OPTIMAL PRODUCTION OF POTABLE WATER

CASE STUDY: AGONA SWEDRU - GHANA WATER COMPANY LIMITED (GWCL)

BY

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DECLARATION

I hereby declare that this submission is my own work towards the MSc. And that, to the best of my knowledge, it contains neither material previously published by another person nor material, which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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DEDICATION

To Him who is able to watch over His words and perform, the Almighty God

and

my father, Mr. Henry Kwabena Nyame, my mother, Mad. Jane Ekua Appiah, my siblings; Comfort, Vivian, Kate, Seth and Dominic and to Bernice Nana Ama Adomah, I dedicate this work.

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ABSTRACT

Water is a constrained natural resource and in many areas of the Planet water shortage is considered to be possibly the most critical issue to be resolved. Water supply chain management and optimization are evolving as the most difficult and urgent problems, since the water demand and availability vary significantly with time. This makes it necessary to reflect upon the long term viability of some of the approaches advocated and their challenges. More specifically, the basic idea of the research is the development and implementation of a beneficial mathematical model using linear programming and the effect level of inputs on the mode in order to optimize the total water value. The collection and analysis of data using optimization techniques from the Kwanyaku Headworks took eight month. The research identified regular power outage leading to high cost of maintenance, electricity cost, chemical cost, capacity of low and high pumps and labour among others as the reasons for the irregular and expensive cost of water treatment to Swedru and its environs. However chemical cost, electricity cost and extra-duty cost (labour) are the major factors influencing water treatment.

An estimated cost used in the research revealed a 7.12% less the treatment cost in the same volume of water (746,520m^3) in the dry season and13.15% less the treatment cost in the same volume of water (787,285.716m^3) in the wet season.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Water forms the largest part of most living matter. Human beings can survive longer without food than without water (Ayoade, 1975, 1988; NEST, 1991).

An average man is two-thirds water and would weigh only 13kg when completely without water (i.e., dry weight). Plants need water for photosynthesis and they take their nutrient from the soil in solution. Water is an important geomorphic agent playing a significant role in weathering the most important energy regulator in the heat budget of the earth (Ayoade, 1988).

According to World Health Organization, 75 liters of water a day is necessary to protect against household diseases and 50 liters a day necessary for basic family sanitation. The international consumption figures released by the 4th World Water Forum (March, 2006), indicate that a person living in an urban area, uses an average of 250 liters/day; but individual consumption varies widely around the globe (THD, 2007).

WHO and UNICEF Joint Monitoring Program currently estimates that 1.1 billion people (17% of the global population) lack access to water resources, where access is defined as the availability of at least 20 liters of water per person per day from an improved water source within a distance of 1 km (Bates *et al.*, 2008).

The number of people who rely on the earth's limited freshwater reserves is increasing everyday. In fact, a scarcity of clean, fresh water is one of the world's most pressing environmental problems (Arms, 2008).

At the 2002 World Summit on Sustainable Development in Johannesburg, South Africa, great concern was expressed about the 1.1 billion people in the world who do not have access to safe drinking water and the 2.4 billion who live without proper sanitation (Cech, 2005). The resulting human toll is roughly 3.3 billion cases of illness and 2 million deaths per year. Moreover, even as the world's population grows, the limited easily accessible freshwater resources in rivers, lakes and shallow groundwater aquifers are dwindling as a result of over-exploitation and water quality degradation (IAEA, 2004).

The UN predicts that by 2025, two-thirds of the world population will experience water scarcities, with severe lack of water blighting the lives and livelihoods of 1.8 billion. According to the UN World Water Assessment Programme, by 2050, 7 billion people in 60 countries may have to cope with water scarcity (Chenoweth, 2008).

People in many parts of the world today are faced with the problem of water paucity and insecurity (Udoh and Etim, 2007).

The most obvious concern about an unsafe water supply is the health risk to family or guests. Wastewater contamination serves as a source of bacteria, viruses, and parasites that can cause gastrointestinal problems or transmit contagious diseases (Arms, 2008; UMES, 2008).

The World Health Organization (WHO) carried out a survey in 1975 which revealed that only 22% of the rural population in developing countries had access to safe drinking water. The findings which were published in 1976, led to the declaration of 1981-1990 as the International Drinking Water Supply and Sanitation Decade, by the United Nations Water Conference (Dada *et al.*, 1988).

In Ghana, the poor (defined by Living Standards Measurement criteria) make up 47% of the total population in urban piped system areas (PURC, 2005). Within urban piped system areas only 15% of the poor have access to piped water either directly or via yard taps [Ibid].

The value of water is determined by two elements, *supply* – the cost of providing the resource in a certain quality, quantity and location which varies in different parts of the country and *demand*- the utility to humans and their willingness to pay for that utility (Cech, 2005).

Water treatment cost is determined by factors such as: electricity cost, chemical cost, availability of raw water, capability of raw water pumps and treated water pumps, number of filters and their efficiency, number of clarifiers and their efficiency, availability and quality of pipelines and labour. Some of the afore mentioned factors are fixed whilst others vary with time. (Anor G.A, Station Manager, Kwanyaku Headworks)

1.1.2 Organizational Profile of Ghana Water Company Limited (GWCL)

Ghana Water and Sewerage Corporation was duly established in 1965 under an act of parliament (Act 310) as a legal public entity. Ghana Water and Sewerage was converted into a limited liability Company in 1999 known as Ghana Water Company Limited under Act 461 as a statutory corporation LI. 1648. The mission of Ghana Water Company Limited is to meet the increasing demand for better service delivery through efficient and effective management of their core business; production, transmission, distribution of water and customer management. (Anor G.A, Station Manager, Kwanyaku Headworks)

1.1.3 Profile of Kwanyaku Headworks

Kwanyaku headwork's with present capacity of 35000 m^3/d (7,700,000 *gal/d*) located 10*km* east of Agona Swedru and abstracting water from the Ayensu River, a medium – sized river which flows almost centrally through the supply area of the Kwanyaku water supply system. Kwanyaku headworks have two treatment plants; the old plant and the Jubilee plant (new plant). The former was commissioned on the 25th January, 1964 by Hon. E.K. Bansah, MP and Minister of works and Housing and the later with a capacity of 21,000m^3/d (4,620,000 *gal/d*) was commissioned on 21st February, 2007 by H.E. John Agyekum Kuffuor, President of the Republic of Ghana. The old plant with the capacity of 12,440 m^3/d (2,728,000 *gal/d*) to serve eight (8) districts all in the Central Region of Ghana with population greater than 5,000 and some 300 surrounding villages and its pipeline estimated over 120*km* . Kwanyaku treatment plant was designed as conversional treatment plant with facilities for aeration, coagulation, flocculation, filtration, disinfection and pH correction, although water is allowed to flow through the entire treatment unit originally provided, such as clariflocculators. (Anor G.A, Station Manager, Kwanyaku Headworks)

Figure 1.0, Title: Map of Central Region

1.2.0 Statement of the Problem

The Station Manager opined that machines in the pumping station use high quantum of energy to start and that the frequent power outage, the ritual of low voltage daily between 19 hours and 23 hours GMT, affects their operations. He argue that with present seasonal average water treatment volume of 746,520m^3 in the dry season and 787,285.71m^3 in the wet season at an average cost of GH¢74,544.16 and GH¢105,348.18 in the dry and wet seasons respectively can be optimized (minimized), that:

- The cost of minimum electrical units consumed and the average cost of extra-duty (labour) should be more than fifty thousand, nine hundred and fourteen Ghana cedis (GH¢50,914) in the dry season and seventy two thousand, eight hundred and seven Ghana cedis (GH¢72,807) in the wet season.
- The cost of minimum bags of chemical purchased and extra-duty (labour) should be more than fifteen thousand, five hundred and thirty one Ghana cedis (GH¢15,531) in the dry season and eighteen thousand, six hundred and seventy nine Ghana cedis (GH¢18,679) in the wet season.

The treated water cost to consumers will reduce if the above proposal is satisfied, because the redundant in treatment will reduce. (Anor G.A, Station Manager, Kwanyaku Headworks).

1.2.1 Water Treatment Process

Raw water is abstracted from the dam at the intake tower and flows by gravity to the six (6) number vertical submersible pumps from where it is moved up through a height of 35m to the one (1) number aerator at the treatment works located about a kilometer (1 km) from the dam.

The raw water is exposed to the atmosphere at the aerator by cascading for removal of dissolved iron, manganese and odour in the water while oxygen is introduced. Alum is added and the water flows by gravity through a dividing chamber to the four (4) clariflocculators where suspended matter is flocculated and resettled. The clarified (settled) water then flows to the twelve (12) numbers rapid gravity sand filters for the removal of residual floccules (flocs) for clear water to emerge. Chlorination, a process where chlorine is dosed for the removal of algae and arrest of any biological growth is performed before lime is added for pH adjustment and correction. The water then flows into a disinfection contact chamber before finally getting into the one (1) million gallon clear well reservoir. The pumps for the various subsystems then lift the water into the transmission mains or lines

Figure 1.1. Title: Flow Chart of Old Dam - Kwanyaku Treatment Plant.

Figure 1.2. Title: Flow Chart of Jubilee Plant - Kwanyaku Water Treatment Plant

Table 1.0, Title: Data on Plants and Equipments – Old Dam

Table 1.1, Title: Data on Plants and Equipments – Jubilee Plant

1.2.2 Operational Problems

G.W.C.L. in the Central Region is faced with many problems. Among the major problems confronting G.W.C.L., Kwanyaku treatment plant in particular are: power outage, pipe burst, inadequate tariffs, broken down machines, inadequate budget allocation for repairs and maintenance of machines, unplanned areas. (Anor G.A, Station Manager, Kwanyaku Headworks)

1.3 Research Objectives

The main objectives of this research is to

1. Develop a beneficial mathematical model using linear programming methods to determine the optimal cost of treating water.
2. Determine the effect levels of inputs applied to the model.

1.4 Justification

Water is a limited resource, the demands for which are fast increasing. Populations in some cities, like Agona Swedru for instance, are expanding at a fast rate. The result is that water managers must struggle to keep taps flowing without compromising water supplies for future generations.

The research would therefore be crucial to Ghana Water Company Limited (G.W.C.L), the residence of Agona Swedru and the Academia.

- G.W.C.L: The research would heighten the operations of the company to embrace workable schemes to effectively supply to the demand of consumers
- Academia: The findings of the research is to intensify the existing store of knowledge on the subject and serve as a spring board for further research on the advanced ways of improving water treatment and supply.
- The Public: The research would school the public on the importance of water preservation.

1.5 Methodology

Linear programming model, theoretical methods used in solving it (Simplex algorithm, Primal-dual interior point algorithm), Microsoft Office Excel and General Interior-Point Algorithm Linear Solver (GIPALS) a software for solving linear programming models are used. Data on inputs of production at Kwanyaku Headworks is collected. The internet and library materials are also used to develop the mathematical model used in minimizing the cost of water production.

1.6 Organization of the Thesis

In chapter one the research considered the historical and geographical background of water among others as introduction; chapter two provides a review of existing theoretical and empirical literature on optimal production of water. Mathematical methods of solving the problem and data on inputs of production at the Kwanyaku Headworks in chapter three, chapter four includes estimation and discussion of results and finally, the summary of findings, conclusions and recommendations are in chapter five.

1.7 Summary of the Chapter

This chapter of the research work considered the background of water production, the statement of the problem, the objective and methodology, justification and scope of the research work. The next chapter deliberates on existing theoretical and empirical literature on the topic under discussion.

CHAPTER TWO

LITERATURE REVIEW

(Biscos, C. et al 2003), presented an approach for the operational optimization of potable water distribution networks. The maximization of the use of low-cost power (e.g. overnight pumping) and the maintenance of a target chlorine concentration at final delivery points were defined as important optimization objectives. The first objective is constrained by the maintenance of minimum emergency volumes in all reservoirs, while the second objective would include the minimization of chlorine dosage and re-dosage requirements. The combination of dynamic elements (e.g. reservoirs) and discrete elements (pumps, valves, routing) makes this a challenging predictive control and constrained optimization problem, which is being solved by MINLP (Mixed Integer Non-linear Programming). Initial experimental results show the performance of this algorithm and its ability to control the water distribution process.

(Ahmed, E. E. et al 2010), presented a mathematical simulation of canal operation for optimizing water allocation within a multiple crop rotation canal. Zero-one linear programming algorithm was made for optimal flow regulation and to optimize irrigation water allocation and sequencing of different outlets in the irrigation canal under the constraints of fixed canal capacity and irrigation interval. The model was coded in a personal computer using Excel – visual basic application language (VBA) and designed to serve as a decision-making tool for operating an existing canal or for appropriate sizing of canal capacity (flow rate and cross-sectional area) of a new one. The model is verified statistically in comparison with published models. The allocation model is applied to the real cases of wet and dry regions of Gezira Scheme – Sudan for sequencing canal outlets for the cases of early and peak season at Sunni Minor canal and Ugud Minor canal. The model sensitivity to changes in outlet inflow rate (working time per outlet) was made for the said two cases. This indicated the model capabilities to effectively provide a constant flow rate into the canal during the operating period, and consequently minimize the need to frequently adjust the settings of canal head regulator. The model capabilities to optimize water scheduling and allocation process can be used to save irrigation water during early stages of crop growth and to upgrade the operation of minor canals in the irrigated schemes in the Sudan.

(Hatami-Marbini A. and Madjid Tavana 2010), proposed a "general" and "interactive" method for solving linear programming problems with fuzzy parameters. In their study, they proposed a revision to the optimal crisp value of the objective function to eliminate the restrictive constraints imposed by (Jiménez et al. 2007). The revised approach can be generalized to solve many real-world linear programming problems where the coefficients are fuzzy numbers. In contrary to the approach proposed by [Ibid], their method is rightfully general and interactive as it provides an optimal solution that is not subject to specific restrictive conditions and supports the interactive participation of the DM in all steps of the decision making process. They also presented a counterexample to illustrate the merits of the proposed method and the drawbacks of the [Ibid] method.

(Rico-Ramirez V. and Westerberg A. W 2002) opine that Interior point methods have recently become an interesting alternative in a number of numerical applications. In particular their performance in the solution of problems involving complementarity equations has been the subject of extensive research and their efficacy is well documented. They cited a brief description of the fundamentals of interior point methods and the globally convergent framework proposed by Wang et al. (Mathematical Programming 74 (1996) 159), they show how they can apply such an algorithm for solving the complementarity representation of a conditional model (Industrial Engineering and Chemical Research 38 (1999) 519), where such models involve sums of complementary products being zero. Furthermore, they modified Wang's algorithm in order to apply a high order strategy designed to improve convergence (SIAM Journal of Optimization 2 (1992) 575). They then used the proposed approach to solve some conditional models encountered in the field of chemical engineering. This technique has been incorporated into the ASCEND modeling environment with the implementation of the solver IPSLV.

(Marc Peeters and Zeger Degraeve 2004) developed a branch-and-price algorithm to obtain proven optimal solutions in the co-printing problem which is a new variant of the bin-packing problem. It finds its origin in the printing of Tetra-bricks in the beverage industry. Combining different types of bricks in one printing pattern reduces the stock. With each brick, a number of colors are associated, and the total number of colors for the whole pattern cannot exceed a given limit. After introducing a Dantzig-Wolfe reformulation for the problem, they derived cutting planes to tighten the LP relaxation. They presented heuristics and developed a branching scheme, avoiding complex pricing problem modifications. They presented some further algorithmic enhancements, such as the implementation of dominance rules and a lower bound based on a combinatorial relaxation. They finally, discussed computational results for real-life data sets. In addition to the introduction of a new bin-packing problem, they illustrated the complex balance in branch-and-price algorithms among using cutting planes, the branching scheme, and the tractability of the pricing problem and showed how dominance rules can be implemented in a branch-and-price framework, resulting in a substantial reduction in computation time.

The local convergence rate of the proposed methods is analyzed under standard assumptions. For each barrier parameter ?, they show that the Maratos effect can be avoided in the proposed methods by second-order correction steps and all iterates in a small neighborhood (roughly within o (?)) of the minimizer of the barrier problem converge Q-quadratically to the minimizer. The overall convergence rate of the iterates to the solution of the nonlinear program is Q-super linear and may be chosen arbitrarily close to quadratic. (Chen, Lifeng 2008).

Motivated by the alternating direction method for variational inequalities, (Zhensheng Yu and Jing Sun 2009) considered a reduced dimension method for the solution of linear programming problems. The main idea is to reformulate the complementary conditions in the primal-dual optimality conditions as a linear projection equation. By using this reformulation, they only need to make one projection and solve a linear system with reduced dimension at each iterate. Under weak conditions, the global convergence is established.

(Winternitz, B. et al 2010) in their dissertation, investigated “constraint-reduced” interior-point algorithms designed to efficiently solve unbalanced LPs. At each iteration, these methods construct search directions based only on a small working set of constraints, while ignoring the rest. In this way, they significantly reduce their per-iteration work and, hopefully, their overall running time. In particular, they focused on constraint-reduction methods for the highly efficient

Primal-dual interior-point (PDIP) algorithms. They proposed and analyzed a convergent constraint-reduced variant of Mehrotra’s predictor-corrector PDIP algorithm, the algorithm implemented in virtually every interior-point software package for linear (and convex-conic) programming. They proved global and local quadratic convergence of this algorithm under a very general class of constraint selection rules and under minimal assumptions. They also proposed and analyzed two regularized constraint reduced PDIP algorithms (with similar convergence properties) designed to deal directly with a type of degeneracy that constraint-reduced interior-point algorithms are often subject to. Prior schemes for dealing with this degeneracy could end up negating the benefit of constraint-reduction. Finally, they investigated the performance of their algorithms by applying them to several test and application problems, and showed that their algorithms often outperform alternative approaches.

Multicommodity-flow problem arises in a wide variety of important applications. Many communications, logistics, manufacturing and transportation problems can be formulated as large multicommodity-flow problems. During the last few years researchers have made steady advances in solving extremely multicommodity-flow problems. This improvement has been due both to algorithmic and to hardware advances. At present the primal simplex method using the basis-partitioning approach gives excellent solution times even on the modest hardware. These results imply that we can now efficiently solve the extremely large multicommodity-flow models found in industry. The extreme-point solution can also be quickly re-optimized to meet the additional requirements often imposed upon the continuous solution. Currently practitioners are using EMNET, a primal basis-partitioning algorithm; to solve extremely large logistics problems with more than 600,000 constraints and 7,000,000 variables in the food industry cited (Richard D. McBride, 1998)

(Rao, C. V. et al 1998) presented a structured interior-point method for the efficient solution of the optimal control problem in model predictive control. The cost of this approach is linear in the horizon length, compared with cubic growth for a naive approach. They used a discrete-time Riccati recursion to solve the linear equations efficiently at each iteration of the interior-point method, and showed that this recursion is numerically stable. Further, they demonstrated the effectiveness of the approach by applying it to three process control problems.

(Herminia, 2005) opined the general flow problem is a minimum cost network flow problem, which has additional side constraints requiring the flow of arcs in given sets of arcs to take on the same value. This model is applied to approach water resource system management problems by involving policy restrictions, which require some arcs to carry the same amount of flow.

(John W. Mamer and Richard D. 2000) proposed and tested a new pricing procedure for solving large-scale structured linear programs. The procedure interactively solves a relaxed sub problem to identify potential entering basic columns. The sub problem is chosen to exploit special structure, rendering it easy to solve. The effect of the procedure is the reduction of the number of pivots needed to solve the problem. Their approach is motivated by the column-generation approach of Dantzig-Wolfe decomposition. They tested their procedure on two sets of multicommodity flow problems. One group of test problems arises in routing telecommunications traffic and the second group is a set of logistics problem which have been widely used to test multicommodity flow algorithms.

(Ziliaskopoulos, K.A, 2000), cited Daganzo as having introduced the cell transmission model—a simple approach for modeling highway traffic flow consistent with the hydrodynamic model. Further used the cell transmission model to formulate the single destination System Optimum Dynamic Traffic Assignment (SO DTA) problem as a Linear Program (LP) then demonstrated that the model can obtain insights into the DTA problem, and addressed various related issues, such as the concept of marginal travel time in a dynamic network and system optimum necessary and sufficient conditions. The model is limited to one destination and, although it can account for traffic realities as they are captured by the cell transmission model, it is not presented as an operational model for actual applications. The main objective of the presentation is to demonstrate that the DTA problem can be modeled as an LP, which allows the vast existing literature on LP to be used to better understand and compute DTA. A numerical example illustrates the simplicity and applicability of the proposed approach.

(Das, B.C., 2009) presented a work based on a comparative study of the methods of solving Non-linear programming (NLP) problem and acknowledged that Kuhn-Tucker condition method is an efficient method of solving Non-linear programming problem. By using Kuhn-Tucker conditions the quadratic programming (QP) problem reduced to form of Linear programming(LP) problem, so practically simplex type algorithm can be used to solve the quadratic programming problem (Wolfe's Algorithm). The work is arranged in two folds as follows, first a discussion about non-linear programming problems and a further discussion on Kuhn- Tucker condition method of solving NLP problems. Finally the solution obtained by Kuhn- Tucker condition method with other methods was compared. For problem so considered MATLAB programming was used to graph the constraints for obtaining feasible region and also plotted the objective functions for determining optimum points and compare the solution thus obtained with exact solutions.

(Hassan, I. et al 2005) applied Linear Programming model to calculate the crop acreage, production and income of the Dera Ghazi Khan Division of Punjab province. The study was conducted on 3913 thousand acres of the irrigated areas from the four districts. Crop included were wheat, Basmati rice, IRRI rice, cotton and sugar cane. The results showed that cotton was the only crop which gained acreage by about 10% at the expense of all other crops. Overall optimal crop acreage decreased by 1.64% while the income increased by 2.91% as compared to the existing situations.

(Georgiou, P. and Papamichail, D. 2008) developed a non-linear programming optimization model with an integrated soil water balance, to determine the optimal reservoir release policies, the irrigation allocation to multiple crops and the optimal cropping pattern in irrigated agriculture. Decision variables are the cultivated area and the water allocated to each crop. The objective function of the model maximizes the total farm income, which is based on crop-water production functions, production cost and crop prices. The proposed model is solved using the simulated annealing (SA) global optimization stochastic search algorithm in combination with the stochastic gradient descent algorithm. The rainfall, evapotranspiration and inflow are considered to be stochastic and the model is run for expected values of the above parameters corresponding to different probability of exceedence. By combining various probability levels of rainfall, evapotranspiration and inflow, four weather conditions are distinguished. The model takes into account an irrigation time interval in each growth stage and gives the optimal distribution of area, the water to each crop and the total farm income. The outputs of this model were compared with the results obtained from the model in which the only decision variables are cultivated areas. The model was applied on data from a planned reservoir on the Havrias River in Northern Greece, is sufficiently general and has great potential to be applicable as a decision support tool for cropping patterns of an irrigated area and irrigation scheduling.

(Lang, Z.X., Horne, R.N., Stanford U. 1983) developed an automatic control procedure for the determination of optimal production schedules. Some production parameters such as injection rates or downhole flowing pressure are considered to be the decision variables, the values of which are to be chosen to maximize oil production. At the same time other production and economic parameters (such as water oil ratio) are to be constrained. The procedures discussed here are a way of using reservoir simulators to optimize production schedules in an automatic manner. The approximation of the non-linear processes in the models in terms of locally linear processes in the models in terms of locally linear processes permits such problems to be solved processes permits such problems to be solved iteratively using linear programming. This in turn results in a procedure which is feasible within reasonable expense. The multistep optimization procedure can be carried out in several different procedure can be carried out in several different ways; step by step, over all time steps at once or using dynamic programming. Step by step optimization converges more quickly but does not take into account influences from one step to the next. Iterating over all time steps is the most desirable but is computationally the most expensive and converges least quickly. Dynamic programming was found to be the most efficient, requiring little additional computational effort beyond the step by step method while still allowing the solution in one time step to influence subsequent time steps.

(Anitha, M., Subramanian, S., Gnanadass, R., 2009), described the application of a novel Particle Swarm Optimization (PSO) method called Fitness Distance Ratio PSO (FDR PSO) algorithm to determine the optimal power dispatch of the Independent Power Producers (IPP) with linear ramp model and transient stability constraints of the power producers. They suggested generally that, power producers must respond quickly to the changes in load and wheeling transactions. Moreover, it becomes necessary for the power producers to reschedule their power generation beyond their power limits to meet vulnerable situations like credible contingency and increase in load conditions. During this process, the ramping cost is incurred if they violate their permissible elastic limits. In their work, optimal production costs of the power producers are computed with stepwise and piecewise linear ramp rate limits. Transient stability limits of the power producers are also considered as additional rotor angle inequality constraints while solving the Optimal Power Flow (OPF) problem. The proposed algorithm is demonstrated on practical 10 bus and 26 bus systems and the results are compared with other optimization methods.

(Szebeszczyka, J. 1985) presented algorithms used for the calculation of the optimal production schedules for the water treatment plant. Optimized performance index is a pumping water daily cost. Optimization proceeds in two phases. In the first phase the approximated performance index is minimized. The optimal solution of the first phase is a starting point for the optimization realized in the second phase. In the second phase the optimized performance index contains the real pumping cost characteristics. In this phase two algorithms of optimization may be used: the separable programming algorithm and the multistage programming algorithm. The simulation results showed that the application of proposed algorithms can significantly decrease the plant's energy costs.

(Cruse, A. et al 2005) suggested that in many real life processes, operational objectives, constraints and the process itself may change over time. This is due to changing product requirements, market demands and other external or internal influences, which constitute a certain scenario. Model-based techniques can provide optimal solutions to the corresponding scheduling and process control problems. This work focuses on those situations, where the objectives and constraints of plant operation depend on the scenario and therefore change over time. A framework is developed, which enables the modeling and scheduling of different operational strategies on the optimization horizon. A case study involving a waste water treatment plant is used to demonstrate the approach. Existing expert knowledge is used to relate certain operational objectives and constraints to corresponding scenarios. It is shown that easily interpretable optimization results are obtained. Also, the results are significantly improved as compared to a weighted average approach only approximating sequential strategies.

(Yang, W. et al 2008) simulated a hydrodynamic behavior of flow in three different reactor clarifiers by three-dimensional, multiphase flow model. The primary construction of reactor clarifier was based on the Bansin Water Treatment Plant, Taiwan. This is the traditional construction, and they call it Type A. The other two were designed in such a way as to improve effluent water quality. The traditional clarifier construction was varied in these to make a large well angle (Type B) and a gradually larger inlet pipe (Type C). Solid effluent flux can be calculated directly from this model. The simulation results showed that under the same daily throughput, the Type C construction of clarifier could decrease up flow fluid velocity in the clarifier and, therefore, reduce effluent water turbidity.

(Kümmel, M. et al 1994) presented application of a nonlinear optimal control technique to an alternating activated sludge process. Faced with the time-varying features of the process, a parameter estimation procedure is designed and implemented based on a relatively simple process model established by them. New process variables are found and defined and a simplified state space model is developed to describe the nitrification and denitrification dynamics. The optimal control problem is formulated based on a criterion to minimize the daily average effluent nitrogen content in the face of a typical diurnal load variation. As the model and control problem exhibits strong nonlinearities, an iterative Newton-Raphson optimization method is applied to the problem. Simulation results and experiments in a pilot plant show that the new model and optimal control approach is successful and effective for improved nitrogen removal in the waste water treatment plant.

(Huck, P and Sozański, M. 2011) reviews drinking water-treatment technology from the perspective of the chemical phenomena and processes on which it is based. Seven goals for treatment are defined: removal of particles (including pathogens), total organic carbon removal, disinfection/inactivation, maximizing biological stability, removal of chemical contaminants, maximizing chemical stability of the finished water, and maintaining quality to the point of use or consumption. The processes required in a given treatment situation are directly linked to the achievement of one or more of these goals. Key chemical and physical principles or phenomena for water treatment such as precipitation/dissolution, oxidation/reduction, and mass transfer are discussed briefly. The fundamental basis of the various processes used in water treatment is presented as is the discussion of the evolving nature of water treatment, for example, the increasing role of membrane processes and the greater stress being placed on energy consumption.

(Xie, L. and Chiang, H.D., 2010) suggested interior point method (IPM), as one of the most efficient methods extended to solve different types of optimization problems in electric power domain. In their work, the nonlinear OPF problem, formulated with a rectangular coordinate form, is solved using the enhanced multiple predictor-corrector interior point method, which is combined with the selection of the optimal composite direction. A two stage line search strategy is also employed to obtain an optimal composite direction to improve the convergence property of MPC. The proposed method is then simulated for several test system ranging in size from 57 buses to 2790 buses. Numerical results demonstrate that the proposed method can lead to convergence with a smaller number of iterations and better computational time. Moreover, the comparison with different methods shows that the proposed method can be faster and robust than that traditional predictor-corrector interior point method and it's variant.

(Mészáros, C., 1999) presented an approach to determine primal and dual step sizes in the infeasible-interior-point primal–dual method for convex quadratic problems are presented. The approach reduces the primal and dual infeasibilities in each step and allows different step sizes. The method is derived by investigating the efficient set of a multiobjective optimization problem. Computational results are also given.

(Fabien, B.C. 2008) presented an algorithm for the numerical solution of constrained parameter optimization problems. The solution strategy is based on a sequential quadratic programming (SQP) technique that uses the $L\infty$ exact penalty function. Unlike similar SQP algorithms the method proposed here solves only strictly convex quadratic programs to obtain the search directions. The global convergence properties of the algorithm are enhanced by the use of a no monotone line search and second-order corrections to avoid the Maratos effect. The work also presents an ANSI C implementation of the algorithm. The effectiveness of the proposed method is demonstrated by solving numerous parameter optimization and optimal control problems that have appeared in the literature.

(Jabr, R. A. 2003) submitted a primal-dual path-following interior-point method for the solution of the optimal power flow dispatching (OPFD) problem. The underlying idea of most path-following algorithms is relatively similar: starting from the Fiacco-McCormick barrier function, define the central path and loosely follow it to the optimum solution. Several primal-dual methods for OPF have been suggested, all of which are essentially direct extensions of primal-dual methods for linear programming. Nevertheless, there are substantial variations in some crucial details which include the formulation of the non-linear problem, the associated linear system, the linear algebraic procedure to solve this system, the line search, strategies for adjusting the centering parameter, estimating higher order correction terms for the homology path, and the treatment of indefiniteness. The presentation discusses some of the approaches that were undertaken in implementing a specific primal-dual method for OPFD. A comparison is carried out with previous research on interior-point methods for OPF. Numerical tests on standard IEEE systems and on a realistic network are very encouraging and show that the new algorithm converges where other algorithms fail.

(Perić, T. and Babić, Z., 2008) indicated by means of a concrete example that it is possible to apply efficaciously the method of multiple criteria programming in dealing with the problem of determining the optimal production plan for a certain period of time. The work presents: (1) the selection of optimization criteria, (2) the setting of the problem of determining an optimal production plan, (3) the setting of the model of multiple criteria programming in finding a solution to a given problem, (4) the revised surrogate trade-off method, (5) generalized multicriteria model for solving production planning problem and problem of choosing technological variants in the metal manufacturing industry. In the final part of the work they reflect on the application of the method of multiple criteria programming while determining the optimal production plan in manufacturing enterprises.

(Shanno, D. F. and Vanderbei, R. J., 1999) extends prior work by the authors on LOQO, an interior point algorithm for nonconvex nonlinear programming. The specific topics covered include primal versus dual orderings and higher order methods, which attempt to use each factorization of the Hessian matrix more than once to improve computational efficiency. Results show that unlike linear and convex quadratic programming, higher order corrections to the central trajectory are not useful for nonconvex nonlinear programming, but that a variant of Mehrotra's predictor-corrector algorithm can definitely improve performance.

(Andersen, E., Roos, C and Terlaky, T., 2000) opined, conic quadratic optimization is the problem of minimizing a linear function subject to the intersection of an affine set and the product of quadratic cones. The problem is a convex optimization problem and has numerous applications in engineering, economics, and other areas of science. Indeed, linear and convex quadratic optimization is a special case. Conic quadratic optimization problems can in theory be solved efficiently using interior-point methods. In particular it has been shown by Nesterov and Todd that primal-dual interior-point methods developed for linear optimization can be generalized to the conic quadratic case while maintaining their efficiency. Therefore, based on the work of Nesterov and Todd, they discussed the implementation of a primal-dual interior-point method for solution of large-scale sparse conic quadratic optimization problems. The main feature of the implementation are based on a homogeneous and self-dual model, handle the rotated quadratic cone directly, employs a Mehrotra type predictor-corrector extension, and sparse linear algebra to improve the computational efficiency.

Computational results are also presented which documents that the implementation is capable of solving very large problems robustly and efficiently.

(Wolfe, O.B., Hawaleshka, O. and Mohamed, A.M., 2003) suggested fractional Linear Programming (FLP) has many applications in management science as well as in engineering. They developed a microcomputer program to solve linear and FLP problems. It is written in TURBO PASCAL which can be used on a wide variety of microcomputers. Because data entry constitutes a large proportion of the total computer solution time, careful attention has been placed on the human factors of human-computer interaction in that stage of program development. A test example is presented to demonstrate the usefulness of this program.

(Kumar, R. and Khepar, S. D., 1980) conducted a study to demonstrate the usefulness of alternative levels of water use over the fixed yield approach when there is a constraint on water. In the multi-crop farm models used, a water production function for each crop could be included so that one has the choice of selecting alternative levels of water use depending upon water availability. Water production functions (square root and quadratic type) for seven crops, viz. wheat, gram, mustard, berseem, sugarcane, paddy and cotton, based on experimental data from irrigated crops were used. The fixed yield model was modified incorporating the stepwise water production functions using a separable programming technique. The models were applied on a selected canal command area and optimal cropping patterns determined. Sensitivity analysis for land and water resources was also conducted. The water production function approach gives better possibilities of deciding upon land and water resources.

(Samani, H. M. V. and Mottaghi, A. 2006) suggested the optimum design of municipal water distribution networks for a single loading condition is determined by the branch and bound integer linear programming technique. The hydraulic and optimization analyses are linked through an iterative procedure. This procedure enables them to design a water distribution system that satisfies all required constraints with a minimum total cost. The constraints include pipe sizes, which are limited to the commercially available sizes, reservoir levels, pipe flow velocities, and nodal pressures. Accuracy of the developed model has been assessed using a network with limited solution alternatives, the optimal solution of which can be determined without employing optimization techniques. The proposed model has also been applied to a network solved by others. Comparison of the results indicates that the accuracy and convergence of the proposed method is quite satisfactory.

2.1 Summary of the Chapter

The chapter deliberated on existing theoretical and empirical literature on the topic under discussion. Resources and methodology used in developing the mathematical model (Linear Programming Model) used in solving the problem are considered in the next chapter.

CHAPTER THREE

METHODOLOGY

The internet and library resources are also used to develop the mathematical model used in minimizing the cost of water production. Linear programming model, theoretical methods used in solving it (Simplex algorithm, Primal-dual interior point algorithm), Microsoft Office Excel and General Interior-Point Algorithm Linear Solver (GIPALS) a software for solving linear programming models are used.

3.2.0 Linear Programming

Linear Programming, a specific class of mathematical problems, in which a linear function is maximized (or minimized) subject to given linear constraints. This problem class is broad enough to encompass many interesting and important applications, yet specific enough to be tractable even if the number of variables is large.

Formulation of a Linear Programming Problem

The formulation of linear programming problem as a mathematical model involves the following key steps.

Step 1: Identify the decision variables to be determined and express them in terms of algebraic symbols such as $x_1, x_2, x_3, \ldots$

Step 2: Identify all the limitations in the given problem and then express them as linear equations or inequalities in terms of above defined decision variables.

Step 3: Identify the objective which is to be optimized (maximized or minimized) and express it as a linear function of the above defined decision variables.

Overview. The general form of a linear program is

$$
\begin{array}{ll}
\textit{maximize} & c_1x_1 + \ldots + c_nx_n \\
\textit{subject to} & a_{11}x_1 + \ldots + a_{1n}x_n \le b_1 \\
 & \quad . \\
 & \quad . \\
 & \quad . \\
 & a_{m1}x_1 + \ldots + a_{mn}x_n \le b_m \\
 & x_1 \ge 0, \ldots, x_n \ge 0
\end{array}
$$

Here $c_1,...,c_n$, $b_1,...,b_m$ *and* $a_{11},...,a_{mn}$, are given numbers, and $x_1,...,x_n$ are variables whose values are to be determined, maximizing the given objective subject to the given constraints. There are *n* variables and *m* constraints, in addition to the non-negativity restrictions on the variables. The constraints are called linear because they involve only linear functions of the variables. Quadratic terms such as x_1^2 *or* x_1x_2 are not permitted. If minimization is desired instead of maximization, this can be accomplished by reversing the signs of $c_1,...,c_n$. **(**Michael L. Overton, 1997**).**

3.2.1. The Simplex Method.

In brief, the simplex method passes from vertex to vertex on the boundary of the feasible polyhedron, repeatedly increasing the objective function until either an optimal solution is found, or it is established that no solution exists. In principle, the time required might be an exponential function of the number of variables, and this can happen in some contrived cases.

In practice, however, the method is highly efficient, typically requiring a number of steps which is just a small multiple of the number of variables. Linear programs in thousands or even millions of variables are routinely solved using the simplex method on modern computers. Efficient, highly sophisticated implementations are available in the form of computer software packages.

3.2.2. Interior Point Method for L.P

The interior-point method for linear programming, combine the desirable theoretical properties of the ellipsoid method and practical advantages of the simplex method. Its success initiated an explosion in the development of interior-point methods. These do not pass from vertex to vertex, but pass only through the interior of the feasible region. Though this property is easy to state, the analysis of interior-point methods is a subtle subject which is much less easily understood than the behavior of the simplex method. Interior-point methods are now generally considered competitive with the simplex method in most, though not all, applications, and sophisticated software packages implementing them are now available.

Interior point method considers the primal Linear Programming LP:

$$\begin{aligned} & Min \quad c^T x \\ & s.t \quad Ax = b \qquad\qquad (1.6) \\ & \qquad x \geq 0 \\ & where\ c, x \in R^n,\ b \in R^m\ A \in R^{m\times n}\ (m < n)\ and\ A\ has\ full\ rank\ m \end{aligned}$$

The dual linear program can be written as

$$
\begin{aligned}
&Max \quad b^T y \\
&s.t. \quad A^T y + z = c \\
&\qquad\qquad z \geq 0 \\
&and\ z \in R^n\ is\ called\ the\ vector\ of\ dual\ slack\ variables
\end{aligned}
$$

The system of primal and dual constraints put together

$$
\begin{aligned}
Ax &= b \\
A^T y + z &= c \qquad\qquad (1.5) \\
(x, z) &\geq 0
\end{aligned}
$$

A feasible solution x, y, z to Equation (1.5) is called an interior feasible solution if $(x, z) > 0$. Let F denote the set of all feasible solutions of Equation (1.5) and F^0 the set of all interior feasible solutions. For any $x, y, z \in F^0$ define $X = diag(x_1, x_2, ..., x_n)$, the square diagonal matrix of order n with diagonal entries $x_1, x_2, ..., x_n$ and $Z = diag(z_1, z_2, ..., z_n)$.

3.2.3. The Primal – Dual Interior Point Methods.

Consider a linear program in the standard form (Tapia, A.R. et al, 1990)

$$
\begin{aligned}
&Min \quad c^T x \\
&s.t \quad Ax = b \qquad\qquad (1.6) \\
&\qquad x \geq 0 \\
&where\ c, x \in R^n,\ b \in R^m\ A \in R^{m \times n}\ (m < n)\ and\ A\ has\ full\ rank\ m
\end{aligned}
$$

The first - order optimality conditions for linear program (1.6) can be written

$$
F(x, y, \lambda) \begin{pmatrix} Ax - b \\ A^T \lambda + y - c \\ XYe \end{pmatrix} = 0, \ (x, y) \geq 0 \qquad (1.7)
$$

where $y \in R^n$ *and* $\lambda \in R^m$ are dual variables, $X = dia(x)$, $Y = dia(y)$ and $e^T = (1, ..., 1) \in R^n$

The point x, y, λ is said to be feasible for problem (1.7), if $Ax = b,\ A^T\lambda + y - c = 0$ and $x, y \geq 0$. A feasible point x, y, λ is strictly feasible $x, \lambda > 0$. It tacitly assumes that strictly feasible points exist.

It is now well understood how the primal – dual interior point method introduced by (Kojima, Mizuno and Yoshise, 1989) can be stated in the framework of a damped and perturbed Newton's method applied to problem (1.7).
In presenting this algorithmic framework, we will write $z = (x, y, \lambda),\ \Delta z = (\Delta x, \Delta y, \Delta\lambda),\ \Delta X = diag(\Delta x),\ and\ \Delta Y = diag(\Delta y)$

We also let *min (u)* denote the smallest part of the vector *u* and ê denote the vector $(0,...,0,1,...,1)^T$, where the number of zeros is $n+m$ and the number of ones in *n*.

3.2.3.1 Algorithm 1 (Primal – Dual Interior – Point Method)

Given $z_0 = (x_0, y_0, \lambda_0)\ with\ (x_0, y_0) > 0,\ \ for\ k = 0,1,..., do$

1. Solve $F^{/}(z_k)(\Delta z) = -F(z_k)\ \ for\ \Delta z_N$ (1.8)
2. Choose $\mu_k > 0$ and

   Solve $F^{/}(z_k)(\Delta z) = \mu_k \hat{e}\ \ for\ \Delta z_c$
3. Set $\Delta z = \Delta z_N + \Delta z_c$
4. Choose $\tau_k \in (0,1)\ and\ set\ \alpha_k = \min(1, \tau_k \hat{\alpha}_k)$ where

$$\hat{\alpha}_k = \min\left(\frac{-1}{\min(X_k^{-1}\Delta x)}, \frac{-1}{\min(Y_k^{-1}\Delta y)}\right) \qquad (1.9)$$

5. Choose $z_{k+1} = z_k + \alpha_k \Delta z$

Actually in most implementation, the formula (1.9) for α_k is further broken down and one step length is used to update the x - variable and another is used to update the y – variable and the λ - variable. While this distinction is of value in practice, it is not an issue in present work.

3.1.4. The Predictor – Corrector Interior Point Method

(Mizuno, Todd and Ye, 1989) suggested and studied algorithm which they labeled a predictor – corrector algorithm. In their algorithm, the predictor step is a damped Newton's step for problem (1.7), producing a new strictly feasible iterate. The subsequent corrector step is a centered Newton step. In this corrector step, the choice of μ, the centering parameter is based on the predictor step. Both the predictor and the corrector steps require essentially the same amount of work, namely, evaluation and factorization of the Jacobian matrix.

(Mehrotra, 1989), later presented the following variant of algorithm 1, which he also referred as a predictor – corrector method. A common feature in these two predictor – corrector approaches is that, the value of the parameter in the corrector step depends on the predictor step. However, unlike Mizuno, Todd and Ye's corrector step, Mehrotra's corrector step does not evaluate a fresh Jacobian matrix. Instead, it reuses the Jacobian matrix used by the predictor 999 step $\hat{e} = (0,...,0,1,...,1)^T$.

3.2.4.1 Algorithm 2 (Predictor – Corrector Interior Point Method)

Given that $z_0 = (x_0, y_0, \lambda_0)$ *with* $(x_0, y_0) > 0,$ *for* $k = 0,1,...,$ *do*

1. Solve $F^{/}(z_k)(\Delta z) = -F(z_k)$ *for* Δz_p

2. Solve $F^{/}(z_k)(\Delta z) = -\begin{pmatrix} 0 \\ 0 \\ \Delta X_p \Delta y_p \end{pmatrix}$ $for\ \Delta z_\mu$

3. Choose $\mu > 0$ and

   Solve $F^{/}(z_k)(\Delta z) = \mu_k \hat{e}\ \ for\ \Delta z_c$

4. Set $\Delta z = \Delta z_\mu + \Delta z_c$

5. Choose $\tau_k \in (0,1)$ *and set* $\alpha_k = \min(1, \tau_k \hat{\alpha}_k)$ where

$$\hat{\alpha}_k = \min\left(\frac{-1}{\min(X_k^{-1}\Delta x)}, \frac{-1}{\min(Y_k^{-1}\Delta y)} \right) \qquad (2.0)$$

6. Choose $z_{k+1} = z_k + \alpha_k \Delta z$

3.2.5 General Interior-Point Algorithm Linear Solver (GIPALS)

GIPALS is 32-bit Windows linear programming software incorporating powerful solver and user-friendly interface to input, import, export and solve linear programs. GIPALS uses primal-dual interior point method (Mehrotra predictor-corrector) to solve a linear program consists of maximum 500,000 variables and constraints. GIPALS can find the solution of any linear program or state that the linear program does not have a solution. The main features of GIPALS User Interface are: The maximum number of variables is 500,000. The maximum number of linear constraints is 500,000. Direct input LP in sparse (using a grid) and compact form (using special constraint body editor). Import LP from files in MPS (Mathematical Programming System) format. Export LP to files in MPS format. Tracing variable values at each iteration. Store LP in XML format. Export the solution in CSV (Comma-delimited), Tab-delimited or HTML file formats. Flexible debug options. Multi-Document Interface (MDI) allows to work with several LP simultaneously. The main features of GIPALS Linear

Solver are: Primal-Dual Interior Point Method (Mehrotra Predictor-Corrector). Adjustable Preprocessor. Scaling of the LP. Detection and extracting dense columns. Sparse Cholesky factorization. Minimal degree ordering, with supernodes. Higher order Gondzio correction strategy. Iterative refinement (using preconditioned conjugate gradient algorithm). (www.optimalon.com/)

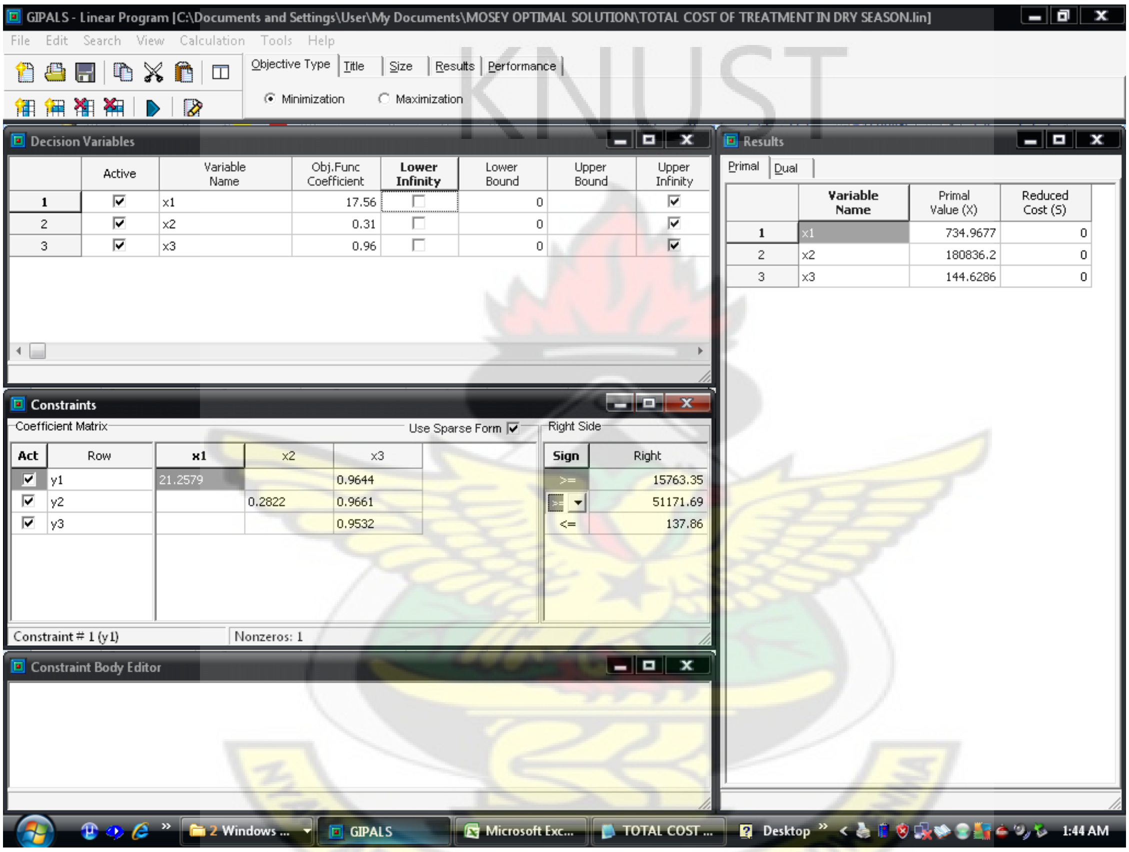

Figure 3.0, Title: General Interior-Point Algorithm Linear Solver

3.2 Summary of the Chapter

The chapter considered different resources and methodologies used in developing the mathematical model. Data on inputs of treatment of water at Kwanyaku Headworks and their effect on treatment in the dry and wet seasons are examined by the use of the mathematical model and software packages in next chapter.

CHAPTER FOUR

INTERPRETATIONS AND ANALYSIS OF DATA

4.0 MODEL

The model examines the effects of seasonal cost (dry and wet) on the volume of water table 4.0 treatment, however the objective function for the seasons are the same but with different constraints.

Objective function: $C_p = C_c + E_c + V_c + F_c$

The objective function is developed based on factors that influence monthly treatment cost such as: total monthly cost of chemicals, total monthly cost of electricity, total monthly extra - duty cost and other fixed cost which indirectly affects production. (Example fuel cost, lubricant)

Where,

C_p, *total cost of treatment at the headwork*

C_c, *cost of chemicals*

E_c, *cost of electricity*

V_c, *cost of extra – duty*

F_c, *cost of fuel*

$$Cost = Unit\ price(u) \times Quantity(x)$$

$$Hence\ Total\ Treatment\ Cost = \sum_{i=1}^{n} u_i x_i = u_1 x_1 + u_2 x_2 + u_3 x_3$$

The coefficients (u_1, u_2, u_3) of the objective function is derived from the quotient of average price for purchasing an item in a month in table 4.1 and the average quantity used in a month in table 4.2 as shown below;

$$Unit\ price\ (chemical)\ u_1 = \frac{average\ price\ of\ chemical}{average\ bag\ of\ chemical} = \frac{20{,}121.40}{1{,}146.67} = 17.55$$

$$Unit\ price\ (electricity)\ u_2 = \frac{average\ price\ of\ electricity}{average\ unit\ of\ electricity} = \frac{71{,}694.36}{233{,}759.75} = 0.31$$

$$Unit\ price\ (Extra\ duty)\ u_3 = \frac{average\ extra\ duty\ \cos t}{average\ working\ hours} = \frac{697.33}{730} = 0.96$$

The objective function is

$$\text{Minimize Treatment Cost } (W) = \sum (unit\ price\ \times\ quantity)$$

$$= \sum_{i=1}^{n} u_i x_i = u_1 x_1 + u_2 x_2 + u_3 x_3$$

$$Minimize\ (W) = 17.56x_1 + 0.31x_2 + 0.96x_3$$

Constraints:

Tables 4.3, 4.4 and 4.5 shows the seasonal average cost, average quantities and usage ratio of chemical, electricity and extra-duty.

The seasonal average cost and quantities were derived by calculating the average monthly cost and quantities (Tables 4.3 and 4.4), the seasons are categorized over a period as Dry Season (from November to March) and Wet Season (from April to October) thus:

$$Seasonal\ Average\ Cost = \frac{Sum\ of\ total\ monthly\ \cos t\ of\ the\ period}{Number\ of\ month}$$

$$Seasonal\ Average\ Quantity = \frac{Sum\ of\ total\ monthly\ quantity\ of\ the\ period}{Number\ of\ month}$$

Whiles the usage ratios were obtained by

$$UsageRatio = \frac{Average\ Seasonal\ Cost}{Average\ Seasonal\ Quantity}$$

The constraints for the model are derived from the above preamble as

1. The first constraints are the sum of the products of usage ratio of chemical by the number of bags used and usage ratio of extra-duty by the number of hours used. The Right Hand Sides are the proposed least cost allocated to the Chemical House.
2. The second constraints are the sum of the products of usage ratio of electricity by number of electricity units used and usage ratio of extra-duty by the number of hours used. The Right Hand Sides are the least cost allocated to the pump house.
3. The third constraints are the sum of the products of usage ratios of extra-duty by the number of hours used. The Right Hand Sides are the proposed maximum seasonal allocation to the transport section.

Table 4.6, Title: Dry Seasonal Allocation of, Chemical, Electricity and Extra-duty in Treatment of Water

Dry Season	Chemical House (GH¢)	Pump House (GH¢)	Transport Section (GH¢)	TOTAL (GH¢)
Chemical Cost	15,531	0	0	15,531.00
Electricity Cost	0	50,915	0	50,914
Extra-Duty Cost	231.87	256.93	137.86	626.66
Total	**15,763.35**	**51,171.69**	**137.86**	

Table 4.7, Title: Wet Seasonal Allocation of, Chemical, Electricity and Extra-duty in Treatment of Water

Wet Season	Chemical House (GH¢)	Pump House (GH¢)	Transport Section (GH¢)	TOTAL (GH¢)
Chemical Cost	18,679.56	0	0	18,679.56
Electricity Cost	0	72,807.12	0	72,807.12
Extra-Duty Cost	244.33	270.74	145.28	660.35
Total	**18,923.89**	**73,077.86**	**145.28**	

4.1 Model Formulation

Model for Dry Season is:

Minimize Total Cost $= 17.56x_1 + 0.31x_2 + 0.96x_3$

Subject to:

$$21.2579x_1 + 0.9644x_3 \geq 15,763.35$$

$$0.2822x_2 + 0.9661x_3 \geq 51,171.69$$

$$0.9644x_3 \leq 137.86$$

$$x_1,\ x_2,\ x_3 \geq 0$$

Model for Wet Season is:

Minimize Total Cost $= 17.56x_1 + 0.31x_2 + 0.96x_3$

Subject to:

$$15.9930x_1 + 0.9490x_3 \geq 18,923.89$$

$$0.3203x_2 + 0.9490x_3 \geq 73,077.86$$

$$0.9490x_3 \leq 145.28$$

$$x_1,\ x_2,\ x_3 \geq 0$$

$x_1,\ x_2,$ *and* x_3, represents the bags of chemical, units of electricity and hours of extra-duty used monthly respectively.

Results obtained by using GIPALS

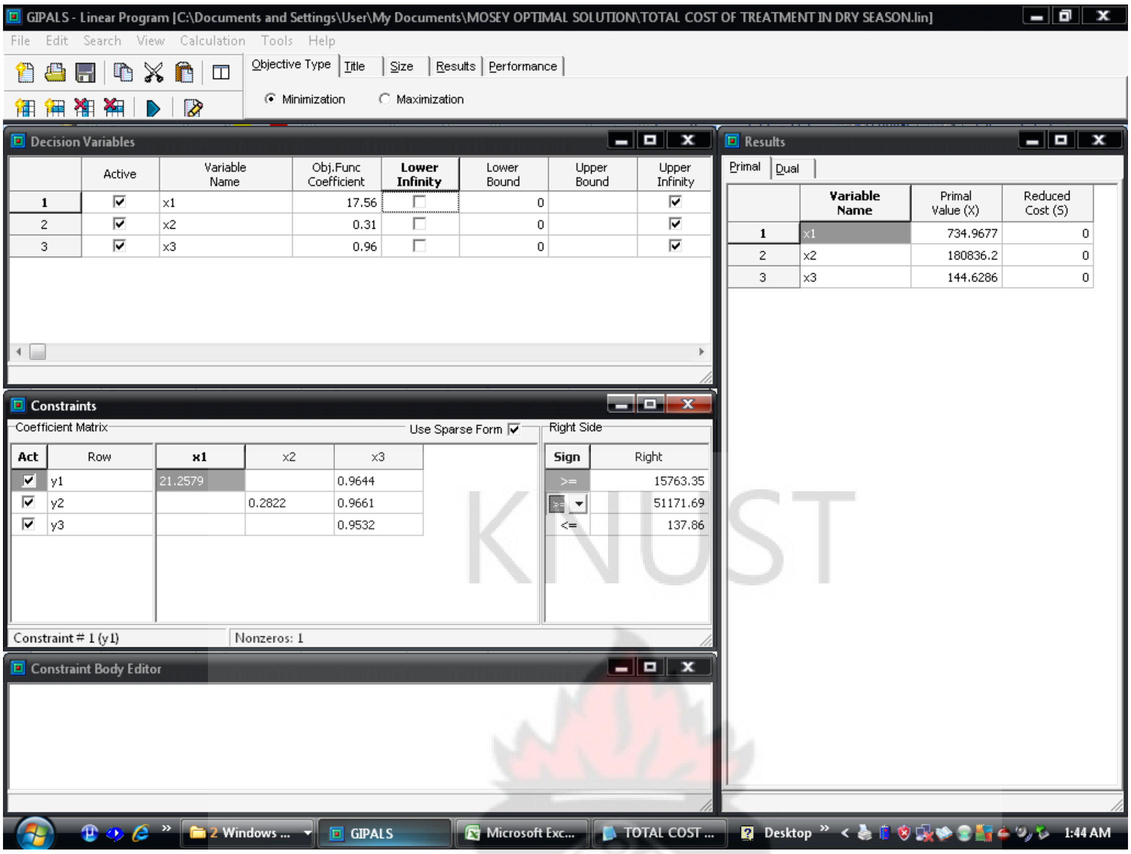

Figure 4.2, Title: the Dry Seasonal Cost Evaluation by use of GIPALS Software

Title: TOTAL COST OF TREATMENT IN THE DRY SEASON
Number of variables:3.
Number ofconstraints:3
Minimization of objective function.

Primary objective function value: 6.91040860586985E+04
Dual objective function value: 6.91040860585685E+04

No.	Name	Value	Reduced Cost	Description
1	x1	734.9677	0	
2	x2	180836.2	0	
3	x3	144.6286	0	

No.	Constraint	Dual Value	Activity (A*x)	Relaxation |b - A*x|
1	y1	0.8260458	15763.35	0
2	y2	1.098512	51171.69	0
3	y3	-0.941996	137.86	0

The total Dry Season Cost = GH¢ 69,104.09, with x_1, $x_{2,}$ x_3 equals 734.9677 bags, 180,836.2 Units and 144.6286 hours respectively.

Problem size in standard form:
Number of variables: 6
Number of constraints: 3
Number of nonzeros: 8

Calculating Initial Point...
Initial Point has been found.

Table 4.8, Title: Dry Season Analysis of Solution of the Problem from GIPALS software

No. Iter.	Objective Function Primal	Objective Function Dual	Infeasibility Primal	Infeasibility Dual	Optimality	Merit Function	Duality measure(Mu)
1	179056	32479.4	2.23175	0.186891	0.0673778	5.68493	12064.5
2	93810.9	53862.6	0.509275	0.00186891	0.128603	1.40135	5741.61
3	71402.9	67895	0.0303492	1.86891E-005	0.0804103	0.108536	578.399
4	69109.1	69096.6	2.93295E-005	4.30713E-008	0.00836924	0.000309124	2.08724
5	69104.1	69104	2.93295E-007	4.30713E-010	3.02039E-005	3.19018E-006	0.0215193
6	69104.1	69104.1	2.93295E-009	4.30701E-012	3.11399E-007	3.19018E-008	0.000215184
7	69104.1	69104.1	2.93295E-011	4.30974E-014	3.11387E-009	3.19018E-010	2.15184E-006
8	69104.1	69104.1	2.9349E-013	4.67846E-016	3.11387E-011	0	

****

Calculation finished with status: Optimal
Iterations Count: 8
Time elapsed: 0:00:00.172 (0.172 seconds)
Time per Iteration: 0.0215 seconds

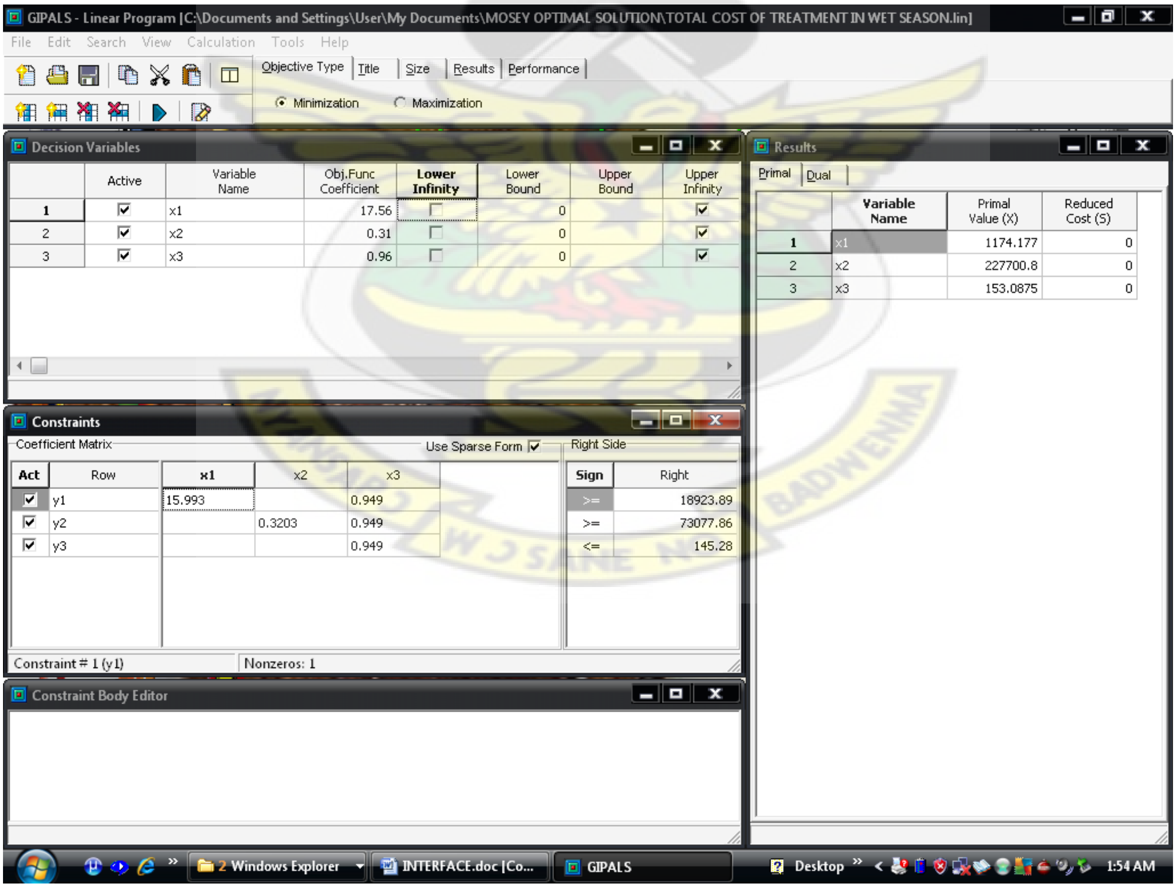

Figure 4.3, Title: the Wet Seasonal Cost Evaluation by use of GIPALS Software

Title: TOTAL COST OF TREATMENT IN THE WET SEASON
Number of variables: 3.
Number of constraints: 3.
Minimization of objective function.

Primary objective function value: 9.13527703680564E+04
Dual objective function value: 9.13527703680564E+04

No.	Name	Value	Reduced Cost	Description
1	x1	1174.177	0	
2	x2	227700.8	0	
3	x3	153.0875	0	

No.	Constraint	Dual Value	Activity (A*x)	Relaxation |b - A*x|
1	y1	1.09798	18923.89	0
2	y2	0.9678426	73077.86	0
3	y3	-1.054232	145.28	0

The total Wet Season Cost = GH¢ 91,352.77, with x_1, $x_{2,}$ x_3 equals 1174.177 bags, 227700.8 Units and 153.0875 hours respectively.

Problem size in standard form:
Number of variables: 6
Number of constraints: 3
Number of nonzeros: 8
Calculating Initial Point...
Initial Point has been found.

Table 4.9, Title: Wet Season Analysis of Solution of the Problem from GIPALS software

----

No. Iter.	Objective Functions Primal	Objective Functions Dual	Infeasibility Primal	Infeasibility Dual	Optimality	Merit Function	Duality measure(Mu)
1	267937	42297	2.25583	0.16834	0.0795094	5.8945	21303.6
2	123720	74021.7	0.618313	0.0016834	0.172191	1.38435	6760.57
3	92527.4	90494.3	0.0151068	1.6834E-005	0.0730648	0.0463936	337.553
4	91368.3	91346.2	0.000151068	3.35049E-008	0.00369438	0.000491462	3.66473
5	91352.9	91352.8	1.51068E-006	9.40653E-011	4.01157E-005	4.28899E 006	0.0292575
6	91352.8	91352.8	6.4969E-016	2.40705E-016	3.20266E-007	1.63331E-014	1.65611E-
7	91352.8	91352.8	1.15448E-016	1.70204E-016	1.81285E-015	0	

****

Calculation finished with status: Optimal
Iterations Count: 7
Time elapsed: 0:00:00.484 (0.484 seconds)
Time per Iteration: 0.0691 seconds

4.2 Sensitivity analysis of the model using excel

	Unit Chemical Cost	Unit Elect. Cost	Unit Extra –Duty Cost
Objective function	17.56	0.31	0.96
Quantity (vol.) Dry Season	734.97	180836.2	144.6286
Quantity (vol.) Dry Season	1174.18	227700.8	153.09

Optimal cost Dry Season	69,104.09	Old cost Dry Season	74,544.16
Optimal cost Wet Season	91,352.77	Old cost Wet Season	105,348.18

Table 4.10, Title: Sensitivity Analysis of Seasonal Cost Using Excel software

Change in unit price	Unit cost			Optima cost	
	Chemical	Electricity	Extra-duty	Dry	Wet
0.01	17.57	0.32	0.97	70,922.79	93,643.05
0.02	17.58	0.33	0.98	72,739.99	95,933.33
0.03	17.59	0.34	0.99	74,557.19	98,223.61
0.04	17.60	0.35	1.09	76,242.74	100,513.9
0.05	17.61	0.36	1.10	78,062.35	102,818
1.00	18.56	1.31	1.96	250,825.5	320,380.9
1.10	18.66	1.41	2.06	268,997.5	343,283.7
1.20	18.76	1.51	2.26	287,169.5	366,186.5
1.30	18.86	1.61	2.26	305,341.5	389,086.3
1.40	18.96	1.71	2.36	323,513.5	411,992.1
1.50	19.06	1.81	2.46	341,685.4	434,894.9

The sensitivity analysis shows that the model will not minimize the total cost if the unit price of a bag of chemical, unit of electricity and extra – duty hours in the objective function is increased by GH¢ 1.00 and GH¢ 0.03 in the wet and dry seasons respectively.

4.3 Summary of the Chapter

The chapter considered levels of inputs applied to the model and their effect on treatment in the dry and wet seasons. Summary of findings, conclusions and recommendations are presented in the next chapter.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS.

5.0 Summary of Findings

The headworks in full operation pumps 35000m^3/d (7,700,000 *gal/d*) of final water to five (5) subsystems for distribution to the communities. The old plant pumps 12,440m^3/d whilst the Jubilee plant pumps 21,000m^3/d. The table below gives the characteristics of the pumps in the subsystems.

Table 5.0

5.1 Summary of Estimated Treatment Cost

The seasonal average water treatment volume of 746,520m^3 in the dry season and 787,285.71m^3 in the wet season at an average cost of seventy four thousand, five hundred and forty four cedis and sixteen pesewas (GH¢74,544.16) and one hundred and five thousand, three hundred and forty eight cedis and eighteen pesewas (GH¢105,348.18) in the dry and wet seasons respectively can be optimized using the linear programming model to sixty nine thousand, one hundred and four cedis and eight pesewas (GH¢ 69,104.08) and ninety one thousand, three hundred and fifty two cedis and seventy seven pesewas (GH¢ 91,352.77) to pump the same of volume of water in the dry and wet seasons respectively.

5.2 Conclusion

The frequent and regular power outage in Kwanyaku and its environs and the ritual of low voltage daily between 19 hours and 23 hours GMT leads to equipment failure and breakdown at the headworks and above all high voltage consumption by the pumps at the initial restoration of power supply. An efficient standby plant or generator would help regular water production and reduce equipment failure and breakdown, extra – duty cost and the judicious use of the low budget allocation for maintenance.

It is worth noting that, rainfall variability (climate change), draining of wetlands, increased environmental degradation, the current increasing rate of households in Swedru municipality and the addition of Kasoa and its surrounding communities to the distribution network possess great challenge to the headworks in meeting future demands. There is therefore the need to acquire high capacity pump and upgrading of the Old treatment plant.

An observation on daily average volume of water treated, revealed that three hundred and fifty two thousand gallons (352,000 g/d) of water representing three percent (3%) total volume of water pump is used as backwash water and sludge. Waste water recycling treatment plant if built would reduce the volume of water wasted in the treatment of process.

5.3 Recommendations

It is recommended that;

- All machinery and equipment at the headwork should be given regular monitoring and maintenance.

- There should be proper arrangement with Electricity Company of Ghana (ECG) for adequate supply of power to the area where the waterworks is located.
- Water for backwashing and sludge should be retreated for laundry services and car washing.

- There should be provision of alternative sources of water supply such as boreholes and public taps in strategic locations in the study area.
- There should be constant repairs of damage pipes and taps in order to reduce leakages.

- Metering and monitoring outfit should be established in the customer service unit to track system problems and to help cut down on waste in the supply chain.

- There should be public enlightenment campaign in mass media against the reckless over-consumption and misuse of water.
- There should be the adoption of water-efficient technologies and encouragement of economic activity that doesn't guzzle water.

5.4 Limitations of the Research

The major limitations to this research are: The research did not

1. Cover all aspect of water treatment and supply. Example facility location in the supply chain, revenue and administration
2. determine the optimal consumption by the use of:

- engineering calculations
- equipment manufacturer’s standards
- maintenance performance
- internal norms and standards

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APPENDIX I

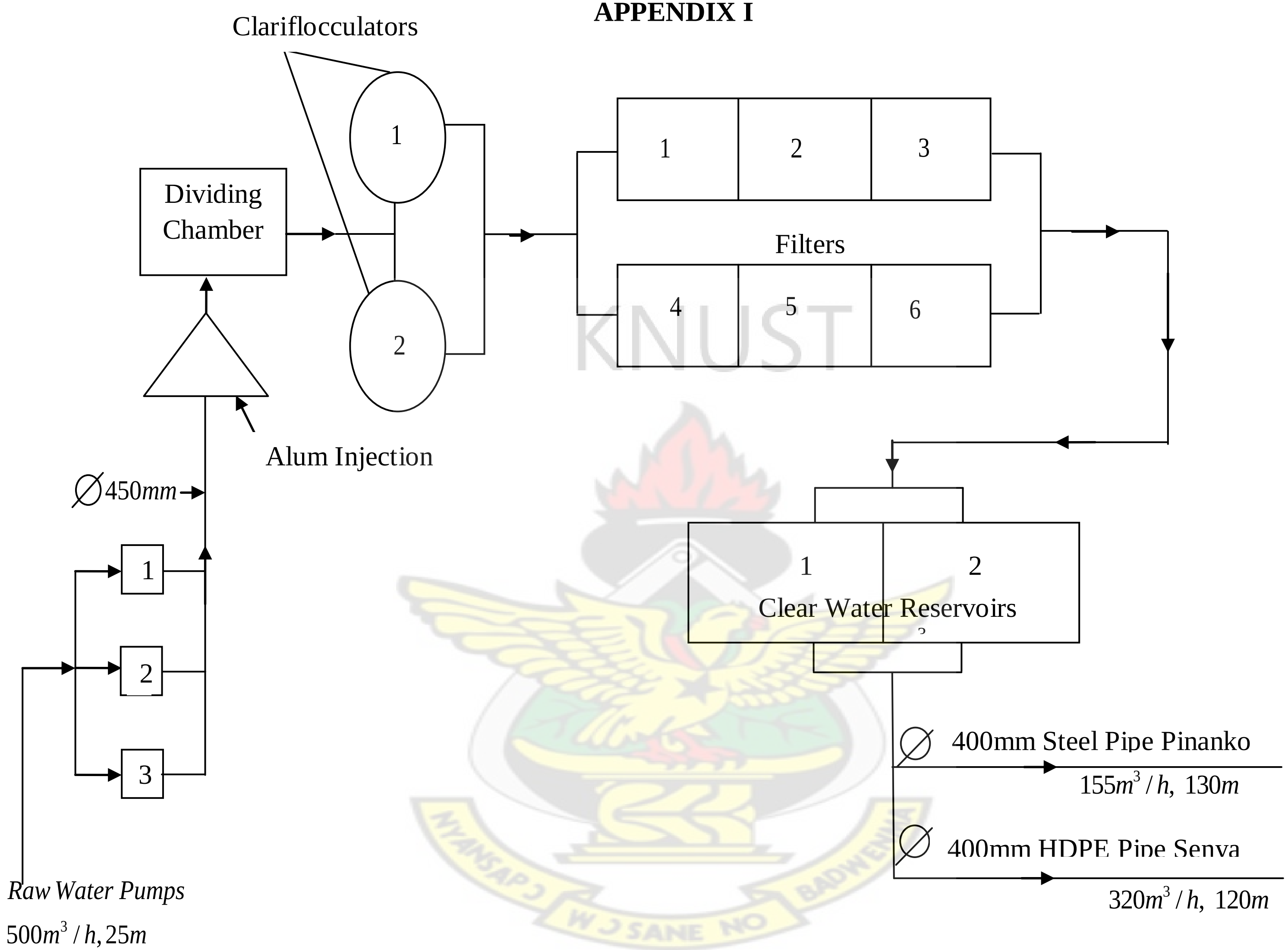

Figure 1.1, Title: Flow Chart of Old Plant – Kwanyaku Water Treatment Plant

APPENDIX II

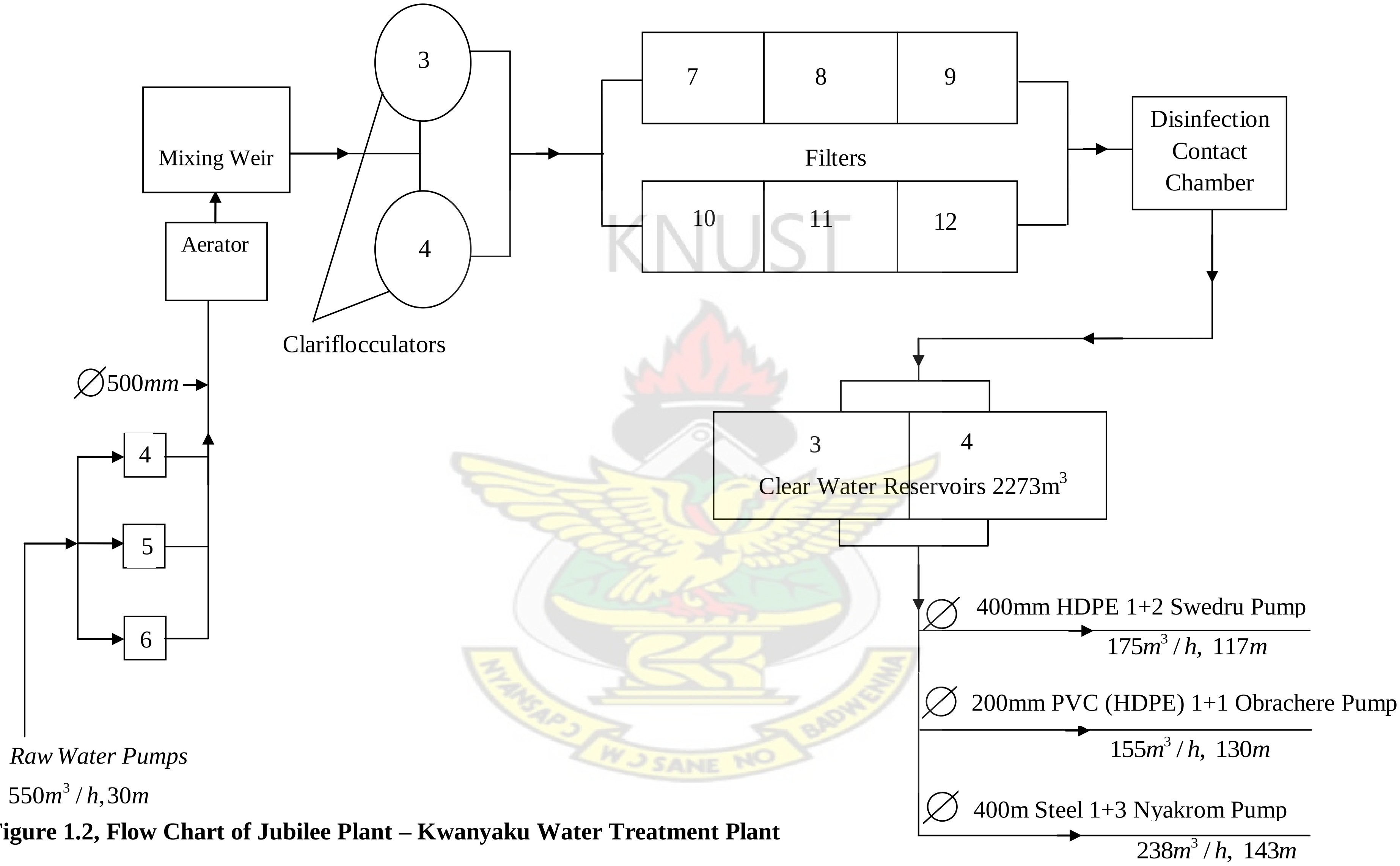

Figure 1.2, Flow Chart of Jubilee Plant – Kwanyaku Water Treatment Plant

APPENDIX III

Table 1.0, Title: Data on plant and equipments Old Dam - Kwanyaku Treatment Plant.

ITEM NO.	EQUIP. DISCRIPTION	MAKE / SERIAL NO.	RATING			REMARKS
			HP	PR	SPEED	
1	Submersible Pump No.1 Motor No. 1	KSB 3-9971349143 236407	62Kw, 119A	$425m^3/h$, 25.2m	1475rpm	Newly supplied
2	Submersible Pump No.2 Motor No. 2	KSB 3-9971349144 236408	62Kw, 119A	$425m^3/h$, 25.2m	1475rpm	-do-
3	Submersible Pump No.3 Motor No. 3	KSB 3-9971349143 236409	62Kw, 119A	$425m^3/h$, 25.2m	1475rpm	-do-
4	Senya Pump No.1 Motor	SIHI 195569 3272474	160Kw, 277A	$320m^3/h$, 120m	1475rpm	Good
5	Senya Pump No.2 Motor	SIHI 195571 3272479	160Kw, 277A	$320m^3/h$, 120m	1475rpm	-do-
6	Senya Pump No.3 Motor	SIHI 195570 3272476	160Kw, 277A	$320m^3/h$, 120m	1475rpm	-do-
7	Pinanko Pump set 1 Motor	LU0216717103 045323	90Kw, 158A	$155m^3/h$, 130m	1500rpm	New pumpset
8	Pinanko Pump set 2 Motor	LU0216717104 045325	90Kw, 158A	$155m^3/h$, 130m	1500rpm	-do-
9	Wash Water Pump No. 1 Motor	SIHI 195402 ABB IEC 2005/m 55	30Kw, 54A	$500m^3/h$, 12.5m	1475rpm	In good condition

10	Wash Water Pump No. 2 Motor	SIHI 195400 ABB IEC 2005/m 55	30Kw, 54A	500m^3/h, 12.5m	1475rpm	-do-
11	Wash Water Pump No. 3 Motor	SIHI 195402 ABB IEC 2005/m 55	30Kw, 54A	500m^3/h, 12.5m	1475rpm	-do-
12	Air Blower Pump No. 1 motor	AERZEN GM 255 730591 ABB IEC 160m/L 42	18.5kw, 31A	1 Bar	2930	In good condition
13	Air Blower Pump No. 2 motor	AERZEN GM 255 730591 ABB IEC 160m/L 42	18.5kw, 31A	1 Bar	2930	-do-
14	Alum dosing Pumpsets Motor					1 is fairly good, 1 is out of service
15	Lime dosing Pumpset Motor					To be replaced under the rehabilitation
16	Bleaching dosing Pumpsets Motor					Good

APPENDIX IV

Table 1.1, Title: Data on plant and equipments Jubilee Plant - Kwanyaku Treatment Plant.

ITEM NO.	EQUIP. DISCRIPTION	MAKE / SERIAL NO.	RATING			REMARKS
			HP	PR	SPEED	
1	Swedru Pumpset 1 Motor	Sterling LU 0216717001 45324	90kW,216A	175m³/h, 177m	1485 rpm	New pumpset
2	Swedru Pumpset 2 Motor	Sterling LU 0216717002 45327	90kW,216A	175m³/h, 117	1485 rpm	-do-
3	Swedru Pumpset 3 Motor	Sterling LU 0216717003 45322	90kW,216A	175m³/h, 117	1485rpm	-do-
4	Nyakrom Pumpset 1 Motor	Sterling LU 021671690 45329	160kW,273A	238m³/h, 143	1486rpm	New pumpset
5	Nyakrom Pumpset 2 Motor	SIHI 195564 ABB 3272472	160kW,273A	238m³/h, 143	1487rpm	Old pumpset from old works
6	Nyakrom Pumpset 3 Motor	SIHI 195565 ABB 3272480	160kW,273A	238m³/h, 143	1487rpm	-do-
7	Nyakrom Pumpset 4 Motor	SIHI 195566 ABB 3272481	160kW,273A	238m³/h, 143	1487rpm	-do-
8	Obrachere Pumpset 1 Motor	Sterling LU 0216171001	90kW,216A	155m³/h, 130	1485rpm	New pumpset
9	Obrachere Pumpset 2 Motor	Sterling LU 0216171002	90kW,216A	155m³/h, 130	1485rpm	-do-
10	Wash Water Pumpset 1 Motor	Sterling MSLA 20605362 45357	37kW,69.4A	1440m³/h, 5m		New pumpsets
11	Wash Water Pumpset 2 Motor	Sterling MSLA 20605363 45357	37kW,69.4A	1440m³/h, 5m		-do-
12	Air Blower Pumpset 1 motor	Atlas Copco A1F0111761 312	34.9Kw	70kPa		New
13	Air Blower Pumpset 2 motor	Atlas Copco A1F0111762 312	34.9Kw	70kPa		-do-

14	Lowlift Pumpset 1 Motor	WILO 650000004	78kw, 141A	600m³/h, 30m		New pumpsets
15	Lowlift Pumpset 2 Motor	WILO 650000004	78kw, 141A	600m³/h, 30m		-do-
16	Lowlift Pumpset 3 Motor	WILO 650000004	78kw, 141A	600m³/h, 30m		-do-
17	Chemical dosers ALLDOS	2 No. Alum, 2No. Lime 2 No. Bleach				New pumpsets

APPENDIX V

Table 4.0, Title: Raw water, water for Treatment and Final water for 2010

Month	Raw Water (m^3)	Water for Treatment (m^3)	Final Water (m^3)	Total Volume (m^3)
Jan.	409600.00	41503	368097.00	819200.00
Feb.	333000.00	30983	302017.00	666000.00
Mar.	292300.00	35250	257050.00	584600.00
Apr.	329900.00	33139	296761.00	659800.00
May.	379400.00	35964	343436.00	758800.00
June	340400.00	30190	310210.00	680800.00
July	432300.00	15865	416435.00	864600.00
Aug.	498400.00	19781	478619.00	996800.00
Sept.	411100.00	19596	391504.00	822200.00
Oct.	364000.00	25596	338404.00	728000.00
Nov.	377600.00	11470	366130.00	755200.00
Dec.	453800.00	21417	432383.00	907600.00
Total	**4621800.00**	**320754**	**4301046.00**	**9243600.00**
Average	**385150.00**	**26729.50**	**358420.50**	**770300.00**

APPENDIX VI

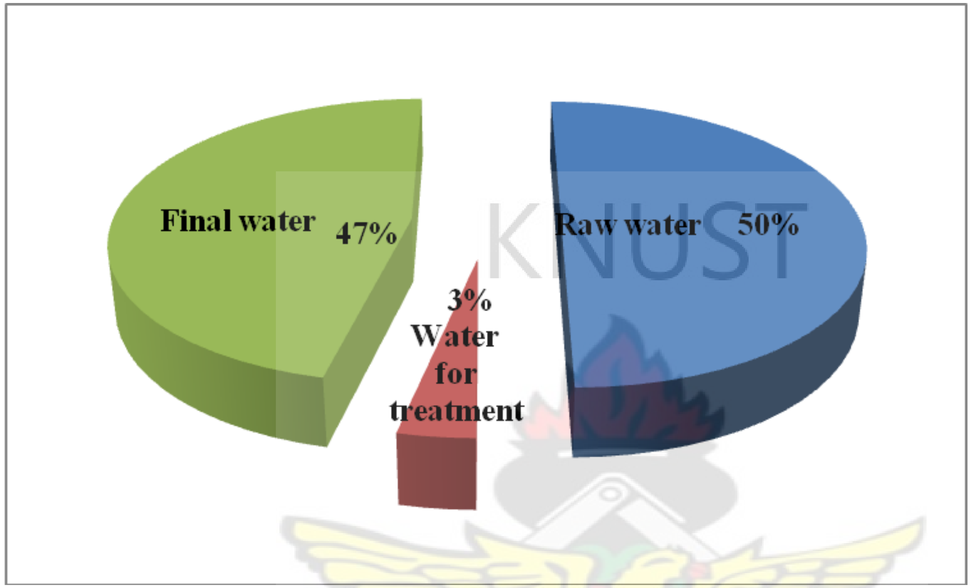

Figure 4.0, Title: Daily Volume of Water Treated for 2010

APPENDIX VII

Table 4.1, Title: The Cost of Extra-duty, Chemical and Electricity in Treatment of Water

Month	Extra Duty Cost (GH¢)	Chemical Cost (GH¢)	Electricity Cost (GH¢)	Production Cost (GH¢)
Jan.	279.00	17,809.62	25,077.86	43,166.48
Feb.	264.00	16,424.00	19,760.49	36,448.49
Mar.	270.00	10,212.97	18,970.99	29,453.96
Apr.	257.00	19,951.56	20,127.96	40,336.52
May.	388.00	27,571.00	28,536.90	56,495.90
June.	488.00	21,906.69	86,002.67	108,397.36
July.	483.00	23,089.61	108,781.04	132,353.65
Aug.	510.00	21,767.54	127,948.53	150,226.07
Sept.	1,353.00	19,387.54	109,517.91	130,258.45
Oct.	1,395.00	21,411.52	96,562.54	119,369.02
Nov.	1,281.00	20,800.50	102,666.06	124,748.56
Dec.	1,400.00	21,123.92	116,379.38	138,903.30
Total	**8,368.00**	**241,456.47**	**860,332.33**	**1,110,157.76**
Average	**697.33**	**20,121.40**	**71,694.36**	**92,513.15**
Ratio/Unit	**0.96**	**17.56**	**0.31**	

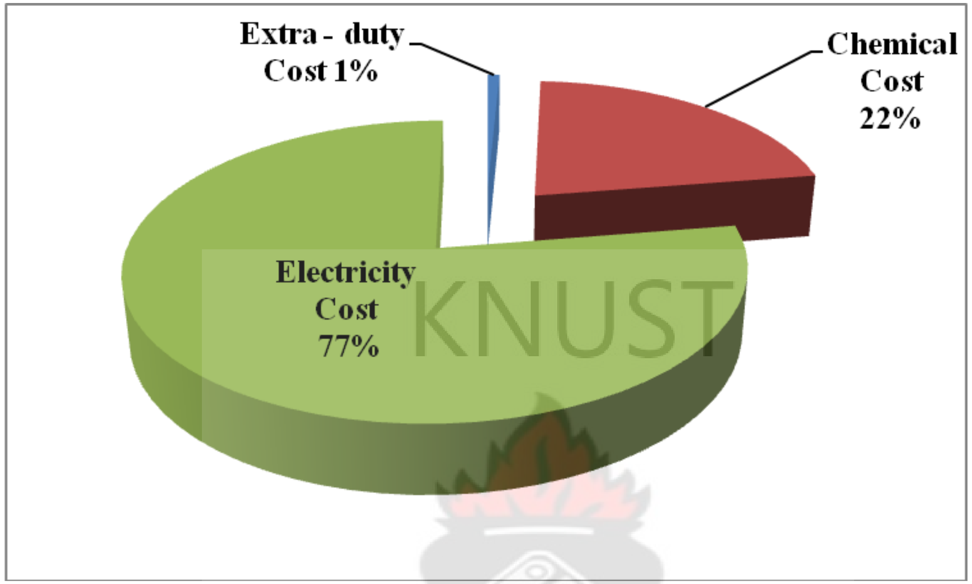

Figure 4.1, Title: Average Monthly Treatment Cost Chart

APPENDIX IX

Table 4.2, Title: The Quantity of Chemical, Electricity and Extra-duty Hours in Treatment of Water

MONTH	Electricity Consumption (Units)	Chemical Consumption (Bags)	Extra-Duty (Hours)
Jan.	152591	459	744
Feb.	122489	409	672
Mar.	110783	593	744
April	118907	1027	720
May	191572	1086	744
June	236472	1592	720
July	308787	1387	744
Aug.	369341	1810	744
Sept.	309776	1598	720
Oct.	267890	1197	744
Nov.	287294	1255	720
Dec.	329215	1347	744
Total	**2,805,117**	**13,760**	**8,760**
Average	**233,759.75**	**1,146.67**	**730**

APPENDIX X

Table 4.3, Title: The Seasonal Average Cost of Extra-duty, Chemical and Electricity in Treatment of Water

	Chemical House		Pump House		Transport Section	
Season	Chemical Cost (GH¢)	Extra-Duty Cost (GH¢)	Electrical Cost (GH¢)	Extra-Duty Cost (GH¢)	Extra-Duty Cost (GH¢)	Total Extra-Duty Cost (GH¢)
Dry	17,257.20	258.62	56,571.96	287.09	152	697.71
Wet	22,155.10	257.63	82,496.80	285.48	153.18	696.29

Table 4.4, Title: The Seasonal Average of Extra-duty Hours, Quantities of Chemical and Electricity in Treatment of Water

	Chemical House		Pump House		Transport Section	
Season	Chemical (Bags)	Extra-Duty (Hours)	Electrical (Units)	Extra-Duty (Hours)	Extra-Duty (Hours)	Total Extra-Duty (Hours)
Dry	812.60	268.18	200,474.40	297.17	159.46	724.81
Wet	1,385.29	271.48	257,535.00	300.82	161.42	733.72

Table 4.5, Title: Usage Ratios of Extra-duty, Chemical and Electricity in Treatment of Water

	Chemical House		Pump House		Transport Section	
Season	Chemical	Extra-Duty	Electrical	Extra-Duty	Extra-Duty	Total Extra-Duty
Dry	21.2579374	0.964352	0.28218545	0.96608	0.953217	0.962611
Wet	15.9930917	0.948983	0.3203323	0.949006	0.948953	0.948986

APPENDIX XI

Table 5.0, Title: Subsystems and Pump Characteristics

Number	Subsystem	Pump	Operation Design
1.	Swedru	3 Number Centrifugal	2 Running + 1 Standby
2.	Obrachere	2 Number Centrifugal	1 Running + 1 Standby
3.	Nyakrom	4 Number Centrifugal	3 Running + 1 Standby
4.	Senya Breku	3 Number Centrifugal	2 Running + 1 Standby
5.	Pinanko	2 Number Centrifugal	1 Running + 1 Standby