WATER AUDIT AND WATER EFFICIENCY OPTIONS IN HOSPITAL
CASE STUDY: A LARGE PRIVATE GENERAL HOSPITAL IN BANGKOK METROPOLITAN

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ABSTRACT

A water audit for the water efficiency options was carried out in Thonburi Hospital, a 435-bed general hospital, located in Bangkok Metropolitan. The purpose of this research was to propose suitable water efficiency alternatives to the studied hospital. The process of the water audit included site study, preparation for a water audit, conducting a measurement of water flowrate and quantity in order to determine water balance, identifying and prioritizing water efficiency options, feasibility evaluation of options, and recommending water efficiency options.

The results from the water balance revealed that the hospital used water at an average quantity of 834.4 m^3/day (1842-l/bed-day). In the details, medical treatment and the patient ward used the most water in the studied hospital with a flowrate of 452.16 m^3/day (54%). The food preparation unit, softened water, dormitory, laundry, and other units were found in the water usage of 158.74 m^3/day (19%), 89.43 m^3/day (11%), 64.36 m^3/day (8%), 58.70 m^3/day (7%), and 11.01 m^3/day (1%), respectively. The possible water efficiency options were identified and prioritized. Some possible options ,found in this research, were not suitable for implementation. Therefore, feasibility studies were conducted for each option through cost-effective analysis based on the payback period. High investment cost options that had long payback period were eliminated.

Finally, there were nine recommended water efficiency options for the studied hospital. The research anticipated that the implementation of all recommended options could save 76,806 m^3/year of water usage, costing 1,305,695 Baht/year, with the investment cost of 197,720 Baht and payback period within 0.15 year. And if the estimated cost reduction from Bangkok Metropolitan Administration central wastewater treatment was included, the research anticipated that the hospital could save the total cost of 1,612,919 Baht/year, with the same investment cost and payback period within 0.12 year.

KEY WORDS : WATER AUDIT / WATER EFFICIENCY / WATER SAVING / WATER BALANCE / HOSPITAL

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การตรวจประเมินและการเพิ่มประสิทธิภาพการใช้น้ำในโรงพยาบาล: กรณีศึกษาโรงพยาบาลเอกชนขนาดใหญ่ในกรุงเทพมหานคร (WATER AUDIT AND WATER EFFICIENCY PROGRAM IN HOSPITAL CASE STUDY: A LARGE PRIVATE GENERAL HOSPITAL IN BANGKOK METROPOLITAN REGION)

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บทคัดย่อ

งานวิจัยนี้เป็นการศึกษาเพื่อหาแนวทางที่เหมาะสมในการเพิ่มประสิทธิภาพในการใช้น้ำของโรงพยาบาลธนบุรี ซึ่งเป็นโรงพยาบาลทั่วไปขนาด 435 เตียง ตั้งอยู่ในเขตกรุงเทพมหานคร โดยการตรวจประเมินการใช้น้ำประกอบด้วย การศึกษาพื้นที่โครงการ, การเตรียมการตรวจประเมินการใช้น้ำ, การวัดอัตราการไหลและปริมาณการใช้น้ำ, การทำสมดุลปริมาณการใช้น้ำ, การบ่งชี้และลำดับความสำคัญของทางเลือกที่เป็นไปได้ในการเพิ่มประสิทธิภาพการใช้น้ำ, การประเมินความเป็นไปได้ของทางเลือกต่าง ๆ, และการเสนอทางเลือกที่เหมาะสมสำหรับการเพิ่มประสิทธิภาพการใช้น้ำ

จากการศึกษาสมดุลปริมาณการใช้น้ำพบว่าโรงพยาบาลใช้น้ำเฉลี่ย 834.4 ลบ.ม/วัน (1842 ลิตร/เตียง-วัน) และปริมาณการใช้น้ำมากที่สุดมาจากกิจกรรมการตรวจรักษาโรคและการใช้น้ำในหอผู้ป่วยเท่ากับ 452.16 ลบ.ม/วัน (54%) รองลงมาคือปริมาณการใช้น้ำจากแผนกโภชนาการและโรงอาหาร, น้ำอ่อน, หอพัก, แผนกซักรีด, และ หน่วยสนับสนุนอื่น ๆ คิดเป็น 158.74 ลบ.ม/วัน (19%), 89.43ลบ.ม/วัน (11%), 64.36ลบ.ม/วัน (8%), 58.70 ลบ.ม/วัน (7%), และ11.01ลบ.ม/วัน (1%) ตามลำดับ

งานวิจัยนี้พบว่าโรงพยาบาลสามารถเพิ่มประสิทธิภาพในการใช้น้ำ โดยมีทางเลือกที่เหมาะสมจำนวน 9 ทางเลือก และหากทางเลือกที่เหมาะสมถูกนำไปปฏิบัติจะทำให้โรงพยาบาลธนบุรีสามารถประหยัดน้ำได้ 76,806 ลบ.ม/ปี คิดเป็นมูลค่า 1,305,695 บาท/ปี ด้วยเงินลงทุนจำนวน 197,720 บาท มีระยะเวลาคืนทุน 0.15 ปี และหากคิดรวมค่าธรรมเนียมในการบำบัดน้ำเสียส่วนกลางของกรุงเทพมหานครที่สามารถประหยัดได้ คาดว่าโรงพยาบาลธนบุรีจะสามารถประหยัดค่าน้ำประปาและค่าธรรมเนียมในการบำบัดน้ำเสียได้เท่ากับ 1,612,919 บาท/ปี โดยการใช้เงินลงทุนเท่าเดิม และ มีระยะเวลาคืนทุน 0.12 ปี

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CHAPTER I
INTRODUCTION

1.1 General background and problem statement

Development of infrastructure is indispensable along with Thailand socio-economic growth. Water as a requisite input to general manufacturing, not only serves industrial and agricultural sectors but also functions on evolution of human beings and other living things. Up to now water resource has been used without realizations of it's value, resulting in depreciation of both water quantity and quality. Usual water quantity problem in Thailand are over amount of water or water shortage, and conflict of water resource allocation to different activities (1). According to water resource situation review, which compiles around 100 countries database, one half are facing the lack of water resource (1). Such a worldwide water resource shortage should before long bring about dispute of water resource allotment among industrial and agricultural sectors.

Water utilization in a hospital takes place in many activities such as medical treatment, food preparing, softening water, dormitory, laundry, and other sectors. So, water used in each activity must be suitable and ample in both quantity and quality to prevent cross-contamination of disease to the water (2). Moreover the water use in various activities came from different water quality and treatment process. So the cost of treatment and the loss of water from those activities are also different. Consequently, the use of water should be considered following its treatment cost and the loss of water to promote best practice in water savings.

It was found that hospital consumes great amount of water thus raising great amount of wastewater as well. According to the quantity of wastewater in Bangkok Metropolitan (2), the wastewater from the industrial sector was around 25% and 75% from the community sector. Hospitals are classified in community wastewater source, which may discharge pathogenic disease to the wastewater stream and public waterway (3). As a matter of fact wastewater from hospital has some different characteristics from community wastewater. Generally, wastewater from hospital comprises small parts of flesh, cloth, pathogenic diseases, cleansing chemicals, disinfectant chemicals, and other chemicals, which are collected to the sewer, and treated by the wastewater treatment plant and afterwards the effluent is finally discharged into the public waterway.

Hence, wastewater from hospital, which own similar aspects to community wastewater, possesses highly contaminated aspects, especially for bacteria, which can induce infection (4). Traditionally a hospital discharges wastewater, occupying an average BOD of 164g/bed-day when the wastewater is not treated and 97g/bed-day when the wastewater is treated by the wastewater treatment plant. And it was found that public hospitals discharge more amount of wastewater than that of private hospitals (5). In 1987 it was found that hospitals' wastewater, discharged to the Chaopraya River, affected to the total BOD of community with the proportion of 2%. This is interesting when comparing with proportion of 54%, 36% and 4% from community, restaurant, and fresh market, respectively (6). Bangkok had the greatest amount of hospital beds or possessed 23.4% hospital beds of all the country. These can be separated to 14,188 public hospital beds and 16,291 private hospital beds. And there are 17 largest private hospitals, of totally 20 largest hospital in Thailand, located in Bangkok metropolitan (7). Accordingly, these private hospitals consume the large amount of water. So, it is quite interesting to investigate the activities in hospital that wipe out the water and find out the way to save the water from such activities.

In 1999, Office of Natural Resources and Environmental Policy and Planning had proposed a guideline to conduct Environmental Impact Assessment (EIA) report for hospital or medical care institute. The guidance requires hospital or medical care institute to propose water use pattern in details, water supply system, water distribution system, water treatment and disinfectant system, available preserved water, water quantity classified by water use activities, quantity and pathway of wastewater from various activities, and water balance (8).

To analyze sources of pollutants, pathway, and quantity is such a step of water resource management in long term integrative planning. Collecting data of water use quantity should fulfill, which then could be employed in establishment of management and control measure to lessen water pollution problem (3).

From the previous citation, the number of private hospital in Bangkok has a tendency to rise up. With the consideration on water demand of private hospital, and concern of wastewater quality discharged from this service sector, in this research, the Thonburi Hospital is selected as a study site. It is a large private hospital in Bangkok Metropolitan and surrounded with the large community.

Water audit, grounded on clean technology, is used in this study for finding out the possible options to save water usage of private hospitals in Bangkok Metropolitan.

1.2 Scope and boundary

1.2.1 Scope

Clean Technology is used as a core concept in this study together with Manual for Conducting Water Audits and Developing Water Efficiency Programs at Federal Facilities, originally published in 1993 by Environment Canada. These core concepts are used to develop water audit, in order to find out options for better water efficiency practices in the study hospital.

1.2.2 Boundary

This study includes water audit, which comprise investigation of water usage quantity, classify by activities of Thonburi Hospital. The study investigation uses water meter installation, personnel interview, data gathering and analyzing in order to search for the possible water saving options in the study site.

1.3 Objective

To propose the possible water efficiency options for water saving in Thonburi Hospital

1.4 Expected Results

1.4.1 Water usage information from various activities such as medical treatment and patient wards, food preparing activity, softening water, dormitory, laundry, and other sectors in the Thonburi Hospital

1.4.2 Recommended water efficiency options for implementation to improve water usage in Thonburi Hospital

CHAPTER II
REVIEW OF LITERATURE

2.1 Principles and concepts for water efficiency practices

The global economic development has been continually growing from the past. Historical milestone revealed the events from the industry revolution in the past through recent globalization. The decrease in natural resource and increase of the pollution are because of the industry expansions. In the past waste or pollution from the production process was generally disposed or discharged without treatment to public space. Subsequently when the pollution increased over the carrying capacity of nature, pollution treatment and disposal, at the end of pipe, became an important issue among most countries. While natural resource has been receding, recently reuse and recycle stepped in and played a crucial role in resource conservation by making waste-economic value. Rapid economic growth brought about high competition in business enterprises. Cost reduction was considered as a way to comply with rivalry atmosphere. Therefore reductions in raw material to production process were regarded as a beneficial way for business and also help reduce the pollution to the environment. As in the past the sequences of pollution management were emphasized at the end of pipe that sequencing as follow: disposal, treatment, recycling, and source reduction. At the present day the priority of pollution management changes to be the source reduction, recycling, treatment, and disposal, respectively. And there are conceptual words that represent the concept focusing on pollution reduction and prevention those are Clean Technology (CT), Cleaner Production (CP), Pollution Prevention (P2), Eco-Efficiency, Waste Reduction, Waste Prevention, Waste Avoidance, Waste Abatement, Waste Elimination, Source Reductions, etc. In this research referred to the 4 cores concepts as follow: Clean Technology, Pollution Prevention, Waste Minimization and water audit and water efficiency. The main concepts are presented as follow:

2.1.1 Clean Technology

End-of-pipe solutions do not usually result in efficiency or productivity gains, therefore expressing as a cost of the production process. Clean Technology, on the other hand, improves the process efficiency. Furthermore, Clean Technology usually reduces pollution emissions to the environments.

Clean Technology has become an important concept following growing international concerns with environmental issues. Clean Technology can be defined as the continual application of an integrated preventive environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment. In the production processes can use Clean Technology for conserving raw materials and energy, eliminating toxic raw materials, and reduction in the quantity and toxicity of all emissions and wastes before they leave a production process. And in the products itself can use Clean Technology for reducing the impacts along the entire life cycle of the product, i.e. from raw materials preparation to the final products and also to the ultimate disposal of the products. In the service sector can use the Clean Technology to reduce the environmental impact for the entire lifecycle as well. This entire life cycle considers the stages from system design and the entire consumption of resources to provide the services (9).

Clean Technology encompasses approaches towards certain criteria as processes, products and services including their design, usages of raw materials and energy and utilization. Thus, Clean Technology considering all types of waste that could be released into the air, water and soil. Clean Technology not only requires the improving of the efficiency and certain tools as know-how and technology but also requires the new managerial skills and policies for design and wise use of the products and services as well.

In conclusion, clean technology is the conceptual way of Source Reduction, Efficient use of resource in production process, and Minimization of hazards and risks to human and environment. While wastes and losses are minimized at source, if there are still waste remain, they should be reused or recycled thus, resulting in as least as possible of waste leftovers (9).

2.1.2 Pollution Prevention is a process or practice aspiring to minimize or eliminate wastes and pollutions on the environment. Pollution Prevention is generally presented in other words but in the same concept such as Waste Minimization, Waste Reduction, Source Reduction, and Pollution Minimization (10).

US-EPA (US-Environmental Protection Agency) defined Pollution Prevention in terms of Source Reduction and Recycling. Source Reduction and Recycling should be carried out before Treatment and Disposal thus leading to reduction of wastes and pollution.

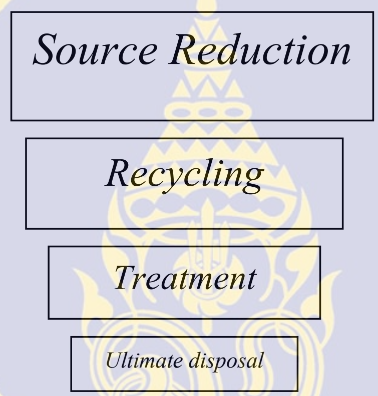

Figure 2-1 Priority of Pollution Prevention Techniques (10)
From: Theodore L. and McGuinn YC (1992 : 107)

Source Reduction, traditionally found in production process, comprises technology capable of minimizing wastes at source: Product Substitution, Technology changes, Input Material changes, and Procedural changes.

Recycling is secondary alternative to Source Reduction. Recycling practice, generally found within period of production process or after period of production, intends to separate usable materials and substances from waste stream

Waste remains will be transmitted to physical, chemical, and biological treatment in order to minimize toxicity and waste quantity before disposal. Such a concept should be applied to practices with varieties of activities (11).

Conducting the Pollution Prevention requires investigation of pollution source, cause of pollution, condition and period of occurring, quantity and characteristic of the pollution, and preventive practices (11).

2.1.2.1 Pollution Prevention Assessment

The various steps of pollution prevention assessment are distinctly presented in figure 2-2 and details as follow:

2.1.2.1.1 Planning and Organization comprises manifest of commitment from management level, establishment of program criteria and goals, and formation of structure and responsibility of task force to proceed P2 in the organization.

2.1.2.1.2 Assessment Phase comprises accumulation of process and facility data within organization, ranking and selecting assessment targets, selection people for assessment teams within organization, reexamination of data and inspected site, generation of options, and screening and selecting of P2 options for implementation.

2.1.2.1.3 Feasibility Analysis Phase comprises technical evaluation, economical evaluation and options selection for P2 implementation.

2.1.2.1.4 Implementation comprises justifying P2 options to be developed to implementation programs and obtain monetary fund, installation of necessary equipment or other modification, carrying out the procedure or implementation program, evaluation of program effectiveness and performance, and continual repeat of the process.

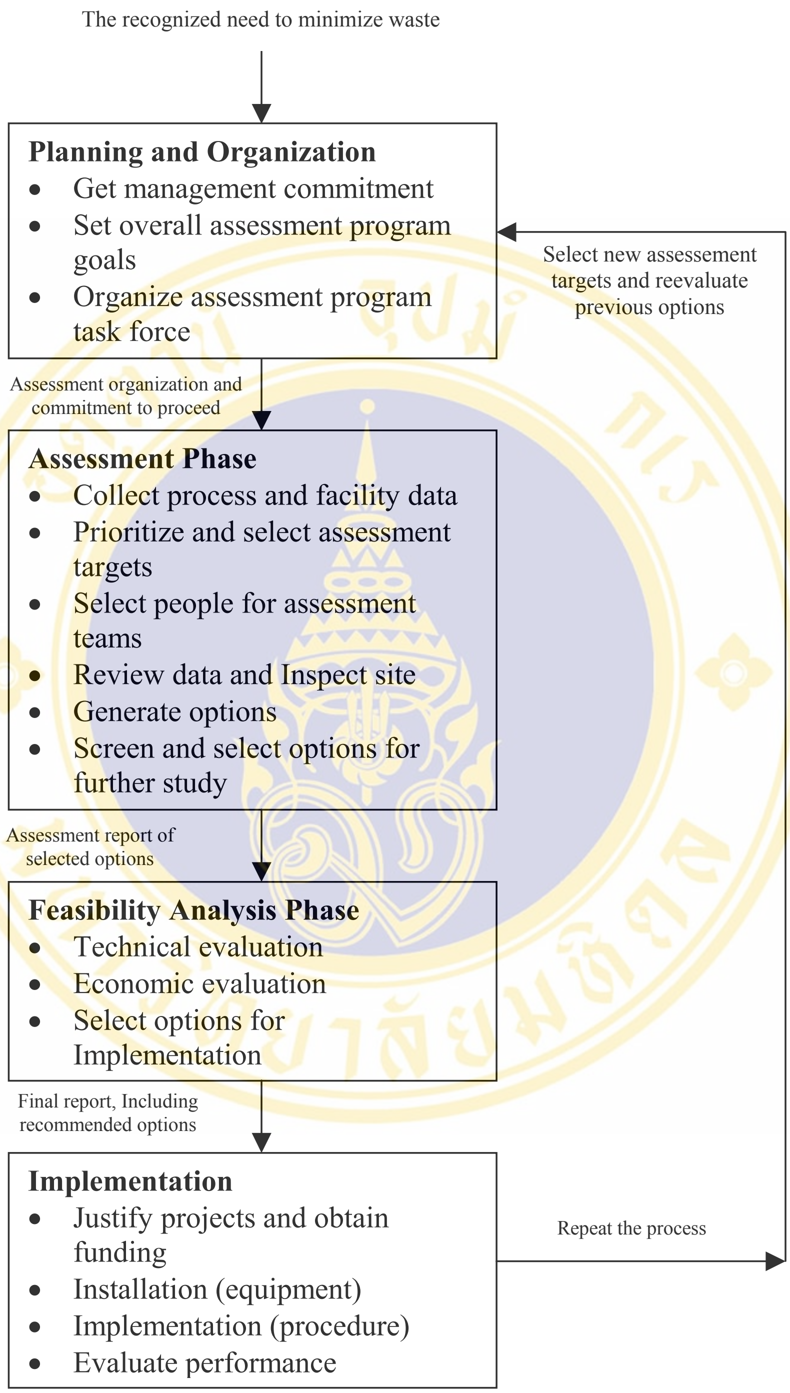

Figure 2-2 Pollution Prevention Assessment (10)
From: Theodore L. and McGuinn YC (1992 : 136)

2.1.2.2 Source Reduction

Source Reduction, of pollution prevention, bears on modification of procedural production process. Source Reduction Techniques can be illustrated as follow:

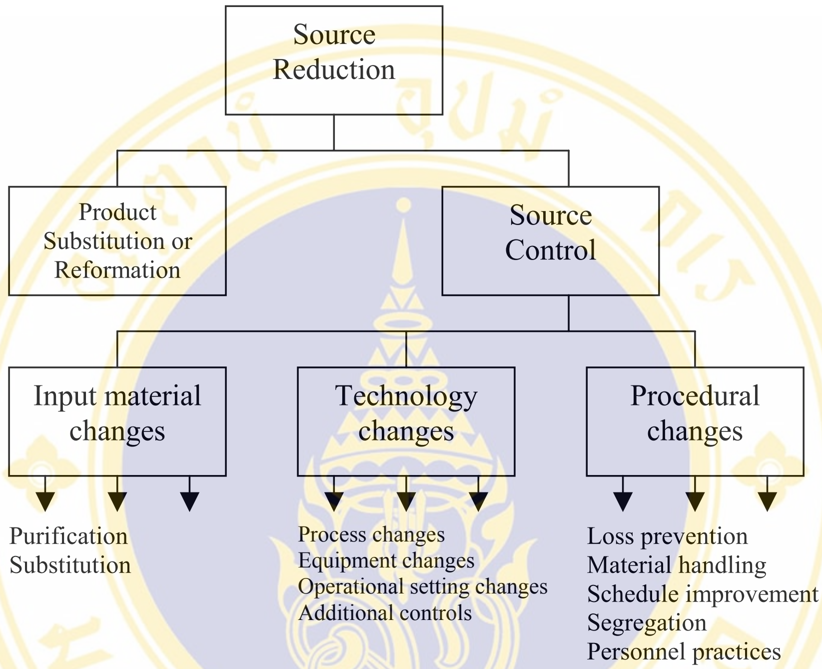

Figure 2-3 Source Reduction Techniques (10)
From: Theodore L. and McGuinn YC (1992 : 151)

2.1.2.2.1 Procedural changes comprise modification of procedure of management, organization reengineering, and personnel structures and responsibilities in production process. Procedural changes are placed at 1st priority due to low cost but high revenue feature. This technique includes lose prevention, material control, work procedure modification, waste segregation, and training of personnel.

2.1.2.2.2 Technology changes comprise waste minimization by means of production process and material modification. This technique employs low to high cost and probably requires proficient specialists to steer, so it is generally inferior to procedural changes in consideration. This technique includes production process modification, regeneration of system, relaying of plumbing system, establishing and controlling state of the art automatic machines, etc.

2.1.2.2.3 Input Material Changes is a technique aiming to minimize or demolish waste before transmitted as input to production process. This technique includes prioritizing and selecting input materials possessing high quality and tendency of zero loss or non-pollution during production process. These may admit purification of input materials before manufacturing.

2.1.2.2.4 Product Substitution or Reformation is a technique aiming to lessen hazard from constituents within products. For instances modification of product formulations in paint industry to water-soluble formula is to reduce the dispersion of toxic substances to the environment.

2.1.2.3 Recycling, in figure 2-4, bears on direct and indirect waste recycling or/and preliminary remediation of waste before recycling. Then reuses it as an input to the process or even to the others, resulting in minimization of waste disposal cost and potential revenue from retrieval recoveries.

Recycling is usually conceived as another alternative to the source reduction.

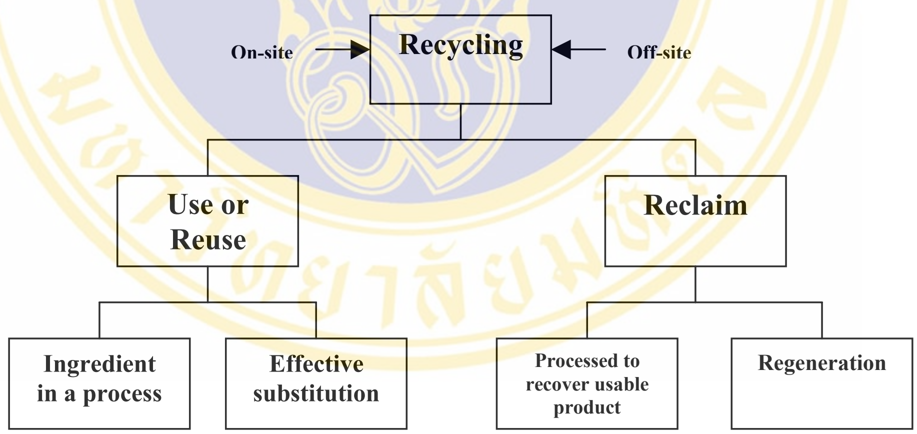

Figure 2-4 Recycling Techniques (10)
From: Theodore L. and McGuinn YC (1992 : 159)

From figure 2-4 Recycling Techniques can be illustrated as followings.

2.1.2.3.1 Reuse is a technique searching for possibility to retrieve then reuse materials or substances compounded within waste stream. These following aspects are deemed when considering potential to reuse: waste chemical compounds, unintended affects to the product quality, economic rate of return, availability of materials and substances extracted from waste stream to be reused.

2.1.2.3.2 Reclaim is a salvation process established in order to retrieve potentially usable materials and substances in waste stream from useless or uncultivated state to be useful as inputs or compounds of varieties of products.

2.1.3 Waste Minimization

Waste Minimization prefers focusing on pollution prevention principle to pollution control (12). Waste Minimization is a means, emphasizing on product and production process, affecting environment and possesses a strategic procedure to minimize waste and pollution, discharged to the environment (13).

For industry sector, waste reduction and waste auditing are critically important for the prevention of upcoming environmental trouble. With these schemes, industry sector could minimize its waste, in the other hand, is capable of the increase in potential of materials and substances efficiently employed, contributing to healthy status of human and environment in the long run (12).

Cheremisinoff (1995) stated that industrial waste minimization includes input raw materials modifications, technology and/or machine modifications, manufacturing procedure improvements and modifications, on-site reuse and recycle of usable materials and substances from waste stream, and product improvements

Even though, in present, there are still no laws and regulations to compel industrial sector to implement waste minimization practices, the sector should volunteer the environmental protection scheme in order to yield an profitable economic revenue founded on pollution prevention (waste reduction) and pollution control (waste management) by employing quantitative and qualitative auditing as a means of environmental concern entrepreneurs to be voluntarily responsible for preventing pollution discarded from their activities and maintaining their environment as well.

Waste Minimization could be performed by means of waste reduction audit in order to find out available data such as characteristics of waste, quantity of waste, and degree of hazard, source of hazardous waste, source of waste within production process, technical feasibility to implement waste minimization.

2.1.3.1 Waste Minimization Practices

Cheremisinoff (1995) suggested some waste minimization practices and affirmed importance of bringing waste minimization to practice. Another source is acquired from UNIDO (1995).

2.1.3.1.1 In-Process Recycling or On-Site Recovery and Reuse has some restriction factors to deal with like ample quantity and quality of recycled waste, unstable of input materials and substances, types of process like continuous or batch process, and complexity of salvage process.

2.1.3.1.2 Operations in the plant and housekeeping play crucial role in preventing loss from leakage. Preventive maintenance and personnel training should improve operations and housekeeping (13).

2.1.3.1.3 Better Process Control is relevant to equipment and machine improvement, data records gathering to meliorate efficiency and lessen pollution from the process (13).

2.1.3.1.4 Input Material Change is relevant to utilization of lower or zero hazard input materials and substances or employing more durable input materials and substances (13).

2.1.3.1.5 Equipment Modification

2.1.3.1.6 Product modification such as modification of some characteristic of product to diminish some negative environmental consequences (13)

2.1.3.2 Waste Reduction Audit is an intermittently and systematically internal audit process to find opportunity of waste reduction (12).

2.1.3.3 Environmental Audit is widely explained as a subjectively systematic procedure to look into a phenomenon within a certain time (12).

Performing environmental audits generally use checklists or outlines as supplements of data recording. Data then brought to comparatively analyze with organization policy and plan. General concept, environmental audits are carried out as tools of management for organizations to meet legislative regulations, be responsible for environment, approach relations between government agencies and private sector, reduce risk and monetary burden, maximize efficiency of management and finally minimize waste.

Cheremisinoff, 1995 suggested factors to be added up in environmental audit as followings.

2.1.3.3.1 Preceding information including site, name, and type of organization, preceding practice following legislations, product and raw material information

2.1.3.3.2 Environmental aspects including discharge outlet, spatial relations with surroundings ecology, environmental controlling measure, environmental standard or criteria

2.1.3.3.3 Water distribution system including demand and supply side analysis, source of use water, potential for underground water utilizing, characteristics of water, water treatment legislations

2.1.3.3.4 Water treatment system including sewage system, flow aspects, wastewater characteristics, pollution loadings, toxic substances, possibility to dispose, discharge to public sewage control

2.1.3.3.5 Air pollution control

2.1.3.3.6 Solid waste disposal

2.1.3.3.7 In-plant operations including general housekeeping, ventilation, training, inventory and raw material control, occupational health and safety measure

Environmental audit consists of at least 3 stages of investigations. Stage1 represents preliminary site survey to identify environmental aspects. Stage2 makes up advance investigation by sampling and data recording to classify and identify pollution affected to environment. Stage3 comprises options initiation to solve the previous 2 stages problem.

Environmental audit objectives are to identify present status according to audit, to identify possible hazard resulting from waste discharge, to identify pollution dispersion path and chemicals leftover in audited site, to compare actual status to legislative standard, to overall assessment to determine procedural practice, policy, master plan, and instruction of waste management, to propose options to improve operation efficiency and finally to minimize recurring risks from the operation.

Environmental audits usually conduct 3 assessment aspects. The aspects are Technical Feasibility Assessment, Economic Viability, and Environmental Analysis.

Technical Feasibility Assessment is a tool set up to evaluate if proposed options are suitable or not. This covers evaluation of options effects on production process, products, production proportion, safety, or even services delivered to customers. The evaluation is usually conducted in laboratory or carried out a trial of the options to get technical feasibility assessment. Economic Viability is of the essence ordinarily considered as the criteria to decision making, whether decision makers accept or reject waste minimization options. Several tools are able to serve this assessment objective such as Payback Period Method, Internal Rate of Return (IRR), Net Present Value (NPV). Environmental Analysis determines options effects on environment in contents of occurred toxicity, cut down in waste generation, waste treatability, and regulatory compliance.

2.2 Water Audit

Water audit is rather new concept occurring to support water management, like steering a business with balance sheet. While balance sheet is used to audit in/out cash flow to be in equilibrium status, water audit is utilized to audit in/out water flow of a specific system (15).

Specific objectives of water audit is to figure out opportunity to safe water use, to prevent and control losses and unaccounted-for water (the amount of non account water less known or estimated losses and leaks), to evaluate water use situation of a particular time, and to offer optional solutions. There were at least 3 elements in completing a water audit those are Meter test, Inspection of leakage points and quantity, and System inventory (16). And a water audit must comprise varieties of wises including structural, practical, economic, political, and social compositions (17).

Gagnon (1984) expressed befits of water audit as it helps reduce manufacturing and maintenance cost, supports water efficiency practices and conserves water resource to suitable allotment, attains water use data base, used to improve and plan water use management, and increase financial gain from water efficiency programs. Water audit is a tool for business units and it’s results give water usage reduction based on activity (18).

Water efficiency utilization may follow Pollution Prevention scheme, which includes Source Reduction (e.g., switch to lesser water use production, increase efficiency of controlling outlet, and Reuse and Recycle (10). For instance wastewater from factory effluent are capable of agricultural input or even mediator of cooling system. Water efficiency program could be arranged through Wastewater and Waste-free Technologies (19). For industrial use, there should be water saving measures to prevent negative affects occurring in future development. These include loss and unaccounted-for water prevention, use of wastewaters-free technologies, on the site reuse, and recycle. Water resource management might be performed along with yearly present and past water balance assessment.

Flack (1981) defined water resource conservation as more efficiency water use at presently allotted proportions through structural, pragmatic, and socio-politic ways. Several water conservation methods for resident had been determined. In 1981 Flack (1981) proposed water conservation methods through various ways such as water meter installation, leak detection, water control and water save fittings installation, procedural change for watering and water use restriction.

In the past water use pattern was customarily ineffective, resulting in water pollution discharged to the environment. Nowadays water management scheme focuses on basic human right to deserve payable clean and hygienic water consumption. Realizing water as an Economic Goods should induce water efficiency expansions, equalization in water use apportioning, and water resource conservation. Water has an economic value in all its competing uses and should be recognized as an Economic Goods.

Water use and wastewater minimization in production process was proposed as determining role of water audit as a tool to water management and conservation, regulating limited quantity used in each activity, and granting good house-keeping practice, preventing leakage by use of well-closed equipment, storage and reusing of wastewater is lower than treatment and disposal cost. Separating rain channel from generally wastewater drainage and providing storage tank for collecting rain is another water saving way. However the collected rain should be subsequently treated until fits activity quality requirement or otherwise disposed, and water reusing by means of tertiary treatment (e.g., filtration, activated carbon filtration, chlorination) which in turn is able to be watered or flushed in certain activities (12).

Water efficiency practices are drawn from water conservation by means of employing water saving equipment or fitting (16). Furthermore water meter establishment might reasonably save water in order that departments or activities engaged in organization should be inspected whether they overuse or being responsible for most portion of water use from all the system (20). Water saving equipments should replace all ineffective fittings. In case the equipments are high cost investment (e.g., low water using shower heads, faucet aerators), individual could partially modify from original fitting. Water quality criterion for water reuse and recycle has been settled. It's guided to use water that possesses low suspended solids, holds lesser dissoluble salt, bears non-hazard level of microorganism, holds no inclination of biological accumulation, and holds suitable pH and solution composition with no disturbance odor (19).

Industrial water saving indices was proposed those were water use and waste occurring per 1 unit product (21). Ahead practicing water recycle, some issues might be reviewed (e.g., water saving revenue, salvaged substances economic value, investment cost, proceeding cost, maintenance cost, and effects to production process potency).

2.3 Water Audit of Canada

The Government of Canada, through its Code of Environmental Stewardship, is dedicated to improving the natural environment. One of the ways this goal can be achieved is by reducing loadings on municipal wastewater treatment plants. To this end, the Government has accepted the Green Plan goal of seeking cost-effective ways to make federally owned facilities water efficient in their operation. This objective is the focus of the Water Conservation Plan at Federal Facilities. The Plan describes the various steps that need to be taken, from inception through financing, for the implementation of water conservation programs. These guidelines outline the procedures for conducting a water audit and for designing and implementing a successful water efficiency program (14).

The first step in developing such a program is to assess the current state of water use at the facility being investigated. A water audit can be done by hiring consultants or by using in-house resources. Either way, the water audit will determine if and where excess water is being used and ways in which its volume can be reduced. The main activities involved in conducting a water audit are defining the water distribution system components, developing an inventory of the water use operations at the facility, and preparing a water balance for the facility. The results of the water audit will indicate the amount and variability of water demanded by each operation. These factors are then gathered for the whole facility. Next, a water efficiency program is designed and implemented to optimize water usage and water savings for the facility by identifying potential water reduction alternatives for the facility, evaluating the potential alternatives against the facility's goals and the social/political, technical, environmental, and financial impacts, developing a recommended water efficiency program for the facility, implementing the program and ensuring its success with user education programs and evaluations for further water reduction opportunities. A schematic representation of the facility's water infrastructure should be prepared to show the entire distribution system from where the incoming water passes through a meter to the final use or distribution points. Water demands may be accounted for as *use* — water used in operations and either consumed, reused, or discharged into the storm or sanitary sewer, *consumption* — water used in operations but not discharged to the sewer system, and *losses* — all unaccounted-for water, such as distribution system leaks, leaking meters, and leaking connections

Thus by the above methodology, the facility's water uses are assessed, the potential water and financial savings are estimated, and water efficiency plans are established and implemented. The results of the pilot studies that follow should recommend easily adapted modifications to common water uses to make them more efficient. The modified processes would result in significant reductions in water use, contribute to protect our environment, and provide financial benefits.

The water audit methodology consists of various basic working processes, sequenced by Environment Canada (14), from Chapter1 to Chapter6 as follow:

2.3.1 Chapter1: System Components

2.3.1.1 Description of facility and scope of study

The audit use existing information to ensure rapid progress in completing the task. All relevant descriptive statements, plans, and tabulations about the physical and geographical characteristics, including details of buildings, should be collected often from various sources.

If possible, a reference on the source of supply and natural quality of water should be included. Both the age of the building distribution system and of the municipal infrastructure connections need to be determined. Some summary remark on water usage might also be made at this point.

The objective of a water audit is to identify each facet of the water distribution system and thus define the system as a whole. And identifying the areas of the facility that are supplied by hot and cold water, area of measured and unmeasured water supplies, all points in the system where water can be extracted, and distribution system design details.

Investigation should provide enough information to set specific objectives for a water efficiency program, such as: a definition of the water distribution system and an outline of procedures for conducting a comprehensive inventory, assembly of a comprehensive inventory, including descriptions, of all water use operations at the facility, outline of procedures to account for all water used at the facility, outline of procedures for developing a list of potential water reduction techniques that could be applied to specific operations, areas, or the facility as a whole, and outline of procedures to design and implement a water efficiency program at the facility.

2.3.1.2 Elements of a water distribution system

The elements of a water distribution system that are considered necessary for the system definition may be grouped in four broad categories those are distribution, measurement, storage, and extraction (toilets, lavatories, faucets, sinks, showers, wash hoses). Relevant information on the various categories may be obtained from plumbing plans, previous reports, publications, etc.

Site inspection and personnel discussion allow for understanding of the water usage activities at the facility.

2.3.1.3 Basic Procedures

Specific steps that may be used to define the system at the facility include a visual inspection at the facility, an inspection of plumbing drawings and transferring of key information to the base maps, an extensive site investigation to verify information.

During the investigation, an unbalanced water flow account might be indicated for loss or leakage. In addition, insufficient pressure or supply in the system should be examined. Sensitive points may require the installation of flowmeters to measure the flowrate in particular areas.

An area site plan preparation with all location of water meters in the facility, along with a schematic diagram of the meters might be carried out. Plans of each section of the facility should include with the water distribution system.

2.3.1.4 Additional procedures required for Water Audit

There might be some other elements of the water distribution system at a facility (in addition to supply lines, meters, and use points) that need to be identified as part of the audit such as fire hoses, water supply pipe sizes, valves, joints, and elbow turns. All of these could be located by site investigation with the plumbing drawings for reference.

2.3.2 Chapter2: Inventory of water use operations

The primary reason for describing the water uses for each point of use is to develop a comprehensive inventory of water usage at the facility and to identify potential water reduction strategies. To obtain such information, contacting and meeting the operators and users should be arranged, observation of personnel water usage in each area and information gathering by using questionnaires should be conducted. The information regarding water usage might be obtained through the use of a specific questionnaire. And the data interpretation with plumbing drawings and building personnel should be defined including category of water use, volume, rate, and frequency of use, water loss or consumed.

2.3.2.1 Procedures for estimating flows

From the experience suggests that although during the audit, almost water usage quantity are not measured. If a flow estimate is needed, published values or field measurements may be acceptable. Tabulated values from published information are available for most conventional water usage to estimate flowrate by specific operations. These may be estimated regarding the number of users per day or duration of use. Estimation of water flowrate might be based on field measurements, which may be suitable for some water use. Methods of field measurement might be acquired by using flow meters at the water distribution system or the water-using equipment (e.g., cooling water pipe), bucket and stopwatch measurement of water extracted for a specific operation, volume/frequency measurement of water used for a specific operation. Indirect methods of flow measurement by logging the operation of water pumps and displacement tests on water storage tanks. It is important to measure flows over the same general time period, because the periodicity and seasonality of flows may affect the water balance equation. Part of the margin of error at a pilot site was due to unknown flows for irrigation and lawn watering. If outdoor use is suspected, the water audit should be carried out during the summer season. However, any other method for measuring flow that appears to be reasonable for the application may be used.

2.3.2.2 Flow meters

An essential element of any water audit is the measurement of the main flow entering the facility. Additional flow measurement into sub-areas is occasionally investigated when significant portions of the total flow are required. Flows can be measured by either permanent flow meters, which give the most reliable results both during the investigation and after the water audit is finished, or temporary recorders, typically situated at a specific location for the short audit period. Temporary flow meters, if not installed correctly, may give incorrected results. Permanent flow meters are costly and have to be fitted into the pipe run. However, they will give highly accurate daily, weekly, monthly, seasonal, and unusual-event data during the water audit, and then continue to give long-term results and trends.

There are two basic types of temporary flow meters, namely, external clamp-on devices and insertion flow recorders. External clamp-on meters send ultrasonic signals through the pipe wall and across the water flow. They are useful where only an indication of the flow range is required and they need no pipework modifications. However, they require a straight section of pipe at least 30 diameters in length for installation. The insertion flow meter requires a point of entry into the main via a small (5 cm or 2 inch diameter) tapping. An electromagnetic head, or a small turbine, measures the velocity of flow at one point in the pipe. The pipe has to be traversed to obtain a flow profile, from which the relationship between measured point velocity and total flow can be calculated. Varying flow profiles and internal pipe corrosion can cause distortions. Results from insertion meters are likely to be more accurate than those from clamp-on meters.

2.3.2.3 Bucket and stopwatch estimation

If the flow is constant and free flowing, as in some cooling waters, a bucket and stop watch approach can be used to estimate flow. The time it takes a bucket of a known volume to be filled by the free-flowing source is measured and a flow can be calculated.

2.3.2.4 Volume/frequency estimation

If the flow is not free flowing but fills a known volume, the frequency with which the volume or tank is emptied or replaced can be used to estimate flow. Occasionally, logging the operation of a domestic cold water pump is the last resort to obtain a set of indirect flow measurement. The lower quality of data by this method still provide an understanding of the water using pattern at a facility and also the information on the operation and control of the pumping system.

2.3.2.5 Leakage detection surveys

Significant lengths of outside underground of water distribution mains are potentially leakage of water. Such conditions, the consideration of a leakage survey is necessary. The leak detection technique involves using an electronic leak correlator and a noise sounder. The leakage of water from a pipe produces unique noises, which the electronic equipment is able to detect. Sensing devices are usually attached to the watermain fittings, such as hydrants and valves, and the survey is completed in a methodical manner around the site. If the results are "quiet," there is no leakage.

2.3.3 Chapter3: Water Balance

The step of water balance calculation needs the information gathered from site inspections, measurements, and discussions with site operators and users. An opportunity should be taken to provide more than just a total volume in the balance.

An analysis is then completed of the average daily, peak, and base flow for each facility. If the results show that the sum of water used in all operations is less than the total water supplied, it is assumed that water uses exist that have not been included in the balance, or that either the main meter or its reading is inaccurate. The water balance should be re-examined until the auditor is satisfied that all operations have been considered.

2.3.3.1 Water meter reading program

The water meter reading for providing the specific data required for a water audit. The alternative method of obtaining flow data from the existing and newly installed flowmeters would have been to use with data recording attached to the meters. With this technique one can gather data much more frequently, by recording the flows at short time intervals.

2.3.3.2 Facility wide water balance

The objective of the facility wide water balance is to add up all of the individual categorized water use volumes and equate them to the volume of water supplied to the facility as recorded by the main meter. The first step in preparing the water balance is to examine the facility as a whole.

2.3.3.3 Main meter water balance

The main meter water balance considers only the total water supplied to the facility and the total water volume supplied to each sub-area. It aims to identify sub-areas of major water use, identify major discrepancies between the main water volume supplied to the facility and the sum of water volumes supplied to each sub-area, highlight sections of concern around which an individual water balance can subsequently be carried out.

2.3.3.4 Sub-area water balances

The primary objectives of the sub-area water balances are to identify the volumes of water used by each operation in the area. And summation volume to account for the total volume of water used in the area should be completed. This information may be shown as flow diagrams for the water balance in each sub-area.

2.3.3.5 Summary

The completion of facility water balances, in which all major water uses are accounted for concludes the water audit part of the process. The water audit results are then used in the next phase for designing a water efficiency program to the facility.

2.3.4 Chapter4: Water Reduction Measures

The areas of water reduction will mainly be associated with physical changes, but user habit change will also be an ingredient in a successful water efficiency program. Implementing water reduction measures will have no effect on human comfort.

Demand management methods that involve reducing the demand for water at the user end of the distribution system include, system optimization, water-saving systems (retrofitting and replacement), reuse/recycle systems, process changes, alternative water sources, user habit changes, and metering.

General supply management approaches, such as leak detection and repair as well as pressure reduction, are effective in reducing the water used by controlling the supply and distribution system.

2.3.4.1 System optimization

Because the system optimization measures are specific to the water use operation, opportunities for water reduction cannot be identified until the water audit has been completed. However, based on the audit, several systems can be considered for optimization, including regular calibration of all water flowmeters, implementation of a preventative maintenance program including leak detection for water-using operations such as toilets and faucets, and optimization of the individual processes and equipment in major water-using areas.

2.3.4.2 Water-saving systems

Selecting water-saving devices that reduce the harm an activity would otherwise cause to the environment could be considered a good environmental choice.

2.3.4.3 Retrofitting systems

Standard retrofitting devices are common for domestic water use components such as toilets, showerheads, faucets, and outdoor hoses.

2.3.4.4 Replacement systems

Replacement of water-using devices with new, low water-using fixtures should be considered for toilets, taps, showers, hoses, and drinking fountains.

2.3.4.5 Reuse / Recycle systems

Reuse and recycle systems are those that use water that has previously been used in another operation; however, treatment may be required before the second use. Both reuse and recycle systems should be considered to reduce water use if large volumes of uncontaminated water are to be discharged to municipal sewers.

2.3.4.6 Process change

Process change describes the replacement of water-using practices with those that perform the same function in a different manner. Process change can also refer to the complete elimination of a water-using practice. Basic approaches that appear to save significant quantities of water include regular equipment maintenance, conversion to chemical or dry processes, and elimination of once-through air conditioning units. Consideration should be given to convert all water-cooled equipment to chilled water or closed-loop glycol cooling systems. This list is for illustration purposes and is not exhaustive since process change steps are regarded as site-specific in nature.

2.3.4.7 Alternative water sources

If the water required for the operation does not need to be municipal grade, then there may be a large cost savings associated with using an alternative supply. Alternative water sources could include direct surface water supply, groundwater supply, and storm water.

2.3.4.8 User Habit Changes

Changes in people's water-use habits could include organizing work to minimize water loss, ensuring that taps are completely turned off and not left running unnecessarily. Reporting leaking faucets, toilets, urinals, and water fountains to appropriate maintenance. The insulating of hot water pipes serving faucets or showers to reduce the time water must run to become hot. And adjusting lawn-watering schedules to low evaporation periods of the day could also save water.

2.3.4.9 Metering

Metering water use is a good way for the facility to gain the data of users involved in the water reduction program, as they will see the results of their efforts. Placing and monitoring a flowmeter on a supply line allows both management and employees of a facility to immediately recognize how much water has been used and whether that usage is within the normal range.

2.3.5 Chapter5: Designing the Water Efficiency Program

The water efficiency program should be designed to incorporate water reduction measures that best achieve the goals set out for the activities at the facility. Steps leading to such a program may include establishment of the goals of the water reduction program, identification of all reasonable reduction measures, identification of positive and negative impacts of the reduction measures, preliminary evaluation to screen out undesirable measures, a cost-benefit analysis, and development and evaluation of the recommended water reduction program.

2.3.5.1 Alternative reduction measure

For each water use category, water reduction measures and practices can be identified specific to the facility. When the list of available measures has been completed, then the intangible impacts, as well as financial and water savings impacts of each measure must be evaluated against the goals set by water efficiency program of the facility.

2.3.5.2 Impacts of water reduction measures

The following impact categories need to be considered: economic, social/political, and environmental/technical. Specific impacts that should be determined for the measures include public (user) and political acceptance, environmental impacts, reliability, short- or long-term effectiveness, and other impacts specific to the goals of the program. The impact of water reduction measures on the goals of the facility needs to be determined.

2.3.5.3 Cost-Benefit analysis

A cost-benefit calculation will determine the net savings that would be made by the most cost-effective water reduction measure. To obtain the information needed to derive the costs and savings, a detailed examination of the potential water reduction measure must be undertaken. In most cases, however, a simple cost-benefit analysis involving the estimated capital cost of the modification works, the net revenue savings, and the resulting payback period should suffice. Other non-quantifiable benefits, including those related to the environment, social well-being of water users, political image and goals, must always be considered although they cannot be included in the calculation of net benefits.

2.3.5.4 Development of recommended water efficiency program

The results of the impact assessment and cost-benefit analysis may be used to develop a water efficiency program to meet the goals of the facility. The resulting program will consist of a number of compatible water reduction measures and will have a net benefit and net water volume savings, as well as a number of non-quantifiable benefits.

2.3.6 Chapter6: Water Efficiency Program Implementation

Major elements that may be considered in the implementation plan include selection of a water efficiency program management and staff, establishment of a schedule of implementation, development of a user education program, implementation of programs, assessment of program effectiveness, update of program elements.

2.3.6.1 Program management and staff

A dedicated and efficient staff organization, working as a team, is required for the implementation of a successful water conservation program at any facility. Lines of responsibility for developing an implementation schedule and coordinating required activities need to be established. Assessing the program's success and updating the program, if necessary, may also be the responsibility of this team. The ability to delegate authority to specific activities is considered to be a key element in ensuring the program's success.

2.3.6.2 Implementation schedule

The water efficiency program management and staff may have to develop a schedule for implementing water reduction measures. This may include all components of the water efficiency program, including education program, installation, and follow-up activities, based on the goals for water savings, the available and projected budget for the current and future years, the staffing available for education and assessment activities.

2.3.6.3 User education

It is vital to any long-term water efficiency program that the water users know why it is important that they use their water wisely. This education has two primary purposes: to encourage the users to follow reduction program procedures, and to facilitate the users' acceptance of water reduction measures implemented by management.

2.3.6.4 Program assessment

Routine progress assessment of water savings may reveal the areas where measures are successful or ineffective. It would also indicate where modifications to the program may be required. Modifications may be carried out and evaluated by the program management and staff of the facility based on examination of the main meter records as well as the various internal meter records to determine overall water savings and water savings in individual sub-areas surveys of user participation and attitude acceptance by facility management reports from the educated coordinator. Program effectiveness reports should be submitted routinely to the facility management and in turn to the users to encourage further participation.

2.3.6.5 Update of program elements

The routine assessment of the program will help to identify which measures are not effective and could potentially be replaced or modified. Replacement measures should be thoroughly evaluated, by impact analysis and cost-benefit analysis, prior to implementation.

The researcher illustrated water audit process of Environment Canada from CHAPTER 1 to CHAPTER 6 through flow diagram in figure 2-5.

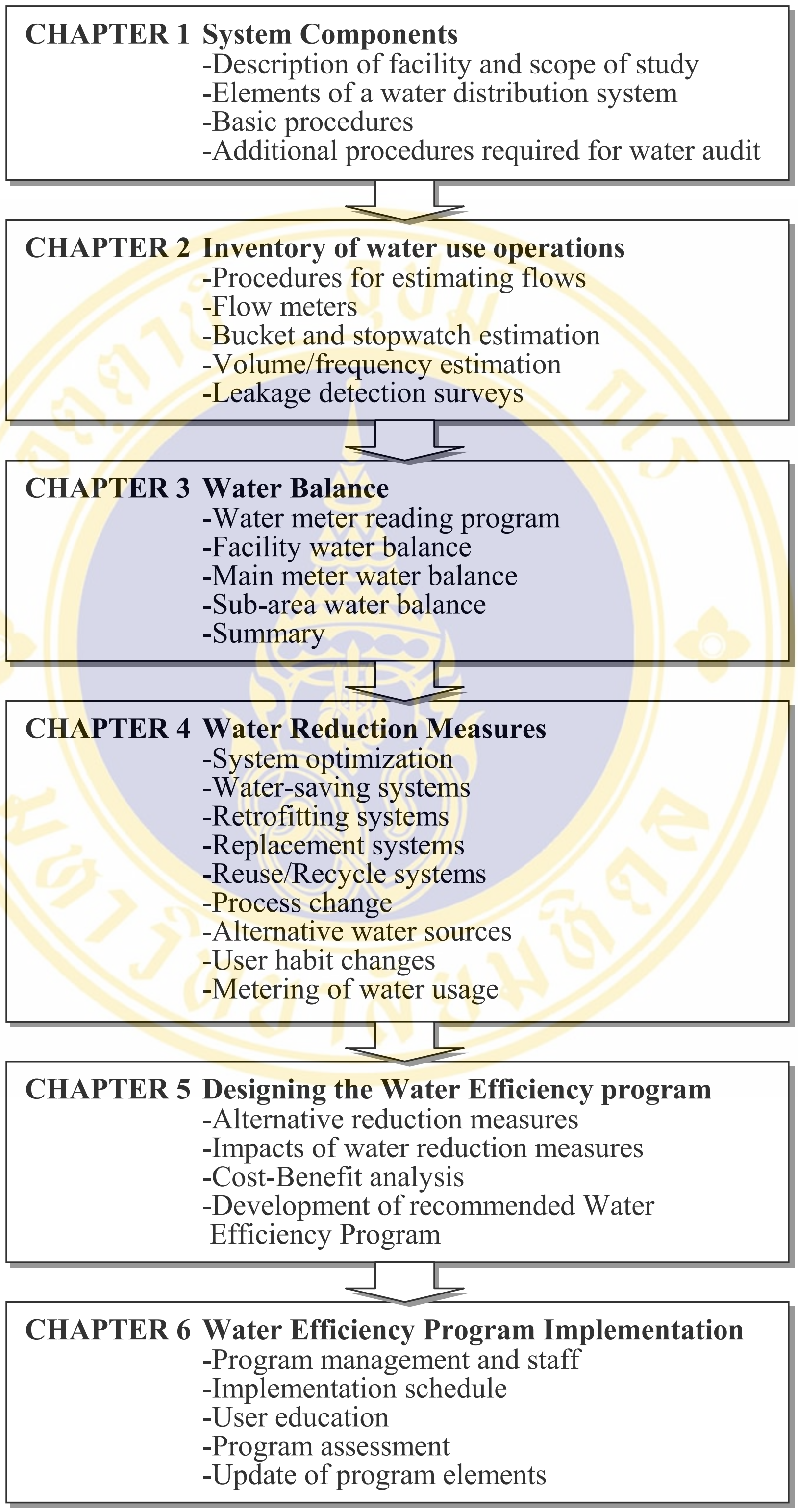

Figure 2-5 Water Audit Flow Diagram

2.4 Relevant Research

2.4.1 Water Audit and Water Efficiency Research

The study illustrated in “The water audit: A New Concept In Conservation” (22), in a period of 4 years for over 50 western U.S. cities, found that over 40% of water usage was unaccounted-for water or lost, and only 60% was utilized for productivity. Actual losses ranged from 4% to 70%. The paper mentions many factors that cause water losses including age of system, type of pipe, management, record keeping, inadequate financing, and public apathy. Of all these, uniformed or untrained management seems to be the single largest factor contributing to continued water loss.

In 1994 water audit had been carried out in the Amari Orchid Resort and the Mermaid’s Beach Resort, a medium and a small sized hotel in Pattaya, respectively. The processes of water audit included water system and management study, meter testing, water consumption measurement and quantification, water quality evaluation, on-site experiments with water saving devices, identification of management options, and application of water balance and distribution models. The Amari’s average water input was 8,356 m^3/month, consisting of well water (76%) and city water (24%), while the other smaller one, the Mermaid’s Beach Resort, was 1,849 m^3/month and consists of city water (73%) and truck water (26%). Both hotels have major consumption in guest rooms. Two water saving devices, showerheads and faucet aerators, were tested for their efficiencies. The inefficiency of the existing showerheads in some of the Amari’s guest rooms had been discovered. The experiments conducted indicated a possible saving of 17.03 m^3/room-month, or 69% of the present consumption, and pay back period less than 5 months. The experiments with faucet aerators yielded ambiguous results. The result at the Mermaid’s rest rooms showed saving result of 0.03 m^3/room-month, or 7% of the water consumption without the devices installed. Possible optimum management options for the studied medium sized hotel were replacement of showerheads, implementation of a rainwater collection system, improvement of garden irrigation practices and sprinklers, covering of the water storage tanks, and improvement of the wastewater treatment plant and training of the operators. Some feasible optimum management options for the small sized hotel were replacement of showerheads, improvement of the existing rain water collection system, raw water and rain water treatment, well water usage change, improvement of the ground water storage tank, and improvement of the existing on-site wastewater treatment plant (23).

For the industry sector, a water audit had been conducted in a large consumer product factory. The study involved a complete inventory of the water supply and distribution system together with a brief description of water use in each unit of the factories. This was followed by a water meter testing and water balance for the complex, making it possible to quantify the water loss from the system. The factory received full time water supply from Industrial Estate Authority of Thailand. The study expressed that there was 43,316 m^3/year of unaccounted-for water, which valued at 216,580 Baht/year (24). However in industrial sectors, water uses are different from residential sectors due to much more amount and variation in demand and this is an obstacle to bring industrial water conservation program to residential practice (23).

Also wastewater reclamations had been considered in many water conservation projects such as water reuses from Belgium food industries processes. In Passendale, a fully abundant food factories city, initiated to reuse partially treated wastewater of the production process. The treatment composed of many steps those were anaerobic pre-treatment, aerobic activated sludge, filtration system, membrane filtration system, ultra filtration, two-step reverse osmosis, and UV treatment. Treated water should be mixed with underground water and then transferred to be process input. This treatment system can bear wastewater flowrate of 40 m^3/hr. with treated water operating cost of 1.03 Euro/m^3 (25).

A pilot project for water efficiency program was studied in Lubeck, Germany, by installing vacuum pumping station, biogas plant, combined heat, and power generation system. In this study the researcher had also tested collecting wastewater through vacuum toilets, using an average of 0.7 liters per flush and vacuum sewers, possessing 40-65 millimeters diameter. These appliances bring wastewater to be amalgamated with bio-waste and then was sterilized and passed through anaerobic digester. Finally at the end of process the researcher got steadily nourished and low contaminants manure. Some of wastewater had been passed to vertical constructed wetlands and consequently treated with membrane bioreactors for reuse purpose. This study suggested the possibility to bring vacuum system for low-dilution black water to practical in urban settlement even though there was some annoying loud noise from vacuum system (26).

There was also a yellow water study in Sweden. Urine separation was conducted by use of urine sorting toilet to derive merely urine as an input of agricultural fertilizer. For the past 10 years Germany had reused non-portable water through biologically treated wastewater (e.g., Rotary Biological Contractor; RBC, Fluidized-Bed Reactor) as toilet flush (27). In Singapore there is restricted watershed area, therefore 60% of water use was necessarily imported. Consequently the governance had continually supported the finding of new water source. Another study is the investigating feasibility of using rain, collected from Nan Yang University of Technology building roof as non-portable water. The total roof area covered 38,700 m^2 making advantages to collect rainwater to in-site use and being able to save water cost around 18,500 Singapore dollars per year (28).

In 2000 there was a study of water pressure control system. The study found industrial sector water use in United Kingdom focused on reduction of leakages from distribution system. Most leakages were from significantly amount of diminutive fissures occurred within pipeline. Pressure control by installing pressure-reducing valve was a cost-effective way in leakage cutback (29).

2.4.2 Water Audit and Water Efficiency in Hospital

By reviewed existing standard in the U.S., Canada, England, Australia and Thailand, Krongkarn (2000) studied physical and environmental structure standard for hospital and integrated the early mentions as draft. By using Delphi technique, the draft was delivered to 19 specialists to assess and rank it in term of significance level. The results indicated that physical and environmental structure should be set as necessity for all hospital, should be set as achievable goal, should be fine adopted to proper hospital, and used in correspondent with Thai society (30). The study found that waste disposal was evaluated as necessity for all hospital (e.g., officer responsible for water treatment plant possesses theoretically technical knowledge and passed criterion of training).

In 1996 water treatment plant efficiency was studied in Chulalongkorn Hospital, a 1,500-bed hospital, and 2,000 m^3/day wastewater was found. Influent possessed 109mg./l of BOD_5, 189mg./l of Suspended Solids, 7.2 pH, 30mg./l of Nitrogen (TKN), 5-6mg./l of PO_4, 4-5mg./l of grease, and MPN at 4.6*10/100ml. When passed through Conventional Activated Sludge (CAS) and following Aerobic Sludge Digestion (ASD), effluent possessed 112 mg./l of COD, 11mg./l of BOD_5, 20mg./l of Suspended Solid, 7.2 pH, 1-2mg./l of Nitrogen (TKN), 1-2mg./l of grease and compliance with the law. In the consideration of using effluent for lawn and garden watering, it was necessary to process a treatment by sand filter and disinfect with chlorination. Due to water quantity used in the hospital gardening was around 2-5% of total wastewater, this had been considered as a high cost investment and not a cost-effective option (31).

In 1997 a study on environmental action plan for a hospital was conducted in a 583-bed Children's Hospital, Bangkok. The study found daily average water consumption of 1,034 m^3/day consisted of hospital use (1,589-l/bed-day) and dormitory purposes (517-l/head-day). The water consumption in the hospital was 2-3 times higher than the other found report and the percentage of wastewater to water supply was 63 percent. As partly the waste audit program, possible water wastage reduction options were identified in dormitories. It was discovered that about 70 m^3/day or 7% of total water consumption were used inefficiently due to bad housekeeping. As a result, the hospital has been losing 263,000 Baht/year. In view of chemical or toxic wastes generated, it had been found that the hospital generated around 57 ml/bed-day. It was noted that approximately 37% of total chemical wastes discharged to sewers was contributed by laundry section which led to be the largest generator of chemical wastes. An environmental action plan for water use improvement was developed in the study. With good house keeping (e.g., good operating and maintenance) was supposed to save 5-7% of water use and replacement of plumbing fixtures (e.g., aerated faucet and shower, flush tank, water saver flush valve) with 5,000,000 Baht investment should gain 7 years pay back period (32).

In 1994 hospital possessing 138-550 beds had been surveyed. The study showed that the hospitals had annual inpatients ranging from 5,100-11,600 persons, and used 15-67.2 million gallon a year. The studied found that health care institution had been the top ten user in community of Boston metropolitan area and consumption of each people in this kind of sector ranged from 40-350 gallon/capita-day (151-1325 liter/head-day) with the water utilizing at the followed proportions; sanitary use 0.42, HVAC (Heat, Ventilation, and Air-Conditioning use 0.23, medical care use 0.14, nutritional unit and restaurant use 0.09, miscellaneous and unaccounted-for water 0.09, and laundry 0.05 (33).

CHAPTER III
WATER AUDIT METHODOLOGY

Water audit was used as a major tool in this study to develop water efficiency options. Research methodology comprised 6 stages, complied with 6 chapters of manual for conducting water audit and developing water efficiency programs at federal facilities (Environment Canada, 1993) (see details in review of literature). And the water audit process of this research was summarized in figure 3-1 and the details as follow:

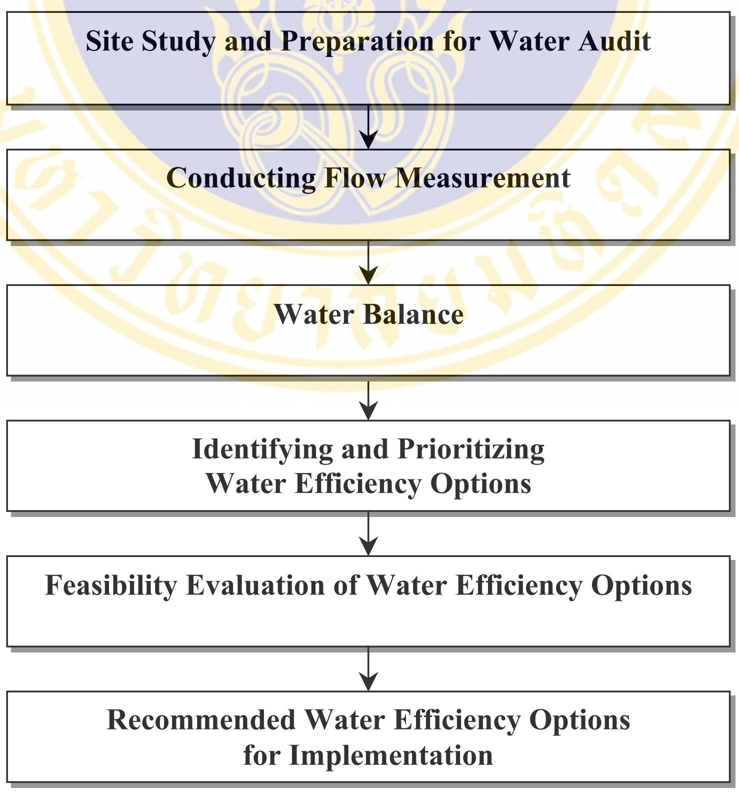

Figure 3-1 The water audit process in this research

3.1 Site study and Preparation for Water Audit

This stage of the study complied with Chapter1: System Components, which consist of description of facility and scope of study, elements of a water distribution system, and basic procedures for a water audit.

Description of facility and scope of study was according with the physical characteristics, including details of buildings which were collected from various sources, mostly from mechanic room. The age of the building was determined. Surveys on points of water use were made at this state. Some points in the system where water usage could be measured were identified, such as existing meters and possible points for ultrasonic flowmeter and water meters installation. And the highly water usage area such as laundry department and nutrition department required the installation of flowmeters in order to measure the quantity of water use in a particular area.

The relevant information on the various categories were obtained from plumbing drawings. Site inspections and discussions with area personnel allowed a truly understanding of the water-using activities at the hospital.

Basic Procedures, specific steps that were used to define the system at the facility included a visual inspection of the facility, an inspection of plumbing drawings. An area site plan was prepared and presented the location of facility's water meters. Plans of each section of the facility showed the major water distribution system. And transferring of key information to the base maps, an extensive site investigation to verify necessary information is required in this state.

The measurement of water usage were planned in several methods as follow:

3.1.1 Flow measurement by ultrasonic flowmeter

Water flow that proceeds in large pipe (e.g., diameter 1, 2, 2.5, 3,and 4 inches) was measured by the use of portable ultrasonic flowmeter. The ultrasonic flowmeter had been borrowed from Energy Program, Asian Institute of Technology (AIT). When attaching sensors outside a pipe and entering all the pipe specification needed, the external clamp-on meter sent ultrasonic signals through the pipe wall and across the water flow. Then the flowrate of water passing through the pipe was measured within a certain range of time. The instrument had been calibrated at the Water Meter Factory of Metropolitan Waterworks Authority (MWA) for diameter sizing 2, 3, and 4inches (size matching available calibrating tanks at Water Meter Factory). Then validate equations for specific testing sizes were employed to transform the measured figures to real flowrates. Finally, actual flowrates at specific measuring time were then averaged and multiplied with the duration of time that was used in the measurement to figure out actual water consumption at specific studied point.

3.1.2 Flow measurement by water meters installation and recording

During the site survey it was found that Thonburi hospital has 2 large city water supply lines and one small city water supply line and other sub-meters that already existed. The large main meter was on the line that serves 12-storey building, 7-storey building, mechanic room, laundry, dormitories including 150-resident dormitory, nutrition department, garage, 4-storey building, out-patient department, administration office, dialysis department, diagnostic rooms, cafeteria and restaurant. The second large main meter was installed on the water supply line that serves 6-storey building. The small meter, received water from city water, was on the line that also served the 150-resident dormitory. Other 6 existing meters were found, 4 at hospital dormitories, 1 at inpatient ward, and 1 at softening water pipeline to dialysis department. The only two large main meters, one small meter of city supply line, and 6 small meters were not enough to measure flowrates at several points of water usage. Therefore, in this research adds more 7 meters on the following points: outpatient department, dialysis department, cafeteria, restaurant, dishwashing sink, garage restroom, and garage. Seven meters at different size were borrowed from Jindasuk Co., Ltd., which were complied with the Metropolitan Waterworks Authority (MWA). These meters were verified by the Division of Water Meter Factory with possible error in the range of ±3%. Totally 16 meters were employed to record water flow in this study. The researcher planned to record the meters on 13-26 August 2002 at a specific range of time (during 9:50 AM-10:10 AM).

3.2 Conducting flow measurement

This stage followed the Chapter2: Inventory of water use operations, which comprised elements as follow:

Procedures for flow estimation were based on field measurements. Methods of field measurement included ultrasonic flowmeter and water flow meters on the water distribution system, and stopwatch measurement of water extracted for a specific operation such as faucets and showerheads. Ultrasonic flowmeter and water meter reading, volume-time flow measurement, water use observation through site visit, and relevant personnel interview, were to be carried out.

3.2.1 Meter reading

An essential element of the water audit was the measurement of the main flow entering the facility. Additional flow measurement into sub-areas was warranted to ascertain significant portions of the total flow. Water audit was to be carried out through the use of ultrasonic flowmeter clamping on specific pipeline. When clamped on the target pipe, the portable flowmeter print out detected flowrates on the paper roll every 10 minutes for consecutive period of time. Another one was the investigations from meters at particular activities in order to record water flow and then water uses in a specific period of time were calculated. All available meters were to be read and recorded simultaneously for consecutive two weeks duration (August 13-26, 2002).

3.2.2 Water use observation

Observing water use pattern included the observation of locations, activities, water use quantity, using time and duration, way and path of discharged wastewater to sewer, and desirable water efficiency alternatives for a specific activity. Some fittings, mostly showerhead and faucets, were to be measured by volume-time method. A bucket and stop watch approach was used to estimate flow in some toilet fittings such as showerhead and faucet in most buildings. It is simply a measurement of time used for water running from one outlet to fill up a known volume container. The flowrate at the outlet can be calculated from the container volume divided by the time used. The time it took a bucket of a known volume to be filled by the free-flowing source is measured and a flow could be calculated. In addition the leak detection was to be carried out during the water audit by sight investigation. If there was water dipping or trace of water dipping, the area should be a suspected as facing leakage.

3.2.3 Staff interview

Interviewing people of concerns and operators made it clear about water being used and its usage pattern. This was useful in classifying water use activities into category.

3.3 Water Balance

This stage followed Chapter3: Water Balance, which used the information, gathered from site inspections, measurements, and discussions with site operators and users. An analysis is then completed of the average daily flow for each facility.

Water balance was used in order to analyze, identify water users and quantify water use that base on various activities. Data gathered from water audit was analyzed to figure out actual water use proportions for each activity and brought into the water use inventory. By using water balance, it was possible to prioritize problems occurring along with water use. Main problem areas were deemed to figure out alternative solutions. In addition, water efficiency proposals deriving from the interviews and information coming from observations were included in data proceeding. This stage consisted of the following:

Water meter reading approach provided the level of data required for a water audit. The flow data was obtained from reading the existing and newly installed flowmeters. For the ultrasonic flowmeter, being equipped with internal data logger it had been planned to used for recording flow rate every 10 minutes for 24-hours a day. The measurement would take an average 5 days per measuring point, covering working days and weekend.

The completion of facility water balances, in which all major water uses were accounted for concluded the water audit part of the process. The water audit results were then used in the next phase for designing a water efficiency options specific to the facility under study.

3.4 Identifying and Prioritizing Water Efficiency Options

This stage complied with Chapter4: Water Reduction Measures. The water efficiency options were designed to incorporate with water reduction measures that best achieved the goals set out for the activities at the hospital. Steps leading to such a program included water audit analysis, interview evaluation, observation outcomes assessment, and relevant literature review. Moreover, testing of flush tank water volume reduction by using plastic bottle filled with water and gravel had been conducted. In this phase 2 criteria that were degree of water usage, and water use figure in comparison with available usage were used to identify prioritize options. The main activities that scored in top rank should be considered to figure out water efficiency options.

Demand management methods that involve reducing the demand for water at the user end of the distribution system included the following.

Retrofitting systems are common for domestic water use components such as toilets, showerheads, and faucets. Replacement of water-using devices with, low water-using fixtures should be considered for toilets, faucets, and showerheads. Water reuse were considered to reduce water use in case large volumes of uncontaminated water such as cooling water in autoclave are to be discharged to municipal sewers.

3.5 Feasibility Evaluation of Options

This stage complied with Chapter5: Designing the Water Efficiency Program. The water efficiency options were designed to incorporate water reduction measures. Steps leading to such options included identification of all reasonable reduction measures, identification of positive and negative impacts of the reduction measures, preliminary evaluation to screen out undesirable measures, a cost-benefit analysis, and evaluation of the recommended water reduction options.

A cost-benefit analysis would determine the net savings that would be made by the most cost-effective water reduction measure. Detailed examinations of the potential water reduction measure were undertaken. However, a simple cost-benefit analysis involving the estimated capital cost of the modification works, the net revenue savings, and the resulting payback period should suffice in this study. Technical Feasibility Evaluation in this study was evaluated through possibility of practical use in the hospital. Each option was evaluated through opinions of researcher and people of concerns. Water saving results from specific options were quantified in order to assess the environmental aspects. The options were prioritized on payback period basis. The results of the cost-benefit analysis might be used to develop water efficiency options. The resulting options consisted of a number of compatible water reduction measures and have a net benefit and net water volume savings.

3.6 Recommended Water Efficiency Options for Implementation

In the results and discussion phase, water efficiency options with cost reduction were identified.

CHAPTER IV
RESULTS AND DISCUSSION

Introduction

Water audit was carried out in Thonburi Hospital to identify water use activities and proportion of their usages. Firstly, instruments for water audit were calibrated for the accurately measurement. These were done through meter testing, especially for the ultrasonic flowmeter, which required correction factors at each available pipe size. The additional flow meters (normal type water meter) were borrowed from the supplier and passed the calibration process from the Division of Water Meter Factory. Then all calibrated water meters were installed at accessible point to detect actual water consumption of some specific users. But, for larger pipes at 4", 3", and 2" diameter, flowrates were measured by using ultrasonic flowmeter at possible measurement point. Therefore, the figures of water consumption and water balance within the studied hospital were discovered. Also water usages and system inventories of large account water users were described. Although there was a limitation in water leakage detector by using technical instrument in this study, only visual investigation was performed during the water audit phase and there was no visible leakage found from the plumbing system. However, there could be possibility of underground water leakages or even leaks occurred within unreachable points of some plumbing system. Consequently water efficiency options in specific areas were proposed at the end of chapter by the evaluation in term of cost-benefit analysis. Mostly high investment projects were rejected since they required too long payback period. In contrast no-cost and low-cost options were found as potential ways to achieve water usage reduction in the studied hospital. And the research results were presented as follow:

4.1 Site Study and Preparation for Water Audit

4.1.1 Site Study

In site preliminary study phase it was found that Thonburi Hospital water supply was distributed through 2 main lines. The first line served 12-storey building, 7-storey building, 4-storey building, mechanic room, laundry, dormitories (including 150-resident dormitory), nutrition department, garage, outpatient department, administration office, dialysis, diagnostic rooms, cafeteria and restaurant. The second line served 6-storey building. And also 1 small city supply line served 150-resident dormitory.

General data found in this stage was described as follow. Thonburi Hospital, a 435-bed general hospital, located in Bangkok Metropolitan. The total area of the hospital was 11 Rai (with total estimated 39,422 m^2 of utilization area) and possessing 1,716 employees. And it held the 6^{th} rank of largest private hospital in Thailand. The hospital daily served 1,200 outpatients with average 0.75 inpatients bed occupational rate (2,098 inpatients/month). Plumbing system in the hospital consisted of PVC and galvanized pipelines along the service area. Water was supplied from two main pipes into two underground tanks of the hospital. The water was then pumped intermittently to the roof tanks in order to use gravity flow for water utilization within the hospital.

The hospital received water supply from MWA (Metropolitan Waterworks Authority of Thailand). In the year 2000 the hospital used approximately 266,216m^3/year of water (22,185 m^3/month) and it cost around 376,696 Baht/month while the hospital water consumption in 2001 was 22,621m^3 costing 384,094 Baht/month according to water bill derived from the hospital financial department. Wastewater from all activities in the hospital was collected to aerobic wastewater treatment system, which was on the basement of 7-storey building. As designed, the plant capacity was around 800m^3/day of wastewater.

Elements of a water distribution system were obtained from plumbing plans in the construction room. Site inspections and discussions with area personnel make it clear about the water supply of the hospital. The water supply diagram was drawn from such information. Figure 4-1 showed the flow diagram of water supply in Thonburi hospital.

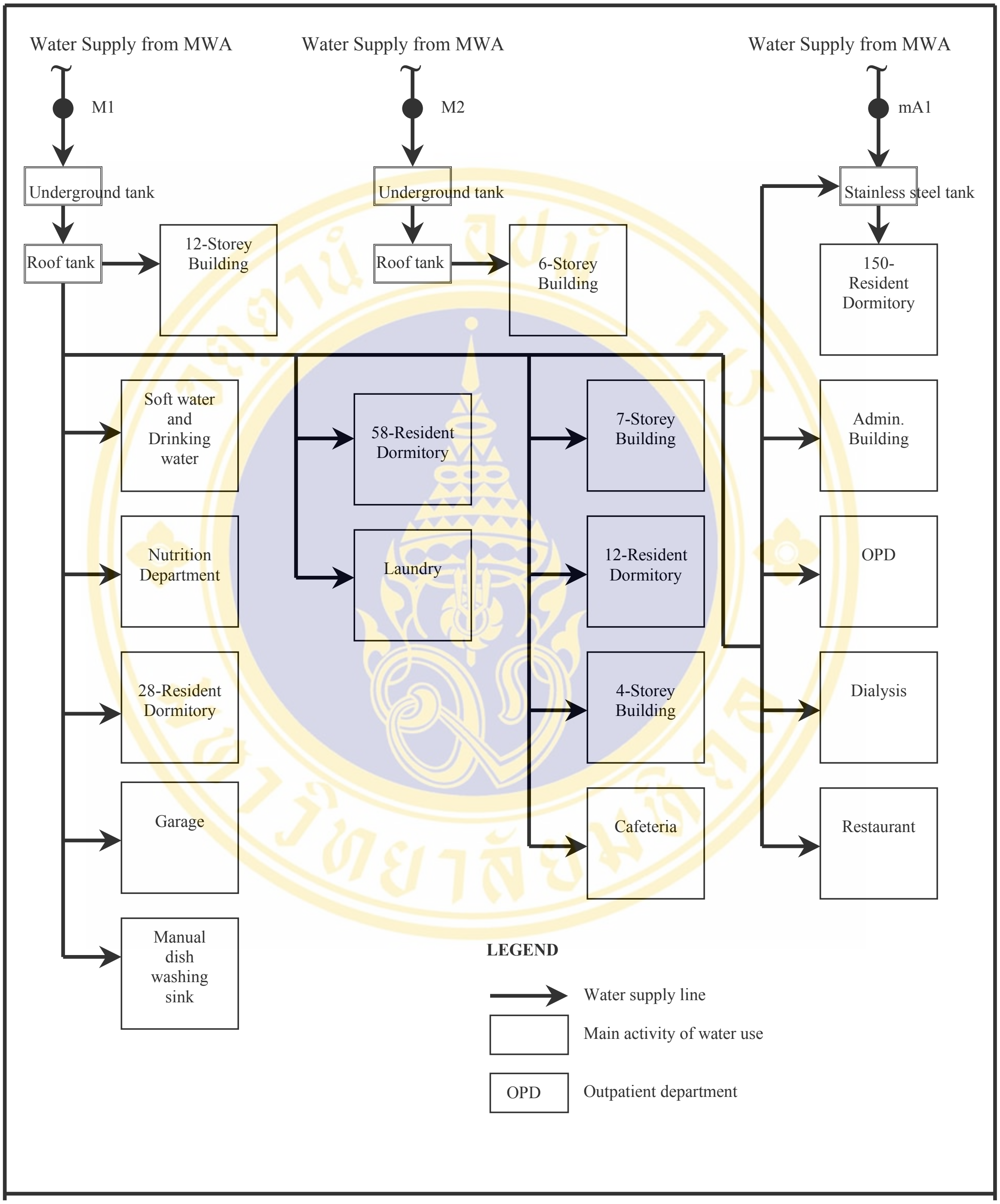

Figure 4-1 Flow Diagram of Water Supply in Thonburi hospital

Further step were the transferring of key information to the base maps and extensive site investigation to verify information. An area site plan was prepared with the facility's water meters shown, depicting installations and buildings served.

Water use measurement was to be conducted through ultrasonic flowmeter and water meters. Ultrasonic flowmeter and water meters were to be installed for flow measurement. The measuring area and code of ultrasonic flowmeter and water meters were shown in table 4-1 and figure 4-2, respectively.

Table 4-1 Measuring area and code of water flowmeter

Code of Water flowmeter	Measuring Area
UFM1	12-S building
UFM2	6-S building
UFM3	4-S building
UFM4	7-S building
UFM5	Laundry line
UFM6	58-dormitory
UFM7	Nutrition line
UFM8	OPD line
UFM9	Softening line
UFM10	Drinking line
m1	OPD3
m2	Dialysis
m3	Cafeteria
m4	Krua-Thai Restaurant
m5	Manual dishwashing sink
m6	Garage restroom
m7	Garage faucet
mA1	150-resident dormitory (Tradition meter)
mA2	150-resident dormitory (Supplementary)
mA3	12-resident dormitory
mA4	IPD rooms (total 6 rooms)
mA5	Dialysis water softening
mA6	28-resident dormitory
M1	12-Storey building
M2	6-Storey building

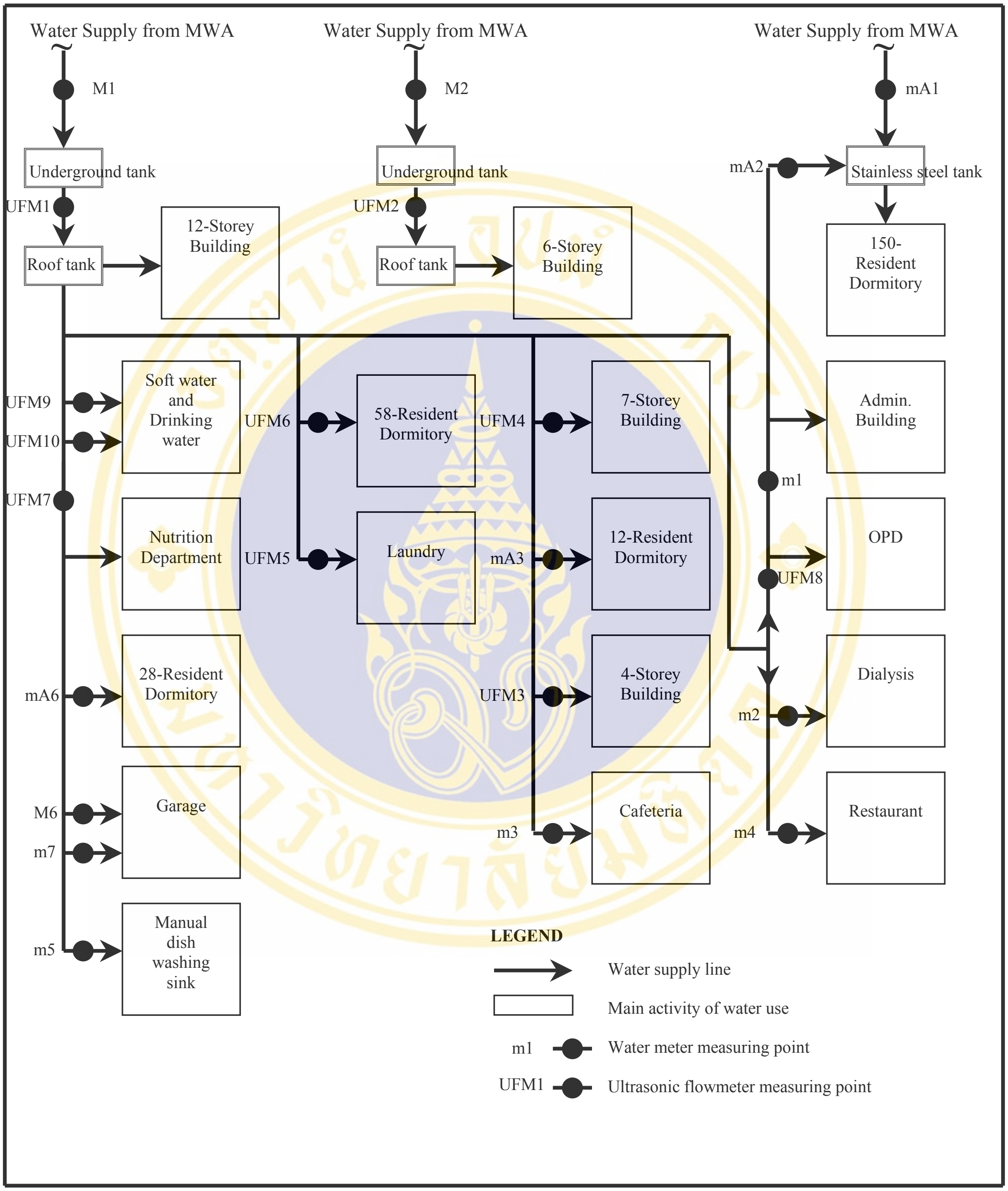

Figure 4-2 Flow Diagram of measuring point for ultrasonic flowmeter and water meter

4.1.2 Preparation for Water Audit

The ultrasonic flowmeter, for the pipe size of 4", 3", 2" in diameter, were calibrated by MWA. And because of the restriction in pipe size for testing by meter-calibrating machine, therefore, the pipe size of 2.5" and 1" were not included in this calibration. Then linear regression equations for each pipe size had been figured out. These correction equations when represented with indicated water meter readings were assumed to yield the actual water flow.

The graphs plotted in figure 4-3, 4-4, and 4-5 presented the MWA water meter calibrating machine readings (real volume-time measurement) versus the ultrasonic flowmeter flowrate readings as follow:

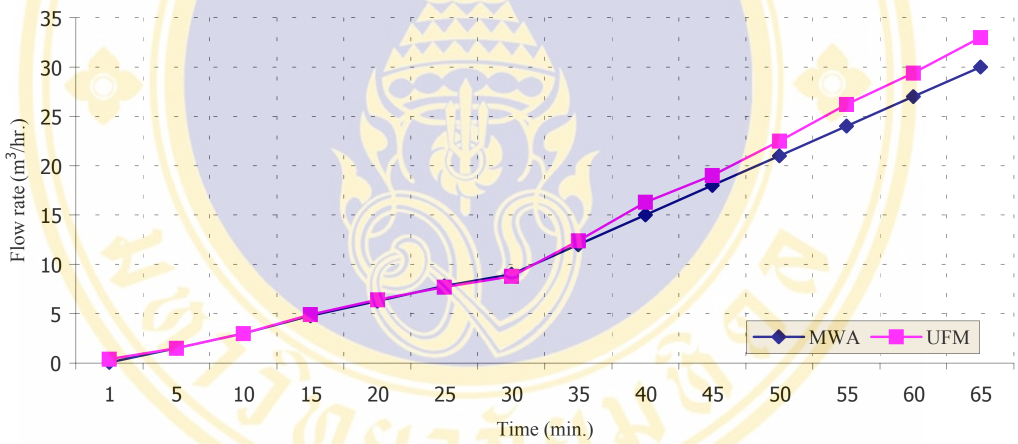

Figure 4-3 Comparison between measured flowrate by meter-calibrating machine and ultrasonic flowmeter (UFM) of 4" pipe diameter

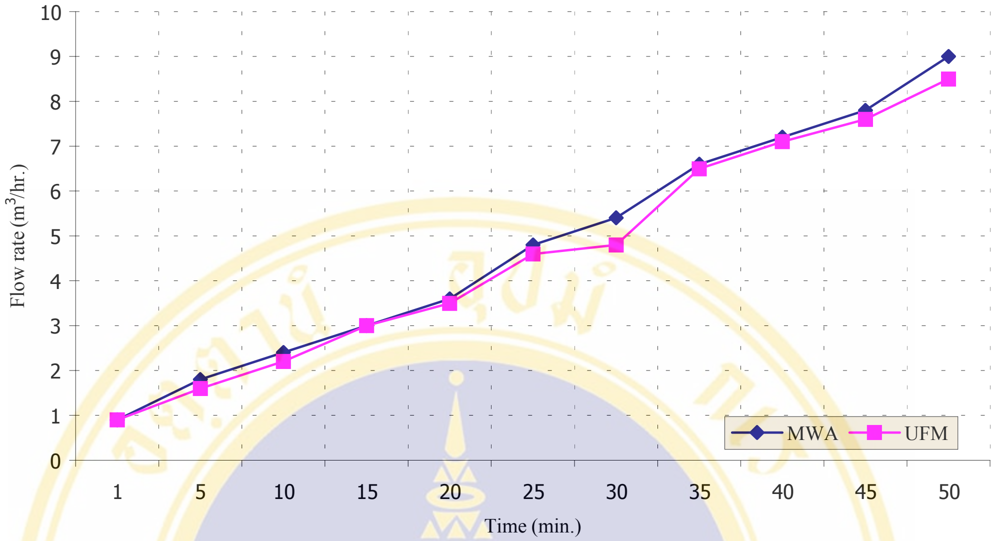

Figure 4-4 Comparison between measured flowrate by meter-calibrating machine and ultrasonic flowmeter (UFM) of 3" pipe diameter

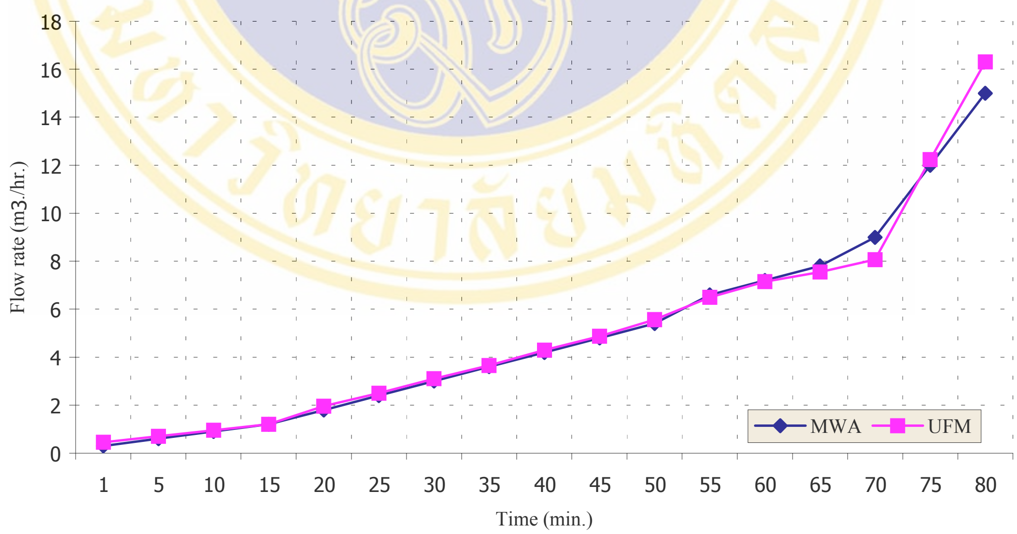

Figure 4-5 Comparison between measured flowrate by meter-calibrating machine and ultrasonic flowmeter (UFM) of 2" pipe diameter

As seen in the graphs, the deviations were quite small. The difference between the water flowrate that was set by the meter-calibrating machine of MWA and the flowrate that was read from the ultrasonic flowmeter was only in terms of magnitude. The graphics were of quite similar pattern.

Flowrates recorded from MWA and UFM in figure 4-3 to 4-5 were analyzed in correlative to get a linear regression equation for each pipe size by using equations as follow: (see details in Appendix)

$$Y = a + bX$$

where $a = \bar{Y}_{i\text{-}j} - b\bar{X}_{i\text{-}j}$

$$b = \frac{\sum X_i Y_i}{\sum X_i^2}$$

and X_i = flowrates recorded from ultrasonic flowmeter

Y_i = flowrates recorded from meter calibration machine

Derived conversion equation for each pipe sizes were shown in table 4-2

Table 4-2 Conversion equation for ultrasonic flowmeter, derived from linear regression analysis with different pipe size

Pipe diameter (inch)	Flowrate available at MWA (l/min.)	Calibrating Flowrate (l/min.)	Conversion Equation
4”	0-500	0-500	Y = 0.08+0.93X
3”	0-160	0-150	Y = 0.01+1.04X
2”	0-250	0-250	Y = 0.03+0.98X

Note: X = each flowrate read from ultrasonic flowmeter at its diameter size
Y = estimated actual flowrate deriving from putting X value into the equation at specific diameter size

Nevertheless if we considered the hypothetical situation, of all water flowrate at the same pipe size at Thonburi Hospital, behaving in a similar characteristic as the flowrate of MWA, especially for equivalent pipe size that had been investigated. Then the same correction equations, also, assumed for using with the same pipe size.

According to table 4-2, it was found from the study that water flowrate in 4” pipe at Thonburi Hospital ranged from 1.28-51.82 m^3/hr. (21-864 l/min.) While flowrates of MWA meter-calibrating machine availed from 0-500 l/min. So calibration was carried out through the conceivable range of 0-500 l/min. for 4”-pipe. Then the conversion equation was derived from Linear Regression Analysis as shown in table 4-2. The pipe size of 2” and 3” were calibrated as the same manner. While 1”-pipe and 2.5”-pipe were not possibly calibrated because of technical limitation. So values measured from the ultrasonic flowmeter were used at it’s own property possessing error variation of ±3% of measured flowrate.

Finally, every flowrate read from ultrasonic flowmeter would be adjusted by suitable equation for each pipe size, and transferred to actual flowrate results.

4.2 Conducting Flow Measurement

4.2.1 Flow measurement by ultrasonic flowmeter

The ultrasonic flowmeter was used on various pipe sizes and measured points as shown in table 4-3. And the water flowrates were measured through ultrasonic flowmeter during June 21-September 16, 2002.

Table 4-3 Number of UFM measuring points at some specific pipe sizes

Galvanized Steel Pipe diameter (inch)	Number of measuring points
4	2
3	5
2.5	1
2	1
1	1

The Thonburi Hospital Water supply flew through the main M1 water-meter before being distributed to the hospital facilities except for 6-storey building which received water from M2 water-meter. Whereas 150-resident dormitory received water from mA1 water-meter and another auxiliary small city water supply line. Water supply from MWA passing through M1 to underground storage tank, in 12-storey building, was pumped up to the roof tank to distribute by gravity flow and booster pump to other facilities in the hospital. This main supply line served mostly the whole facilities, 747.10 m^3/day (see details in table 4-4). Thus it could be used as a representative behavior of the hospital’s water usage. Consequently at the first time, ultrasonic flowmeter was installed at UFM1 (clamped on the outlet side of 12-S building underground tank) to detect water use pattern of the hospital. The core purpose for clamping at this point is to determine suitable time for water meter recording, which require rather stable water use pattern for at least a short period to guarantee that water flow would not fluctuate during recording time. Figure 4-6 illustrated average 24-hour water flowrate measured during June28–July3, 2002 (covering working days and weekends) at UFM1. Therefore, this research used the time between 10:00 to 11:00 a.m. for recording the water flowrate.

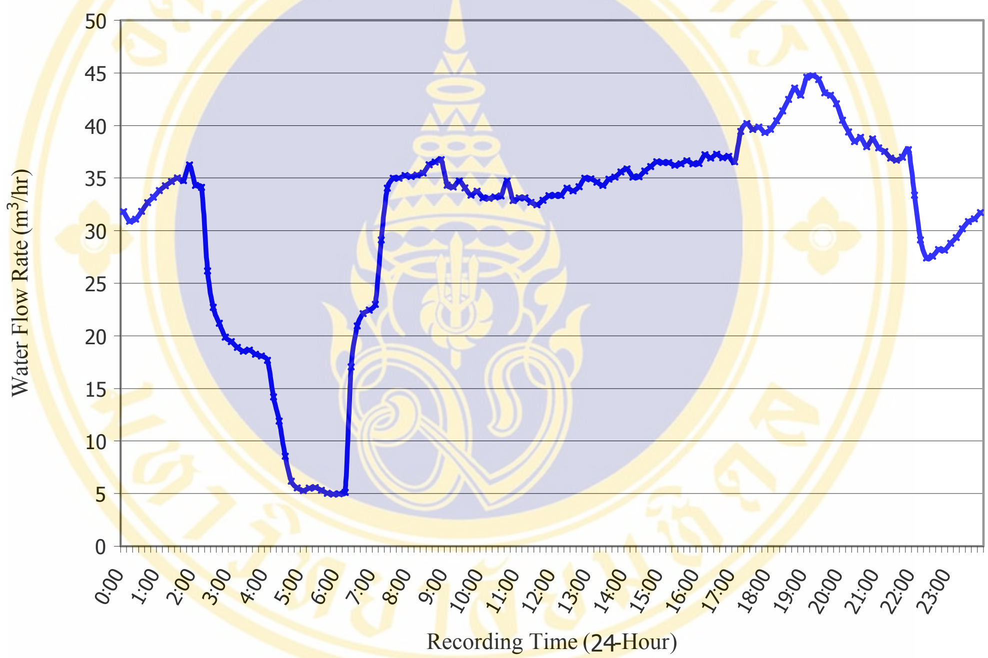

Figure 4-6 Average water flowrates measured during June28–July3, 2002

It was notified that all water supplying through 12-Stroey building line passed this measurement point, even though, at downstream, the water was pumped to 12-Storey building roof tank before the distribution. However Figure 4-6 should partly represent the profile of Thonburi Hospital water use. Normally the hospital had 24-hour operating time so it was not such strange that water flow never stop running. At the minimum 5m^3/hr, the hospital still operated inpatient wards, outpatient department, X-Ray department, operation room, ICU, infant and birth operation department, laboratory, housekeeping, etc. Also 3 dormitories were in duties to support their residents 24 hours a day. At the lowest flowrate, water ran through hospital facilities, some of which possessed their own storage tanks in order to fill up and keep the high water level in the tank. Water use activities started around 6:00 when nutrition department began its operation, preparing inpatient dietary. Additionally, flowrate rose up sharply when laundry subsequently started up it's routine at around 7:30 and carried on till 16:00. With all functions proceeding, flowrates tended to gradually fluctuate among the office hour: 8:30-17:00. From 17:00 water flowrates continually boosted up due to the flux of outpatient and inpatient visitors and reached the peak at 19:30. Afterwards flowrates slowly decreased till quick dropping at 22:00. Fluctuation flow occurred around mid-night coming from turning shifts of nurses at 23:30. In addition, dormitory domestic uses took part in this flow variation amongst 23:30-2:00. Passing 2:00, flowrates fell down repeatedly until hitting off-peak 5 m^3/hr at 5:00. From 5:00-6:00, flowrates were at the steadiest state, holding calm before the next cycle start out over again.

Average water usage detected by using the ultrasonic flowmeter during June-September 2002, were shown in table 4-4. (see records in Appendix)

Table 4-4 Average water usage recorded by ultrasonic flowmeter

Code of water flowmeter	Measuring Area	Water Usage Activity	Average water usage quantity (m^3/d)
UFM1	12-S building	Medical treatment, OPD, and Inpatient ward	747.10
UFM2	6-S building	Medical treatment, OPD, and Inpatient ward	75.73
UFM3	4-S building	Medical treatment, OPD, and Inpatient ward	54.17
UFM4	7-S building	Medical treatment, OPD, and Inpatient ward	17.82
UFM5	Laundry line	Laundry	58.70
UFM6	58-dormitory	58-resident dormitory domestic use	13.89
UFM7	Nutrition line	Nutrition, 28-Dorm, Manual dishwashing, Garage	163.43
UFM8	OPD line	OPD	65.93
UFM9	Softening line	Water softening used in medical hygiene	82.98
UFM10	Drinking line	Filtered and UV infiltrated water for drinking	6.44

4.2.2 Flow measurement by water meter

With the MWA coordination for borrowing water meters from Jindasuk Co., Ltd. the meters were calibrated and certified with possible error variation of ±3% from the Division of Water Meter Factory, MWA. Therefore records accuracy would be within ±3% of error variations.

As seen in table 4-5 various sizes of calibrated meters including 1½ ”, 1”, ¾”, and ½”, were encoded as m1 to m7. And they were installed at 7 investigated points to find out exactly daily water consumption at each destination facility. Also 6 meters belonging to the hospital were encoded as mA1 to mA6. Other 2 main meters of the hospital were coded as M1 and M2 respectively. Water usage recorded from meters in this study was shown in table 4-5. Even M1 and M2, the existing main meters of Thonburi Hospital still work in recording period, but the results from M1 and M2 were not used in water balance because of its old and possible error in water flow measurement. Therefore, this research used the water usage measured from UFM1 and UFM2 for water balance.

Table 4-5 Average water usage recorded by water meter

Code of water flowmeter	Water meter size	Measuring Area	Meter Installing Date	Data Recording Time[1]	Average Water Usage Quantity (m^3/day)
m1	1 ½”	OPD3	July 25,02	10:04	28.41
m2	1 ½”	Dialysis	July 25,02	10:06	4.22
m3	¾”	Cafeteria	July 23,02	10:08	8.55
m4	½”	Krua-Thai Restaurant	July 23,02	10:08	4.76
m5	½”	Manual dishwashing sink	July 23,02	10:10	8.06
m6	1”	Garage restroom	July 23,02	10:09	0.97
m7	¾”	Garage faucet	July 23,02	10:09	1.73
mA1	½”	150-resident dormitory (Tradition meter)	Existing	10:02	11.57
mA2	1 ½”	150-resident dormitory (Supplementary)	Existing	10:02	20.10
mA3	¾”	12-resident dormitory	Existing	09:55	3.50
mA4	1½”	IPD rooms (total 6 rooms)	Existing	09:50	2.28
mA5	1½”	Dialysis water softening	Existing	10:06	17.04
mA6	1 ½”	28-resident dormitory	Existing	10:10	15.30
M1	4”	12-Storey building	Existing	09:58	682.60
M2	3”	6-Storey building	Existing	10:00	47.86

[1]According to figure 4-6 the water usage was rather stable within 9:50-10:10 so data recording were done within this time frame

Water flows were recorded through water meter during August 13-26, 2002 covering working days and weekends and the average water use at each end user derived from average measured water flow.

4.2.3 Flow measurement of plumbing fixture

Volume-time measurement was used in this study to find out water use in a given period of time for some fittings that were highly use.

Bucket-Stopwatch was used to find out average water consumption rate of showers and faucets in the hospital. And water usage of toilet flush valve, 16 l/flush, was identified by specification of the manufacturer according to the model installed in the site. Toilet flush tanks were sampled and then filled up with known volume of water to normal use water level in the tank. More or less 16 liters of water were required in filling up the tank. The results from water measurement were shown in table 4-6.

Table 4-6 Volume-time flow measurement of toilet-fitting

Site situated	Specific Area	Shower (l/min)	Faucet (l/min)	Toilet[1] (l/flush)
General				
12-Storey building	1st fl. restroom	-	10.9	16 (FV)
	5th fl. restroom	10.2	7.1	16 (FV)
	7th fl. restroom	12.5	8.8	16 (FV)
	9th fl. restroom	10.4	7.5	16 (FV)
	11th fl. restroom	14.9	10.6	16 (FV)
6-Storey building	2nd fl. restroom	11.1	7.2	16 (FV)
	4th fl. restroom	10.7	6.8	16 (FV)
	6th fl. restroom	-	9.2	16 (FV)
7-Storey building	2nd fl. restroom	-	7.5	16 (FV)
	4th fl. restroom	-	6.6	16 (FV)
	6th fl. restroom	13.2	9.1	16 (FV)
4-Storey building	2nd fl. restroom	10.8	7.5	16 (FV)
	4th fl. restroom	10.3	7.2	16 (FV)
Nutrition	1st trial	-	10.5	-
	2nd trial	-	10.1	-
Washing sink faucets	1st trial	-	13.2	-
	2nd trial	-	12.7	-
Garage	Field faucet	-	10.8	-
	Total Average	11.56	8.6	16 (FV)
Dormitory				
150-resident dormitory	1st trial	10.9	7.8	16 (FT)
	2nd trial	10.1	8.2	16 (FT)
58-resident dormitory	1st trial	13.3	7.6	-
	2nd trial	14.7	7.1	-
28-resident dormitory	1st trial	11.1	6.6	16 (FT)
	2nd trial	10.8	6.3	16 (FT)
12-resident-dormitory	1st trial	-	6.9	-
	2nd trial	-	7.3	-
	Total Average	11.82	7.23	16 (FT)
	Grand Total Average	**11.56**	**8.1**[(2)]	**16**

Note: (-) meant record due to no fitting at the site
(1) (FV) = flush valve toilet, and (FT) = flush tank toilet. According to Siam Sanitary Fitting Testing Department, Thonburi Hospital present toilet flush tanks were of 16 l/flush specifications and flush valves were in the possible range of 12-20 l/flush with originally set flows at norm position or at 16 l/flush
(2) Excluded 13.2, and 12.7 l/min from dish washing rinse faucet (wash sink), which possessed average 13 l/min flowrate

Since the hospital purchased asset in bulk, same models were bought and installed at same building. Consequently the same flowrate of models was assumed with an average inlet water pressure of 1 bar (million dynes per square centimeter).

According to sanitary fittings water usage survey at Thonburi Hospital, toilet flush valves and flush tanks were average of around 16 liters per flush while showers had an average flow of 11.56 l/min. Normal faucets and dish washing rinse faucets had average flows of 8.1 and 13 l/min respectively according to table 4-6.

In addition sanitary fitting survey was carried out in this study to find out exactly number of fittings being used in the hospital. This was useful when water efficiency alternatives were discovered and when it was necessary to calculate value of investment in case of retrofit.

Table 4-7 presented the number of water closet and showerhead in the hospital.

Table 4-7 Total number of water closet and showerhead in the hospital

Site \ Fittings	Water Closet		Showerhead	
	Flush Valve	Flush Tank	Hard stem	Soft string
12-Storey Building	280	3	220	-
7-Storey Building	26	-	3	-
6-Storey Building	54	-	-	-
4-Storey Building	25	11	-	-
Administration Building	-	8	-	-
150-resident dormitory	-	14	-	18
58-resident dormitory	-	-	14	-
28-resident dormitory	-	11	-	11
12-resident dormitory	-	1	-	-
Total	385	48	239	29

4.3 Water Balance

By the use of ultrasonic flowmeter, water meter, volume-time measurement, staff interview and fittings survey, leading to calculation for Thonburi hospital water balance account as demonstrated in table 4-8, sequencing from highly water usage to low water usage. And the flow diagram of Thonburi Hospital water balance was presented in figure 4-7

Table 4-8 Thonburi Hospital Water Balance

The Activity of water use	Water use (m^3/day)	Water use Percentage	Water Measurement Instrument
12-Storey building	262.70	31.5	UFM1-(all of below-UFM2-mA1)
Nutrition Department	137.37	16.5	UFM7-(m5+m6+m7+mA6)
Water softening	89.43	10.6	UFM9+UFM10
6-Storey building	75.73	9.0	UFM2
Laundry	58.70	7.0	UFM5
4-Storey building	54.17	6.4	UFM3
OPD	37.52	4.4	UFM8-m1
150-resident dormitory	31.67	3.7	(mA1+mA2)
7-Storey building	17.82	2.1	UFM4
28-resident dormitory	15.30	1.7	mA6
58-resident dormitory	13.89	1.6	UFM6
Cafeteria	8.55	1.6	m3
Administration building	8.31	1.0	m1-mA2
Manual dishwashing sink	8.06	1.0	m5
Restaurant	4.76	0.6	m4
Dialysis	4.22	0.6	m2
12-resident dormitory	3.50	0.4	mA3
Garage	2.70	0.3	m6+m7
Total	834.40	100.0	

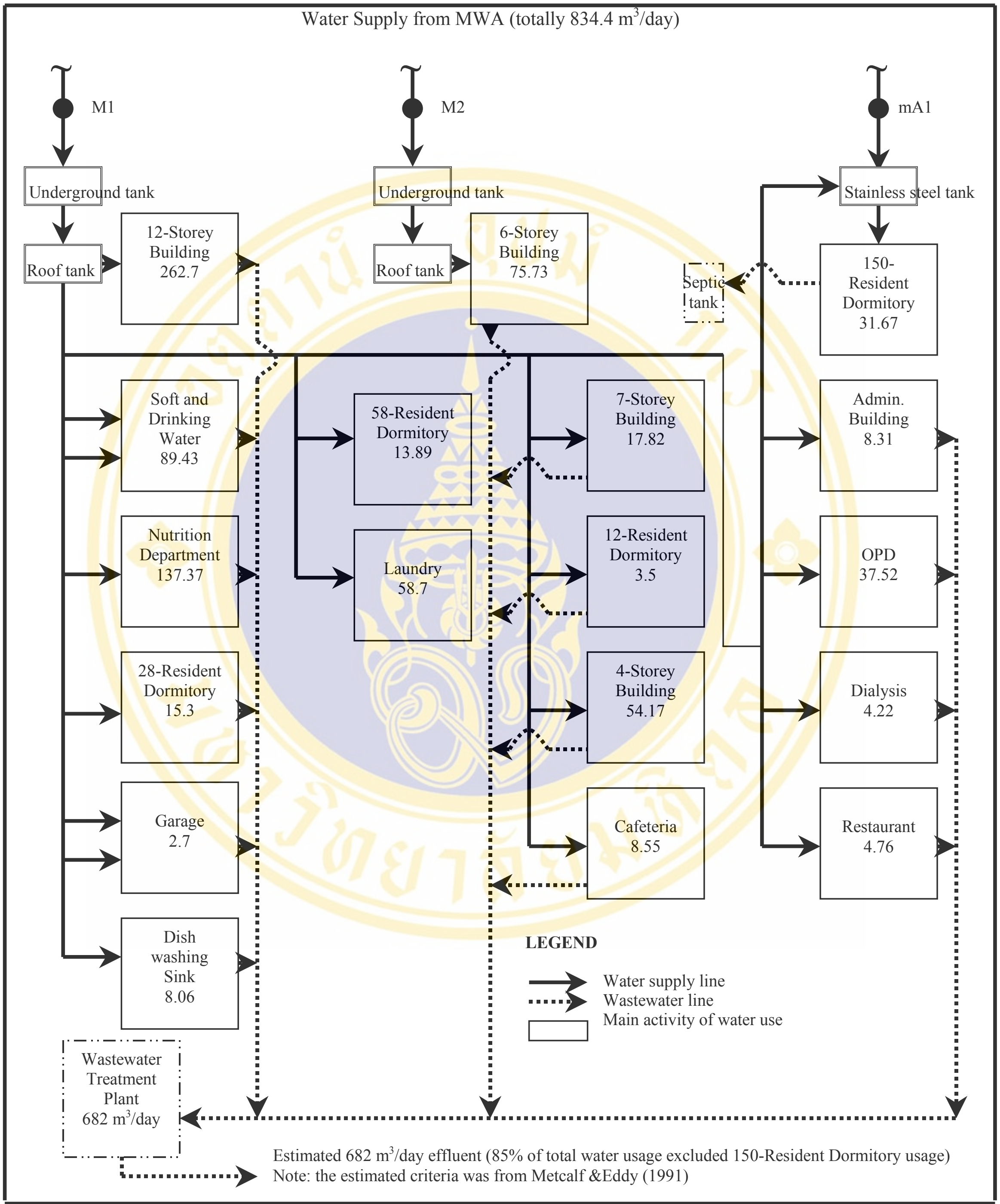

Figure 4-7 Flow Diagram of Thonburi Hospital Water Balance

Water usages in this study derived mainly on records of water meter and ultrasonic flowmeter. The codes m1-m8 referred to average water usage figures recorded from the installed meters at specific points. The codes UFM1 to UFM10 referred to average water usage figures measured from ultrasonic flowmeter at specific points. The codes mA1-mA6 referred to average water usage figures recorded from Thonburi Hospital water meters that had been installed at various specific points.

According to table 4-8 the highest quantity of water usage belonged to 12-Storey building and was classified in high usage category. This building aging a decade, possessed many medical activities such as radiology center, physical therapy department, dentistry department, corpse room, ICU, operation room, and assorted 248 beds inpatient ward. There were many other technical supports locating within this building. From the water audit it was clearly seen that major water user in this area belonged to inpatient ward which each separate room/bed used water with the average of 380 l/room-day (the figure came from sub-measuring by meter number mA4, during the water audit). During the water audit, occupancy rate in 12-Storey building reached its maximum loads. Therefore, the inpatient ward water usage in 12-Storey building was figured out of around 94.24 m^3/day. Sanitary fitting surveys were included in this study in order to find possibility alternatives to improve water efficiency for inpatient ward.

Nutrition department, the second largest water user, was classified in medium usage category. Nutrition department alone uses 137.37 m^3/day (16.5%) of water. The main activities in water utilization were washing and food preparing. The department started its operation at 5:30 for inpatient food tray preparing and began tray and dish washing at 9:30. Trays and dishes were washed through manual wash using 8.06 m^3/day (1%) and a dishwashing machine. The 8-year dishwashing machine operated 3 rounds a day (9:30, 13:30, and 18:30). In conclusion for this department, daily preparing and cleaning 280 inpatient food trays required 137.37 m^3 (491 l/tray). In addition, due to plumbing that had been laid under old construction at the first year of functioning, this building was assumed to possess the largest amount of unaccounted-for water (the amount of non account water less known or estimated losses and leaks).

Based on activity characteristic facilities utilizing water were classified into 6 main groups. Following portion of water account, 6 classifications were shown respectively in sequence as 1) Medical treatment and patient ward 2) Food preparing unit, 3) Water softening, 4) Dormitory, 5) Laundry, and 6) Other sectors. Wastewater from all facilities, excluding 150-resident dormitory was transmitted to wastewater treatment system because wastewater from 150-resident dormitory was discharged to its on-site septic tank. This study could not directly measure influent and effluent, of wastewater treatment plant, due to unavailable length of pipe meeting ultrasonic flowmeter requisite. Thus the result was estimated by the application of Metcalf and Eddy general wastewater flow proportion averaged from industry sector as 85% of total water input to process (38). And the calculation presented that the wastewater flowrate of Thonburi Hospital was around 682 m^3/day.

Water consumption classified by activity and water usage percentage of Thonburi Hospital were demonstrated in table 4-9 and figure 4-8, respectively.

Table 4-9 Thonburi Hospital water consumption classified by activity

Main Water Use Category	Water consumption rate (m^3/d)	Percentage	Water use activities in
(1) Medical treatment	452.16	54.20	Water usage in inpatient and outpatient ward (generally in restrooms and some medical equipments)
(2) Food Preparation	158.74	19.02	Manual/Machine dish washing, Inpatient preparing food, a cafeteria and a restaurant
(3) Water softening	89.43	10.72	Boiler/condensate input, Staff drinking water, Autoclave input, Medical equipment cleaning, Use in Laboratory diagnosis, Supply to dialysis
(4) Dormitory	64.36	7.71	General domestic use; toilet flushing, cloth washing, showering, faucet, and other domestic use
(5) Laundry	58.70	7.03	Hospital cloth washing; patient blanket, bed spread, towel, etc.
(6) Other sectors	11.01	1.32	Administration building use, car wash and care
Total	834.40	100.00	All water use activities

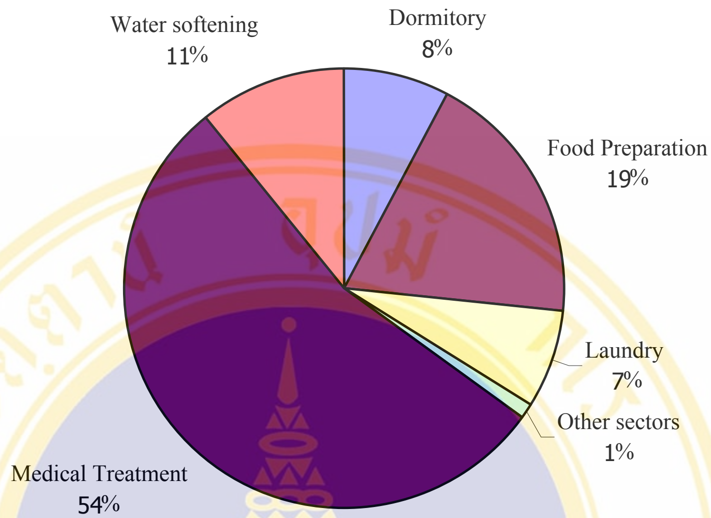

Figure 4-8 Thonburi Hospital main water usage percentage classified by activity

From table 4-8, Thonburi Hospital water balance, the various activities could be summarized into main activities those were medical treatment, food preparation, water softening, dormitory, laundry, and other sectors. The medical treatment water usage came from 12-Storey building, 7-Storey building, 6-Storey building, 4-Storey building, outpatient department, and dialysis department. The food preparation water usage came from nutrition department, cafeteria, dishwashing sink, and restaurant. The water softening water usage came from water softening plant. The dormitory water usage came from 150-resident dormitory, 58-resident dormitory, 28-resident dormitory, and 12-resident dormitory. Laundry water usage came from laundry department. And other sectors water usage came from administration building and garage.

The water use in medical treatment included water usage in inpatient and outpatient department generally in restrooms, diagnostic room, operation room, laboratory, and some highly water consumption medical equipment such as autoclave and X-Ray machine.

Surprisingly altogether food preparing area possessed the second largest water use portion despite previous public hospital study indicating the third rank coming after laundry and dormitory consecutively (36). Food preparing units comprised water use in hospital nutrition department, manual dish washing faucets, conveyer dish washing machine, hospital cafeteria, and a restaurant. Field observation detected much possibility of underground leakages due to aged plumbing laid under old construction. This could cause large amount of unaccounted-for water.

Water softening referred to water used in laundry boiler, UV treated drinking water, medical equipments such as autoclave input, medical equipment cleaning, and some laboratory diagnosis process. In addition water softening was also utilized in dialysis or kidney machine.

In dormitory area, water was used through general domestic purposes. Dormitories toilet equipments comprised similar sanitary wares at various ages such as toilets, faucets, and showerheads, all of which were conceived as old and water inefficient ones.

Laundry constituted once-through boiler and 4 washing machines, which washed 4,000 kilograms/day of cloths, using 16.8m^3/day of water following washing machine specification. Total use in laundry unit, including input to boiler, consumed 58m^3/day of water. This brought about the laundry water use of 14.5 l/kg. In contrast with the previous public hospital study (36) which showed first rank of hospital laundry water use account, this study found laundry as the fifth rank with percentage account of 7% (the previous study showed percentage account of 27%), coming after medical treatment, food preparing unit, water softening, and dormitory area. This implied that Thonburi Hospital performed rather good practice in laundry operation through good housekeeping and maintenance for instances; washing full loads, implementing soil-sorting procedures through proper set of washing machine programs (infected/non infected) to ensure that heavily soiled materials were correctly sorted to minimize over washing of lighter loads or to eliminate the need for rewashing.

Other sectors, which used water at the least amount, consisted of general employee toilet use, and use in car wash activities. Result of this study from garage faucet sub-metering showed that maintaining 12 hospital automobiles to be frequently washed requires 1.73 m^3/day of city water. In other word, Thonburi hospital called for 144 l/car-day for keeping up with freshly look ambulances.

After conducting water audit in Thonburi Hospital, a 435 beds hospital granting 1,200 outpatients/day, it was coming out that the hospital water use was 770m^3/day (1,842 l/bed-day with 96% occupancy rate or 418 occupied beds during the water audit) excluding dormitory area.

4.4 Identifying and Prioritizing Water Efficiency Options

In this study 2 criteria were used to identify and prioritize possible improvement options. The 2 criteria were 1) Degree of water usage which were classified in High, Medium, and Low water usage categories. 2) The water usage in comparison with available previous study or benchmark. The activity that consumed more water than the previous study could be identified as an ineffective one. This could be further prioritized from best to worst by using the proportion comparison with the specific benchmark. The main activities that scored 1st to 3rd rank should be considered to figure out water efficiency options.

4.4.1 Degree of water usage

According to water balance in table 4-8, water use facilities were classified in to 3 groups based on category score interval, those were high usage category, medium usage category, and low usage category. Interval score between categories derived from following simple equation.

$$\text{Interval score} = \frac{\text{Number of maximum usage} - \text{Number of minimum usage}}{\text{Number of required category}}$$

$$= \frac{262.7 - 2.7}{3}$$

Interval score = 87

Table 4-10 Water usage category classified by degree of water usage

Degree of Water Usage	Score Interval Range (m^3/day)	Score rate	Main activity of water use
1) High water usage	177.7 - 263.7	5	Water usage in 12-Storey building
2) Medium water usage	90.7 - 176.7	3	Nutrition department
3) Low water usage	2.7 - 89.7	1	Other water usage activities except for water use in 12-Storey building and Nutrition department

4.4.2 Water usage in comparison with available previous study

It was important for this study to compare the audit results with other similar study outcomes. In order to find out the efficiency options for the hospital, it was necessary to compare with other similar activities. In this research, benchmarking was used as a tool for comparing water use with the other similar activities. Benchmarking is a process of comparing one's own operational performance to other organization's to become "best in class" and make continual improvements. Benchmarking is more than simply setting a performance reference or comparison; it is a way to facilitate learning for continual improvements. The key to the learning process is looking outside one's own business to other business sectors that have discovered better ways of achieving in performance improvement. Benchmarking can be performance based, process based, or strategic based and can compare financial or operational performance measures, methods or practices, or strategic choices (11). Accordingly, it was important to compare the results of the study to other hospital water audit outcomes.

Table 4-11 Thonburi Hospital Non-Dormitory facility water use being compared with other sources

Source[1]	Water Requirement (liter/bed-day)	
	Range	Typical
1. Ministry of Urban Development, New Delhi, India, 1991:		
- bed	NA	650
- employee	NA	NA
2. Al-layla et al., 1978:		
- bed	200-650	425
- employee	NA	NA
3. Tchobanoglous and Schroeder, 1985:		
- bed	500-1000	750
- employee	20-60	40
4. Metcalf and Eddy, 1991		
- bed	492-984	738
- employee	19-57	38
5. Department. of Health, Indonesia, 1990:		
- bed	600-900	750
6. AWWA; American Water Works Association (1996)		
- bed	303-568	454
- employee	19-57	38
Average of sources 1-6		
- bed	419-820	628
- employee	19-58	39
Thonburi Hospital		
- bed	1,733-1,888[(2)]	1,842[(3)]
- employee with showers	52-113[(2)]	81[(3]

[1] Source 1-5 were from (36) and source 6 was from (37)
[2] Water usage range of Thonburi hospital (see details in Appendix)
[3] Average water usage of Thonburi hospital (see details in Appendix)

From table 4-11 compared to other sources, Thonburi Hospital consumed the highest amount of water usage. (1842 l/bed-day or 293% of average result). The result figured out that the hospital needed to improve its water use.

Employees in this study were classified in 2 types: employee without showers and employee with showers. Employee without showers referred to those who worked on shift without necessity to shower, and employee with showers referred to those who normally showered after completing duties such as mechanic, driver, operation staff and doctor and laundry officer.

There were 13 officers within the administration building and they were used to study the water usage of general employee (employee without showers). However there was Ratchathon nursing school that also used administration building among weeks. According to Ratchathon nursing school secretary, in a week, there were approximately 80 students using the building on various days.

Student water usage in a school without cafeteria and gym was 25 gallon/student-day (94.63 l/student-day) (37). Therefore, in a week 80 students would use water around 7,570 liters. Administration building average water usage was 8,310 l/day (58,170 l/week) so exactly employee usage was around (58,170 l/week - 7,570 l/week) = 50,600 l/week (7,229 l/day) for 13 employees. Therefore employee without showers water usage is 556 l/head-day. The usage seemed inconceivable since water usage among employee with showers, of this hospital, was figured out as 81 l/head-day, which was much lesser than the usage of employee in this building. This implied that administration building was possibly facing leakage problem.

Dormitory sector ranked the 4th order of the prominent water user (8% of the whole water use). It was also interesting to compare this studied figure to other results of available previous studies.

In table 4-12 with average figure of 260 l/head-day, the hospital dormitory water consumption still exceeded average figure of 5 dormitory water audit reports, one of which had been performed in New Delhi and the others had been completed in the US. There was dormitory usage from Water Wiser, 262 l/head-day, which was a little more than requirement of Thonburi Hospital dormitory. Dormitory domestic water use should be potentially improved through sanitary fittings retrofit/replacing options.

Table 4-12 Comparison of dormitory water requirement between Thonburi Hospital dormitory and previous studies

Source[1]	Dormitory water requirement (liter/head-day)
1. Ministry of Urban Development, New Delhi, India, 1991	132
2. Tchobanoglous and Schroeder, 1985	135
3. Metcalf and Eddy, 1991	150
4. AWWA; American Water Works Association (1996)	76-170
5. Water Wiser (Federal water use indices; Water Wiser) total water residential indoor water use(1996)	262
Average water requirement of sources 1-5	160
Thonburi Hospital dormitory	260

[1]Source 1-3 were from (36) and source 4, 5 were from (37)

Table 4-13 Comparison of water usage of various activities between Thonburi Hospital (TH) and previous studies

Activities	Unit	Average water usage		Comparison in percentage of water usage between TH and previous studies
		Previous Study	Thonburi Hospital	
-Hospital water use (excludes dormitory)	l/bed-day	628	1,842	293%
-Inpatient Ward	l/bed-day	NA	380	NA
-Laundry	l/kg cloth	31[(1)]	14.5	47%
-Nutrition preparing and cleaning	l/food tray	6.3[(2)]	491	7,794%
-Car wash and care	l/car-day	NA	144	NA
-Employee with showers	l/head-day	NA	81	NA
-Employee without showers	l/head-day	39[(3)]	556	1,426%
-Dormitory	l/head-day	160[(4)]	260	163%

[1] (37) see the calculation in Appendix
[2] (37) see the calculation in Appendix
[3] Average from table 4-11
[4] Average from table 4-12

Water usages of Thonburi hospital were compared in percentage with the average water usage from previous studies (see details in table 4-13). From table 4-13

Nutrition preparing and cleaning activity of Thonburi Hospital used water as much as 7,794% of average water usage in previous studies. The employee without showers usage was 1,426% of previous studies water usage. The entirely hospital water usage was 293% of former researches water usage. Thonburi Hospital dormitory water usage was as much as 163% of the comparable average figure. The 4 areas were of concern in water over-use when compared with other sources. While car wash and care, and employee with showers water usage had no comparing cases. The other one, Laundry service, possessed only 47% of previous studies average water usage. The results showed that the laundry service was in good operating practice in water usage.

Percentages of water usage in comparison with other study average figures were considered in this study. Main activities of water use were prioritized from bad to worst by using the proportion comparison with the specific key figure.

According to table 4-14, activities of water use were classified into groups based on category score interval in order to rate the significant of water efficiency options with water usage category. Laundry that had lower water usage than other studies average was rate at –1 score. Score of other water activities that had no comparing results were rated at 0. Interval score between categories derived from equation as follow:

$$\text{Interval score} = \frac{\text{maximum in proportion difference} - \text{minimum in proportion difference}}{\text{Number of required category}}$$

$$= \frac{7{,}794 - 163}{5}$$

Interval score=1,526

Table 4-14 Water use category appraisal results classified by percentage of water usage in comparison with available previous study

Benchmark Comparing Category	Range of score interval (comparison in percentage of water usage between Thonburi hospital and previous studies)	Score rate
Worst	6,268 – 7,794	5
Worse	4,742 – 6,267	4
Bad	3,216 – 4,741	3
Most unfavorable	1,690 – 3,215	2
Unfavorable	163 – 1,689	1
Null	No comparing results	0
Good	Lower 100	-1

Table 4-15 Priority of possible water efficiency options

Main Activity of Water Use	Total Score	Criteria										
		Score for water usage category				Score for benchmark comparing category						
		Water Usage (m^3/d)	1	3	5	-1	0	1	2	3	4	5
1) Nutrition Department	8	137.37		X								X
2) 12-Storey building	7	262.70			X				X			
3) Dormitory	2	64.36	X					X				
4) Administration building[1]	2	8.31	X					X				
5) Water softening	1	89.43	X									
6) 6-Storey building	1	75.73	X				X					
7) 4-Storey building	1	54.17	X				X					
8) OPD	1	37.52	X				X					
9) 7-Storey building	1	17.82	X				X					
10) Cafeteria	1	8.55	X				X					
11) Manual dishwashing sink	1	8.06	X				X					
12) Restaurant	1	4.76	X				X					
13) Dialysis	1	4.22	X				X					
14) Garage	1	2.70	X				X					
15) Laundry	0	58.70	X			X						
Note: Score for water usage category and score for benchmark comparing category came from the appraisal in table 4-10, 4-14, respectively			m^3/d			%						
			2-89	90-176	177-263	Lower 100%	No compare results	164-1,689	1,690-3,215	3,216-4,741	4,742-6,267	6,268-7,794

[1] Administration building was inspected in term of Employee without showers water usage (also see table 4-12)

From the conclusion of table 4-15, there were some possible options for water use improvement in following areas and were orderly shown as follow:

1) Water use in nutrition department

From the investigation and observation, there were some suggested options for further analysis as follow: laying new plumbing system for nutrition department, and dishwashing sink faucet retrofit.

2) Water use in 12-Storey building

From the investigation and observation, there were some suggested options for further analysis as follow: water reduction of toilet flush tank, toilet flush valve adjustment, toilet flush valve modification, toilet flush valve retrofit, toilet flush tank retrofit, and hard stem showerhead modification.

3) Water use in dormitory

From the investigation and observation, there were some suggested options for further analysis as follow: water reduction of toilet flush tank, toilet flush tank retrofit, hard stem showerhead modification, and soft string showerhead modification.

In addition this researcher supposed other options for water efficiency improvement those were some high water consumption medical machines that were water inflow reduction of autoclave, installing cooling tower in autoclave and valve adjustment of X-Ray film processor.

4.5 Feasibility evaluation of possible options

4.5.1 Identifying water efficiency options with no investment cost

4.5.1.1 Reducing water inflow of Autoclave

This option was advised by the hospital subcontractor. There were two autoclaves being used 10-15 times per day and each time took around 45 min. Consequently tap water was passing through autoclave cooling 9,000-13,500 l/day (average 11,250 l/day).

Previously, the cooling flowrate was 1,200 l/hour leading to 9,000-13,500 liters of water use per day. The cooling wastewater as high temperature water possessed the same quality as a tap water. This caused around 4,106.25m^3 of yearly water loss (69,806 Baht/year).

Adjusting needle valve (cooling water feeding valve) to proper minimum position could reduce water flowrate up to 600 l/hour (50% reduction) from ordinary flowrate leading to water saving 2,053m^3/year, valuing 34,903 Baht/year.

Discharged cooling water temperature ranging from 50-60°C was released to wastewater collecting system. The water was mixed up with large amount of wastewater from other hospital activities. Therefore, the mixture temperature would reduced to the room temperature within a short period of time before flowing to wastewater treatment plant.

4.5.1.2 Flush tank water displacement

Because the bottles filled of water could displace and reduce the water volume in flush tank. The device was inexpensive and easy to install, but required regulary maintenance. Bricks or other friable materials were not suitable for used in water volume displacement because some of its scraps could obstruct the proper closure of the flapper and damage flow valves (40).

The traditional 16 liters flush tanks were tested in the study by laying six of 0.75 liters water-filled plastic bottles in the bottom of flush tank. By this way, the water pressure was not changed but could decrease the water volume in the tank for around 4.5 liters per flush by displacement of water-filled bottles. A full dish of food waste was used as test media. The food waste was poured into the toilet for roughly testing of the performance.

There were 48 flush tank water closets, 16 l/flush flush, in the hospital. And they were from the same manufacturer and were of the same model (tank, bowl, flapper, and water inlet mechanism specification). Consequently the two flush tanks at 2nd floor of administration building gentleman toilet were chosen for the experiment and testing. The results from the testing of the 2 toilets were assumed to be representative of other toilets with the same model. The first toilet was set as control unit, taking 16 liter/flush as usual. The second one was set as a water saving closet (11.5 l/flush) by using six 0.75 liters water-filled bottle for displacement of water in the flush tank. A full dish of food waste was used as toilet performance testing media. Three kilograms of food junks, composed of pieces of veggie, rice, meat, and grease and oil, were collected from the hospital cafeteria then the junks were unified by stirring in plastic bucket. The well mix-up was then scooped into a plastic plate weighing 250 grams. Each test trial consisted of pouring a full dish of junks into the bowl then flushed just one time. Subsequently the researcher observed the result. The performance was preferable if a full dish of scraps was clearly washed down in one time. Either control or test units were repeatedly tested in 5 times. The results from testing were illustrated in the following table 4-16.

Table 4-16 Performance test results between the control and testing toilet

Number of test closet	Testing Result	Remarks
1) Control closet without water displacement (16 l/flush)		
1st trial	✓	All food wastes were fairly cleaned up. There were no floating or submerging junks left in the control toilet bowl of all trials
2nd trial	✓	
3rd trial	✓	
4th trial	✓	
5th trial	✓	
2) Water saving closet with water displacement of 4.5 liters (11.5 l/flush)		
1st trial	✓	All food wastes were cleaned up
2nd trial	✗	Some floating oil was detected but there was no food waste left in the toilet bowl
3rd trial	✓	All food wastes were fairly cleaned up. There were no floating or submerging junks left in the testing bowl
4th trial	✓	
5th trial	✓	

Note: (✓) Satisfied
(✗) Unsatisfied

The outcomes were preferable with almost the same results as the original flushes. There was no tested food waste left in the toilet bowls after flushing in both kinds of tanks. There was some floating oil in the second trial of 5 trials of the water saving closet. This option would help the hospital save water as much as 788.4 m^3/year equal to the cost of around 13,403 Baht annually.

4.5.1.3 X-Ray film processor valve adjustment

This option was advised by technician of Kodak (Thailand) Co.Ltd., the hospital's supplier. Thonburi Hospital used 1,111.5 l/day in X-Ray film processing for 130 cases (8.55 liter/case). The film processor was equipped with automatic feeding valve, therefore, can effectively control water feed at saving rate. However there was an adjustable valve existing in front of automatic feeding valve allowing operator to adjust the input rate. Reducing the flowrates in rinse baths to the minimum recommended by the manufacturer (a flowrate of two gallons per minute or less was enough for effective processing). With this method the operator may try out the possible minimum position of adjustment to minimize use rate but still keep film processing functioning effectively.

4.5.1.4 Flush valve adjustment

This option was used to improve water usage by advice from Siam sanitary fittings technician. There were totally 385 flush valve water closets. And the average water usage of each closet was around 10 flushes/day. Therefore, the estimated volume of water usage in each day was around 385*16*365 = 2,248.4 m^3/year. After the study about water reduction by adjustment of flush valve from 16 l/flush to 12 l/flush, the results showed that the closets still work in proper function according to Siam Sanitary Fittings Co., ltd fittings testing department. The revenue from valve adjustment alone could retrieve 95,557 Baht and save water for 5,621 m^3 annually. And the hospital could implement this option easily without investment cost. The figures came from following calculation:

Water saving from this option = 4 l/flush per toilet*10flush/day-toilet*385 toilet

= 15.4m^3/day (5,621m^3/year)

Water cost saving from this option

= 5,621m^3/year *17Baht

= 95,557Baht/year

4.5.2 Feasibility evaluation of water efficiency options for Nutrition Department

4.5.2.1 Laying new plumbing system

The existing of dishwashing and food preparing for a family of four persons used water around 15gallon/day (57 l/day) and 5gpd (19 l/day) respectively (37). This led to the consumption rate of 76 l/day of water consumed by 4 people for food preparation and dish cleaning up (6.33 l/head-meal). This research inferred 6.3 liters as a figure of water usage for a general food-preparing unit. This meant that the activities, including food preparing, water used in icemaker, dishwasher, and utensil cleaning and washing used 6.3 liter of water for a food tray. With average 280 trays being prepared for a day, the hospital actual water consumption should be around

1.764 m^3/day. Astonishingly, Thonburi Hospital Nutrition department alone consumed water of around 137.37 m^3/day (491 liters/tray). The over consumption could be resulted from underground leakage. Thus this department possibly overly lost 135.6 m^3/day of leakage. This resulted in 49,494 m^3/year losing 841,398 Baht/year.

Overhaul plumbing system could resolve leakage problem in this case. In order to relocate 40 meters of 2" galvanize pipe on ground cost around 17,000 Baht (estimated by the hospital's subcontractor). The payment included 11,200 Baht of material, 800 Baht of wage, and 5,000 Baht of operating cost.

$$\text{Payback period} = \frac{17{,}000}{841{,}398}$$

$$= 8 \text{ days}$$

This option was very likely to be put through since there was no technical affect in practical way.

4.5.2.2 Dish washing sink faucet retrofit

From audit observations, this area was usually employed to rinse off dishwashing liquid delivered from previous immersed in washing basin. Original 6 faucets were general ball valve with 13 l/min flowrate specification consuming 8.06 m^3/day.

With 4 l/min faucets retrofit pricing 675 Baht per unit, the hospital was able to save up to 9 l/min (69%saving) for utilizing a faucet. When equipped with 4 l/min specification, this area could save 5,561.4 l/day (2,029.91 m^3/year) with 34,508 Baht savings per year bringing about 1 month and 10 days payback period.

$$\text{Payback period} = \frac{4{,}050}{34{,}508}$$

$$= 1 \text{ month } 10 \text{ days}$$

This alternative was likely to be carried out because there was no affect in technical way but still needed some change in personal behavior.

4.5.3 Feasibility evaluation of water efficiency options for domestic use

Since domestic water usage in hospital and dormitory was accounted for an average of 24% of water usage in hospital (34), water efficiency sanitary fitting was considered as one of significant options to be put in water efficiency alternatives.

This study employed 10 users/toilet-day figure, granted from averaging public lavatory use rate of USEPA (1998) ranging from 5-14 users/toilet-day and used the minimum 5 min/use in case of showering calculations. The hospital water cost was calculated through 17 Baht/m^3 according to MWA bill. And the worker wage was calculated through 25 Baht/man-hour rate according to Thonburi Hospital 200 Baht/day mechanic wage.

Hospital typical toilet flush valves could be considerably replaced by more effective fittings. According to the US federal, its regulations required that all toilets manufactured after January 1, 1994, consumed no more than 1.6gpf (6 l/flush) (39). This specification was classified as ULFT (ultra-low-flow toilet), a toilet that didn't use more than 1.6 gallons/flush.

Sanitary fitting market review was executed in this study and it was found that 6 l/flush flushometer, which possessed the least flow per flush specification in the market was commercialized amongst manufacturers in Thailand.

This study included toilet flush valve (flushometer), toilet flush tank, and showerhead in retrofit/replacement option for water savings.

4.5.3.1 Flush Valve Water Efficiency Improvement

Alternative (a) Flush valve modification

Replacing flush valve (6 l/flush) parts of existing 385 flushometers required an investment of 8,239 Baht (20 Baht/unit) while helped save 14,052.5 m^3/year of water valuing 238,892.5 Baht/year. According to the manufacturer, one unit could take 10 minutes in replacing a new part; so 385 units should take 65 hours for installation. This led to 1,625 Baht replacement wages (25 Baht/man-hour).

In case using hospital own staff to replace

$$\text{Payback period} = \frac{8,239}{238,892.5}$$

= 11 days

In case including extra wages in replacement

$$\text{Payback period} = \frac{9,864}{238,892.5}$$

= 15 days

This option had some inferior aspect in that the effectiveness of flushing was a bit lowered due to reduced volume being flushed. However the pressure was still the same level at an average of 1 bar. This led to rather effective flush for general evacuated waste; defecate and urine in accordance with the sanitary fitting manufacturer (Siam Sanitary Fittings Co., ltd) and consequently was satisfactory in technical way.

Alternative (b) Flush valve retrofit

The water saver model costing 3,050/unit was used in retrofit cost-benefit analysis. Nevertheless the cost per unit should be added up with 700 Baht of removal and installation leading to 3,850 Baht cost/ unit.

Total 385 units that were 16 l/flush flush valves were included in retrofit calculation. The hospital was able to save 38,500 l/day of water or 14,052.5 m^3/year valuing 238,892.5 Baht/year (385units*10uses/day*10liters water saving) from retrofitting with 6 l/flush flushometers. Moreover existing bowl, when retrofitted with the saver ones, could gradually fulfill good flushing efficiency in accordance with manufacturer testing results. Presently (2003) the model price was 3,050 Baht/unit added up with 700 Baht/unit dismantling and installing cost, initial investment was finally 3,750 Baht/unit or 1,443,750 Baht as a whole.

According to toilet fitting manufacturer, average maintenance cost for a flushometer attaining 17 Baht/unit-year (totally 6,545 Baht/year) was to be subtracted from net cash inflow. So payback period was calculated following the equation.

$$\text{Payback period} = \frac{1,443,750}{(238,892.5)-6,545}$$

Payback period = 6 years 2 months

In addition, payback period could be decreased to 5 years in order that the hospital dismantled and installed all toilets by its own staff.

Moreover toilet bowl suiting 6 l/flush flush valve was being produced with 2,000 Baht/unit price. If considered toilet bowl in retrofit program, payback period should be over 9.52 years. Still unimaginable, this option was likely to be rejected due to pertinent annoying affects to patient satisfaction that should not be interrupted.

4.5.3.2 Flush tank retrofit

Existing 48 units of 16 l/flush flush tanks were included in retrofit calculation. The hospital was able to save 4,800 l/day of water or 1,752 m^3/year valuing 29,784 Baht/year (48units*10uses/day*10liters water saving) from retrofitting with new 6 l/flush flush tanks. Presently (2003) the model price was 1,940 Baht/unit adding up with 1,000 Baht/unit dismantling and installing cost, initial investment finally was at 2,940 Baht/unit or 141,120 Baht as a whole.

According to toilet fitting manufacturer, average maintenance cost for a flush tank attaining 50 Baht/unit-year (totally 2,400 Baht/year) was to be subtracted from net cash inflow. So payback period was calculated following the equation.

$$\text{Payback period} = \frac{141{,}120}{(29{,}784)-2{,}400}$$

$$= 5 \text{ years } 2 \text{ months}$$

Most toilet tanks were established in dormitory area so this alternative should not affect hospital operation and was considerable acceptance.

4.5.3.3 Soft string showerhead modification

There were totally 29 soft string showers, which possess 12 l/min flowrate According to manufacturer, the present model could be filled in with packing part, a water regulator functioning as a 3 l/min inlet flow reducer in soft string showerhead. The modification cost 466 Baht (15 Baht/unit excluding vat). When considering 29 units in dormitory, the units were daily used 336 times by 168 persons. Possible water saving was 5,040 l/day (3 l/min saver*5min/time*336times/day) or 1,839.6 m^3/year valuing 31,273.2 Baht/year.

$$\text{Payback period} = \frac{466}{31{,}273.2}$$

$$= 4 \text{ days}$$

Since all soft string showers were established in dormitory area, so this alternative was not concerned with customer satisfaction. This option should be used in technical way.

4.5.3.4 Hard stem (wall type) showerhead modification

Showerhead was compelled through The US Energy Policy Act to allow a 2.5 gallon/min (9.5 l/min) at 80psi. This rate was presently used in lavatory and kitchen faucet. Following 11.6 l/min of showerhead average flow found in the study clarified the possibility to improve water efficiency. In order to replace an 11.6 l/min showerhead with a 9 l/min one, allowed the hospital to save water for 3 liters/shower-min. While 8.1 l/min average flow of lavatory faucet found in the survey was lesser than the regulated 9.5 l/min flow, the existing lavatory faucets were consequently considered as water efficiency ones. However it was necessary to notify that the US standards based on 80-psi (5.60 bar) pressure while TISI standards based on 1 bar pressure. It was clear that the US regulated stricter due to similar coerced flowrate at higher pressure. Moreover many lavatory faucets witnessed in the survey were of spring loaded valve or timer type, which were considered as water saver equipments so the hospital would rather complementarily install flow restrictors or faucet aerators on highly used faucets wherever possible.

There were totally 237 hard stem showers, which possess 12 l/min flowrate (14 units in dormitories and 223 units in wards). According to manufacturer, the present model could be filled in with water flow regulator functioning as a 3 l/min inlet flow reducer. The modification cost 6,340 Baht (25 Baht/unit excluding vat). According to USEPA (1998), a person took shower for 5-15 min/time. This study used the minimum 5 min/use in calculations. When considering 14 units in dormitories, the units were daily used 160 times by 80 persons. Possible water saving was 2,400 l/day (3 l/min saver*5min/time*160time/day) or 876 m^3/year valuing 14,892 Baht/year. While 223 units in hospital wards were used twice a day per unit in minimum estimation. Possible water saving from hospital wards was 6,690 l/day (3 l/min saver*5min/time*446times/day) or 2,441.85 m^3/year valuing 41,511.45 Baht/year. Consequently total saving from this option alone was 3,318 m^3/year valuing 56,404 Baht/year.

$$\text{Payback period} = \frac{6,340}{56,404}$$

= 1 months 10 days

This alternative was concerned with water flow that was minimized and consequently should not meet customer threshold of showering pleasure. This worry should be eliminated through further studies that test the modified showerhead performance.

4.5.4 Feasibility evaluation of Installing cooling tower in Autoclave

This option was advised by the technician of Technical Equipment Co.Ltd., the hospital subcontractor. Cooling tower could be used to cool down high temperature water discharged from once through cooling outlet. The series comprised cooling tower, circulate plumbing, water pump and filling valve. This cooling series functioned as a close system, receiving outflow from 2 autoclaves to chilled and then circulated water back at its original. Doing this could preserve water in accordance with zero discharge schemes and could recycle all 11,250 l/day water flow or 4,106.25 m3/year (saving water cost around 69,806.25 Baht/year). High investment cost of 160,000 Baht led to possible 2.29 years payback period.

$$\text{Payback period} = \frac{160{,}000}{69{,}806.25}$$

$$= 2.29 \text{ years}$$

The summary of possible options for water efficiency in Thonburi hospital were presented in table 4-17

Table 4-17 Possible water efficiency options of Thonburi hospital

Possible water Efficiency Options	Initial investment (Baht)	Yearly Maintenance cost[1] (Baht/year)	Yearly Saving		Payback period (year)
			Water quantity (m^3/year)	Cost (Baht/year)	
1. No investment cost					
1.1 Autoclave: reducing inflow	-	-	2,053	34,903	-
1.2 Flush tank water displacement	-	-	788	13,403	-
1.3 X-Ray film processor valve adjustment	NA	NA	NA	NA	NA
1.4 Flush valve adjustment	-	-	5,621	95,557	-
2. Low investment cost					
2.1 Soft string showerhead modification	466	-	1,840	31,273	0.01
2.2 Laying new plumb in Nutrition department	17,000	-	49,494	841,398	0.02
2.3 Flush valve modification	9,864	-	14,053	238,893	0.04
2.4 Dishwashing faucet retrofit	4,050	-	2,030	34,508	0.1
2.5 Hard stem showerhead modification	6,340	-	2,442	41,511	0.1
3. High investment cost					
3.1 Autoclave: installing cooling tower	160,000	NA	4,106	69,806	2.29
3.2 Flush tank retrofit	141,120	2,400	1,752	29,784	5.15
3.3 Flush valve retrofit	1,443,750	6,545	14,053	238,893	6.21

[1]Yearly maintenance cost referred to the depreciation cost of replacement parts

4.6 Recommended Water Efficiency Options for Implementation

Based on economic evaluation, all possible options found in this study were evaluated to be the recommended options.

All recommended options of water efficiency were shown in table 4-18. It was interesting to evaluate these options in financial way as well as expected amount of water saving. When considering high investment cost category, it was clearly seen that all three options required much more initial investment, maintenance cost and pay back time were longer than the options with no investment cost and low investment cost category. In this study following Thonburi Hospital management board, initial investment was considered as a major issue for bringing the options to practice. This led to feasible options prioritized on payback period basis as shown in table 4-18.

Table 4-18 Recommended options prioritized on payback period basis

Water Efficiency Options	Initial investment (Baht)	Yearly Maintenance cost (Baht/year)	Yearly Saving		Payback period (year)
			Volume of water (m^3/year)	Cost (Baht/year)	
1. No investment cost					
1.1 Autoclave: reducing inflow	-	-	2,053	34,903	-
1.2 Flush tank water displacement	-	-	788	13,403	-
1.3 X-Ray film processor valve adjustment	NA	NA	NA	NA	NA
Sub Total 1.	-	-	2,841	48,306	-
2. Low investment cost					
2.1 Soft string showerhead modification	466	-	1,840	31,273	0.01
2.2 Laying new plumb in Nutrition department	17,000	-	49,494	841,398	0.02
2.3 Flush valve modification	9,864	-	14,053	238,893	0.04
2.4 Dishwashing faucet retrofit	4,050	-	2,030	34,508	0.1
2.5 Hard stem showerhead modification	6,340	-	2,442	41,511	0.1
Sub Total 2.	37,720	-	69,859	1,187,583	-
3. High investment cost					
Autoclave: installing cooling tower	160,000	NA	4,106	69,806	2.29
Sub Total 3.	160,000	-	4,106	69,806	-
TOTAL(1)	**197,720**	**-**	**76,806**	**1,305,695**	**0.15**
[1]Central wastewater treatment cost reduction following Bangkok Metropolitan Administration (BMA) = 4 Baht/m^3	-	-	76,806	307,224	-
TOTAL(2) (Included wastewater treatment cost reduction)	**197,720**	-	**76,806**	**1,612,919**	**0.12**

[1]From the BMA officer interview by phone, when the BMA wastewater treatment plants are finished, the hospital situated in the plants service area might pay the wastewater treatment cost at the rate of 4 Baht for every m^3 of water that was used

The hospital should initially implement with no investment cost practices. A low investment cost options that need the hospital to immediately follow was renewing main water supply line in nutrition department. Doing this alone, Thonburi Hospital was expected to save 841,398 Baht of water cost annually. Other low investment options possess very short payback period. The results in table 4-18 anticipated that the implementation of all recommended options (excluding central wastewater cost reduction) could save 76,806 m^3/year of water usage, valuing 1,305,695 Baht/year. In other word the hospital could save 25% of present water use by conducting water efficiency options and the payback period was within 0.15 year for all options implementation. In addition, after the central wastewater treatment plant have completed, the Bangkok Metropolitan Administration will charge for the wastewater treatment 4 Baht/m^3. Therefore, water usage reduction of 76,806 m^3/year could be estimated to reduce the wastewater treatment cost of around 307,224 Baht/year. Then the totally estimated savings from the implementation of recommended water efficiency options, including the wastewater treatment cost reduction, should be 1,612,919 Baht/year with the payback period within 0.12 year.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Water audit procedure was used in this study as a crucial method to find out water usage of activities in the studied hospital. It was necessary to test the validity of measuring instrument used in the audit. The ultrasonic flowmeter was tested under the actual volume-time basis and subsequently resulted in correction factors used in figures conversion. Consequently flow rates resulting from conversion were hypothesized to be actual ones. Water meters used in this study had been tested by MWA authorized factory. Therefore, the flow rate measurements were reliable.

In the audit it was found that water use activities started at 6:00. Water use rose up sharply at 7:30 when most activities operated and carried on untill 16:00. From 17:00 water use boosted up due to the increase of outpatients and inpatient visitors and reached the peak at 19:30 while off-peak was around 5:00.

Medical treatment and patient wards possessed the largest water use account and the food preparation unit was in the second rank. Softening water, dormitory, and laundry ranked in the 3rd to 5th, respectively. This finding was contrast to previous study that had found laundry as the firstly major water usage in the hospital. In fact, Thonburi Hospital laundry seemed to follow good operating practice in water use. And this resulted in lesser amount of water use for washing a kilogram of cloth (14.5 l/kg cloth) when compared with other sources. In nutrition department it was found that the inpatient food preparation used very high water consumption, 491 l/tray, comparing to 6.3 liter/meal of comparable food preparation figure. Later it was identified from the study that the major leakage occurred at underground plumbing and then an opportunity for water leakage solving was identified and evaluated in term of economic feasibility.

The recommended options were particularly explicated basing on investment and revenue together with some technical consideration. Twelve options were later put in 3 categories of investment; no investment cost, low investment cost, and high investment cost. Finally when considering with lucrative aspects, 9 options were left as recommended options for water efficiency program. All 9 options could be arranged following the payback period from lesser to greater as follow:

No investment cost options comprised 1) Autoclave reducing flow, 2) Flush tank water displacement, and 3) X-Ray film processor valve adjustment.

Low investment cost options comprised 1) Soft string showerhead modification, 2) Laying new plumb in Nutrition department, 3) Flush valve modification. 4) Dishwashing faucet retrofit, and 5) Hard stem showerhead modification. And high investment cost options referred to autoclave cooling tower installation.

Finally, the nine recommended water efficiency options were proposed for the studied hospital. The research anticipated that the implementation of all recommended options could save 76,806 m^3/year of water usage, costing 1,305,695 Baht/year, with the investment cost of 197,720 Baht and payback period within 0.15 year. And if the estimated cost reduction from Bangkok Metropolitan Administration central wastewater treatment was included, the research anticipated that the hospital could save the total cost of 1,612,919 Baht/year, with the same investment cost and payback period within 0.12 year.

5.2 Recommendations

5.2.1 Recommendations from the study

5.2.1.1 Plumbing blueprints should be developed and regularly updated as well as other concerning water system in order to enable future improvement and maintenance of the system.

5.2.1.2 Water flowmeter installation for the main units should be considered for water audit and monitoring.

5.2.2 Recommendations for further study

Water audit process should be used in the other industries for effectiveness of water resource usage. Some food industry manufacturer and aquaculture were the examples for studies about water audit to figure out improvement of water use. And interested service sectors should be figured out water saving practices particularly for high water consumption business such as hotel, massage enterprise, resort and spa for instances.

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APPENDIX

CALCULATION

1. Finding flow rate conversion equation for the use of ultrasonic flowmeter by using Simple Regression Analysis

To get estimated actual flows, flow rates recorded from ultrasonic flow meter at its diameter size were put in the equation:

$Y = a + bX$

where $a = \bar{Y} - b\bar{X}$

and $b = \dfrac{\sum X_i Y_i}{\sum X_i^2}$

1.1 Regression Analysis with 4 inch galvanize pipe

	Flow rate (m^3/hr)		XY	X^2	Y^2
	X (Ultrasonic)	Y (MWA)			
	0.4	0.06	0.024	0.16	0.0036
	1.5	1.5	2.25	2.25	2.25
	3	3	9	9	9
	4.9	4.8	23.52	24.01	23.04
	6.4	6.3	40.32	40.96	39.69
	7.7	7.8	60.06	59.29	60.84
	8.8	9	79.2	77.44	81
	12.4	12	148.8	153.76	144
	16.3	15	244.5	265.69	225
	19	18	342	361	324
	22.5	21	472.5	506.25	441
	26.2	24	628.8	686.44	576
	29.4	27	793.8	864.36	729
	33	30	990	1089	900
SUM	191.5	179.46	3834.774	4139.61	3554.824

$a = \bar{Y} - b\bar{X}$

$= 0.08$

$b = \dfrac{\sum X_i Y_i}{\sum X_i^2} = 0.93$

$Y = a + bx$

$Y = 0.08+0.93X$

1.2 Regression Analysis with 3 inch galvanize pipe

	Flow rate		XY	X^2	Y^2
	X (Ultrasonic)	Y (MWA)			
	0.9	0.9	0.81	0.81	0.81
	1.6	1.8	2.88	2.56	3.24
	2.2	2.4	5.28	4.84	5.76
	3	3	9	9	9
	3.5	3.6	12.6	12.25	12.96
	4.6	4.8	22.08	21.16	23.04
	4.8	5.4	25.92	23.04	29.16
	6.5	6.6	42.9	42.25	43.56
	7.1	7.2	51.12	50.41	51.84
	7.6	7.8	59.28	57.76	60.84
	8.5	9	76.5	72.25	81
SUM	50.3	52.5	308.37	296.33	321.21

$a = \bar{Y} - b\bar{X}$

$= 0.01$

$b = \frac{\sum X_i Y_i}{\sum X^2_i} = 1.04$

$Y = a + bx$

$Y = 0.01 + 1.04X$

1.3 Regression Analysis with 3 inch galvanize pipe

	Flow rate		XY	X^2	Y^2
	X (Ultrasonic)	Y (MWA)			
	0.45	0.3	0.135	0.2025	0.09
	0.7	0.6	0.42	0.49	0.36
	0.95	0.9	0.855	0.9025	0.81
	1.21	1.2	1.452	1.4641	1.44
	1.96	1.8	3.528	3.8416	3.24
	2.5	2.4	6	6.25	5.76
	3.1	3	9.3	9.61	9
	3.65	3.6	13.14	13.3225	12.96
	4.3	4.2	18.06	18.49	17.64
	4.87	4.8	23.376	23.7169	23.04
	5.57	5.4	30.078	31.0249	29.16
	6.5	6.6	42.9	42.25	43.56
	7.15	7.2	51.48	51.1225	51.84
	7.55	7.8	58.89	57.0025	60.84
	8.07	9	72.63	65.1249	81
	12.23	12	146.76	149.5729	144
	16.3	15	244.5	265.69	225
SUM	87.06	85.8	723.504	740.0778	709.74

$a = \bar{Y} - b\bar{X}$

$= 0.03$

$b = \frac{\sum X_i Y_i}{\sum X^2_i} = 0.98$

$Y = a + bx$

$Y = 0.03+0.98X$

2. Water Usage Calculation

2.1 Water Usage from table 4-11

2.1.1 Water usage range

2.1.1.1 Water usage range per bed-day was calculated as follow:

	Maximum (m^3/day)	Minimum (m^3/day)
UFM1	771.95	719.80
UFM2	81.57	69.15
UFM1+UFM2	853.52	788.95
Subtracted 64.36 m^3/day of Dormitory usage	789.16	724.59
Divided by 418 beds	**1.89**	**1.73**

2.1.1.2 Employee with showers water usage range

	Maximum (l/day)	Minimum (l/day)
Garage WC sub metering records	1,360.0	620.0
Divided by 12 employees per day	**113.3** l/head-day	**51.6** l/head-day

2.1.2 Average water usage

2.1.2.1 Average water usage per bed-day was calculated as follow:

(1) Total water usage 834.4 m^3/day
(2) Water usage of dormitory 64.36 m^3/day
(3) Hospital water usage = (1)-(2) = 770.04 m^3/day (770,040 l/day)
(4) Occupied beds of Thonburi hospital during the study was 418 beds (from total 435)
(5) Hospital average water usage = (3)/(4) = **1842** l/bed-day

2.1.2.2 Average employee with showers water usage

(1) Average water usage of garage toilet during the study was 974 l/day
(2) There were 12 employees in the garage department
(3) Average employee with showers water usage = (1)/(2) = **81** l/head-day

2.2 Average water usage in table 4-13

2.2.1 Laundry average water usage derived from:

American Water Works Association (AWWA) (2003) determined that the water efficient washing machine used more than 40 l/kg of clothes, and that the most efficient washing machine or AAA type washing machine used less than 22 l/kg of clothes. The average figure was calculated through (40+22)/2 = **31** l/kg of cloth

2.2.2 Nutrition preparing and cleaning average water usage

From the estimation of AWWA an American family of four used 150 gallon/week of water for dish washing and 35 gallon/week of water for food preparation. So 140 gallon/week was used for dishwashing and food preparation.

Four persons used 140/7 = 20 gallon/day. One person used 20/4 = 5 gallon/day. And one person used 5/3 = 1.67 gallon/meal or **6.3** l/meal (1.67*3.785).

3. Cost-Benefit analysis for Flush valve retrofit option

Investment cost	Cost/unit	Unit	Total cost
Flush valve Removal and Installation cost	3,050 Baht 700 Baht	385 385	1,174,250 269,500
			1,443,750

Maintenance Parts	lifespan	Cost/unit	Cost/ unit-year	Unit	Total cost/year
Rubber O-ring	3 years	50 Baht	17 Baht	385	6,545 Baht/year

Water Saving (l/unit-day)			Total Water Saving		
l/flush	Times of use	Water saving	*total 385 units	Water save/yr (*365)	Water cost saving/yr. (*17)
10	10 times	100 liters	38.5m^3/d	14,052.5 m^3/year	238,892.5 Baht/year

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Water cost saving/year} - \text{Maintenance cost/year}}$$

$$\text{Payback Period} = \frac{1,443,750}{238,892 - 6,545}$$

= 6.21 years (6 years 2 months)

EXAMPLE OF INTERVIEW FORM

1. Interview form in English

Interview Questionnaire for Thonburi Hospital	**Interviewee:** **Position:**
	Department/activities:
Remarks:	**Date:**
	Tel.

Identify water use in department/activities in details

1. Explain about operation concerning water use in your department/activities.

(More details: Operation time/Characteristic of water use in operation/Peak-Off peak/Number and characteristic of staff on duty/Number and characteristic of in-outpatient/etc.)……………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

2. Is there water use equipment that consume significant volume of water?

(More details: Age of the equipment/Model specification/water use flow rate/duration of use per day or per round/maintenance requirements/etc.)
…………………………………………………………………………………………………
…………………………………………………………………………………………………

3. Wastewater discharge pathway and its specific characteristic. Is there disinfections use such as Chlorine, Chlorine dioxide, Ozone, etc. discharged to wastewater collecting channel?……………………………………………………………………………………………

4. Is there any unaccounted-for water recurring in the department or activity? Identify the known specific point and quantity of the unaccounted-for water.
…………………………………………………………………………………………………..

5. Is there any leakage, occurring from the lack of maintenance, subsidizing or supporting from the management?
…………………………………………………………………………………………………

6. At present, is there water saving measure for your department? Please explain.
…………………………………………………………………………………………………

7. Please address the way your department can save up water use or use it in efficient way…………………………………………………………………………………………

Additional plumbing or water use equipment layout (not to scale)

2. Interview form in Thai

แบบสัมภาษณ์เกี่ยวกับการใช้น้ำสำหรับโรงพยาบาลธนบุรี	**ผู้สัมภาษณ์:** **ตำแหน่ง:**
	แผนก/กิจกรรม:
<u>หมายเหตุ</u>:	**วันที่สัมภาษณ์:**
	เบอร์โทรศัพท์ติดต่อ:

โปรดระบุรายละเอียดการใช้น้ำในแผนก หรือกิจกรรมของท่าน

1. โปรดอธิบายการทำงานที่เกี่ยวข้องกับการใช้น้ำภายในแผนก หรือกิจกรรมของท่าน (เวลาปฏิบัติงาน, ลักษณะของน้ำที่ใช้, ช่วงที่ใช้น้ำสูงสุดและต่ำสุด, คุณลักษณะของพนักงานเช่นมีการอาบน้ำระหว่างที่ปฏิบัติงานหรือไม่, จำนวนผู้ป่วย และ อื่น ๆ

………
………
………

2. มีเครื่องจักรที่ใช้น้ำปริมาณมากหรือไม่ ถ้ามีโปรดระบุรายละเอียดเกี่ยวกับ อายุ ยี่ห้อ รุ่น ของเครื่องและรายละเอียดอื่น ๆ เช่น อัตราการไหลของน้ำ เวลารวมที่ใช้เครื่อง หรือจำนวนครั้งที่ใช้ต่อวัน รายละเอียดเกี่ยวกับการซ่อมบำรุง และอื่น ๆ

………
………

3. น้ำเสียจากแผนกทิ้งลงที่ไหน มีคุณลักษณะอย่างไร มีการใช้ยาฆ่าเชื้อเช่น คลอรีน คลอรีนออกไซด์ โอโซน และอื่น ๆ และเจือปนลงสู่ระบบรวบรวมน้ำเสียสู่ระบบบำบัดหรือไม่

………

4. มีการรั่วไหลของน้ำเกิดขึ้นหรือไม่ ที่ไหน อย่างไร

………

5. ปัจจุบันมีมาตรการประหยัดน้ำในแผนกหรือไม่ อย่างไร

………

6. โปรดระบุวิธีการที่จะช่วยให้แผนกของท่านสามารถประหยัดน้ำ หรือใช้น้ำอย่างมีประสิทธิภาพ

………

แผนผังหรือรายละเอียดเพิ่มเติมเกี่ยวกับเครื่องจักร หรืออุปกรณ์การใช้น้ำ

SANITARY FITTINGS SURVEY

1. Sanitary Fittings at 4 dormitories (Surveyed in October, 2002)

List \ Dorm.	150-resident	58-resident	28-resident	12-resident	Total
# Resident	150	58	28	12	248
Water use (liter/day)	31670	13890	15300	3500	64,360
liter/head-day	211.13	239.5	546	292	260
Toilets (unit)					
Flush Valve	-	-	-	-	0
Flush Tank	14	-	11	1	26
Sink Faucet (unit)					
C. Type faucet	12	12	6	6	36
Washing faucet	-	2	-	-	2
Showerhead					
Hard stem shower	-	14	-	-	14
Soft string shower	18	-	11	-	29
Faucets (ball valve)	15	2	5		

2. Sanitary Fittings at Hospital facility excluding dormitory (Surveyed in October, 02)

Fitting \ Facility	4-Storey Bldg.			6-Storey Bldg.		7-S Bldg	12-S Bldg	Adm Bldg	Total
	OPD Fl.1	OPD 3	OPD 4	OPD Fl.1	IPD				
Toilets									
Flush Valve	9	8	8	6	48	26	280	-	385
Flush Tank	4	3	4	-	-	-	3	8	22
Urinal (push/press)	4	3	-	3	-	-	16	-	26
Sink Faucet									
C. Type faucet	16	4	13	6	51	8	100	-	198
Washing faucet	-	23	3	20	19	26	181	6	278
Elbow touch faucet	-	-	-	-	-	5	10	-	15
Shower									
Hard string shower	2	-	-	-	-	3	220	-	223
Soft string shower	-	-	-	-	-	-	-	-	-
Faucets (ball valve)	-	1	-	1	3	-	25	-	30
Bed Pan	-	1	-	-	-	2	8	-	11
Bath tub	-	-	-	-	-	-	6	-	6

WATER METER USAGE RECORD

Water flow records from available meters (record time were 9:50-10:10 of August 13-26, 2002)

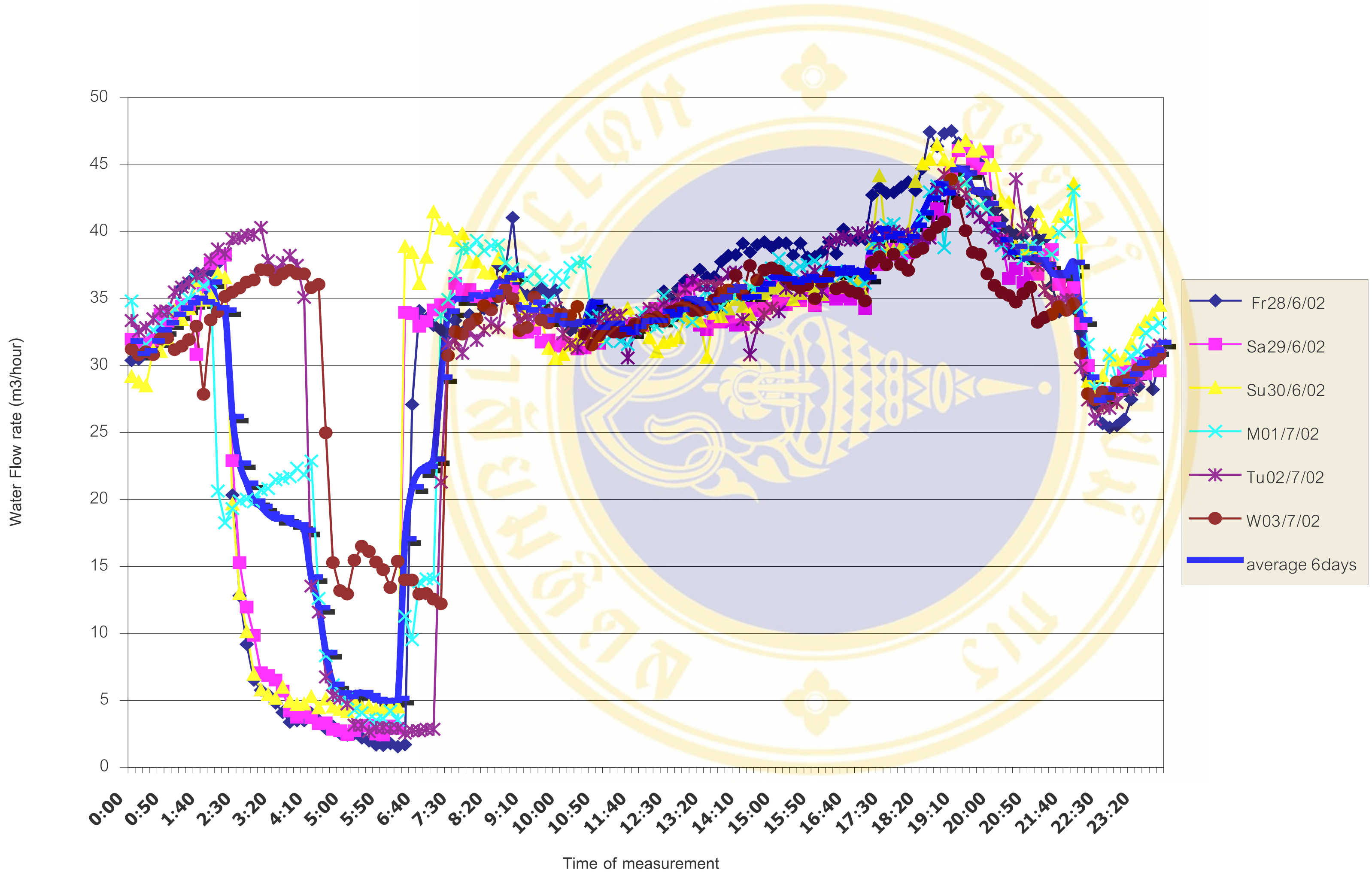
Aug, 2002		Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon					Weekday	Weekend
Meter	locate	13	14	15	16	17	18	19	20	21	22	23	24	25	26	AVG.	SD.	MAX.	MIN.	AVG.	AVG.
mA4	6-bed IPD	2.2	1.64	2.1	1.9	2.81	2.1	2.43	1.86	2.17	2.14	2.27	2.76	2.87	2.71	**2.283**	0.38	2.87	1.64	2.142	2.635
mA3	12-dorm	4	8	8	3	3	3	5	2	2	2	2	2.5	2.5	2	**3.5**	2.09	8	2	3.8	2.75
M1	12-S bldg.	726	748	714	705	663	613	670	703	675	669	650	672	665	684	**682.6**	34.2	748	613	694.4	653.25
M2	6-S bldg.	37	43	48	53	44	48	40	54	44	54	52	51	52	50	**47.86**	5.43	21	4	47.5	48.75
mA1	150-dormo	8	7	17	21	20	20	14	10	9	9	9	7	4	7	**11.57**	5.69	26.1	11.4	11.1	12.75
mA2	150-dorm+	26.1	25.5	14.9	12	11.4	11.8	12.6	24.9	22.4	23.1	23.1	23.4	26.1	24	**20.1**	5.98	26.1	11.4	20.8774	18.1565
m1	OPD3	33.6	33.5	24.1	21.1	19	20.5	25.1	28.9	30	33.4	31.7	30.6	34	32.3	**28.41**	5.39	34	19	29.367	26.0125
mA5	soft water	16.4	19.4	19.3	16.1	21.8	6.8	21.6	17.3	20.7	19.1	14.9	15.7	10.3	19.2	**17.04**	4.25	21.8	6.8	18.4	13.65
mA6	28-dorm	16.1	15.8	15.7	15.5	16.7	14.2	14.5	14.8	16.4	16.1	15.1	13.9	14.3	15.1	**15.3**	0.88	16.7	13.9	15.51	14.775
m2	Dialysis.	4.52	5.59	4.96	4.28	4.59	2.34	4.46	3.75	5.13	4.9	4.04	4.2	1.39	4.97	**4.223**	1.12	5.59	2.34	4.66	3.13
m4	Restaurant	4.63	5.13	3.83	4.28	5.13	7.44	5.66	4.13	5.03	3.82	3.25	4.29	5.2	4.85	**4.761**	1.02	7.44	3.25	4.4605	5.51325
m3	Cafeteria	8.55	7.91	10.1	8.65	8.24	7.62	7.97	8	8.81	7.54	9.54	9.43	8.08	9.25	**8.55**	0.78	10.1	7.54	8.632	8.3435
m7	Garage	4.4	1.93	2.38	1.23	0.68	1.58	1.87	0.88	1.24	1.23	2.05	2.83	1.45	0.51	**1.733**	1	4.4	0.51	1.7717	1.6365
m6	Garage WC.	0.76	1.18	1.23	0.62	0.69	1.09	0.91	1.36	1.24	0.84	0.91	1.05	0.62	1.13	**0.974**	0.24	1.36	0.62	1.0187	0.86175
m5	Dish washing	8.38	8.16	8.65	8.43	8.15	7.04	8.08	7.9	8.42	7.69	8.02	8.33	7.7	7.96	**8.063**	0.41	8.65	7.04	8.1665	7.8055

ULTRASONIC FLOWMETER USAGE RECORD

1. Conclusion of record from the use of Ultrasonic Flowmeter

UFM Code	Installation Site	MAX	Day	MIN	Day	Average	Working day	Weekend	Day of Measurement
UFM1	12-Storey Building	771.95	Wed.	719.8	Sat.	**747.1**	755.43	734.61	28 June-3 July
UFM2	6-Storey Building	81.57	Thu.	69.15	Mon.	**75.73**	75.16	76.87	9-15 July
UFM3	4-Storey Building	59.09	Mon.	51.32	Sun.	**54.17**	55.35	52.4	3-7 August
UFM4	7-Storey Building	23.44	Tues.	12.31	Sat.	**17.82**	21.05	12.97	31 August-4 September
UFM5	Laundry	65.5	Sun.	52.18	Fri.	**58.7**	56.92	63.14	20-26 July
UFM6	58-Dormitory	15.1	Tues.	12.47	Mon.	**13.9**	14.2	12.6	28 July-1 August
UFM7	Nutrition line	173.55	Sat.	148.42	Sun.	**163.43**	165.07	161	15-19 August
UFM8	OPD line	67.97	Sun.	63.8	Fri.	**65.93**	64.14	67.71	22-25 August
UFM9	Softening Water line	88.86	Mon.	75.04	Sun.	**82.98**	84.3	81	6-10 September
UFM10	Drinking Water line	9.23	Fri.	3.17	Thurs.	**6.44**	6.16	6.85	12-16 September

2. UFM1 water flow rate 24-hour measurement during June28-July1, 2002 covering Friday to Wednesday



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