1.2.7 How does weather variation affect system performance?
	C1.3 Mechanical reliability	I1.3.1How often would unplanned maintenance events be caused due to mechanical (component) failures?
		I1.3.2 What is the possibility that mechanical (component) failures can cause violations of effluent quality?
P2. Simplicity/ Complexity	C2.1 Ease of plant construction, system installation and startup	I2.1.1 What is the overall complexity of plant construction?
		I2.1.2What is the overall complexity of system installation?
		I2.1.3 How difficult will it be to start the system?
		I2.1.4 How much time is needed for plant construction?
		I2.1.5 How much time is needed for system installation?
		I2.1.6 How much time is needed to start-up the system?
	C2.2 Operation and maintenance requirement	I2.2.1 Complexity of operation and maintenance
		I2.2.2 Skill and personnel requirement
		I2.2.3 Time requirement for training
		I2.2.4 Special operating and maintenance requirements
		I2.2.5 Special manufactured or imported equipment and spare parts
P3. Efficiency	C3.1 Removal of wastewater constituents	I3.1.1 Removal efficiency of BOD
		I3.1.2 Removal efficiency of Suspended Solids
		I3.1.3 Removal efficiency of Total Nitrogen
		I3.1.4 Removal efficiency of Total Phosphorus
		I3.1.5 Removal efficiency of pathogens

(Continued)

Concepts (Principles)	Dimension of Interest (Criteria)	Specific questions or Measures (Indicators)
Socio-Economic Aspects		
P4. Land Requirement	C4.1 Size of land requirement	I4.1.1 Total area of wastewater treatment facility
		I4.1.2 Plant footprint
		I4.1.3 Buffer zone around the plant facility
	C4.2 Favorable land conditions	I4.2.1 Impact of groundwater level on the system operation
		I4.2.2 Impact of soil type on the system operation (i.e. infiltration effect)
		I4.2.3 Flooding risk
P5. Affordability	C5.1 Initial construction cost	I5.1.1 Construction cost (excluding land cost)
		I5.1.2 Land cost
		I5.1.3 Cost subsidy from the government
	C5.2 Annual operation and maintenance costs	I5.2.1 Operational cost (excluding energy cost)
		I5.2.2 Maintenance cost (material and equipment)
		I5.2.3 Personnel cost
		I5.2.4 Energy cost
		I5.2.5 Administration cost
		I5.2.6 Source of revenue for operation and maintenance
P6. Social (public) Acceptability	C6.1 General social (public) acceptability	I6.1.1 Public acceptability of the system operation
		I6.1.2 Public support for wastewater fee collection (fee collection rate)
		I6.1.3 Public participation in system operation and maintenance
	C6.2 Environmental Impact/Perception	I6.2.1 Odor production
		I6.2.2 Noise impact
		I6.2.3 Breeding insects and other parasites
		I6.2.4 Aerosol production
		I6.2.5 Groundwater quality impact
		I6.2.6 Landscape/visual impact
		I6.2.7 Traffic impact
Environmental Aspects		
P7. Sustainability	C7.1 Continuity of system provision or operation	I7.1.1 Life expectancy of the system
		I7.1.2 Possibility to upgrade or extend the plant operation for future development
		I7.1.3 Limitation factors (i.e. cost, land and technology) for the system upgrade or extension
	C7.2 Possibility of resource recovery	I7.2.1 By-product (biogas)
		I7.2.2 Ability to reuse the treated wastewater
		I7.2.3 Non-contact irrigation
		I7.2.4 Irrigation of non-food crops
		I7.2.5 Irrigation of food crops
		I7.2.6 Groundwater recharge via surface infiltration
		I7.2.7 Recycling of organic matter or fertilizer

APPENDIX C

EXAMPLE OF QUESTIONNAIRE: EXPERT SURVEY

Expert Survey: (Domestic) Wastewater Treatment System Evaluation

- *This form is organized around the three hierarchical elements, namely; Principles, Criteria, and Indicators. Ranking and Rating methods are applied to evaluate and select a set of decision criteria and indicators that could be used for assessing the appropriate wastewater treatment technology in Thailand.*
- *The form's structure will start with Criteria analysis first, then Indicators, and finally the Principle.*

Name:_____________________ _______________ **Organization:** ________________________________

Job Title: _________________________________ **Filed of Expertise:**____________________________

Years of Experience in the Wastewater Treatment: __________**Years**

Criteria Analysis

- ***Ranking Method:*** *Please assign a rank depending on its perceived importance. Ranks are assigned according to the following* ***nine-point scale*** *(1=Unimportant; 3= Less Important; 5= Moderately Important; 7=Important; 9=Extremely Important).*
- ***Rating Method:*** *Please give each Criterion(C) a rating score between 0 and 100 according to your opinion in the importance of each Criterion relative to the Principle, in particular, and overall assessment of appropriate wastewater treatment technologies in Thailand. The scores for all the elements being compared must add up o 100.*

Principle 1: Reliability

Criterion	Ranking (scale 1 - 9)	Rating	Remarks
C1.1 Plant performance: Long-term operation: *events occurring over the lifetime of the treatment plant)*			
C1.2 Plant performance: Short-term operation: *events occurring during annual operation*			
C1.3 Mechanical reliability			
	Total =	**100**	

Principle 2: Simplicity

Criterion	Ranking (scale 1 - 9)	Rating	Remarks
C2.1 Ease of plant construction and system installation and startup			
C2.2 Operating and maintenance requirement			
	Total =	**100**	

Principle 3: Land Requirement

Criterion	Ranking (scale 1 - 9)	Rating	Remarks
C3.1 Size of land requirement			
C3.2 Favorable land conditions			
	Total =	**100**	

Principle 4: Affordability

Criterion	Ranking (scale 1 - 9)	Rating	Remarks
C4.1 Initial construction cost			
C4.2 Annual operation and maintenance cost			
	Total =	**100**	

Principle 5: Efficiency

Criterion	Ranking (scale 1 - 9)	Rating	Remarks
C5.1 Removal efficiency of BOD			
C5.2 Removal efficiency of Suspended Solids			
C5.3 Removal efficiency of Total Nitrogen			
C5.4 Removal efficiency of Total Phosphorus			
C5.5 Removal efficiency of Coliform			
	Total =	**100**	

Principle 6: Social (public) Acceptability

Criterion	Ranking (scale 1 - 9)	Rating	Remarks
C6.1 Social (public) acceptability			
C6.2 Environmental Impact			
	Total =	**100**	

Principle 7: Sustainability

Criterion	Ranking (scale 1 - 9)	Rating	Remarks
C7.1 Life expectancy			
C7.2 Resource recovery			
	Total =	**100**	

Indicator Analysis

- ***Ranking Method:*** *Please assign a rank depending on its perceived importance. Ranks are assigned according to the following* ***nine-point scale*** *(1=Unimportant; 3= Less Important; 5= Moderately Important; 7=Important; 9=Extremely Important).*
- ***Rating Method:*** *Please give each Indicator (I) a rating score between 0 and 100 according to your opinion in the importance of each Indicator relative to the Criterion, in particular, and overall assessment of appropriate wastewater treatment technologies in Thailand. The scores for all the elements being compared must add up o 100.*

C1.1 Plant performance: Long-term operation: ***events occurring over the lifetime of the treatment plant)***

Criterion	Ranking (scale 1 - 9)	Rating	Remarks
I.1.1.1 What is the probability that the plant is operating "properly" over its life expectancy?			
I.1.1.2 What is the probability that the effluent will consistently meet the requirements?			
I.1.1.3 How often could the operational shutdown possibly occur due to hardware or process problems?			
I.1.1.4 What is the probability that system failures can cause violations of effluent quality			
	Total =	**100**	

C1.2 Plant performance: Short-term operation: ***events occurring during annual operation)***

Criterion	Ranking (scale 1- 9)	Rating	Remarks
I.1.2.1 How well can the process respond to **high flow**?			
I.1.2.2 How well can the process respond to a **periodic shock BOD loading**?			
I.1.2.3 How well can the process respond to an **extremely low BOD loading**?			
I.1.2.4 How well can the process respond to **toxic contaminations** (Pesticides, Heavy metal, etc.)?			
I.1.2.5 How often the process will be upset by the above conditions?			
I.1.2.6 How do such occurrences (system upset) affect the quality of the effluent?			
I.1.2.7 How does the weather variation negatively affect the system performance?			
	Total =	**100**	

C1.3 Mechanical reliability

Criterion	Ranking (scale 1- 9)	Rating	Remarks
I.1.3.1 How often would unplanned maintenance events be made due to mechanical (component) failures?			
I.1.3.2 What is the probability that mechanical (component) failures can cause violations of effluent quality?			
	Total =	**100**	

C2.1 Ease of plant construction and system installation and startup

Criterion	Ranking (scale 1- 9)	Rating	Remarks
I.2.1.1 The overall complexity of plant construction			
I.2.1.2 The overall complexity of system installation			
I.2.1.3 The overall complexity of system startup			
1.2.1.4 How much time is needed to construct, install and start the system			
1.2.1.5 How much time is needed to construct, install and start the system			
1.2.1.6 How much time is needed to construct, install and start the system			
	Total =	100	

C2.2 Operating and maintenance requirement

Criterion	Ranking (scale 1- 9)	Rating	Remarks
2.2.1 Complexity in operation and maintenance			
2.2.2 Skill and personnel requirement			
2.2.3 Time requirement for training			
2.2.4 Special operating and maintenance requirements			
2.2.5 Special manufactured or imported equipment and spare parts			
	Total =	**100**	

C3.1 Size of land requirement

Criterion	Ranking (scale 1- 9)	Rating	Remarks
3.1.1 Total area of wastewater treatment facility			
3.1.2 Plant footprint			
3.1.3 Buffer zone			
	Total	100	

C3.2 Favorable land conditions

Criterion	Ranking (scale 1- 9)	Rating	Remarks
3.2.1 Groundwater level			
3.2.2 Soil type			
3.2.3 Flooding risk			
	Total	100	

C4.1 Initial construction cost

Criterion	Ranking (scale 1- 9)	Rating	Remarks
4.1.1 Construction cost (excluding land cost)			
4.1.2 Land cost			
4.1.3 Cost subsidy from government			
	Total	100	

C4.2 Annual operation and maintenance cost

Criterion	Ranking (scale 1- 9)	Rating	Remarks
4.2.1 Operational cost (excluding energy cost)			
4.2.2 Maintenance cost (material and equipment)			
4.2.3 Personnel cost			
4.2.4 Energy cost			
4.2.5 Administration cost			
4.2.6 Source of revenue for operation and maintenance			
	Total	100	

C6.1 Social (public) acceptability

Criterion	Ranking (scale 1- 9)	Rating	Remarks
6.1.1 Public acceptability of the plant operation			
6.1.2 Public's willingness-to-pay for wastewater charge			
6.1.3 Public participation in the process of plant operation			
	Total	100	

C6.2 Environmental Impact

Criterion	Ranking (scale 1- 9)	Rating	Remarks
6.2.1 odor production			
6.2.2 Noise impact			
6.2.3 Creation of insect and other parasites			
6.2.4 Aerosol production			
6.2.5 Groundwater quality impact			
6.2.6 Landscape/visual impact			
6.2.7 Traffic impact			
	Total	100	

C7.1 Life expectancy

Criterion	Ranking (scale 1- 9)	Rating	Remarks
7.1.1 Life expectancy of the system			
7.1.2 Possibility to upgrade or extend the plant operation for future development			
7.1.3 Limiting factors to the system upgrade and extension (i.e. cost, land, technology)			
	Total	100	

C7.2 Resource recovery

Criterion	Ranking (scale 1- 9)	Rating	Remarks
7.2.1 By-product (biogas)			
7.2.2 Ability to reuse the treated wastewater			
7.2.3 Non-contact irrigation			
7.2.4 Irrigation of non-food crops			
7.2.5 Irrigation of food crops			
7.2.6 Groundwater recharge via surface infiltration			
7.2.7 Recycling of organic matter or fertilizer			
	Total	100	

Principle Analysis

- ***Ranking Method**: Please assign a rank depending on its perceived importance. Ranks are assigned according to the following **nine-point scale** (1=Unimportant; 3= Less Important; 5= Moderately Important; 7=Important; 9=Extremely Important).*
- ***Rating Method**: Please give each Principle (P) a rating score between 0 and 100 according to your opinion in the importance of each Principle relative to overall assessment of appropriate wastewater treatment technologies in Thailand. The scores for all the elements being compared must add up o 100.*

Criterion	Ranking (scale 1- 9)	Rating	Remarks
P1.Reliability			
P2. Complexity/ Simplicity			
P3. Land Requirement			
P4. Affordability			
P5. Efficiency			
P6. Social Acceptability			
P7. Sustainability			
	Total	**100**	

Suggestion :

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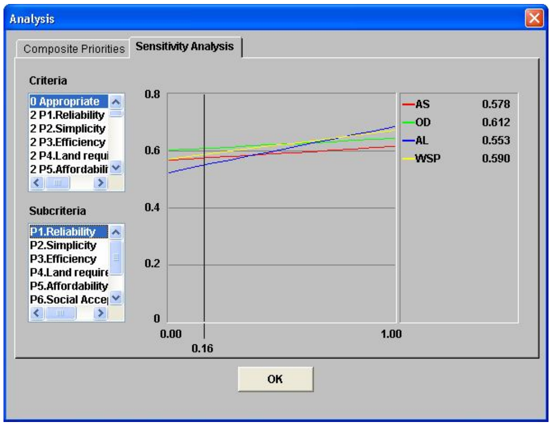
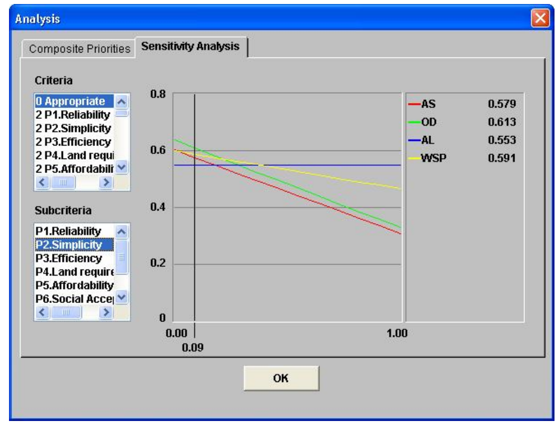
APPENDIX D

SENSITIVITY ANALYSIS

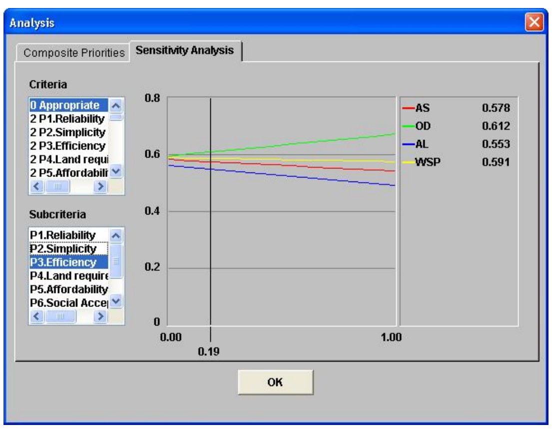
P1 System Reliability



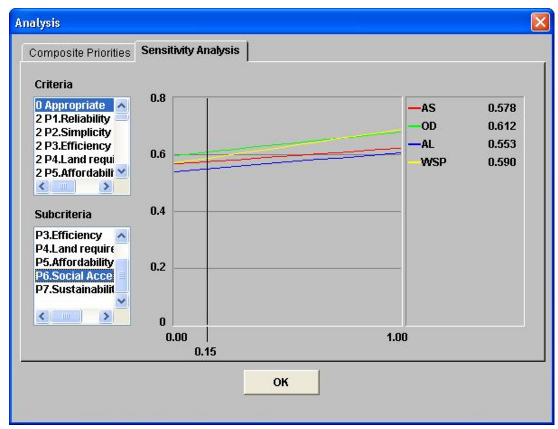
P2 Simplicity



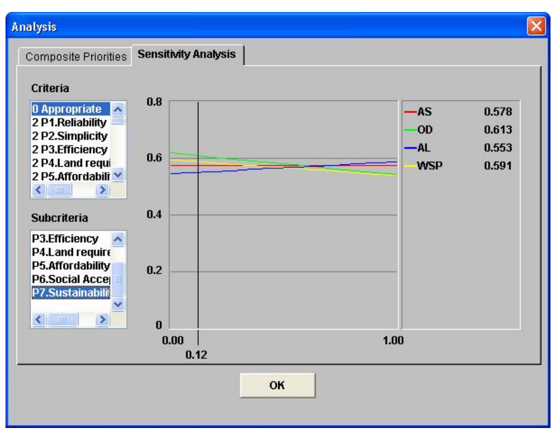
P3 Efficiency



P6 Social (public) Acceptability



P7 Sustainability



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