OPTIMIZATION OF WATER RESOURCES ALLOCATION IN ANAMBRA-IMO RIVER BASIN

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CERTIFICATION

This is to certify that this work, "**Optimization of Water Resources Allocation in Anambra-Imo River River Basin"** was carried out by OBI, LAWRENCE E. (20074609588) in the Department of Civil Engineering, Federal University of Technology, Owerri, under our supervision.

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DEDICATION

This research is dedicated to

My friend, sister

And

Beloved Wife- Fidelia Nwanneka Law-Obi.

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ABSTRACT

The research work was aimed at the optimization of water resources allocation to optimally allocate water to communities within the Anambra- Imo River Basin Development Authority area of jurisdiction. The study concentrated on the sub-river basins of Njaba, Mmam, Otamiri and Aboine as sample areas. The optimization process yielded optimal results. Based on the optimal values for the respective communities, allocations for the purposes of domestic use, ecology, energy, industries and mitigation of water leakages/losses were made. In Njaba river basin, the communities of Amucha, Okwudor, Umuaka, Awo-Omama and Nkwesi were allocated 124,410m^3, 316,185m^3, 539,260m^3, 582,196m^3 and 56,352m^3 quantities of water respectively for domestic and drinking purposes. Domestic use got the biggest quantity while energy use had the least. For instance, in Mmam river basin the corresponding values were 81.3% and 0.10% of the available water. The quantities of water in these sub-basins were estimated and the results showed that the sub-river basins of Njaba, Mmam, Otamiri and Aboine had in storage the total quantities of 86,313,000m^3, 52,202,880m^3, 228,044,160m^3 and 118,428,480m^3 volume of water. Sensitivity and post optimality analysis revealed that the unit rise in population input parameter in Mmam and Otamiri river sub-basins gave rise to 25% and 54% increase in the quantity of water allocated for domestic use respectively. The optimised allocation system resulted in cost reduction as seen in Aboine river basin where the existing allocation cost was reduced from 6.04 trillion naira to 5.70 trillion naira. It was therefore recommended that the water resources within the Anambra-Imo River Basin be optimized for the equitable and fair allocation of water within the basin.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Water has far reaching importance which ranges from health improvement, industrial development, hydro-electric power generation, agricultural development, recreation to navigation and it possesses the potentiality of sustaining the existence of the fauna and flora in the earth. It is obvious that direct consumption of water by plants and animals is top among other important uses of water. Water has other important functions as it can be used for washing, transportation, recreation, industrial applications, chemical uses, fire extinguishing, electric power generation, etc (Ayoola, 2011).

Water makes up more than two-thirds of human body weight and life cannot be sustained for few days without water. The human brain is made up of 95% water, blood is 82% and lungs 90%. A mere two percent drop in body water supply can trigger signs of dehydration and fuzzy short memory (Garg, 2010).

Water serves as a lubricant in digestion of food and it helps to lubricate our joints and cartilages and allows them to move more freely. Water plays a significant role in moderation and regulation of body temperature, water helps in transporting blood within the body and circulates antibodies from the immune system. The entire world uses world water day to highlight the importance of water. In 1992, the United Nations declared March, 22nd of every year world water day (Igali, 2011).

The United Nations conference on sustainable development in Rio de Janeiro in June 2012 (Rio+ 20 Summit) stated that water is the blood stream of green economy. Water, energy and food are interlinked and interdependent, securing them is central to alleviating poverty and to creating a climate of resilient and robust green economy. Population growth, expanding cities and accelerating economic activity increase the demand for energy and food and create unsustainable pressure on our water and land resource (Esan, 2002).

By definition, water resources allocation entails making water available for distribution to users for their peculiar purposes at any point in time and space. It targets at distributing available resources to various end users who hold some entitlements. These entitlements could be for domestic use, irrigation, hydropower, industrial, environmental, aquatic life conservation and other purposes (Cherg, 2007).

The effective management of available water in arid and semi-arid regions in general and Nigeria in particular has increased in importance in recent times due to limited water availability (Coe and Fooley, 2001). In Nigeria, water supply for various uses is highly unsustainable because of the neglect of water resources allocation concept. The attendant consequences have been lack of potable water in the midst of much water resources and the absence of considerations for apportioning available water resources for the ever increasing demands for ecological, industrial, hydropower, and recreational purposes. It is obvious that the world's craze for industrial, technological and recreational increasing demand and even the domestic and crop production needs make proper water distribution or allocations for various entitlements inevitable. The issue of thorough understanding of available water and the competing needs remains a challenge to engineers and others who must guarantee that future generations will be served with adequate water supply and equally ensure high level of environmental sanitation (Andah, 2003).

According to Raymond L. Nace of the U.S. Geological Survey, water resources are a global problem with local roots, in view of the problems facing water resources, a veritable approach for water resources managers will be to create a balance between supply and demand of water. Increased population growth, rapid economic growth and environmental degradation have driven an increasing demand on water (GWP, 2000).

Surface water management and water transfer should be given priority, while underground water extraction should then be the last option where possible. Human environment should therefore be seen as a system and sub-system that is interdependent in function which needs proper planning and management by professionals for sustainability (Dukiya, 2011).

1.2 Problem Statement

The Stockholm statement to the 2012 United Nations Conference on Sustainable Development in Rio De Janeiro (Rio + 20 Summit) stated that by 2030, in a business as usual scenario, humanity's demand for water could outstrip supply by as much as 40 per cent. This would place water, energy and food security at risk, increase public health costs, constrain economic development, lead to social and geopolitical tensions and cause lasting environmental damage. The problem of the limited nature of water resources and the albatross of the unlimited quest for its usage are enigmatic as it is conflicting and desire a solution which can be found through objective allocation.

Countries lack plans and facilities to deal with the calamity that will result from the next widespread regional drought, and the affected public does not even conceive of the impending disaster (Gupta and Gupta, 2010). Water resources in Nigeria (like in many other parts of the world) are poorly managed, under-utilized and utterly neglected and the trend has locked up the capacity for the appropriation of the potentialities of these natural resources. The neglect of the water resources are partly attributable to the under-development of most communities, local government areas, states and nations at large. The prevailing deterioration and eventual extinction of our water resources are the consequences of the unco-ordinated activities allowed in the water resources. The poor management of water the water sector has exacerbated the problem of aquatic life destruction, watershed degradation, over-cultivation of the river banks and the distortion of allocation equilibrium. The attendant consequences of poor and inappropriate management include under-utilization, extinction, deterioration, under-development and conflict in the water resources thereby created an imbroglio in the scenario of water resources development.

When a country lacks the capacity to manage water resources efficiently the consequence will be for her citizens or populace to suffer poor sanitary conditions. As a result of inappropriate management; there will be inadequate specifications, poor standards and ineffectiveness on the part of the institutions that are charged with the responsibility of regulating the activities and other oversight functions needed in the sector. From the foregoing, it can be observed that there are persisting problems of lack of water allocation programme, extinction of water reservoirs, and the underdevelopment of water resources and the catchment basins.

1.3 Objectives of the Study

The study seeks to:

1. Obtain data on water allocation parameters to various sectors in the Anambra – Imo River basin and any other relevant information.
2. Develop an optimization model for optimal water allocation to competing sectors in Anambra – Imo River Basin.
3. Obtain a solution of the optimization problem and perform sensitivity analysis.
4. Verify the computational accuracy of the software and compare the model results with those of an existing model.

1.4 Justification for Research

The research is necessary because of the spatial, temporal and purposeful imbalance in the allocation of water resources in the Anambra

– Imo River Basin. The imbalance had impacted negatively on the economic, health and environmental integrity of the sub-areas and localities in the basin. The research will help in making sure that the available water in the basin is equitably allocated on the principles of fairness, equity, objectivity and efficiency. It will balance the purposeful allocation of water as against the present scenario where most water usage purposes are never given priority but utterly neglected.

The project is expected to contribute to research efforts as the model can be used effectively in conflict resolution and optimal water allocation in river reservoir systems or basin. It will also provide valuable guidance for major capital development projects, residential growth and economic development consistent with state and local policies and plans.

1.5 Project Scope and Limitation

The scope of this project will be limited to investigations and data collection within the areas and rivers of the Anambra-Imo River Basin of Nigeria area of juriscription. The data collection is concentrated within the sample sub-basins of Njaba, Mmam, Otamiri and Aboine rivers and their catchment communities. The data collected were used to formulate model equations. The developed model solution will be verified and compared with the result from the manual solution. The data collected had direct relationship with the allocation priorities and they are limited to domestic water use, industry, ecology and energy use within the Anambra-Imo River Basin Development Authority area of jurisdiction.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of Water Resources

Throughout history, water has been considered a natural resource critical to human survival. From the earliest evaluation of hominid species around the lake shores of northern Kenya to the development of the main civilization on the banks of certain major rivers, human history can generally be considered to be water-centered. The early important civilization developed and flourished on the banks of major rivers such as the Nile, Euphrates, Tigris and Indus. Human history can, in fact, be written in terms of interactions and interrelations between humans and water (Biswas, 1997).

It is not difficult to realize why civilization and habitat often developed along the banks of several strategically important rivers. Easy availability of water for drinking, farming and transportation was an important requirement for survival. Human survival and welfare generally depended on regular availability of and control of water. Because water played a very important role, when Rishi Narada of India, probably the earliest leading authority on politics who lived many centuries before the Christian era, met the great Pandava kings, Yuddhistira, his greeting was water centered because of its importance; "I hope your realm has reservoirs that are large and full of water, located in different parts of the land, so that agriculture does not depend on the caprice of the Rain God"

Proper management and control of water means that the ravages due to drought and subsequent famines could be significantly reduced (Colin, 2011).

It is unarguably certain that water is one of the most important resources of a country and the entire communal society. After air, water is the next essential need for the sustenance of life on planet earth. This is true because no life is possible without water. Water can be harnessed to satisfy various purpose and needs. Water can therefore be put into such uses (water allocation priorities) as

- Running of hydroelectric turbines
- Navigation of ships, recreation, etc
- Domestic use/Drinking Water
- Irrigation
- Agro-industries and non-agricultural industries
- Ecology

Water is the basis of life, an ecological resource for the flora and fauna of the earth and a fundamental necessity for human life. Without an adequate supply of water, there is no hope of improving the health of the people in any given community. World Health Organization estimates that 80% of all diseases is in one way or the other connected with contaminated water usage (Murty and Madan, 2009). Without a good functional system, human water system, human productivity will tend to zero, be it agriculture, industry or trade. Despite, the estimable importance of water, almost half of the population of developing countries have neither the quantity nor the quality of water they need and even fewer people have access to sustainable disposal facilities for sewage. Sustainable development means overcoming conflicts between environmental protection and economic growth and implementing concepts that are socially balanced, economically efficient and environmentally sound (Anis et al, 1977).

The demand for water by individuals or consumption of water by any community is a function of place or time. In the design of any supply scheme, it is necessary to estimate the present need of the people and the projected expected demand putting into consideration among other things, the demographic data and the socio-economic conditions of the locality concerned. It has been observed that about 10% of water supply to communities is lost in wastages through broken pipes, leaking tanks and damaged water facilities. A typical domestic water consumption in a Nigerian city is shown in Table 2.1

Table 2.1: Typical Domestic Water Consumption in Nigeria.

S/N	**WATER USES**	**DEMAND/DAY(L/D)**
1	Drinking and Cooking	6.0
2	Kitchen Washing and Cleaning	20.0
3	Laundry	20.0
4	Car Washing	4.0
5	Garden and Recreation	50.0
6	Flushing and Disposal	50.0

Source: Ayoola, 2011

Table 2.1 shows that garden and recreation with flushing and disposal takes a lion share of the domestic water used in Nigeria while car washing takes least. This suggests that environmental cleanliness depends on water availability.

2.2 Global Water Concern for the Future

There are two key factors which assume the centre stage of the global concerns for the future availability of freshwater particularly safe drinking water. First among the duo, is the total withdrawals of freshwater which had dramatically been on the increase in the recent time. In fact, the withdrawals have doubled over the past forty years. This has resulted in current syndrome of depletion of groundwater aquifers faster than they are being recharged or replenished, this is most prevalent in India, China, Nigeria and the United States. The second key factor of concern has been the relentless rise in population in various parts of the world, particularly in developing countries. Global population is expected to increase by 1.5 billion over the next 25 years (the figures may reach up to some 8 billion people by 2025). If this population increase comes into effect, the amount of available freshwater per person per year will drop by 40% - from more than 8000 cubic metres to about 5000 cubic metres. Nigeria's population of more than 140 million inhabitants is likely to increase tremendously in the next ten years (Colin, 2011).

It should also be noted that the total volume of freshwater that can be used in any country generally cannot be significantly increased by artificial transportation over long distances. Low unit price of water means that unlike oil, it is generally not economical to transport water from one country to another. Furthermore, in contrast to the export of all other natural resources, even discussion of water export from a water surplus to a water deficient country generally generates strong public emotions. Even for two neighbouring countries like Canada and United States of America that have historically had good natural diplomatic and economic relations, the issue of export of water, from Canada, a highly water surplus country, to the U.S.A has always becomes so emotional and politically charged. This has made successive governments of Canada to have taken the pains to consistently consider the technical analysis and continual discussions making further water export unacceptable. This situation is not different in many parts of the world. Accordingly as the total global population increases, so do the aggregated human activities, which in turn, would increase water requirement. This contributes to two contradictory bends which further complicate the water management process. On one hand, a country's water requirements steadily increase with high level of human activities, on other hand, per capita water available declines, as the freshwater available is limited (Donkor, 2003).

The degree of available freshwater determines to some extent the quality of life of any nation's citizenry. This has exacerbated worries being expressed in some quarters about the fast depletion of surface water which is one of the world's major sources of freshwater. This has shifted massive and uncoordinated attention and exploitation to the groundwater which invariably may face its own risk of depletion in future.

2.3 Water Stress In African Communities

In recent years there have been noticeable shrinkages of lakes and rivers resulting in the reduction of water levels due to global and local causes: climatic change and vesting increasing competing demands on these lakes and rivers. The withdrawal of water from water supply and other sources has impact on the environment.

Increase in demand for water implies that our water sources are under pressure (Coe and Fooley, 2001). The temporal and spatial distribution of water resources is naturally uneven and their uncoordinated use through human abuse is a major source of worry that has generated water crises in many parts of the world. There are insufficient data to understand and predict the current and future quality and quantity of water resources, and political protocols and imperatives for sharing data are inadequate (WWAP, 2009).

Water stress can be defined as the situation where the available water is grossly inadequate when compared with the high demand placed on it. Conversely, it is also a situation created by the high demand per capita on available water resources. Water stress is directly related to the amount of water per person in a community based on the present and future time frames. Communities and areas in serious water stress condition have greater household water demands in relation to the current effective rainfall. Alternatively, this can also be seen as a situation where the predicted future effective rainfall will be in short supply to meet the projected population increase. When the demand for water is high, it results to a serious level of demand on available water resources (Dami et al, 2010).

Africa in particular, remains mired in poverty despite recent economic growth trends in some countries. Comparatively, in developed countries, inspite of global water crises, there are reliable sources for irrigation, water supply and hydropower

as well as buffer for flood management. Countries in Africa, store only 4% of renewable flows, co

mpared with 70% to 90% in many developed countries (UNW-DPC, 2009). The first African Water week convened in Tunis in March, 2008, opened a call for greater efforts to ensure water security nationally and regionally. Donald

Kaberukah, president of African Development Bank Group , emphasized that it is no longer tolerable for African countries to utilize only 4% of its water resources, when a huge proportion of the people do not have safe drinking water, and when large population are faced with frequent water stress, floods, in addition to food and energy shortages (Donkor, 2003). The water stress on our water resources is characterized by drastic reduction in volume of water recharge from rainfall and this has negative impact on the people. This further strengthens the clarion call for the establishment of facilities that can monitor and evaluate water levels.

Water availability is also directly subject to the impacts of climate change, which also can exert additional pressures on the other water resources. The result of these combined and interacting forces is continuously increasing demand for finite water resources for which there are no known substitutes yet (Global Water Partnership, 2000). There is evidence that the global climate is changing and sometimes, the change is human induced (IPCC, 2007). The major consequence of climate change on human beings and environment is noticed through water. Competition for water and other shortcomings in managing it to meet the needs of the people and environment call for enhanced societal responses through improved management, better legislation and more effective transparent allocation mechanisms (Dami et al, 2010). Strategies for water resources should include evaluation of availability and needs in the water sector, possible reallocation or storage expansion in existing reservoirs, more emphasis water on demand management , a better balance between equity and efficiency in water use , expunging inadequacies in legislative and institutional frameworks and contending with the rising financial burden of ageing infrastructure (Oteze, 1981).

2.4 Estimation of Groundwater

Available quantities of groundwater in an area are difficult to quantify because of other related processes such as evaporation, transpiration (or evaportranspiration) and infiltration which must first be measured to estimate the balance. Groundwater recharge which can also be called deep drainage or deep percolation is described as a hydrologic process where water moves downwards from the surface to the sub-surface into geologic formations called aquifers. Recharge occurs both naturally (through water cycle) and through anthropogenic processes such as artificial ground water recharge where rainwater or reclaimed water is routed to the subsurface (Dukiya, 2011).

Groundwater recharge may be impeded by such human activities as road construction, pavement construction, building roof, etc. These activities lead to enhanced runoff generation and will lead to reduction in recharge. Groundwater recharge is an important element in sustainable groundwater management since the volume of water extracted from an aquifer in the long term should be less than or at worst equal to the volume that is being used to recharge. Artificial groundwater recharge is becoming increasing important in most countries where over – pumping of groundwater has led to groundwater resources becoming depleted. In 2007, on the recommendation of the International Water Management Institute, the Indian Government allocated US$400 million to fund dug-well recharge projects in areas water stored in hard rock aquifer had been over-exploited (Colin, 2011).

Groundwater Estimation Methods

Available quantities of groundwater are difficult to quantify, since other related processes such as evaporation, transpiration or evaporation and infiltration process must first be measured or estimated to determine the balance. Recharge has been defined as the process of addition of water to the saturated zones. Due to the fact that it is almost impossible to measure directly, recharge is usually estimated by indirect means (Dunni et al, 1992).

Methods of Estimation

(i) **Physical Method:** Use method of soil physics to estimate recharge. The direct physics methods are those that attempt to actually measure volume of water passing below the root zone. Indirect physical methods rely on the measurement or estimation of soil physical parameters, which along with soil physical principles can be used to estimate the potential or actual recharge.

After months without rain, the level of the rivers under humid climate is low and represents solely drained groundwater thus the recharge can be calculated from the base flow if the catchments area is known.

(ii) **Chemical methods:** utilize presence of relatively inert water soluble substance such an isotopic tracer or chloride moving through the soil as deep drainage occurs.

(iii) **Numerical models**: recharge can be estimated using numerical methods with such codes as HELP, UNSAFH, SHAW, WEAP MIKE SHE. And HYDRUSID. These codes use generally climate and soil data to arrive at a recharge estimate and use Richards' equation in some form to model groundwater flow in the vadose zone.

(**iv) Darcian Method:** applied to steady flow condition in the unsaturated zone. This method is based on knowledge of the unsaturated hydraulic conductivity (K) at a point (usually deep) in the unsaturated zone where flow is downward and steady .If flow under field conditions is steady and driven by gravity alone, then according to Darcy's law, downward percolation rate will be numerically equal to the hydraulic conductivity of the material at the measured in – situ water content. The Darcian unit gradient method was originally used to establish long term average recharge rates in arid regions with unsaturated zones where, below some depth, flow is considered to be steady and driven by gravity alone.

(v) Water Table Fluctuation Method: provides an estimate of groundwater recharge by analysis of water level fluctuation in observation wells. The method is based on the assumption that rise in water table elevation measured in shallow wells is caused by the addition of recharge across the water table.

Recharge by WTF method is estimated as

R (tj) = Sy DH (tj)………………………2.1

where R (tj) in cm is recharge occurring within the time tj

Sy = specific yield (dimensionless).

DH (tj) =Peak water level rise attributed to the recharge period. in cm

Application of the method WTF involves two steps.

(i) Estimating the water level rise, DH(tj)

(ii) Estimating specific yield, Sy

Because of the simplicity of the method and wide availability of water level hydrographs from observation wells, the WTF method has been used for years (Crosble et al, 2005).

2.5 Requirements of Water for Various Uses

Water is required by a community, by a state or a country, for fulfilling its numerous needs. The determining elements for water demand are the population and desired quality of life. Amid rapid pace of urbanization and other telling factors, Nigeria is facing the mammoth challenges of water management and governance and to have the proportion of people living without access to safe drinking water and basic sanitation reduced: these are huge but surmountable challenges. The issues bedeviling the water sector ranges from poor long-term investment, corruption, poor management, weak government and contamination of water supply in urban, rural and small towns infrastructure. The 2005 report of the Millenium Development Goals have indicated that 51.6% of Nigerians live below the poverty line of one dollar per day (Jidda, 2011).

In view of the importance of water as one of the essential components necessary for the survival of human life, animal life and plant life, its role in bettering the quality of the lives of individuals and nations cannot be over stated. In a modern society water is generally needed to achieve the followings:

- Municipal and Industrial Water Supplies
- Irrigation Purposes
- Hydropower generation
- Navigation, recreation, etc

2.5.1 Demand For Municipal And Industrial Water:

Water is needed by the public for various uses such as domestic, industrial and commercial, public, fire fighting, compensation losses, leakages and thefts.

(i) Domestic water demand included the water required in private buildings for drinking, cooking, bathing, lawn sprinkling, gardening, sanitary uses, etc. The amount of domestic water consumption per person shall vary according to the living conditions of the consumers. On an average, the domestic consumption under normal conditions in an Indian city is expected to be around 135 litres per capita. In a developed and affluent country like U.S.A., the figure goes as high as 340 litres/day/capita. The total domestic consumption generally amounts to 55%-60% of the total water consumed for municipal and industrial purposes (Anis et al, 1977).

Table 2.2: Average Domestic Water Consumption in India

Use	**Consumption L/Day/Capita**
Drinking	5
Cooking	5
Bathing	55
Washing of Clothes	20
Washing of Utensils	10
Washing/Cleaning of Houses and Residences	10
Flushing of Latrines etc	30
Total	**135**

***Source*:** Vazirani and Chandola, 2006

The total domestic water demand shall be equal to the total design population multiplied by the per capita domestic consumption.

(ii) Industrial and commercial water demand includes the quantity of water required to be supplied to offices, factories different industries, hotels, hostels, hospitals, etc. The quantity will vary considerably with the nature of the city and the number and types of industries and commercial establishments in the locality. On an average, a provision of 20-25% of the total public water consumption is generally allowed for these uses.

In small residential communities, the industrial use may be as low as 45 litres per day but in industrial cities, it may be as high as 450 litres per day. The approximate quantities of water required by various industries per units of production in a developing country are shown in Table 2.3.

Table 2.3: Water Requirements for Some Industries.

S/N	Industry	Unit Of Production	Water Requirement in Kilo Litres
1	Automobites	Vehicle	40
2	Distillery	Kilo litre (Proof Alcohol)	120 – 170
3	Fertilizer	Tonne	80 – 200
4	Leather	Tonne (tanned)	40
5	Paper	Tonne	200 – 400
6	Special Quality paper	Tonne	400 – 1000
7	Straw Board	Tonne	75 – 100
8	Petroleum Refinery	Tonne (Crude Refined)	1 -2
9	Steel	Tonne	200 – 250
10	Sugar	Tonne (Cane Crushed)	1 – 2
11	Textile	Tonne	8 – 140

Source: Garg 2010.

Commercial districts include office buildings, ware- houses, stores, hotels, etc and their demands are not high, averaging about 45 litres per day per capita. The water requirements for buildings other than residences as per a developing country such as India are given in Table 2.4.

Table 2.4: Water Requirements for Commercial Buildings

S/N	Types of Building	Average Consumption in litres/Day/Capita
1	Factories a) Where bathrooms are required to be provided	45
	b) Where no bathroom is required	30
2	Hospitals (based on unit bed) (a) Number of beds less than 100 b) Number of beds exceeding 100	 340 450
3	Hostels	135
4	Hotels (per bed)	180
5	Restaurants (perseat)	70
6	Offices	45
7	Cinemas, auditorium, and theatres (perseat)	15
8	Schools a) Day Scholars b) Residential	 45 135

Source: Vazirani and Chandola, 2006

(iii) Demand for public uses includes the quantity of water required for public utility purposes such as watering of public parks, gardening, washing and sprinkling on roads, use in public fountains, etc. These needs are not regarded as essentials and a nominal amount not exceeding 5% of the total consumption may be added to meet this demand on an arbitrary basis.

iv) Fire Demand: In densely populated and industrial areas, fire generally breaks out and may lead to serious damages if not controlled effectively. Fire fighting personnel require sufficient quantity of water so as to throw it over the fire at high speeds. A provision should therefore be made in municipal water supply schemes for fighting fire. The quantity of water required for controlling fire should be easily available and accessible and kept always stored in storage reservoirs. The water is accessed through manholes connected to the dedicated water line. However, the total quantity of water required is generally very small and it is of the order of 1litre/day/capita. Although the actual yearly consumption of water for fire fighting is very small, the rate of use during a conflagration is very high and can even govern the sizing of distribution system components (Agunwamba, 2001)

(iv) Water required in compensating losses, wastes, thefts, etc. These include the water lost in leakage due to bad plumbing workmanship or damaged pipe, stolen water due to unauthorized water connections and other losses and wastes. In the best managed public water supply schemes, these losses amount to about 15% of total consumption.

Fire hydrants, are mounted along a water distribution system at intervals to provide water for fighting fire. Hydrants are located.

- Where they will not interfere with traffic
- Where they are easily identifiable (by painting or marking) and accessible

- At each intersection with additional ones where necessary.

The distance between them will not exceed 150m for residential areas and not more than 6m-90m for business and industrial areas.

An auxiliary gate value should be installed in the lateral between the hydrant and the main to permit inspection and repair without shutting down mains.

The maintenance and operation of hydrants should be given due attention and priority even at the design stage. Since it is possible to damage the hydrant by excessive torque, it should be carefully handled, opened and closed without too much force. Hydrants deserve regular maintenance so as to keep them serviceable, preferably twice a year. The maintenance process should involve,

- Visual inspection of each hydrant for external damage.
- Removal of the nozzle caps and greasing the screw thread.
- Recording the static pressure and testing the flow
- Checking the operation valve, inspecting the barred damage, oiling the stem nuts and repainting the hydrant if necessary (Franklin, 1982).
- Assessment of the adequacy of water supply is one of the important steps in determining the overall readiness of a fire department to combat fire outbreak. The water supply system should be capable of delivering the maximum daily consumption rate and the maximum fire flow needed for a period of 10 hours (Agunwamba, 2000). Hydrants are planned to cover an area within a radius of 60m with nozzle diameters varying from 25mm to 40mm (Fair, 1971).

Total Requirements for Municipal Supplies

The emerging water crises arising from increased competition for use and other factors affecting water demand is essentially a crisis of governance. Societies are facing a number of social economic and political challenges on how to utilize water wisely hence the recognition that water resources are an integral component of the ecosystem, a fragile and limited natural resources, that is social and economic in nature (Ibrahim, 2011).

The total yearly water requirement for public supplies in litres can be obtained by multiplying the per capita demand in litres/day/person by the expected design population and 365 days. The per capita demand is the annual average amount of daily water used by an individual for all his needs including domestic, industrial, commercial, wastes, etc. The breakdown of per capita water demand tenable in a developing country such as India is shown in Table 2.5 below;

Table 2.5: Total Water Requirements For Municipal Use

S/N	**Purposes**	**Consumption (Litres/day/Capita)**	**Percent Consumption Per day per Capita**
1.	Domestic use	135	50.00
2.	Industrial Use	50	18.52
3.	Commercial Use	20	7.41
4.	Civic or Public Use	10	3.70
5.	Wastes, Thefts, etc	55	20.37
	Total	**270**	**100%**

Source: Vaziran and Chandola, 2006

Besides, the average water consumption, the peak demands are also important while designing public water supplies.

2.5.2 Water Demand for Irrigation

Nigeria is an agrarian nation. Therefore, genuine development of the economy of Nigeria is impossible without giving the deserved attention to agricultural production and industrial sector. 70% of the Nigerian population reside in rural areas and are pre-occupied in agricultural production. In Nigeria, rural areas contribute about 80% of the national agricultural production. (Adewumi et al, 2011). Yet the potentials of these rural dwellers are under utilized due to non-provision of dams, and other irrigation facilities. Crops require certain quantity of water during the period of growth. If the natural rain is sufficient and timely to satisfy this requirement, no irrigation water is required for raising the crops. In the tropics and in the sub-Saharan region the natural rainfall is either insufficient or the water falls at intervals not required by the crops. Therefore, water has to be augmented artificially from some outside sources such as irrigation methods. The relationship between the irrigation water and the area of crop that matures fully with the amount of water is known as duty of water while delta refers to the depth of water required excluding rainfall for the full crop period (Murty and Madan, 2009).

The total quantity of water required by a crop for its full-fledged growth, when expressed as cm depth of water standing over the irrigated area is known as delta. This total quantity of water must be supplied to the crop during the period of its growth in a number of waterings at suitable intervals, as per the needs of a particular crop. The average values of delta for certain crops are shown in Table 2.6. These values represent the total water requirement of the crops. The actual requirement of irrigation water may be less, depending upon the useful rainfall. Moreover these values represent the values on field, i.e., "Delta on field" which includes the evaporation and percolation losses.

Table 2.6: Average Approximate values of Delta for certain important Crops

S/N	CROP	DELTA ON FIELD (cm)
1	Sugar Cane	120cm (48^{11})
2	Rice	120cm (48^{11})
3	Tobacco	75cm (30^{11})
4	Garden fruits	60cm (24^{11})
5	Cotton	50cm (22^{11})
6	Vegetables	45cm (18^{11})
7	Wheat	40cm (16^{11})
8	Barley	30cm (12^{11})
9	Maize	25 cm (10$^{11)}$
10	Fodder	22.5cm (9^{11})
11	Peas	15cm (6^{11})

***Source*: Michael et al, 1977**

Another important term which describes the water requirement of a crop is called Duty. The "duty" of water is the relationship between the volume of water and the area of crop it nurtures. Duty of water for a crop, is the number of hectares of land which the water can irrigate. Therefore, if the water requirement of the crop is more, it will irrigate less hectares of land for a given volume of water.

2.5.3 Water Requirement for Hydropower Generation.

The high costs of electricity provision to the rural areas through extension schemes can gulp up to USD 50000/Km in comparison to a decentralized renewable energy system like small hydro power (SHP) which is considered to be cheaper (Esan, 2002). Micro hydropower is recognized as a renewable energy resources, which is economic, non-polluting and environmentally sustainable and ideal for rural electrification with proven and well advanced technology.

Small Hydro potential sites abound in most states of Nigeria's river basin authority areas of coverage. Unexploited sites with SHP potentials, with total capacity of 7342 MW exist in various states (Esan 2002). However, international collaboration and public private partnership PPP is suggested for such developments. The provision of electricity to rural areas through extension schemes of the grid transmission are heavily burdened by expensive equipment with the overhead costs attached to such schemes. It is cheaper to invest in a decentralized renewable energy system like mini and micro hydro SHP than to pay for connecting local communities to existing national grid which can consume about USD50000/km. Hydropower is a widely available resource and has most economically feasible potential in developing countries. It is environmentally friendly as it does not involve fossil fuel for its generation.

Hydro power systems have lowest operating, longest plant life about 40 to 50 years and can produce multipurpose benefits (Esan, 2002).

Hydroelectric power plants convert the energy from flowing water (hydro potential) in rivers and streams into electricity. Exploiting water resources has many advantages and energy generation is just one of them. SHP can therefore maximize the value of water, not only by contributing to more security of power supply but also water management such as flood control, irrigation, water storage and water supply. Exploitation of resources is considered as a key area for developmental change as contained in Brundland Report of 1987 during the World Conference on Sustainable Development. Water is yet to be maximized as a major resource for developmental change. The exploitation of economically feasible potential as alternative to fossil fuel brings a reduction in global carbon dioxide production (Makoju, 20003).

2.5.4 Water Demand for Navigation and Recreation

Navigation is another important use of water which provides a cheap means of transportation without any consumption of water. In the present modern day, in addition to providing transport of heavy cargoes which cannot be lifted and packed on wagon trains or trucks, it provides us recreational boating, however sufficient quantity of water is needed through the years, so as to enable the ships, motorboats, steamers, etc to safely float over it with minimum drag. A minimum depth of 2.7 metres is generally required for navigating safely and economically, although a depth of about 3.7 metres is generally required in the final development of a navigable water way (Garg, 2010).

Navigation facilities are provided for transportation of goods and passengers. The various works adopted for navigation include dams, reservoirs, canals, locks, channel improvement etc. For the purposes of recreation, facilities are provided through water for the health and welfare of the people. The various works that can be used for that purpose include reservoirs, swimming pools, facilities for boating and water sports (Arora, 2007).

2.6 Demography and Socio-Economy

Reliable and accurate demographic data, mainly population size and population growth rates are essential for the planning and design of water allocation and distribution system. Population statistics are usually derived from checks which have to be made with information obtained from town/household surveys or the planner has to rely fully on his own survey. Population forecasting is very vital in water supply system designs because such systems are planned to serve the present and future needs of the community. Population changes arise due to births, deaths and migration. The various methods for population forecasting include graphical, arithmetical, geometrical and comparative methods (Anis and Jose, 1977).

The factors that influence the spatial distribution of population are varied. They include topography and habitability of land area, climate and vegetation, as well as historical, economic, social and cultural factors. The greater concentration of population in large urban centres in south western region, for example, is mainly attributed to historical and socio-cultural factors. Administrative decisions taken to create forest reserves and games parks have greatly affected the pattern of distribution of the rural population in parts of the country. The spatial distribution of the population of Nigeria is so uneven that extensive areas in Chad Basin, the middle Niger valley, the grass plains north of Oyo and the Niger Delta among others are sparsely populated. By contrast, large areas of very densely populated rural districts, supporting more than 400 persons per Km^2, occur in parts of Akwa Ibom, Imo, Anambra, and Enugu States as well as around Kano, Katsina, and Sokoto Towns, (Kadejo, 1998). One important consequence of the very uneven distribution of rural population in the country is the great pressure of population on the land resources of some districts. It can be established that the states under the coverage of Anambra and Imo River basin has a relatively high population density and this calls for proper management of the water resources within the area (Kadejo, 1980).

2.7 Water Demand

The total water demand for community use in sub-areas or towns consists of the consumption from public taps, yard taps, house connection and non-domestic use, i.e., all consumption other than by families. The above connections clearly exclude use of water for ecological irrigation and industrial uses. The estimates of per capita consumption levels for design purposes preferably would have been based on current consumption figures in a similar town that already has a properly functional piped water supply system. However, one could not find a suitable town to conduct measurements of actual water use supply in the towns that have piped water but the supply system appears to be on a rotating basis for a few hours per day or for some days, to one day a week only, which means that demand is not fully met. The variation in water demand is usually assessed by evaluating water meter records or performing measurements in existing system. Unfortunately, no water consumption data are available for rural piped water supply systems in the river basins (Garg, 2010).

The volume of a distribution reservoir is related to the total demand and its other needs such as fire fighting and other emergencies in a system with three different service connections, each having their own consumption level, demands have to be combined first. Storage is provided to balance the daily variation in demand and the production. The supply is governed by the pumping capacity which in rural system is preferred to be constant. Additionally, storage may be provided to cover to some extent short duration interruptions in the supply.

2.8 Water Resources Allocation Priorities

In the planning and operation of systems, water allocation should be broadly, apportioned as follows,

- ❖ Drinking Water
- ❖ Irrigation
- ❖ Hydropower
- ❖ Ecology
- ❖ Agro-industries and non-agricultural industries
- ❖ Navigation and Recreation, etc.

In the project planning, water resources development projects should as far as possible be planned and developed as multipurpose projects. Provision for drinking water should be a primary consideration. There should be an integrated and multi-disciplinary approach to the planning, formation, clearance and implementation of projects, including catchments areas treatment and management, environmental and ecological aspects, the rehabilitation of affected people and command area development. The planning of projects in hilly areas should be taken into account the need to provide drinking water, possibilities of hydropower development and the proper approach to irrigation in such areas, in the context of physical features and constraints of the basin such as steep slopes, rapid runoff and the incidence of soil erosion. The economic evaluation of projects in such areas should also take these factors into account. Adequate safe drinking water facilities should be provided to the entire population both in urban and in rural areas, irrigation and multipurpose projects should invariably include a drinking water component, wherever there is no alternative source of drinking water. Drinking water needs of human beings and that of animals should be the first charge on any available water (Arora, 2007).

2.9 Water Resources In Nigeria

The climate of an area, will dictate the direction of many weather elements which will invariably affect the water cycle of that area under study. The climate of Nigeria is controlled by the dynamics of the south western winds emanating from the Atlantic Ocean that moves from the South to the North and the North Eastly wind from North East moving down south. These two major winds are responsible for the two main seasons in Nigeria namely: rainy and dry seasons or wet and harmattan seasons respectively .The major Nigerian rivers meet at Lokoja, then move in a southerly direction into an extensive delta before discharging into the Atlantic Ocean (Akanmu et al, 2007).

Nigeria has been divided into eight hydrological areas or provinces. The total and percentage areas covered by each hydrological area is shown in Table 2.7.

Table 2.7: Hydrological Areas/Surface Water Provinces in Nigeria

Area code	Designation	No. of Principal Sub-basins	Percentage of Total Area
1.	Niger North	15	13.6
2.	Niger Central	23	16.9
3.	Upper Benue	17	16.9
4.	Lower Benue	16	8.0
5.	Niger South	12	5.9
6.	Western Littoral	16	11.1
7.	Easter littoral	17	6.5
8.	Lake Chad	21	21.1
	TOTAL	153	92.4 ha (100)

Source: Federal Ministry of Agriculture and Water Resources, 2006

The Niger River, the principal river system in Nigeria, belongs to a regime that is typical of tropical rivers which have the complex regime of the second degree and characteristic of most of the world's large river such as the Nile and the Zambezi. The torrential regime is exemplified by some of the headwaters of the Hadeija and Rima River. The flows are intermittent occurring mainly during the short rainy season. The regime characteristics discussed above are important determinants of the usefulness of the rivers for the navigation, hydro-electric power generation or any other purpose which requires a certain minimum stage or flow over a given period of time. The Chad basin area with more than 21 percent has the largest percentage total area, while the Niger South has the smallest area. The decrease in the density of the drainage network from south to north is easily noticed: it is due to the combined effect of hydro-climatic and geological factors. The river regimes also influence the cost and efficiency of developing water resources for human survival. Where the volume of flow is adequate and sufficiently stable under natural conditions, it becomes cheaper to harness the river for development, e.g., for hydropower production, without having to incur large expenses on complex regulating structure. In general, the more favorable the river regime is, the less storage capacity is needed to be provided in order to maximize available yield or runoff.

Coast of Nigeria is a belt of mangrove swamps traversed by a network of creeks and rivers and the great Niger delta. Beyond these lie successive belts of tropical rain forests (that break into a more open wood land, with hilly ranges) and the undulating plateau (with hills of granite and sandstone), rising from 609.6 metres on the average to 1,828.8 metres eastwards. Midway north of the country, the vegetation is grassland interspersed with trees and shrubs, which terminate in the Sahel Savannah region of the semi and north east. The specific yield is the discharge per unit area of the basin. The specific yield gives clear indication of the humidity or aridity of the basin in question. A basin which receives high rainfall over all or much of its area normally bestows high specific yield to rivers draining it. On the other hand, rivers draining dry or semi-arid basins have low specific yield. For example the Benue drains much more humid area than the Niger and contributes some 60 percent of the Niger-Benue system flow, even through it accounts for less than 35 percent of the basin area. The rivers carry their sediment load as bed load (5 – 6 percent), suspended and siltation solution load. The latter load is responsible for the building up of the alluvial valley and an important factor of reservoir sedimentation. The implication of excessive sediment transport include aspects of impaired water quality, basin degradation, soil loss and deterioration, valley aggravation and reservoir sedimentation (Akunmi et al, 2006).

Nigeria is situated entirely in the tropics where the climate is semi-arid in the north and humid in the south. Annual rainfall varies from over 4,000mm in the South-East to below 250mm in the extreme North-east. It is also highly seasonal with the wet season of July-September. Geographically, in the far south are low-lying swamp forests followed in a northerly direction by general flat dense rain forests, hilly shrub lands in the far north. The central part of the country is marked by crystalline rock outcropping and gently rolling hills. The average rainfalls is about 500mm/year in the north, occurring between April and September, and increasing to about 3,000mm/year in the South from March through October. Many rivers in the north are intermittent having water in them only in the rainy season but the majority of the rivers in the South are perennial, flowing all year round, and are important sources of drinking and irrigation water.

Many people take it for granted that the river basin is the natural geological unit for the planning and management of water resources. However, the river basin is not a natural political basis for planning. Policy is an outcome of potential process not hydrological processes, although it is obviously heavily influenced by them. Other systems and decisions from outside the basin tend to influence solution to water problems (Akanmu et al, 2006).

The range of function laid down for the River basin development Authorities (RBDAS) in 1976 was extraordinarily wide. They encompassed:

- Irrigation
- Watershed management
- Pollution control
- Fisheries and Navigation

Others include activities remote from water resources such as: seed multiplication, livestock breeding and food processing. Their remit also covered a number of activities to be shared by state agencies such as the provision of agricultural services and rural electrification. However, in practice these hopes were not realized. The RBDAS have tended to concentrate on large scale single purpose projects, particularly irrigation schemes. The issues here became one of competition between the RBDAS and the various state authorities. The interface was not managed properly, the roles, functions and co-coordinating mechanisms not defined clearly, and quite obviously far too much was attempted. As a result, the original goals and objectives were not attained and the erroneous notion developed that the river basin approach was a disaster (Onu, 2010).

2.10 River Basin Management In Nigeria

Before August 1993, when the Water Resources Decree 101 was enacted and promulgated, there was virtually no single agency charged with the responsibility for an integrated river management on use and conservation of water resources and river systems. The defunct Ministry of Water created in 1975 was not given the responsibility of administering the nations rivers neither was the Federal Inland Water Department which managed the inland navigation of Niger and Benue rivers. Currently in Nigeria, the following river basin development authorities (RBDAS) are in existence:

1) Anambra – Imo River Basin Development Authority
2) Benin – Owena Basin Development Authority
3) Chad River Basin Development Authority
4) Cross-River Basin Development Authority
5) Hadeijia-jama' are River Basin Development Authority
6) Lower Benue River Basin Development Authority
7) Lower Niger River Basin Development Authority
8) Niger Delta Basin Authority

9) Ogun – Osun River Basin Development Authority

10) Upper Benue River Basin Development Authority

11) Upper Niger River Basin Development Authority

12) Sokoto-Rima River Basin Development Authority

River runoff over Nigeria is definitely seasonal with the wet season occurring between July and September in general; accordingly, the dams and reservoirs are basically required to utilize the surface water throughout the year for irrigation agriculture, domestic and municipal water supply and hydropower generation. As of 1991, the number of dams as completed or under construction has reached 160 sites with a total effective storage of 30.7 x 10 cubic metres and they are shown in Table 2.8 below;

Table 2.8: No. of Dams and Reservoir Capacities in Nigeria

Zones	**North West**	**North East**	**South South**	**North Central**	**South West**	**South East**	**Total %**
Purpose							
Irrigation	10	17	12	11	11	11	71 (44)
Water Supply	9	6	18	21	21	21	83 (52)
Hydropower	1	0	2	3	0	0	6 (4)

Active Reservoir

Capacity 10^6m^3							
Irrigation	1,175	5,885	489	2,225	840	0	11,164 (36)
Water Supply	44	66	441	139	213	2	905 (4)
Hydro Power	11,500	0	7,050	49	0	0	18,589 (60)
Total	13,269	5,951	7,980	2413	1,053	2	30,668 (100)

Source: Federal Ministry of Agriculture and Water Resource Bulletin, 2006

For the hydropower, the large scale dams and reservoirs at Kainji and Jebba along the Niger and at Shiroro were constructed by PHCN (formerly NEPA) while the NASCO is operating the local mini-hydropower in the Jos Highland with the construct of nine small –scale water storages. General observation indicates that the hydropower generation as mentioned above is well-functioning in spite of the obsolescence of equipment.

The water storage dams for irrigation and water supply have been constructed throughout the country. In the Northern Region, there are many large-scale dams constructed since the onset of Sahelian drought which occupy their active reservoir capacity of $7.7x10^9$cum or 63 percent of the nations total for these objectives. The Central and South West Regions have in general many medium and small scale dams with some large scale ones, while there are only small-scale dams with the function close to diversion dams in the South East Region. It may be noted that the current water use rate of these existing reservoirs is quite low at 10 to 20 percent in general because the downstream facilities for conveyance and distribution have been in slow progress for construction mainly due to he lack of reservoir water operation rule (Akanmu et al, 2006).

The establishment of twelve River Basin Development Authorities (RBDAs) in the mid 1970's marks the beginning of the development of surface water scheme in Nigeria and also provided the leap for dry season agriculture and effective vitalization of water as one of the most natural resources for growth and development both in industries and population growth. River Basin Development Authorities were charged with the responsibility of imparting effective regional co-ordination of water resources planning and development of these resources in the delineated areas of their jurisdiction.

The effects of climate change scenario which has led to increasing environmental temperatures and lower rainfalls- this evidence has shown

that RBDAs in the country need to ensure effective new ways of implementing water resources development programmes to achieve a stable and sustaining supply of these resources in their areas of operation, as Nigeria's population of 140 million increases rapidly. Hence, the urgent need for awareness among the populace for sustainable development of water resources based on sound environmental principles. To complement this effort therefore, there is need to develop data necessary to model and forecast the potentialities of surface water resources available in Nigeria upon which a sustainable programme would be put in place to ensure continual availability of these natural resources for economic growth and advancement (Adewumi et al, 2011).

In pursuance of its role of development of water resource in her area of jurisdiction, Anambra Imo River Development Authority (AIRBDA) has impacted positively in her effort to close the gap of dearth of hydrological data. Over the years a lot of hydrological data have been gathered from hydrological gauging stations operated by the agency. The first attempt at publishing such data was made in 1984 when the authority’s first hydrological year book was published. Since then, it has not been possible to publish another year book despite the fact that collection of data from the gauging stations has been sustained on a regular basis (Nwude, 1988).

The importance of these records cannot be over-emphasized, when it is realized that without adequate hydrological data our dams, reservoirs drainage channels, irrigation systems and erosion control measures would either be ineffective, non-functional or totally collapse in a catastrophic manner. This further strengthens the relevance of generating and preserving hydrological data.

However, it was discovered that the gauging records on some of the rivers by the Anambra- Imo River Basin Authority commenced only in 1988. The gauging stations were abandoned but were later revived in 2007/2008 hydrological year.

2.11 Water Supply In Cities

Water supply schemes in major cities were started in 1911 by the colonial administration with a key role that the improved water supply could play in the elimination and control of common diseases and in the raising of health level and general welfare of people. By 1970, there were 261 (two hundred and sixty-one) urban water supply schemes including the reservoir construction and borehole sinking for state capitals. At this stage, it may be understood that inadequate water supply remains one of the major problems in urban centres. In fact, the supply of improved water can be said to be adequate in none of them (Akanmu et al, 2006).

Until recently, virtually all the states gave a relatively low priority to water in their rural development efforts, and in many areas, the rural people regard water more in terms of convenience than of health benefits. Many tube wells were sunk in the North region in the 1940's to early 1960's without active involvement of the local people. Thus, the people were not made to accept to take care of them. With the establishment of the RBDAs in 1976, a new era opened in the provision of rural water supply, and a great number of boreholes have been sunk in various parts of the country. Because of inadequate supply, technical problems and public ignorance many of the rural communities served in this way have not derived the maximum benefits (Akanmu et al, 2006).

2.12 Water As An Economic Good.

There is an emerging consensus that effective water resources management should include the management of water as an economic resource. For example, the Dublin statement of International Conference on Water and the Environment states that "Water has an economic value in all its competing uses and should be recognized as an economic good" (Long, 2002). The interaction of three critical factors – the value of water, the use of water and the opportunity cost of the resource as explored gives rise for the placement of water as an economic good (Jubril, 2011).

The emergence of water as an economic commodity made it an integral component of the Gross Domestic Product (GDP) of any community or nation. GDP refers to the market value of all commodities produced in a country or an area in a given period. GDP per capita is often considered as an indicator of a country's standard of living .

The formula for determining GDP from the expenditure perspective as stated by Kuznets (1934) is ;

$$GDP = C+I+G+(X-M) \quad \text{......} 2.2$$

where, C=Private Consumption, I= Gross investment, G=Government spending, X=Exports, M =Imports

Industrial GDP can be obtained for any area using the relation as outlined in equation 2.2. From the available records at International Monetary Fund, the nominal GDP for Nigeria in 2011 was put at two hundred and thirty eight thousand, nine hundred and twenty million dollars - 238,920 million dollars (IMF,

2011) and the GDP for the country from 1990 – 2010 was one hundred and ninety three thousand, six hundred and sixty nine million dollars- 193,669 million dollars (World Bank, 2010).

2.13 Multipurpose Water Resources Project

A multipurpose project may be defined as a project which is designed and operated to serve more than one purpose. When two or more uses of water are combined together while designing a multipurpose project, increased benefits without a proportional increase in the costs may be obtained, thus enhancing the economic justification of the project. Therefore, water resources allocation management involves optimal utilization of our water resources. It becomes absolutely necessary to make the maximum use of water resources in a unified and a co-coordinated manner and hence, the multipurpose use of water becomes imperative. Water allocation targets at apportioning water for various uses and purposes in an objective and fair manner. From the definition, it can be seen that multipurpose projects utilize the concept of water allocation for efficiency. The multiple function and their benefits are usually much more advantageous in water investment cost reduction.

2.13.1 Requirements of Various Objectives In A Multipurpose Project

The success with which the storage capacity of a reservoir can be jointly used depends upon the extent to which the various objectives are compatible with each other. In order to achieve the maximum possible harmony and compatibility between the various objectives which is required for an efficient operation, there should be an agreement between the individual requirements and purposes of the water uses. For instance, the objectives of irrigation, navigation and water supply, separately require the volume of water which cannot be jointly used by these objectives, and hence a multiple-purpose project planned for serving these objectives must provide separate storage for each of the objectives (Arora, 2007).

Water is not consumed for hydropower and hence, the water which is released from the reservoir for other objectives can be used for power generation. Low dams, required for creating pools for slack water navigations, may also be useful in power production. Hence the objectives of power production can fit well and is most compatible with other objectives of irrigation, water supply and navigation (Hividt, 1995).

2.13.2 Cost Allocations To Various Uses

Multipurpose project often serves various functions and therefore serves different groups of beneficiaries. It is therefore necessary to allocate the costs among the several groups of beneficiaries. It is therefore necessary to allocate the cost among the several uses with a view to facilitating the fixing of price of water, of power, or to determine the contribution required from flood mitigation beneficiaries. The total cost of the multipurpose project must be suitably divided among its various beneficiaries. To determine the costs or share, among the uses is not easy as there is no general satisfactory method which may be applicable to all the projects (Raghunath, 2009).

Methods of Water Costs Allocation to Various Uses

i. Separable Cost Method

Every such method of cost allocation will first set aside the separable costs, which are clearly chargeable to a single project function. For instance, the cost of construction of a power house and other ancillary works will be set aside as the separable costs of power. Also the cost construction of a fish ladder may be kept aside as the separable cost of fish and wild life. Also the cost of navigation locks can be kept under navigation. In this way, the separable costs of various function for which the project is designed are first of all worked out. The joint cost or common cost is thus computed by subtracting the cost of the separable costs from the total project cost. In dividing the joint or common cost into different functions, the following methods could be used.

ii. Remaining Benefits method

In this method the joint cost, i.e., the total project cost minus the summation of the separable costs, is assumed to be distributed in accordance with the difference between the separable cost and the estimated benefits of each function. However, the benefits are assumed not to exceed the cost of an alternate single-purpose project which would

provide equivalent benefits. These benefits limited by alternative cost are used to work out the remaining benefits by subtracting from them the separable cost. The joint cost is then distributed in proportion to the remaining benefits among the various functions

iii. Alternative Justifiable Expenditure Method

In this method, the joint costs are assumed to be distilled in accordance with the differences between the separable costs and the estimated costs of the single purpose project which would provide equivalent services and would be economically justifiable.

iv. Facilities used Methods

This method is based upon dividing the joint cost among different functions, in accordance with the ratio of the developed facilities, used by each function. For instance, the joint cost may be divided among the chief functions or in accordance with the quantity of water utilized for each function. The capacity of the reservoir used by different functions or the quantities of water utilized for different functions must however be suitably weighted by considerations of adjustments made in the pattern of releases in the interests of these functions, before using them for ratio determinations or computations. The cost so allocated to different functions can be reviewed if and when a significant change occurs in the use of the developed facilities among the functions.

2.14 Water Allocation Models

Water allocation models refer to models which estimate the quantity (and sometimes quality of water resources available for allocation to users at a particular point in space and time. The model then allocates the available resources to various users who hold some entitlement. These entitlements could be for irrigation, urban, hydropower, environment or other purpose (Wolf, 1999).

Water allocation models provide two main services:

- Insight into the likely consequences of policy changes, changes to physical infrastructure or change to natural process such as, climate, runoff processes, etc.
- Help set expectation of water users with respect to reliability or security of supply.

To meet these requirements, those models usually need to have a relatively large spatial scale covering multiple catchments, defined by a mix of institutional boundaries and physical boundaries. In general, water allocation models operate using water balance formulation combined with some sort of optimization process to govern the routing of water in space and time. Typically, the optimization is based on minimizing criteria such as losses and restrictions. There are varying degree of maturity in approaching the domains: supply, demand and allocation.

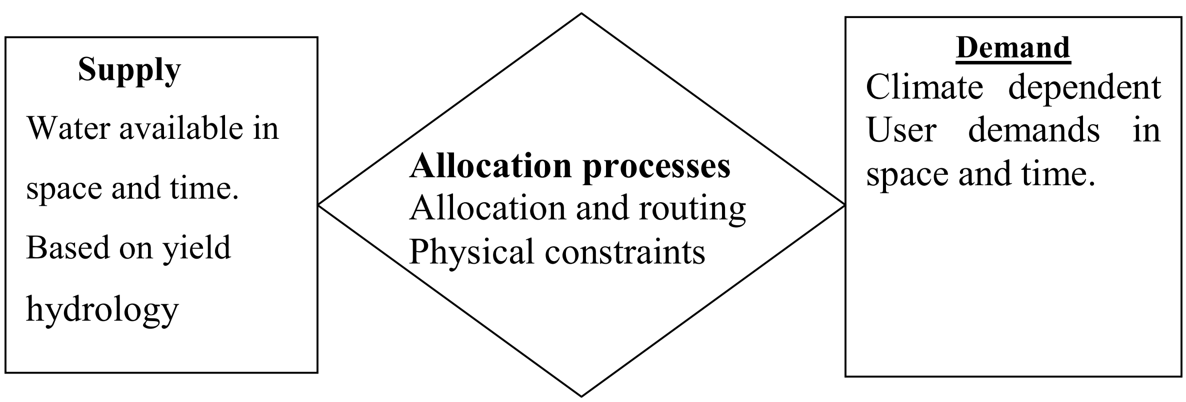

Fig. 2.1 Key domains in water allocation modeling

Source: Etchells and Malano, 2006

2.14.1 Aquarius

This is a state of art-computer model devoted to the temporal and spatial allocation of flows among competing water uses in a river basin and it uses exponential format in its operations.

In the model, water allocation throughout a river system and for an entire planning horizon is based on a global objectives which is to maximize the sum of all economic benefits emanating from the in-stream and off stream use of water, as expressed by their willingness to pay, subject to the operational constraints of the system such as reservoir storage limits. Firm water supply level, max/min in stream flows, max./min diversions, seasonality of water demands, etc. one of the unique characteristics of Aquarius is its implementation using object – oriented programming (OOP) language, where each system component (Reservoir, demand area, diversion point, etc) is conceptualized as an equivalent object in the programming environment (Diaz and Brown, in press).

Given demand function for the various water users j, the global benefits function (B) to be maximized over the various time periods is i

$$B = \sum_{i=1}^{np} \sum_{i=1}^{nu} \int_{0}^{a} f_0(X_0) dX_0) - - - - - - - - - - - - - - \quad 2.5$$

where

np	=	total number of time periods : j = water uses
nu	=	total number of water uses : i = time periods
x0	=	the level of output demand function f(x)
a	=	the level of allocation.

It should be remembered that B is maximized when aij are set such that the marginal prices are equal for all i.j. In other words, total benefits are maximized when the level of consumption is such that the marginal benefits for each use across all users and time periods are equal. The global benefits functions are specified. If unspecified, the model can still be used by adding the necessary physical constraints to the formulation.

2.14.2 General Mathematical Optimization

This model is for water resources allocation. A multiple-objective approach is used in the model to deal with the complexity of water allocation involving multiple purposes. The model is policy oriented and uses the mechanism of goal programming. User interactions with the model include selecting the model type (linear for considering water quantity only or nonlinear for including water quality also), specifying initial conditions and target for objectives, setting preferences (weights) for the objectives and setting policy control constraints. With this goal in mind the modeling system includes multiple objectives such as:

1. Satisfy existing or projected water demands primarily for irrigation to the extent possible
2. Minimize the difference in water deficits among all demand sites
3. Maximize the flow to downstream river nodes
4. Maximize hydropower generation
5. Minimize the concentration of salt in the system

6. Minimize water diverted from other basins by integrating these objectives with the system; physical, political and operational constrains into an optimization model, one can analyze the tradeoffs between the conflicting objectives and develop a number of water allocation scenarios to aid decision making, investigate the effect of uncertainties in the supply and demands and develop optimum operating rules for the principal reservoirs and surface ground water systems (Sharma, 2009).

2.14.3 The REALM Model (Resource Allocation Model)

REALM is a useful tool to address complex water allocation issues in water stressed basins and can help mangers in complex decision making. The model uses a node-link network to represent the river basin where nodes represent the physical entities such as rivers, pipeline and canals and links represent the connection between them. The nodes include:

a. Source nodes such as river, reservoirs, aquifers, etc.

b. Demand nodes include urban supply and irrigation.

The REALM modeling approach is based on integrating resources availability and use through a network allocation model. The resource allocation model (REALM) which is a well proven tool to aid water resources planning and management in both urban and rural water supply system was used to represent the system network. REALM has been developed in close collaboration with a diverse range of users in the water industry (James, 1996). REALM is a network allocation model based on combination of water balance combined with a linear optimization algorithm that enables the use-defined penalties to impose constraints and preferential resource use. This model's capability is particularly useful to generate a large number of alternative policy scenarios reflecting legal physical and other constraints as well as uses of the resource.

REALM applications generally involve the following steps:

i. Defining the problem and developing system components and simulation.
ii. Simulating current scenario which includes actual water demand resources available and supply.
iii. Building new scenario based on future population trends climatic change, cropping pattern, etc.
iv. Evaluating the economic and environmental impact of future scenarios.

REALM consists of three major components namely input processing, simulation and output.

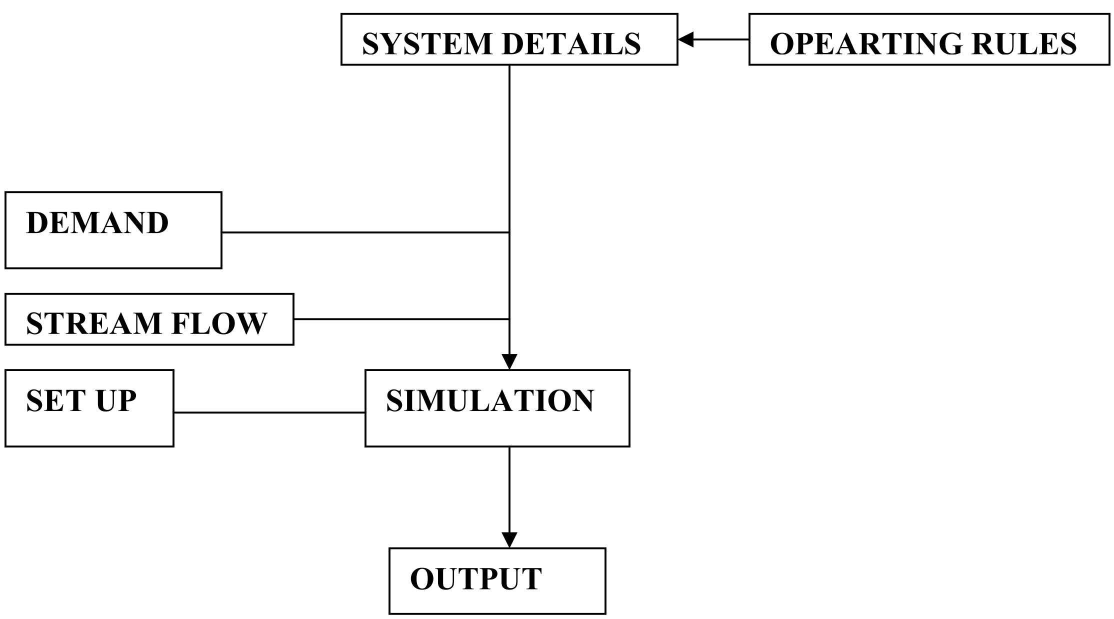

Fig. 2.2: REALM model set up steps.

Source: Taha, 2007

The REALM model requires three input files namely steam flow, demand and system files. The stream flow file contains the stream flow and climate data (evaporation, rainfall, etc). The demand file contains the demand for each node in the system. The system file contains the information on the node and carries long-term operating rules controlling inter-related reservoir transfers and demand restrictions. Simulation involves two basis steps: the first step defined the runtime parameters like start and end date, input files reservoir levels and desired level of details of model output. The second step combines the information specified in the model set up with input files and performs the simulation. The REALM output file includes reservoir end storage, unrestricted and restricted demand, spillage, shortfall carries flows, etc. as output variables (Nilson, et al 2007).

2.14.4 Multicommodity Flow Model

Water from different sources with different qualities is considered as district commodities which concurrently share a single water distribution system. The multi-commodity flow model is for regional water distribution system often represented as a network consisting of nodes and arcs. In general, inflow sources, water demand reservoirs and hydraulic diversion structures are represented by nodes. Rivers, canals and pipes are represented by arcs. When flow directions in the arcs are known before hand, a directed network can be used to characterize such a system. Diba (1995) used a directed graph algorithm as a preprocessor to produce a network representation of a large scale water distribution system and created an input file for linear programming.

A commercially available optimization solver, LINGO (2001) is used as the basic nonlinear solver for the multi-commodity flow model. LINGO is capable of solving linear, nonlinear; and interrelated programming problems. LINGO implements the generalized reduced gradient (GRG) algorithm, which is a gradient-based algorithm that is frequently used to solve large scale nonlinear problems. In general, a global optimization algorithm can effectively reach a near global solution which then slowly converge to the global optimum. It has been combined with local optimization for solving nonlinear and non-convex problem (WHO,2010).

2.14.5 Goulbourn Simulation Model (GSM)

Goulbourn Simulation Model is a calibrated version of REALM and covers and focuses primarily on regulated surface water allocated in space and time but uses very different conceptual approaches. GSM operates on monthly time-step at an irrigation district level. This system has six major parameter types; infrastructure, including storages, the river and channels network, weirs and demand centers, operating rules such as storage reserve policies, minimum release requirements, etc.

GSM allocates water based in demand determined from a separate model called PRIDE (programme for Regional Irrigation Demand Estimation). Studies show that PRIDE also has significant issues of robustness. Allocation processes within GSM rely on resource allocation curve that dictate the allocation that can be announced when a particular volume of water is available. It uses inflows and monthly demand as its two main forcing functions, which are coupled with the parameters, to drive six major processes. The results of GSM rely on particular operating rules assumptions regarding the level of development which influences the volume of demand (Wolf, 1999).

2.14.6 Murray Simulation Model (MSM)

MSM is designed to address similar objectives like GSM: to model the demands storage behaviour, system operation and flows in the basin (Close, 2002). It operates using a monthly time step and provides delivery information. It does not separate districts, only diversions from the rivers. Also, MSM does not input demand as a forcing function, rather uses regression equations based on historical data. In particular, the regression equations are based on parameters including rainfall, temperature, declared allocations, last month's rainfall, temperature and trend over time.

Given the dependence on historical data in determining future usage, MSM suffers from similar shortcoming like GSM in potentially under-estimating future usage. Close (2003) noted that there is no guarantee that the historical relationship between declared percentage allocation and water use will not be exceeded, especially if more irrigators take advantage of temporary trading.

2.14.7 Mathematical Equations Of A Model

The model consists of two sets of equation which maintain equilibrium, always keeping a balance between water supply and demand. According to Wang et al (2004), the equation of equilibrium is stated as:

The model consists of two sets of equation which maintains equilibrium, always keeping a balance between water supply and demand. According to F. Wang et al (2004) the equation of water equilibrium is stated as:

$$Q = \sum iK \left(\underset{1}{\overset{K}{Q_o}} + \underset{i}{\overset{K}{W}} \right) = \sum_{i\ \ i} wLx_i N + iwe \text{ x } iA + iwp \text{ } xi \text{ } GDP = D \text{......} 2.4$$

The superscript K denoted the types of water use.

Q = total water supply, I = community life, e = ecology, p = economic production.

The sub-area i, ∑iw=w.

$^K W$ = volume of river water used by requirement K and allocated to water storage sub area i.

iQ_o = Local water resources in sub area i

$iQ_{k\,o}$ = Local water resources used by requirement K in sub area i.

iQ = Total water used by requirement K in sub-area i. and total water supply is

$$s = \sum_{ik} (\underset{1}{\overset{K}{Q}}) = \sum ik (\underset{1}{\overset{K}{Q_o}} + W) \text{..} 2.5$$

On the demand side,

iwl = water quota per capita for community use per year in sub-area i (m^3/person/year).

iwe = water quota for ecological use per year in sub-area i (mm/year)

iwp = water quota for economic production per year in sub-area i (tonne/10,000)

iN, iA, iGDP = population, territorial area and GDP of sub-area i.

Then,

Domestic water demand in sub-area i is: $DL = iwlx\ iN$

Ecological water demand in sub-area i is: $iDE = iwe \times iA$

Economic water demand in sub-area i is: $iDP = iwpx\ iGDP$

Total water demand is also stated in accordance to Wang et al (2004), as

$$D = \sum_{I} ({}_{i}DL + {}_{i}De + {}_{i}Dp) = \sum_{I} ({}_{i}wL \times {}_{i}N + {}_{i}we \times {}_{i}A + {}_{i}wpx \times {}_{i}GDP$$

This can be represented in a relationship described by a water allocation balancing and decision system.

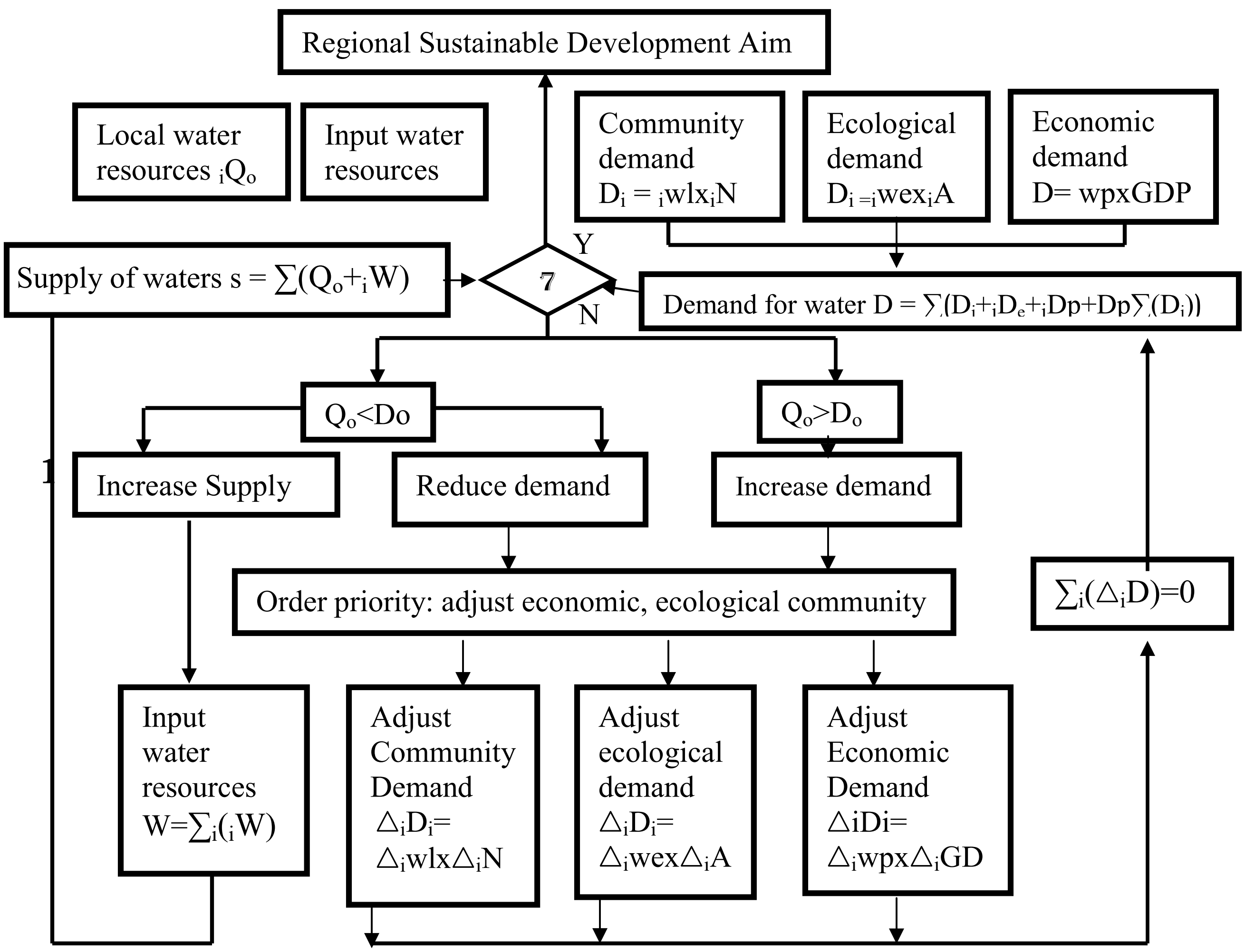

Fig. 2.3 Water Allocation Balance and Decision System

Source: **Etchells, 2006**

2.15 LINEAR PROGRAMMING (LP) MODEL

Linear programming is a general model for optimum allocation of scarce limited resources to competing products or activities. Under such assumption as certainty, linearity, fixed technology and constraint profit or cost per unit (Ewurum, 1995). It is a method of determining an optimal programme of interdependent activities in view of time. The term linear implies proportionality and additivity. The term program refers to a maximization or minimization of some measure or criteria of effectiveness such as profit, cost or output. The word programming refers to a systematic procedure by which a particular programme or plan of action is designed: programming consists of a series instructions and computational rules for solving a problem that can be executed manually or can be fed into a computer. The term activity refers to any services, project or product that are competing among themselves for limited resources (Ewurum, 1995). A specific amount of production of a product measures its activity level (Dantzig, 2007).

2.15.1 General Structure of a Linear Programming Problem

In order to develop and apply specific operations research techniques that can be used to determine the optimal choice, among other several courses of action, including the evaluation of specific numerical values (if required), there is need to construct (or formulate) a mathematical model. The term formulation refers to the process of converting the verbal descriptions and numerical data into mathematical expressions, which represent the relationships among relevant decision variables (or factors), objective and restrictions (constraints), on the use of resources such as labour, material, machine, time, warehouse space, capital, energy, etc., to several competing activities, such as products, services, jobs, new equipment, projects, etc., on the basis of a given criterion of optimality. The phrase scarce resources refer to resources that are not available in infinite quantity. The criterion of optimality, is generally either performance, return on investment, profit, utility, time, distance and the like. The usefulness of this linear programming model is enhanced by the availability of user-friendly computer software such as STORM, TORA, QSB, LINDO, etc. However, there is no computer software for building an LP model. Model building is an art that improves through experience and practice (Sharma, 2009). In any linear programming problem, a measurable objective or criterion of effectiveness must be identified (Orga, 2006). This type of objectives can usually be quantified and become the objective function of the problem. Assumption of linearity implies that it is a linear objective function. The objective function is nothing more than a mathematical expression that describes the manner in which profit accumulates as a function or the loss reduces as a function of the number of different services or products produced. The maximization or minimization of any linear function does not make sense without imposing some sort of additional constraints. The technical specifications of a linear programming problem and how they relate to fixed resource capacities are expressed by a set of structural constraints. The assumption of linearity implies that such a set is linear. Since any production programming must be such that it cannot demand resources in excess of the given capacities, the linear structural constraints for linear programming problems, must be expressed as inequalities or the "less than or equal to" or "greater than or equal to" type.

2.15.2 Solving Linear Programming Problems

Among the methods of solving linear programming problems, include the graphical approach and the simplex method among others.

i The Graphical Approach

The graphical approach is limited to those cases in which either the number of rows or the number of columns is two or less. Hence the graphical method cannot be used for models that have three or more variables. Although the graphical method is valuable it is not useful for general application due to its limitation and incapacitation in solving LP model equations with more than two variables. In the method, the constraints are used to plot graphs to determine the feasible region and its points of optimality.

ii The Simplex method

The simplex method utilizes matrix algebra to arrive at optimal solution. The simplex method is a general approach often applied in LP problems. Most LP problems which are formulated have more than two variables and they are difficult to be interpreted with the use of the graphical solution method. The simplex method can be used to solve any LP equations no matter the number of variables and constraints involved. However, it is observed that as number of variables and constraints increase, the time of attaining an optimal solution increases. In the simplex method, the LP equations are put into tableau through the introduction of slack and artificial variables. Further mathematical operations, result in the determination of key rows and columns and the pivot numbers.

In this approach, the model is put into the form of a table and then a number of mathematical steps are followed in developing subsequent tables. The mathematical steps are actually movements from one extreme point on the solution to another. While in the graphical method, we search through all the solution points to find the best one, the simplex method moves from one better solution to another until the best one is found (Williams, 1985).

Taylor (1986) outlined the following steps of solving LP problems as captured in Fig. 2.4

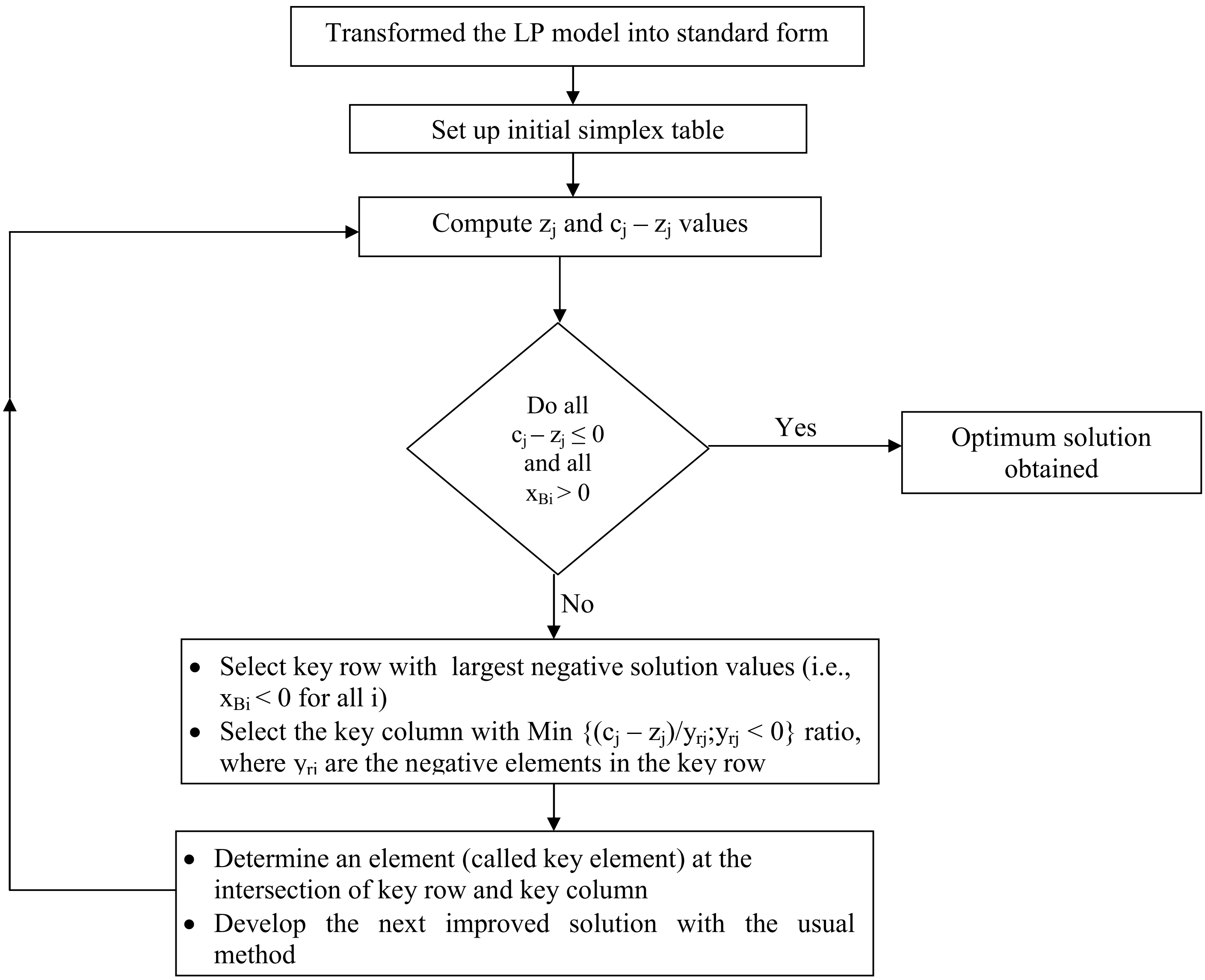

Fig 2.4: Flow chart for The Solution of LP Problem

2.16 Water Resources Management

It is certain that water mismanaged during the periods of water scarcity and even at the time of water sufficiency could be fatal and life-threatening. This single statement underscores the indispensability of water management in attaining sustainable water supply system. Furthermore, there is no aspect of environment that does not relate to water in one way or another. Such environmental issues like land, air, climate, etc are related to water and their interrelatedness exposes the dynamics and complex interconnections of water with the entire environment. It is obvious that as water becomes scarce, the competition for its various uses increases and the imminence of improved water management becomes glaring. The world's craze for industrial, technological and recreational increasing demand and even the domestic and crop production needs make the proper understanding of water critical and inevitable, This issue of thorough understanding of available water and the competing needs remains a challenge to engineers and others who must guarantee that future generations will be served with adequate water supply and equally ensure high level of environmental sanitation (Wolf, 1999).

It is quite clear as it is obvious that the world water sector is facing serious and multiple challenges in providing services to its citizens. The great problem and challenge persuaded the United Nations to evolve and develop a programme called the Millennium Development Goals with water and sanitation as a critical component. Cognizant of some of the situations that created the water problems, it is pertinent to observe that it will be difficult to overcome the challenges at the same level of reasoning that created them. This calls for the entrenchment of sound water management which has been lacking seriously in the scheme of things. Planning should commence on how to resolve these challenges particularly in most Nigerian States which should include the understanding of nature, scope and origin of the issues blocking the emergence and applications of good practices in modern water management. This will go a long way to sustain the hung investments made in the water sector which will directly and indirectly culminate in sustainable water availability to the citizens. In recognition of the importance of water management, the water and sanitation reform policy has called for more emphasis on better planning and ensuring quality and sustainability of services. The policy observed that management is a priority area where most work needs to be done to improve the functional integrities of the water system. There is an urgent need to improve the functional capacities of water agencies so that they can fastly attain financial self-sufficiency. Water management requires water resources database since the absence of data makes the determination of water balance for a river basin impossible. The prevailing ugly situation of dearth of hydrological and hydrogeological data makes modeling which is an indispensable instrument of engineering between extraction, storage and usage of water based on the qualities and flows available- this stands out as the dream of ensuring sustainable water supply availability (Onu, 2010).

The absence of water management has led to catastrophic situation in the country's water sector characterized by breakdown of existing facilities, unaccounted for losses, poor pressures, scarcity, poor funding, etc. and their associated unpleasant consequences. The recent report in 2008 when the WHO/UNICEF joint monitoring programme (JMP) estimated that about a third of the population of Nigeria have access to improved sanitation with 20% practicing open defecation did not come to us as a surprise. Without sustainable water supply there cannot be improved 100% sanitation attainment (Paul, 2011).

2.16.1 Water Management Approaches.

Achievement of a sustainable water supply in Nigeria is hinged on the application of the modern water management techniques based on reigning tools of instrumentation, planning, forecasting and policy implementation to enhance an effective water allocation. The sustainability of water supply in this country calls for total overhauling and financing of water supply components which must include investment in production and distributions infrastructure, institutional re-engineering and organizational development and institutional and human capacity building.

A crucial point in water resources management is the determination of the amount of water that can be effectively allocated to various uses. If a technical approach is used, small amounts are going to be adopted as reference. On the other hand, the use of political approach will create most probably a trend of increasing the volume of water to be granted which will automatically decrease the reliability. Technically, mathematical optimization model is employed in management of water resources to allocate water by using the multi-objective approach to cater for the complexity of water allocation involving multiple purposes.

There are three approaches under which water resources management can be typically considered namely supply management, demand management and integrated management. Supply management involves those activities required to locate, develop and exploit new sources of water. In Nigeria, water management has concentrated on the supply approach. This approach involves the construction of dams, reservoirs, treatment plants and other hydraulic structures associated with water supply.

Demand management addresses mechanisms to promote more desirable levels and patterns of water uses. Demand management borders on the water requirements of various uses and approaches to streamline them. Demand management is increasingly becoming a topical issue for residential water supply authorities throughout the world. Population growth coupled with the dwindling available water supplies have forced operators to place more emphasis on demand management through pricing structures and other strategies. In Nigeria, water sources are under pressure of depletion and this is tending towards exhaustion while population and per capita water use is increasing due to technological development, urbanization and lack of population control measures. It is therefore expected that more capital investment and price adjustment strategies should be employed to help promote more sustainable use of available water. Water utility is not economically treated because water is over consumed and the price does not reflect its importance. Water demand has a lot to do with water pricing which must be designed to meet the needs of current and future generations with the view of achieving resources use efficiency, full cost recovery, the economic viability of the water utility, equity, and fairness for different user. There should be longstanding efforts to improve residential water demand and wider concerns should be geared towards industrial and agricultural demands in terms of pricing to attain a more general water supply sustainability. Water demand management strategy has received accolades as a reliable urban water consumption management tool which has stimulated interest among water utility managers and policy makers. However, in as much as water pricing has been recognized as an important component of demand management, it has been suggested that non-price strategies such as public education campaigns, rationing, water use restrictions, etc should be emphasized in most cases.

Integrated water management is a holistic approach to water management where the supply and demand approaches are married to achieve sustainable results. The integrated water management brings about a balance between the supply and demand requirements with a view of attaining a realistic model, it is increasingly understood that the integrated management approach is required not only to balance supply and demand but to unlock paths to sustainable development. Water productivity, yields and the welfare of the citizens can be improved through integrated water management. This approach is seen as one that ensures sufficient water during the periods of drought and optimal water use allocation during rainfall or wet periods.

CHAPTER THREE

METHODOLOGY

3.1 Area of Study

The areas of study are within the Anambra Imo River Basin area of jurisdiction and the rivers of study include Njaba, Mmam, Otamiri and Aboine. The host communities consist of Egbu, Nekede, Ihiagwa, Eziobodo, Mgbirichi and Umuagwo for Otamiri River while Amucha, Okwudor, Umuaka, Awo omama & Nkwesi were used for Njaba River. Inyi, Awlaw, Akpugoeze and Ufuma communities are hosting Mmam river while Obolloafor, Ikem, Eha Amufu and Nkalaha communities are hosting Aboine river. These areas are sub-basin areas within the Anambra Imo River Basin.

3.1.1 Geographical Map of the Study Area

The digital geographical map of the Anambra-Imo river basin was contrived. The map shows the entire basin with particular reference to selected rivers and the sample areas of study. The map is shown in Fig. 3.1

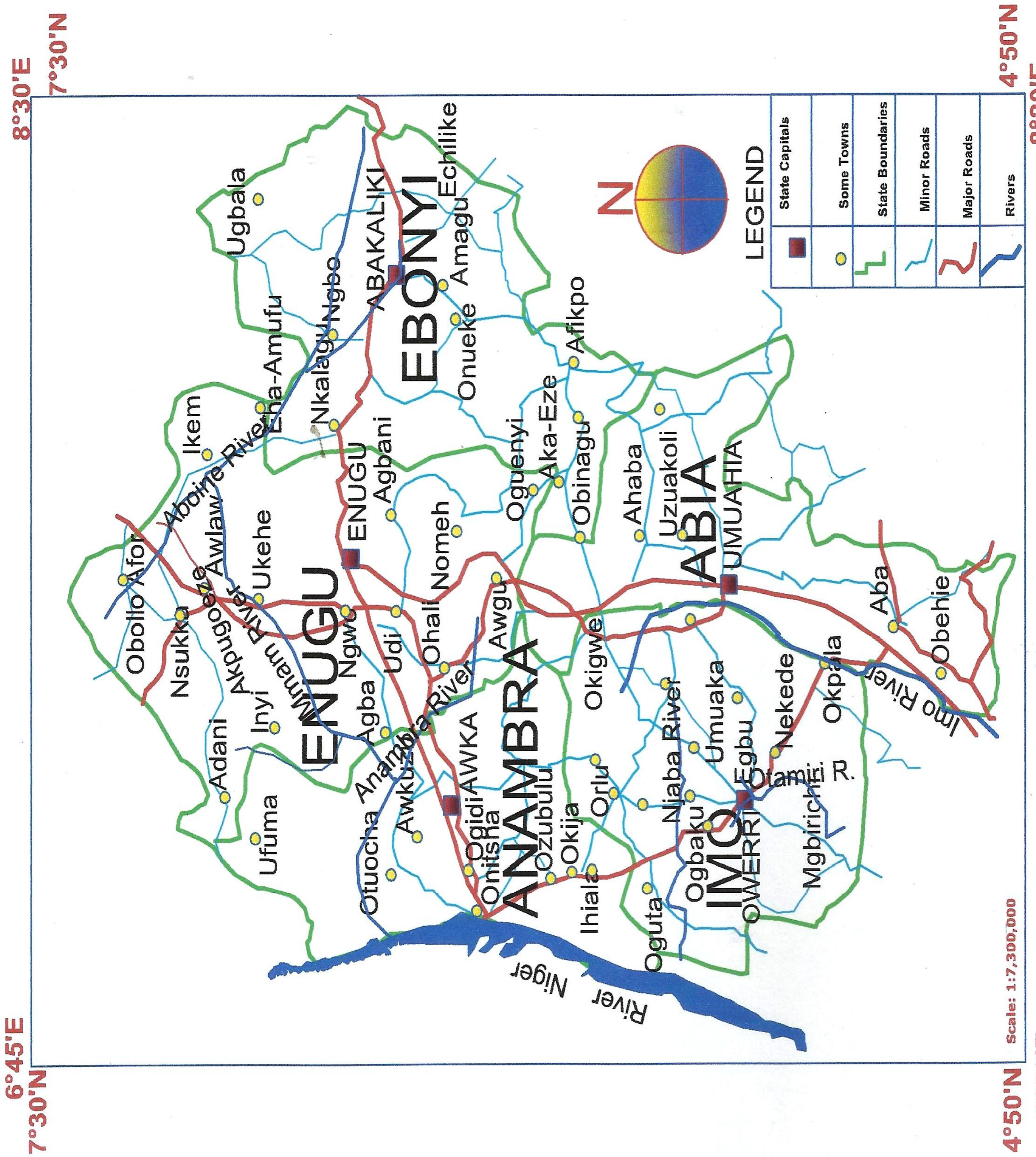

Fig. 3.1: Map of the Study Area Showing the Selected Rivers

From the Figure 3.1, it can be observed that the selected rivers have a high degree of geographical spread of the entire basin. Such data as areas of communities were obtained from local maps while others came from interviews volunteered by the elites of such communities

3.1.2 Study Area Description

The Study Area I (Njaba River Basin)

Njaba river is a notable river in the Anambra – Imo River Basin Development Authority's area of jurisdiction. It is located in the mainstream of Njaba Local Government area and extends to Isu, Oru East and Oguta local Government areas of Imo state. The river flows towards the Southern part of the Njaba Local Government area and later diverts western ward. The river originated from Amucha Community and transverses through Okwudor and Umuaka communities and emerges at Awo- Omama and flows through Nkwesi until it empties into Oguta Lake. The river is perennial and it is used as a source for the community water use. The river bed sediments consists of fine to medium to coarse aggregates and as a result the excavation of coarse aggregates takes place along the river bed.

The river has high turbidity level and this is manifested in its characteristic brown colour. Towards the upstream side, the river is subjected to high profile erosion of its bank. This condition is threatening the forest ecology of the river. At the moment the situation is being controlled through the introduction and establishment of cashew plantation. This development has impacted positively on the economic life of the host communities and it has provided employments for a good number of their citizens. The river is housing and boosting a lot of economic activities ranging from fishery to riverside all–the-year cropping syndrome.

Due to the prevailing climatic changes, these have been a reported reduction in the flow of the river. The river also serves as a recreation sport for swimmers and divers. During the rainy season, the river level is relatively high, those interviewed attested to high preponderance of catfish in some sections of the river. Njaba river transverses through communities of diverse orientations and backgrounds, with high communal ambitions and goals. Due to demand for water rights, conflicts usually arise and if not checked and brought under control the situation might escalate into a breach of peace thereby undermining economic development and inter-communal co-existence and harmony.

Study Area II (Mmam River)

Mmam river basin is in Anambra–Imo River Basin Development Authority area of coverage. It is located in the border between Enugu State and Anambra State bordering such communities as Awlaw town, Inyi town and Akpugoeze town all in Oji River Local Government Area of Enugu State and Ufuma town in Orumba North Local Government Area of Anambra State. The river flows along the southern boundaries of Awlaw, Inyi, and Akpugoeze towns and empties its water into Ezu River in Ugwuoba town. The basin located in the middle reaches of the river is a commodity grain production base with developed irrigation farming. The well known Mmam forest reserve stretches along the river banks as well as sand excavators sites. The Mmam forest reserves are the prominent agricultural industries in the area including the exploitation of timber and palm products. Other privately owned cottage industries and enterprises stimulate and promote economic activities in the area. Climatic changes and excessive extraction over the years have caused surface runoff to decrease sharply in the river's lower reaches which has resulted in the loss of large area of wetland vegetation and decreased economic activities.

The Mmam basin comprises four communities or sub-areas namely Awlaw, Inyi, Akpugoeze, and Ufuma. The Mmam River is the major water source for the communities apart from minor streams and scattered pipe borne water schemes in Inyi. The Mmam river basin waterfalls and natural swimming pools in the Akpugoeze sector, provides exciting tourist attractions. Each of the communities is in a state of critical water balance, conflicts over water rights and use between the communities or subareas are becoming more much severe and if unchecked could impede sustainable development and endanger peace in the area and perhaps between the two states of Enugu and Anambra States in particular and between people, communities and regions in general.

The Study Area III (Otamiri River)

Otamiri River basin is a sub-area in the Anambra Imo River Basin Development Authority area of coverage. It is located in the border Owerri North and transcends through Owerri West and Ohaji Egbema Local Government Areas in Imo State. The river flows across the some major communities in Owerri North, Owerri West and Ohaji Egbema Local Government Areas. It is a peremial river that stands as an economic feature within the local government areas through which it transverses. The river flows along the western boundaries of the Owerri municipal and serves such communities as Egbu, Nekede, Ihiagwa, Obinze, Mgbirichi and Umuagwo. Otamiri River started from Egbu Community and empties into Okorcha River at Etche town Rivers State of Nigeria. The sub-basin located in the adjoining areas of the river consists of crop farmers with a less developed irrigation farming system. The forest ecology of the river stretches along the bank on its both sides and serves as sand dump sites. The lands adjacent to the river are utilized for all- year- round crop cultivation. The forest ecology of the river has a high timber potential which positions it for timber and palm product exploitation. As a flowing river, Otamiri provides employment for local and industrialized sand excavators. The river has attracted companies with high dredging equipments which they used for sand excavation from the river bed. There are some fishery outlets at the various community reaches of the river. The river is a major source of water supply to industries and the host communities for washing, cooking and other domestic purposes. The river has been promoting and stimulating economic activities in the communities. Climatic changes and excessive abstractions over the years have caused surface runoff to decrease sharply in the river. The wetland vegetation is gradually reducing due to the unchecked interference into the watershed through timber felling and incessant/unplanned farming activities. This leads to the destruction of the watershed, thereby exposing the river to much abstraction through evaporation of the river body. The river is a major source of water for the communities apart from the private ground water boreholes and moribund city pipe-borne water located in some of the communities.

Each of the communities is in a state of critical water balance, conflicts over the water right and use between the communities are raising up its ugly head and if unchecked could impede future sustainable development and endanger peace in the areas and perhaps between the local Government areas in particular and between the people in general. At the upstream reach, very close to its source, the river houses the water treatment plant for Owerri metropolis. At the Egbu section a weir is constructed and used for the diversion of water to the intake works of the treatment plant. At Umuagwo area, the river boosted economic activities through the establishment of the Graduate farm where youths, corpers and other graduates are largely employed for meaningful agricultural activities. Otamiri River which is part of the Imo River system hosts a major irrigation scheme in River State. Abstractions, catchments degradation or pollution activities on this River within Imo state will surely affect the sustainability of this Irrigation scheme in River state.

Study Area IV (Aboine River Basin)

The Aboine river basin is also in the Anambra-Imo River Basin development Authority area of jurisdiction. It is located in the border between Benue State in the North and Ebonyi State in the South with Enugu in the center. The river flows along the Northern East boundaries of Obollo-Afor traversing Ikem town before emerging at Eha-amufu town and emerging itself into the Nkalaha River in Nkalaha, Ebonyi State. The river is perennial and suitable as a source for the community water use. The river bed sediment consists of medium to coarse sand and as such, excavation of aggregates takes place along the river bed.

Little information found on the flow level indicated that the river has a dry season flow that can stand a major water scheme. It is therefore considered acceptable for a rural water system. Due to climate changes and excessive abstraction by means of river banks or riverbed filtration, there have been reductions in river flow especially to town and communities at the lower reach of the river. The river also serves as a recreation spot for swimmers and divers as the case may be. Along the coastlines are crude furrow for broad irrigated farmlands. During raining season, the river level is very high, those interviewed attested to the presence of high number catfish in some sections of the river channel.

Aboine river basin comprises four communities of Obollo-afor, Ikem, Eha-amufu and Nkalaha towns. Due to demand for water rights, conflicts usually arise and if unchecked could deteriorate and endanger economic activities and development in the affected areas.

3.2 Instrument of Data Collection.

The questionnaire was divided into three sections A, B, and C. The section A contained items designed to obtain personal information of respondents. The items have options and blank spaces to enable the respondents tick as appropriate. Section B was designed for residents while Section C was for industries and Section D is for health institutions. The Section B was structured to obtain information of whether the respondent uses river as the main source of water supply or the borehole. When the source of water supply was established, it enabled us to gather data on the quantity of the water used. Section C was meant for industries and it was targeted to know the quantity of water used for industrial purposes. With these, the water quota and industrial water quota were obtained respectively.

3.2.1 Population of Study

The population for the study was taken as 5% of the entire population which considered as sample population. The respondents were residents in the host communities and the administration of the questionnaires was skewed to cover the representative geographical spread of the individual communities. The typical populations of the entire host communities were also employed.

3.2.2 Sample and Sampling Technique

A convenient sample of five percent of the entire population for each community was used to serve as respondents and from the data the degree of water usage for consumption and domestic were obtained. The industries in the individual communities were used to establish the water quota. The health institutions were used to obtain data on the extent of prevalence of water-related diseases.

3.2.3 Sample Population

The sample population was obtained as five percent of the communal populations in the representative sub river basins. Efforts were made to ensure that the sample population is a true representative of the target population through good geographical spread of the sample areas (Eboh, 2009). The researcher administered copies of the questionnaires to the sample population in the individual communities through the research assistants. The researcher was also assisted to make the observation of water withdrawals from the rivers at the strategic points through the help of research assistants. The research assistants were trained by the researcher to enable them estimate the volumetric measures of commonly used water containers.

3.2.4 Survey Research Method

The survey research method was used for the study. This method is suitable for the study because it enabled the researcher to obtain information from people, who are considered to be representative of the entire population (Nworgu, 2006). Iwuama, Ogbebor and Onwuegbu (2010) stated that survey research method uses questionnaire or interviews to collect data from a sample that has been selected to represent a population and the area to which the finding of the data analysis can be generalized. Observation method was also used to establish some critical parameters necessary in the allocation of water resources. At the major points of the rivers, in the various host communities research assistants were stationed to collect the estimate of volume of water used by the residents on daily basis spanning for domestic uses over a period of four years. The volume of water drawn by tanker drivers for the purposes of industrial and domestic uses were also obtained by the research assistants. Documentations on relevant information and data wee obtained from existing literature and statutory bodies. Information was also gathered on industries in the area to obtain the industrial Gross Domestic Product of the study areas. The health institutions volunteered information on the number of patients suffering from water causing diseases and the possible cost of treatment.

3.3 Selection of Sub-River Basins:

The sub-river basins used for the research were selected based on spread and the suitability of their resident rivers as dry-weather flow rivers. Ephemeral streams which characteristically dry up completely in rainless periods cannot be used for conventional hydropower. Notable rivers in Anambra- Imo River basin include Ezeaku, Otamiri, Oramiriukwa, Eme, Law-Law, Nnom Njaba, Adada, Ajali, Ivo, Iyinwoba, Urasi, Mamm, Eme, Ebonyi, Igwu, Idemili, Okija, Okwakpu, Kalawa, Iyindelle, Odah, Ezu, Aboine, etc. These rivers and many others not mentioned are within the basin of Anambra-Imo River system. The rivers chosen for the work include Njaba, Mamm, Otamiri and Aboine.

The rivers used for the research were selected based on simple random sampling due to their coverage and the coherence of their communities as typical areas within the Anambra-Imo river basin. The simple random sampling technique is suitable when population is homogenous with respect to the characteristic interests (Dennis, 1974). The position of these rivers which have considerable ground water contribution resulting in high volume of flow in dry season period and higher volume of flow in wet season due to the runoff contributions from the catchment areas makes them very suitable for this research. With this flow pattern, sustainable allocation of water can be achieved for the various sectoral needs of the areas. The rivers selected cut across four out of the five states that constitute Anambra-Imo River Basin and this establishes their representativeness of the entire Anambra-Imo River basin.

3.4 Derivation of Equations Used For The Study Areas

The proposed model distributes water fairly among different localities or sub-areas following the principle of optimality in the order of community, ecological, industrial and energy uses. The water lost due to leakages, theft and poor worksmanship is minimized in the model. Optimality in this context refers to the inevitable water that can be realistically expected to be available in areas of water scarcity. Economic demands are met according to the marginal revenue for water in each sub-area

The above optimization problem is given mathematically as:

The objective function:

$$Min\ Z = \sum_{j=1}^{n} C_i X_j ----------------3.0$$

Initial Model Equations

$$\sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} X_{ij}$$

Subject to the constraints:

$$\sum a_{ij} X_{ij} \leq b ----------------3.1$$

where C_{ij} and a_{ij} are coefficients

X_i represents that quantity of variable i that produces the optimum value for the criterion

b = limitation

i = the sectoral allocations while

j = the sub – areas

The above may be written out in full to facilitate understanding. The full substitutions of the coefficients from the data collected from the areas are attached.

The mathematical model for the Study Area I (Njaba River) can be stated thus;

Objective Function

$$Min\ Z = \sum_{j-1}^{5} C_i X_j -----------------------3.2$$

Initial model equations

$$Min\ Z = \sum_{j=1}^{5} \sum_{j=1}^{7} C_i X_j -----------------------3.3$$

Subject to the constraints

$$\sum_{j-1}^{5} X_{1j} = 36942$$

$$\sum_{j-1}^{5} X_{2j} = 192$$

$$\sum_{j-1}^{5} X_{3j} = 140$$

$$\sum_{j-1}^{5} X_{4j} = 44$$

$$\sum_{j-1}^{5} X_{5j} = 55 ------------------3.4$$

Under the Non-negativity conditions

X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}, X_{21}, X_{22}, X_{23}, X_{24}, X_{25}, X_{37}, X_{41}, X_{42}, X_{43}, X_{44}, X_{45}, X_{47}, X_{51}, X_{52}, X_{53}, X_{54}, X_{55}, X_{56}, X_{57} ≥ 0 ---------------------**3.5**

Similarly, for Study Area II (Mmam River) basin parameters, the coefficients from the collected data from the basin when substituted in the mathematical model result to:

Objective Function:

$$Min\ Z = \sum_{j=1}^{4} C_i X_j ---------------3.6$$

Initial Model Equations

$$Min\ Z = \sum_{i=1}^{5}\sum_{j=1}^{4} C_{ij}X_{ij} ------------- 3.7$$

Subject to the constraints

$$\sum_{j=1}^{4} X_{1j} \leq 211{,}26$$

$$\sum_{j=1}^{4} X_{2j} \leq 272$$

$$\sum_{j=1}^{4} X_{3j} \leq 120$$

$$\sum_{j=1}^{4} X_{4j} \leq 39$$

$$\sum_{j=1}^{4} X_{5j} \leq 28 --------------- 3.8$$

In like manner, the Study Area III (Otamiri River) area will have such model equations as:

Objective Function

$$Min\ Z = \sum_{j=1}^{7} C_i X_j -------------- \quad 3.9$$

Initial Model Equations

$$Min = \sum_{i=5}^{5} \sum_{j=1}^{7} C_{ij} X_{ij} ---------- \quad 3.10$$

Subject to the constraints

$$\sum_{j=i}^{7} X_{1j} \leq 97688$$

$$\sum_{j=i}^{7} X_{2j} \leq 155$$

$$\sum_{j=i}^{7} X_{3j} \leq 220$$

$$\sum_{j=i}^{7} X_{4j} \leq 60$$

$$\sum_{j=i}^{7} X_{5j} \leq 51 ----------------- \quad 3.11$$

Also the model for the Study Area IV (Aboine river) basin will be:

Objective function:

$$Min\ Z = \sum_{j-i}^{4} C_i X_j \text{ --------------- } 3.12$$

Initial Model Equation

$$Min\ Z = \sum_{i=1}^{5}\sum_{j=1}^{4} C_{ij} X_{ij} \text{ -------------- } 3.13$$

Subject to the constraints

$$\sum_{j=1}^{4} X_{1j} \leq 189511$$

$$\sum_{j=1}^{4} X_{2j} \leq 104$$

$$\sum_{j=1}^{4} X_{3j} \leq 140$$

$$\sum_{j=1}^{4} X_{4j} \leq 65$$

$$S\sum_{j=1}^{4} X_{5j} \leq 31 \text{ ------------------ } 3.14$$

The non-negativity expressions in equation 3.3 remain valid in respect of River basin activities of Mmam, Otamiri and Aboine rivers.

3.5 Solution of the Model Equations

The problem has been identified to be linear programming problem. The mixed linear programming model is proposed. This involves determining the optimum solution using the Tora Optimization System software Windows version 2.00 of Oct. 2009. Optimal allocations for the usage areas in the different sub-areas are proposed and determined. Finally, results were compared with existing results and recommendations made.

3.5.1 Sensitivity Analysis

Post-optimality analysis was performed investigating the sensitivity varying scenarios in the input data. The input variables of population, gross domestic product, land area, power generation capacity and the losses were varied to the tune -5%, -2.5%, 0%, 2.5% and 5% and the optimal results arising from them were observed. A graph of variable input change and the optimal values were plotted.

3.6 Estimation of Quantity of Available Water For Allocation

In this research work, the rivers used were gauged to establish the discharges for the various months. The discharges determined were used to draw hydrographs for the various rivers. As required in river gauging, gauging stations were established at reaches of the river with easy accessibility and stable cross section. The data generated were used to determine the quantity of groundwater and runoff within the basins

The research assistants were used to monitor the stations and take the necessary readings. The gauging data were obtained from Anambra - Imo River Development Authority except the Aboine river which was gauged by the research student. The floatation method was applied in the estimation of the velocity of flow. The steps and procedures followed include:

(i) The width of chosen point at the river reach was divided into convenient section and strips to enable the mean depth of the river to be determined. It was at this point that the width of the river was also determined.

(ii) From the chosen point, a distance L_m was established and marked out downstream.

(iii) At this point, floats were introduced and allowed to float through the marked distance and the time taken to make the travel was recorded using stop watch. It was recorded in seconds. This step was repeated to establish more reliable values. At this point an average velocity V_m was determined.

(iv) The depth d_m was collected on a daily basis and was used to calculate the discharges. The monthly summaries were used to design a hydrograph. The hydrograph was used to determine the total flows in the various rivers. The processes encountered in the various components of flow are illustrated in Figure 3.2

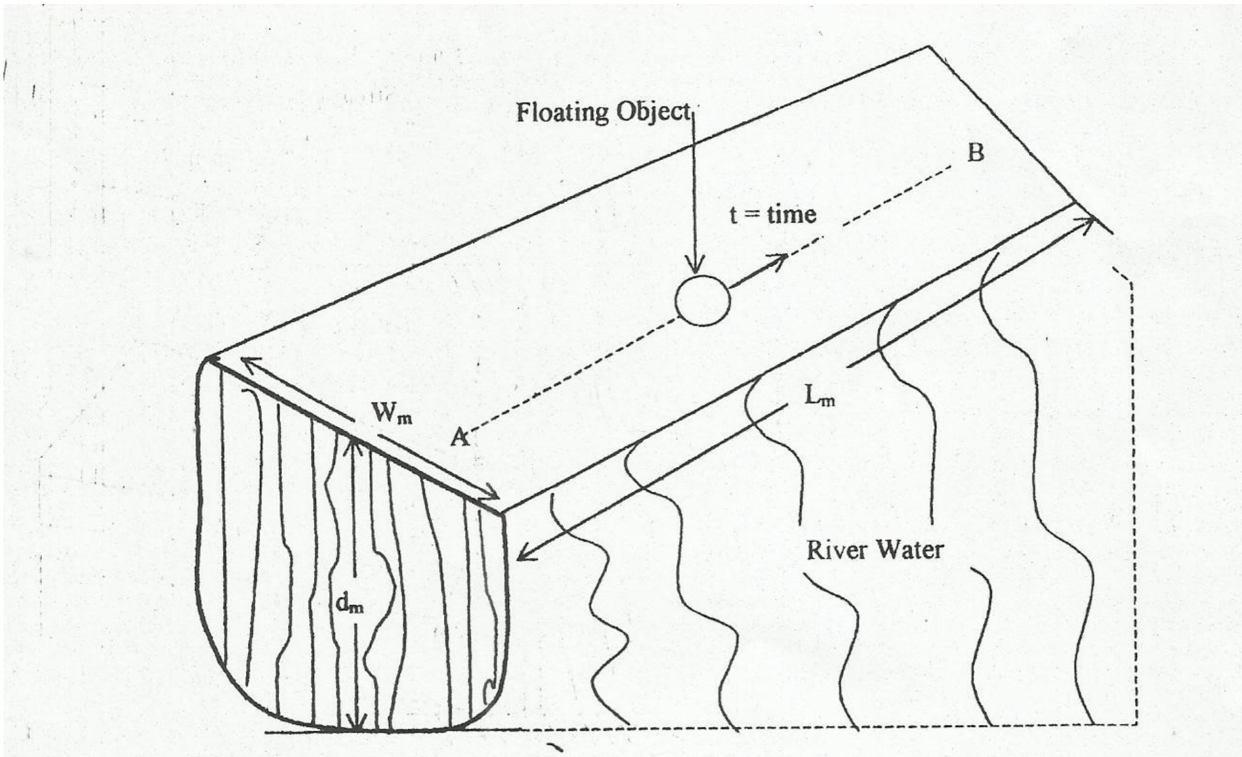

Fig. 3.2: River Gauging Technique

The data determined included:

(i) Measured width of the river, b in metres

(ii) Average depth d_m of the river was determined by finding the average depth of the depths at the various sections.

(iii) The cross sectional area of the river is determined thus;

$A_C= bd_m$ in m^2…………………….. 3.15

(iv) The surface velocity was determined by dividing the traveled distance L_m by the time T taken for the travel thus;

$V_s = L_m/ T$ in m/s………………………………….. 3.16

(v) The discharge for each day was determined thus;

$Q = A_C V_S= bd_m V_S$ in m^3/s…………………………… 3.17

The discharges were determined from January to December of the respective years.

(vi) Correction of surface velocity

The surface velocity is corrected using the correction factors as shown in Table 3.1

TABLE 3.1: CORRECTION FACTORS FOR VARIOUS STREAM CONDITIONS

Stream Conditions	Correction factor (f)
Concreted Channel Rectangular section	0.85
Large, slow, clear stream, A> $10m^2$	0.75
Medium, regular stream, smooth bed	0.65
Shallow (0.5m), turbulent river	0.45

Source: *Kuale, 2001*

Corrected surface velocity $V_s = fv_s$.............. 3.18

(vii) The volume of water in the river was estimated by finding the area within the hydrograph. The volume is expressed in cubic metres.

The full details of the daily discharge data obtained are attached in Appendix III.

Determination of Baseflow and Surface Water Quantity

The average discharges and their corresponding time were obtained for each sub- basin and used in drawing the hydrographs. The baseflow was obtained by drawing a tangent horizontally to the abscissa linking the two rising limbs of the hydrograph. The surface water quantity represented by the upper part of the separated hydrograph, was determined by calculating the entire upper area which was divided into regular shapes. The baseflow or the groundwater within the sub-basin, constitutes the lower part of the separated hydrograph. The computations done to that effect are included in the Appendix III.

CHAPTER FOUR

PRESENTATION AND ANALYSIS OF RESULTS

4.1 Presentation of Results

The results obtained in the course of this research are presented in this section and they included water use parameters in the study areas, the degree of use of surface and groundwater, optimal allocation of water for various uses, existing water allocation, and sensitivity analysis.

4.1.1 Collected Data From The Study Areas

The data collected for the various parameters of the study areas are shown in Tables 4.1 to 4.4.

Table 4.1: Water Use Parameters In Njaba River Basin Sub-Areas

S/N	Parameters/Uses	Amucha	Okwudor	Umuaka	Awo Omama	Nkwesi
1	Population	2,471	8619	10,879	13,538	1,435
2	Established Water Quota at 120 lpcd (m^3/yr)	108229.80	377,512.20	476500.20	592264.40	62853.00
3	Water Usage (m^3/yr)	141.20	247.31	298.75	302.47	110.62
4	Area x10^4(ha)	19.40	35.70	50.70	70.30	15.62
5	Ecological Water Reqt per duty for crop (maize)	45cm	45cm	45cm	45cm	45cm
6	Water Duty x10^4 (m^3/yr)	8.73	16.07	22.82	31.64	7.03
7	Industrial GDP x ₦10,000.00	15.00	25.00	35.00	50.00	10.00
8	Industrial Water Use (m^3/day)	1.50	2.10	2.60	3.00	1.5
9	Industrial Water Quota (m^3/yr)	547.50	766.50	949.00	1095.00	547.50
10	Power Generated Installed Capacity (mw)	8.00	9.00	9.50	10.00	7.50
11	Efficiency/Head factors	58860	58860	58860	58860	58860
12	Power Generation Water Quota (m^3/yr)	135.92	152.91	161.40	169.89	127.42
13	Total Water Requirements (m^3/yr)	196354.42	539,378.92	706109.35	910,231.76	133938.54
14	Losses/leakages (15%)	29453.16	80,906.84	105,916.40	136534.76	20,090.78
15	Grand Total	225807.58	620,285.76	812025.75	1046766.52	154,029.32
16	Per capita reqd. (m^3/yr)	91.30	71.97	74.64	77.32	107.34
	Policy use population	2471	8619	10,879	13538	1435

Table 4.2: Water Use Parameters In Mmam River Sub-Areas

S/N	Parameters/Uses	Inyi	Awlaw	Akpugoeze	Ufuma
1	Population	71,136	28,955	48,394	62,778
2	Established Water Quota at 120 lpcd (m^3/yr)	3115756.80	1268236.00	2119671.22	2749676.40
3	Water Usage (m^3/yr)	110.23	88.55	98.67	108.27
4	Area x10^4(ha)	50.90	61.3	90.7	68.6
5	Ecological Water Reqt per duty for crop (maize)	25cm	25cm	25cm	25cm
6	Water Duty x10^4 (m^3/yr)	12.8	15.33	22.68	17.15
7	Industrial GDP x ₦10,000.00	50	16	46	78
8	Industrial Water Use (m^3/day)	2.5	1.5	1.5	2.5
9	Industrial Water Quota (m^3/yr)	912.50	547.5	547.5	912.50
10	Power Generated Installed Capacity (mw)	15.00	8.00	10.00	15.00
11	Efficiency/Head factors	58860	58860	58860	58860
12	Power Generation Water Quota (m^3/yr)	254.84	135.92	169.89	254.84
13	Total Water Requirements (m^3/yr)	3245034.37	1422307.97	2347,188.61	2,922,452.01
14	Losses/leakages (15%)	486755.16	213346.20	320073.29	438,367.80
15	Grand Total	3731789.53	1635654.17	2,699260.90	3,360,819.81
16	Per capita (m^3/yr)	52.46	56.50	55.78	53.53
	Policy use population	71,136	28955	48,394	62,778

Table 4.3: Water Use Parameters In Otamiri River Basin Sub-Areas

S/N	Parameters/Uses	Egbu	Nekede	Ihiagwa	Eziobodo	Obinze	Mgbirichi	Umuagwo
1	Population	15696	31,261	10,135	5755	18,469	7252	9,120
2	Established Water Quota at 120 lpcsd (m^3/yr)	687,484.80	1,369231.80	443913.00	252,069.00	808942.20	317637.60	399456.00
3	Water Usage (m^3/yr)	70.55	90.60	88.45	68.70	69.88	78.40	81.30
4	Area x10^4(ha)	20.07	28.40	25.67	20.02	20.15	19.81	21.50
5	Ecological Water Reqt per duty for crop (maize)	25.00cm	25.00cm	25.00cm	25.00cm	25.00cm	25.00cm	25.00cm
6	Water Duty x10^4 (m^3/yr)	5.02	7.10	6.42	5.01	5.04	4.95	5.38
7	Industrial GDP x ₦10,000.00	45.00	40.00	35.00	25.00	30.00	25.00	20.00
8	Industrial Water Use (m^3/day)	3.00	3.50	3.80	2.00	2.00	1.50	1.50
9	Industrial Water Quota (m^3/yr)	1095.0	1277.50	1387.00	730.00	730.00	547.50	547.50
10	Power Generated Installed Capacity (mw)	9.50	8.50	9.50	7.00	9.00	8.00	8.00
11	Efficiency/Head factors	58860.00	58860	58860	58860	58860	58860	58860
12	Water Quota (m^3/yr)	161.40	144.41	161.40	118.93	152.91	135.92	135.92
13	Total Water Requirements (m^3/yr)	739011.75	1,377,844.31	509749.85	303,086.63	870394.99	367899.42	454,020.72
14	Losses/leakages (15%)	110,851.76	206,676.65	76,462.48	45462.99	130,559.25	55,184.91	68,103.11
15	Grand Total	849,863.51	1,584520.96	586212.33	348549.62	989339.24	423084.33	522,123.83
16	Per capita (m^3/yr)	54.15	50.69	57.84	60.56	53.50	58.34	57.25
	Policy use population	15,696	31,261	10,135	5755	18,469	7252	9120

Table 4.4: Water Use Parameters In Aboine River Basin Sub-Areas

S/N	Parameters/Uses	Obollo Afor	Ikem	Eha Amufu	Nkalaha
1	Population	52,422	24568	92787	19734
2	Established Water Quota at 120 lpcd (m^3/yr)	2296083.60	1076078.40	4064070.60	864349.20
3	Water Usage (m^3/yr)	108.20	96.70	112.50	92.40
4	Area $x10^4$(ha)	27.40	24.50	30.35	21.40
5	Ecological Water Reqt per duty for crop (rice)	120cm	120cm	120cm	120cm
6	Water Duty $x10^4$ (m^3/yr)	32.88	29.48	36.48	25.68
7	Industrial GDP x ₦10,000.00	75.00	20.00	30.00	15
8	Industrial Water Use (m^3/day)	2.5	1.5	1.75	1.5
9	Industrial Water Quota (m^3/yr)	912.50	547.50	638.75	547.50
10	Power Generated Installed Capacity(mw)	20	10	25	10
11	Efficiency/Head factors	58860	58860	58860	58860
12	Power Generation Water Quota (m^3/yr)	339.79	169.89	424.74	169.89
13	Total Water Requirements (m^3/yr)	2626244.09	1370892.49	4430046.59	1121958.99
14	Losses/leakages (15%)	393,936.61	205633.87	664506.99	168293.85
15	Grand Total	3020180.70	1576,525.87	5094553.58	1290252.04s
16	Per capita (m^3/yr)	57.61	64.18	54.84	62.38
17	Policy use population	52,422	24568	92787	19734

The data collected in Tables 4.1 to 4.4 were used to form linear programs as shown in Tables 4.5 to 4.8.

Table 4.5: Njaba River Basin Linear Program

Basic	X_1	X_2	X_3	X_4	X_5	b
Minimize	91.30	71.97	74.64	77.32	107.34	
Subject to						
1	2471	8619	10879	13538	1435	= 36,942
2	19.40	35.70	50.70	70.30	15.62	= 191.72
3	15.00	30.00	35.00	50.00	10.00	= 140
4	8.00	9.00	9.50	10.00	7.50	= 60
5	11.90	9.40	9.70	10.10	14.0	= 51.10
Lower Bound	0.00	0.00	0.00	0.00	0.00	
Upper Bound	Infinity	Infinity	Infinity	Infinity	Infinity	
Unrest(y/n)?	n	n	n	n	N	

The original data for Mmam river basin is used to form a linear program as shown on Table 4.6

Table 4.6: Mmam River Basin Linear Linear Program

Basic	X_1	X_2	X_3	X_4	b
Minimize	52.46	56.50	55.78	53.53	
Subject to					
1	71136	28955	48394	62778	= 211263
2	50.90	61.30	90.7	68.60	= 270
3	50.00	16.00	46.00	78.00	= 190
4	15.00	8.00	10.00	15.00	= 48
5	6.80	7.40	6.60	7.00	= 27
Lower Bound	0.00	0.00	0.00	0.00	
Upper Bound	Infinity	Infinity	Infinity	Infinity	
Unrest(y/n)?	N	n	n	n	

The original data from Otamiri river were used to form a linear program as shown on Table 4.7.

Table 4.7: Otamiri River Basin Linear Program

Basic	X_1	X_2	X_3	X_4	X_5	X_6	X_7	b
Minimize	54.15	50.69	57.84	60.56	53.56	58.34	57.25	
Subject to								
1	15696	31261	10135	5755	18469	7252	9120	= 97688
2	2007	28.4	25.67	2002	20.15	19.81	21.50	= 155
3	45.00	40.00	35.00	25.00	30.00	25.00	20.00	= 220
4	9.50	8.50	9.50	7.00	9.00	8.00	8.00	= 59
5	7.2	6.60	7.50	7.90	7.10	7.60	7.50	= 51
Lower Bound	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Upper Bound	Infinity	Infinity	Infinity	Infinity	Infinity	Infinity	Infinity	
Unrest(y/n)?	N	n	n	n	n	n	n	

The original data on Aboine River were used to form a linear program as shown on Table 4.8.

Table 4.8: Aboine River Basin Linear Program

Basic	X_1	X_2	X_3	X_4	b
Minimize	57.61	64.18	54.84	65.38	
Subject to					
1	52422	24568	92787	19734	= 189511
2	27.40	24.50	30.35	21.40	= 104
3	75.00	20.00	30.00	15.00	= 140
4	20.00	10.00	25.00	10.00	= 65
5	7.50	8.40	7.20	8.50	= 31
Lower Bound	0.00	0.00	0.00	0.00	
Upper Bound	Infinity	Infinity	Infinity	Infinity	
Unrest(y/n)?	N	n	n	n	

4.1.2 Mathematical Model Equations Developed

The model equations may be written in full to facilitate understanding by expanding the equations using all the data collected from the sub- basins. This transforms the model equations into the following equations for the various sub- areas.

Mathematical Models, Njaba river

This transforms the model equations into the following equations for the various study areas

Njaba river

The Objective Function

$\text{Min } Z = 91X_1 + 71X_2 + 74X_3 + 77X_4 + 107X_5$

THE INITIAL MODEL EQUATIONS

$\text{Min } = 2471x_{11} + 8619x_{12} + 10879x_{13} + 13538x_{14} + 1435x_{15} + 19.4x_{21} + 35.7x_{22} + 50.7x_{23} + 70.30x_{24} + 15x_{25} + 15x_{31} + 20x_{32} + 24x_{33} + 30x_{34} + 12x_{35} + 8x_{41} + 9x_{42} + 9.5x_{43} + 10x_{44} + 7.5x_{45} + 11.9x_{51} + 9.4x_{52} + 9.7x_{53} + 10.1x_{54} + 14.0x_{55}$

Subject to the following constraints

$X_{11} + x_{12} + x_{13} + x_{14} + x_{15} \leq 36942$

$X_{21} + x_{22} + x_{23} + x_{24} + x_{25} \leq 192$

$X_{31} + x_{32} + x_{33} + x_{34} + x_{35} \leq 102$

$X_{41} + x_{42} + x_{43} + x_{44} + x_{45} \leq 44$

$X_{51} + x_{52} + x_{53} + x_{54} + x_{55} \leq 56$

Under the non-negativity conditions ;

$X_{11}, X_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, x_{21}, x_{22}, x_{23}, x_{24}, x_{25}, x_{26}, x_{27}, x_{31}, x_{32}, x_{33}, x_{34}, x_{35}, x_{36}, x_{37},$

$x_{41}, x_{42}, x_{43}, x_{44}, x_{45}, x_{46}, x_{47}, x_{51}, x_{52}, x_{53}, x_{54}, x_{55}, x_{56}, x_{57}, \geq 0$

Mmam River, Study Area

In like manner, the Study Area II (Mmam River) area will have such model equations as:

Objective Function

$\text{Min. } Z = 52X_1 + 56X_2 + 55X_3 + 53X_4$

Initial Model Equation

$\text{Min.} = 71136X_{11} + 28955X_{12} + 48394X_{13} + 62778X_{14} + 50.9X_{21}$

$+61.3X_{22} + 90.7X_{23} + 68.6X_{24} + 50X_{31} + 16X_{32} + 46X_{33} + 78X_{34} + 15X_{41} + 8X_{42} + 10X_{43} + 15X_{44} +$

$6.84X_{51} + 7.37X_{52} + 6.61X_{53} + 6.98X_{54}$

Subject to the constraints:

$X_{11} + X_{12} + X_{13} + X_{14} \leq 211{,}263$

$X_{21} + X_{22} + X_{23} + X_{24} \leq 270$

$X_{31} + X_{32} + X_{33} + X_{34} \leq 48$

$X_{51} + X_{52} + X_{53} + X_{54} \leq 27$

Under the non-negativity conditions;

$X_{11}, X_{12}, X_{13}, X_{14}, X_{21}, X_{22}, X_{23}, X_{24}, X_{31}, X_{32}, X_{33}, X_{34}, X_{41}, X_{42}, X_{43}, X_{44} \geq 0$

Otamiri river, Study Area

Objective Function

Min Z= $54x_1 + 51x_2 + 58x_3 + 60x_4 + 53x_5 + 58x_6 + 57x_7$

Initial Model Equations;

$15696x_{11} + 31261x_{12} + 10135x_{13} + 5755x_{14} + 18469x_{15} + 7252x_{16} + 9120x_{17} + 20x_{21} + 28x_{22} + 25x_{23} + 20x_{24} + 20x_{25} + 19x_{26} + 21x_{27} + 45x_{31} + 40x_{32} + 35x_{33} + 25x_{34} + 30x_{35} + 25x_{36} + 20x_{37} + 9.5X_{41} + 8.5X_{42} + 9.5X_{43} + 7X_{44} + 9X_{45} + 8X_{46} + 8X_{47} + 7.2X_{51} + 6.6X_{52} + 7.5X_{53} + 7.9X_{54} + 7.1X_{55} + 7.6X_{56} + 7.5X_{57}$

Subject to Constraints

$X_{11}+X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + X_{16} + \leq 97688$

$X_{21} + X_{22} + X_{23} + X_{24} + X_{25} + X_{26} + X_{27} \leq 155$

$X_{31} + X_{32} + X_{33} + X_{34} + X_{35} + X_{36} + X_{37} \leq 220$

$X_{41} + X_{42} + X_{43} + X_{44} + X_{45} + X_{46} + X_{47} \leq 59$

$X_{51} + X_{52} + X_{53} + X_{54} + X_{55} + X_{56} + X_{57} \leq 51$

Under the non-negativity conditions;

$X_{11}, X_{12}, X_{13} + X_{14}, X_{15}, X_{16}, X_{17}, X_{21}, X_{22}, X_{23,} \ldots\ldots\ldots, X_{57} \geq 0$

Aboine River Study Area

Objective function

Min Z = $57X_1 + 64X_2 + 54X_3 + 65X_4$

Initial Model Equations

$$Min\ Z = 52422X_{11} + 24568X_{12} + 92787X_{13} + 19734X_{14} + 27X_{21} + 24X_{22} + 30X_{23} + 15X_{24} + 75X_{31} + 20X_{32} + 30X_{33} + 15X_{34} + 20X_{41} + 10X_{42} + 25X_{43} + 10X_{44} + 7.5X_{51} + 8.4X_{52} + 7.2X_{53} + 8.5X_{54}$$

Subject to the constraints

$X_{11} + X_{12} + X_{13} + X_{14} \leq 189{,}511$

$X_{21} + X_{22} + X_{23} + X_{24} \leq 104$

$X_{31} + X_{32} + X_{33} + X_{34} \leq 140$

$X_{41} + X_{42} + X_{43} + X_{44} \leq 65$

$X_{51} + X_{52} + X_{53} + X_{54} \leq 31$

Under the non-negativity conditions;

$X_{11}, X_{12}, X_{13}, X_{14}, X_{21}, X_{22}, X_{23}, X_{24}, X_{31},$

$X_{32}, X_{33}, X_{34}, X_{41}, X_{42}, X_{43}, X_{44}, X_{51},$

$X_{52}, X_{53}, X_{54} \geq 0$

4.1.3 Results of Solution of Model Equation.

These original data are used to form the equations which are solved to obtain the optimal solutions as shown on Tables 4.9 to 4.12

TABLE 4.9: ITERATION 12: OPTIMAL VALUES FOR WATER ALLOCATION IN NJABA RIVER BASIN

Basic	X_1	X_2	X_3	X_4	X_5	RX6	RX5	RX6	RX8	Solution
Z (MIN)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.99	0.00	419.380
X_2	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.837
X_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.895
RX7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.650
X_3	0.00	0.00	0.00	0.00	0.00	-1.25	0.00	0.00	0.00	1.131
X_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.983
X_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.148
Upper Bound	Infinity	Infinity	Infinity	Infinity	Infinity	Infinity				
Lower bound	0.00	0.00	0.00	0.00	0.00					

TABLE 4.10: ITERATION 10: OPTIMAL VALUES FOR WATER ALLOCATION IN MMAM RIVER BASIN.

Basic	X_1	X_2	X_3	X_4	RX5	Solution
Z (MIN)	0.00	0.00	0.00	0.00	0.00	217.989
X_3	0.00	-1.00	0.00	0.00	0.00	1.097
X_2	0.00	0.00	0.00	-7.00	0.00	0.963
X_4	0.00	0.00	0.00	0.00	0.00	0.741
RX6	0.00	0.00	0.00	0.00	0.00	8350
X_1	0.00	0.00	0.00	0.00	0.00	1.241
Upper Bound	∞	∞	∞	∞		
Lower bound	0.00	0.00	0.00	0.00		

TABLE 4.11. Optimal Values For Water Allocation In Otamiri River Basin

Basic	X_1	X_2	X_3	X_4	X_5	X_6	X_7	RX8	RX9	RX10	Solution
Z (MIN)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	389.05
X_7	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.951
X_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.154
X_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.204
RX11	0.00	0.00	0.00	-30.77	0.00	0.00	0.00	0.00	0.00	0.00	7010
X_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.300
X_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.682
X_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.586
Upper Bound	∞	∞	∞	∞	∞	∞	∞				
Lower bound	0.00	0.00	0.00	0.00	0.00	0.00	0.00				

TABLE 4.12: Optimal Values For Water Allocation In Aboine River Basin.

Basic	X_1	X_2	X_3	X_4	X_5	Solution
Z (MIN)	0.00	0.00	0.00	0.00	0.00	235.38
X_4	0.00	-1.00	0.00	0.00	0.00	0.829
X_2	0.00	0.00	0.00	0.00	0.00	1.089
RX6	0.00	0.00	0.00	0.00	0.00	7700
X_3	0.00	0.00	0.00	0.00	0.00	1.009
X_1	0.00	0.00	0.00	-9.99	0.00	1.007
Upper Bound	∞	∞	∞	∞		
Lower bound	0.00	0.00	0.00	0.00		

4.1.4 Computed Water For Allocation

The water available for allocation in the various river basins are obtained and presented in Table 4.13

TABLE 4.13: Computed Values of Available Groundwater and Runoff in the Sample Sub-River Basins

Sub-River Basin	Groundwater (m^3/yr)	Run Off (m^3/yr)	Total Available Water (m^3/yr)
Njaba	27,669,600	58,644,000	86,313,000
Mmam	18,182,880	34,020,000	52,202,880
Otamiri	226,100,160	1,944,000	228,004,160
Aboine	85,380,480	33,048,000	118,428,480

Table 4.13 contains data that are used to ascertain availability of water and to satisfy the proposed water allocation. The analysis of available water was done using the available gauging data as attached in Appendix III. The data were used in developing the hydrographs as shown in Fig. 4.1

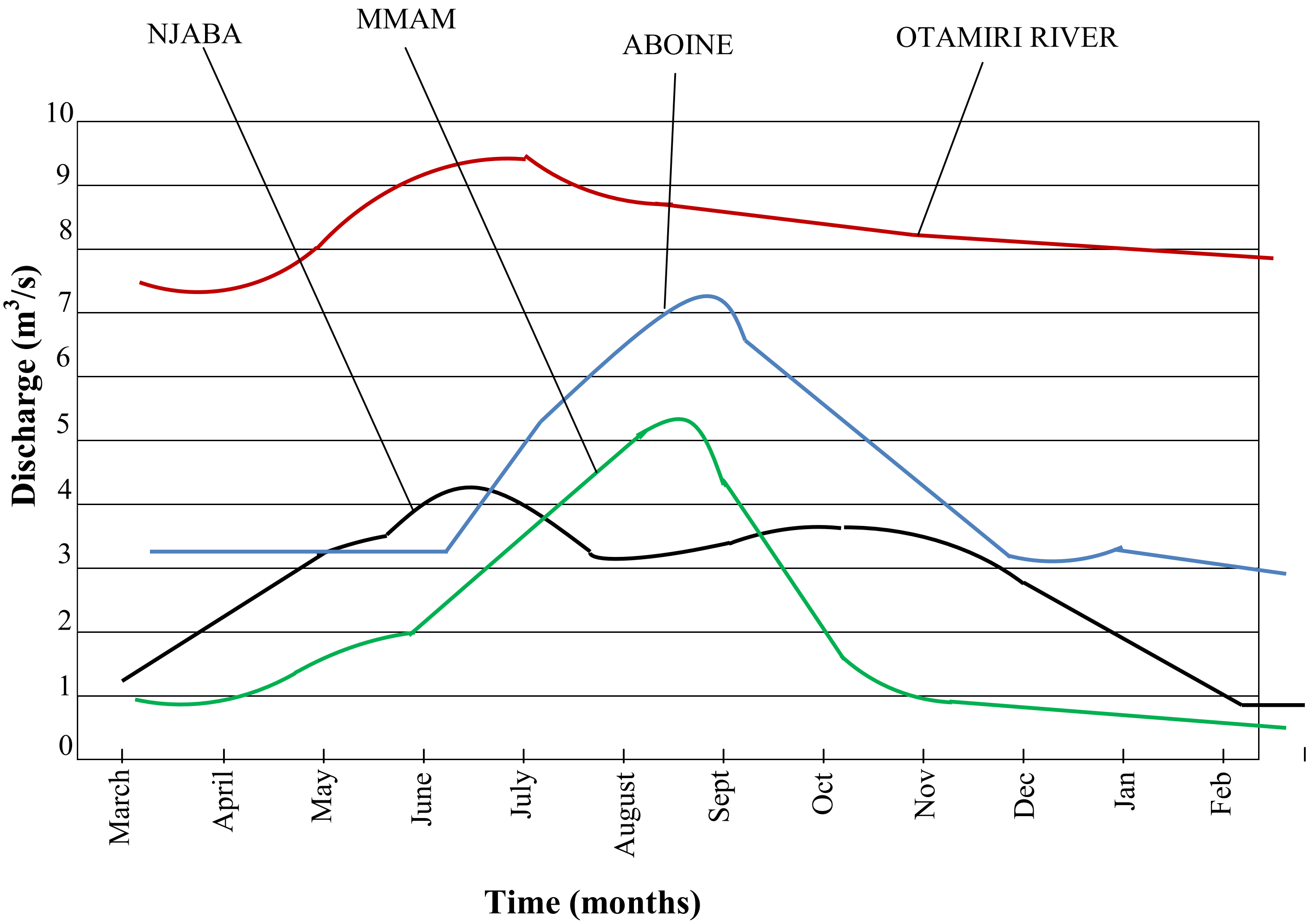

Fig. 4.1 Hydrographs of Njaba, Mmam, Otamiri and Aboine River Sub-basins

4.2 Results of Model Equation

The model equations for the various sub-basins were solved using the Tora optimization software and the determined optimal allocation values were used to compute the water allocations for the various sub- areas within the basin. The resulting optimal water allocation (allocation limits) for Njaba, Mmam, Otamiri and Aboine sub-river basins are presented in Tables 4.14 to 4.17 respectively.

Table 4.14: Computed Values for Subarea Sectoral Allocation In Njaba River Basin

S/N	USAGE AREAS		ALLOCATION LIMITS FOR SUBAREAS				
		Amucha (x_1)	**Okwudor X_2**	**Umuaka X_3**	**Awo-Omama X_4**	**Nkwesi X_5**	**Total amount (m^3x10^2)**
1.	Consumption & Domestic Use (m^3/yr)	124410	316185	539,260	582196	56352	16184.03
2.	Ecological use (m^3/yr)	100220	134506	258094	311021	62919	8667.60
3.	Industrial use (m^3/yr)	629	642	1073	1076	490	39.10
4.	Energy use (m^3/yr)	156	128	183	167	114	7.48
5.	Leakages mitigation (m^3/yr)	33812	67719	119791	134214	17981	3735.17
6.	**Total**	**259227**	**519180**	**918401**	**1028674**	**137856**	**28,633.38**

Table 4.14 portrays the summary of the optimal allocation of water to the various usage requirements in the different subareas within the Njaba sub-river basin. However, the optimal solution as represented by the objective function, Ƶmin is equal to 419.38 with X_1 = 1.148, x_2 = 0.837, x_3 = 1.131, x_4 = 0.983, x_5 = 0.895 and Rx = 7.649 which is an excess of 750 m^3 of water. An excess of 0.2% of the total minimum optimal solutions was observed.

Table 4.15: Computed Values For Subarea Sectoral Allocation For Mmam River Basin

S/N	USAGE AREAS		ALLOCATION LIMITS FOR SUBAREAS			
		Inyi (x_1)	**Awlaw X_2**	**Akpugoeze X_3**	**Ufuma X_4**	**Total amount (m^3x10^2)**
1.	Consumption & Domestic Use	3,866791	1221396	2325388	2937591	94511.66
2.	Ecological use (m^3/yr)	158848	147628	248800	129675	6849.51
3.	Industrial use (m^3/yr)	1523	527	1001	811	38.62
4.	Energy use (m^3/yr)	316	131	186	189	8.22
5.	Leakages mitigation (m^3/yr)	604053	205452	351120	324831	14854.56
6.	**Total**	**4631541**	**1575134**	**2926495**	**2168591**	**116262.57**

The optimal solution for the Mmam sub-river basin shows Ƶmin amounts to 217,997 and X_1 = 1.241, X_2 = 0.963, X_3 = 1.097, X_4 =0.741, with Rx= 1.241, which is an excess of 124.1m^3 of water. It was observed that there is an excess of 0.06% over the minimum total solution.

Table 4.16: Computed Values Subarea Sectoral Allocation In Otamiri River Basin

S/N	USAGE AREAS		ALLOCATION LIMITS FOR SUBAREAS						
		Egbu (x^1)	Nekede X^2	Ihiagwa X^3	Eziobodo X^4	Obinze X^5	Mgbirichi	Umuagwo	Total amount (m^3x10^2)
1.	Consumption & Domestic Use	105884	933878	978579	399890	1860567	459100	779497	55173.95
2.	Ecological use (m^3/yr)	7731	48422	141497	79457	115920	71528	104964	11390.33
3.	Industrial use (m^3/yr)	169	837	3057	1158	1679	791	1068	87.59
4.	Energy use (m^3/yr)	25	98	318	189	352	196	265	14.43
5.	Leakages mitigation (m^3/yr)	17071	140953	168523	72104	300286	79742	132896	9115.58
6.	**Total**	**130880**	**624188**	**1291974**	**552798**	**2278804**	**611357**	**1018663**	**75,781.88**

From the results of the solution, the total minimum allocated water Ƶmin is equal to 387,995 while X_1 = 0.154, x_2 = 0.682, x_3 = 2.204, x_4 = 1.586, x_5 = 2.3, Rx = 7.012 which amounts to 701.2m^3. This represents an insignificant percentage of excess water.

Table 4.17: Computed Values For Subarea Sectoral Allocation In Aboine River Basin

S/N	USAGE AREAS	ALLOCATION LIMITS FOR SUBAREAS				
		Obollo afor (x_1)	**Ikem X_2**	**Eha-Amufu X_3**	**Nkalaha X_4**	**Total amount (m^3x10^2)**
1.	Consumption & Domestic Use	2312265	1169802	4100761	716622	82994.50
2.	Ecological use (m^3/yr)	331102	320448	368083	212887	12325.20
3.	Industrial use (m^3/yr)	919	595	665	454	26.33
4.	Energy use (m^3/yr)	342	185	429	141	10.57
5.	Leakages mitigation (m^3/yr)	396694	223524	670488	139516	24302.22
6.	**Total**	**3041322**	**2214554**	**5140426**	**1069620**	**114659.22**

Aboine river basin has a minimum total allocation Ƶmin of 235,379 with X_1 = 1.007, x_2 = 1.087, = 0.682, x_3 = 1.009, x_4 = 0.829 and, Rx = 7.702 representing an excess water of 770.2m^3.

4.3 Field Survey Result

The field survey conducted through the use of questionnaires administered on the sample population of the river basin in the various subareas yielded results on the assessment of the degree of usage of groundwater and surface water. The usage of groundwater and surface water in the subareas is shown in Table 4.18.

Table 4.18: Groundwater And Surface Water Usage In the River Basin.

S/N	SUB-RIVER BASIN	SUB-AREAS	SAMPLE POPULATION	POPULATION USING GROUNDWATER (%) (RESPONDENTS)	POPULATION USING SURFACE WATER (%) (RESPONDENTS)
1	Njaba	Amucha	124	48 (60)	52 (64)
		Okwudor	431	39 (168)	61 (263
		Umuaka	544	53 (288)	47 (256)
		Awo omama	677	46 (311)	54 (366)
		Nkwesi	72	49 (35)	51 (37)
2	Mmam	Inyi	3557	35 (1245)	65 (2312)
		Awlaw	1448	36 (521)	64 (927)
		Akpugoeze	2420	40 (968)	60 (1452)
		Ufuma	3139	48 (1507)	52 (1632)
3	Otamiri	Egbu	785	75 (589)	25 (196)
		Nekede	1563	74 (1157)	26 (406)
		Ihiagwa	507	78 (395)	22 (112)
		Eziobodo	288	81 (233)	19 (55)
		Obinze	923	85 (785)	25 (138)
		Mgbirichi	363	73 (265)	27 (98)
		Umuagwo	456	70 (319)	30 (137)
4	Aboine	Obollo Afor	2621	58 (1520)	42 (1101)
		Ikem	1228	46 (565)	54 (663)
		Eha Amufu	4639	56 (2598)	44 (2041)
		Nkalaha	987	47 (464)	53 523)

4.4 Analysis of Water Allocation In The Sub-Basins

Through the estimated available quantity of water in the basins, it was observed that the available quantities of water were enough to satisfy the various use requirements, it therefore follows that there is enough water for allocation as shown in Table 4.13. In Njaba sub-river basin, the allocated quantity of water as prescribed by the developed model amounted to 2,8633,383 m^3 (refer to Table 4.14) while the available groundwater and runoff were estimated to be 86,313,000m^3 as shown in Table 4.13. The groundwater is only 33.4% of the total quantity of available water for allocation. This may be responsible for the 47% average usage of groundwater in the basin. The available water for allocation in Mmam river basin was estimated to be 52,202,880m^3 while the total water allocated to the basin for various purposes amounted to 11,626,257 m^3 as shown in Tables 4.13 and 4.14 respectively. The average percentage usage of groundwater in the basin was put at 39.8% while that of surface water stood at 60.3%.

From the information on Table 4.13, the Otamiri river basin has a heavy ponderance of groundwater. The quantity of groundwater is put at 228,044,160 m^3 which represents a high percentage value of 91.1% of the total available quantity of water. This may be linked to 76.6% of the population using groundwater. The model allocated the total quantity of 757,818 m^3 to the basin and this value is very low compared with the total available water quantity of 255,104,640m^3. In Aboine river basin, the model allocated a total quantity of 11,465,922m^3 of water for various purposes while the available water quantity is 118,428,480m^3. The degree of allocations as reflected in the existing and proposed systems for the various uses in the respective river basins are shown in Tables 4.19 to 4.22.

Table 4.19: Allocations for the Various Uses in Njaba River Basin

S/N	**Sectors for Water Use**	**Existing Amount (%)**	**Proposed Amount (%)**
1	Consumption & Domestic Use	47.90	56.50
2	Ecological Use	38.70	30.30
3	Industrial Use	0.24	0.14
4	Energy Use	-	0.02
5	Leakages/Losses Mitigation	13.10	13.04

From Table 4.19, the proposed model allocated more than 50% of the optimal output for domestic and consumptive purposes while less than 0.5% was allocated for industrial use. The model based its output and allocation on the input and the prevailing conditions of the river basin. The ecology got 30.3% of the allocation and this can be considered as a reasonable share of the allocation. Comparatively, the proposed system allocated more water for consumption and domestic uses than the existing system.

Table 4.20 Allocations for Various Uses in Mmam River Basin

	Sectors for Water Use	Existing Amount (%)	Proposed Amount (%)
1	Consumption & Domestic Use	74.70	81.30
2	Ecological Use	4.50	5.90
3	Industrial Use	0.01	0.02
4	Energy Use	-	0.06
5	Leakages/Losses Mitigation	20.74	12.72

Mmam River basin has her highest allocation given to consumption and domestic uses with energy use receiving the minimum allocation of 0.01%. The allocation of 5.9% allowed for ecological uses is attributable to relative smallness the area capacity. The industrial use got 0.03% which suggested state of the development. The proposed system allocated 12.72% of water for leakages and losses mitigation which is less than the 20.74% allocation of the existing system. This shows that the optimized allocation reduced the losses than might result from water usage.

Table 4.21: Allocations for Various Uses in Otamiri River Basin

S/N	Sectors for Water Use	Existing Amount (%)	Proposed Amount (%)
1	Consumption & Domestic Use	67.47	72.80
2	Ecological Use	14.00	15.06
3	Industrial Use	0.06	0.12
4	Energy Use	-	0.04
5	Leakages/Losses Mitigation	18.42	12.00

The river basin of Otamiri has an appreciable allocation for its industrial uses in the proposed system but consumption/domestic use still has the lion share of the allocation. The allocation for ecological use of the proposed system rose to 15.06% from its 14.00% value in the existing system.

Table 4.22: Allocations for Various Uses in Aboine River Basin

S/N	Sectors for Water Use	Existing Amount (%)	Proposed Amount (%)
1	Consumption & Domestic Use	49.90	69.56
2	Ecological Use	8.60	9.98
3	Industrial Use	0.20	1.42
4	Energy Use	-	0.04
5	Leakages/Losses Mitigation	41.29	20.20

The water allocated to mitigate losses and leakages in the proposed system was relatively high to the tune of 20.2% with domestic and consumption use having 69.56%. The percentage allocated for consumption and domestic use is relatively low compared with the other river basins. The proposed system reduced the quantity of water for losses mitigation to 20.2% as against the 41.29% allocated by existing system. The scenarios above can be appreciated better through the application of bar charts to illustrate the degree of the allocations for the various uses as contained in the existing and proposed systems in the respective river basins. The bar charts for Njaba, Mmam, Otamiri and Aboine river basins are shown in Figures 4.2, 4.3, 4.4 and 4.5 respectively.

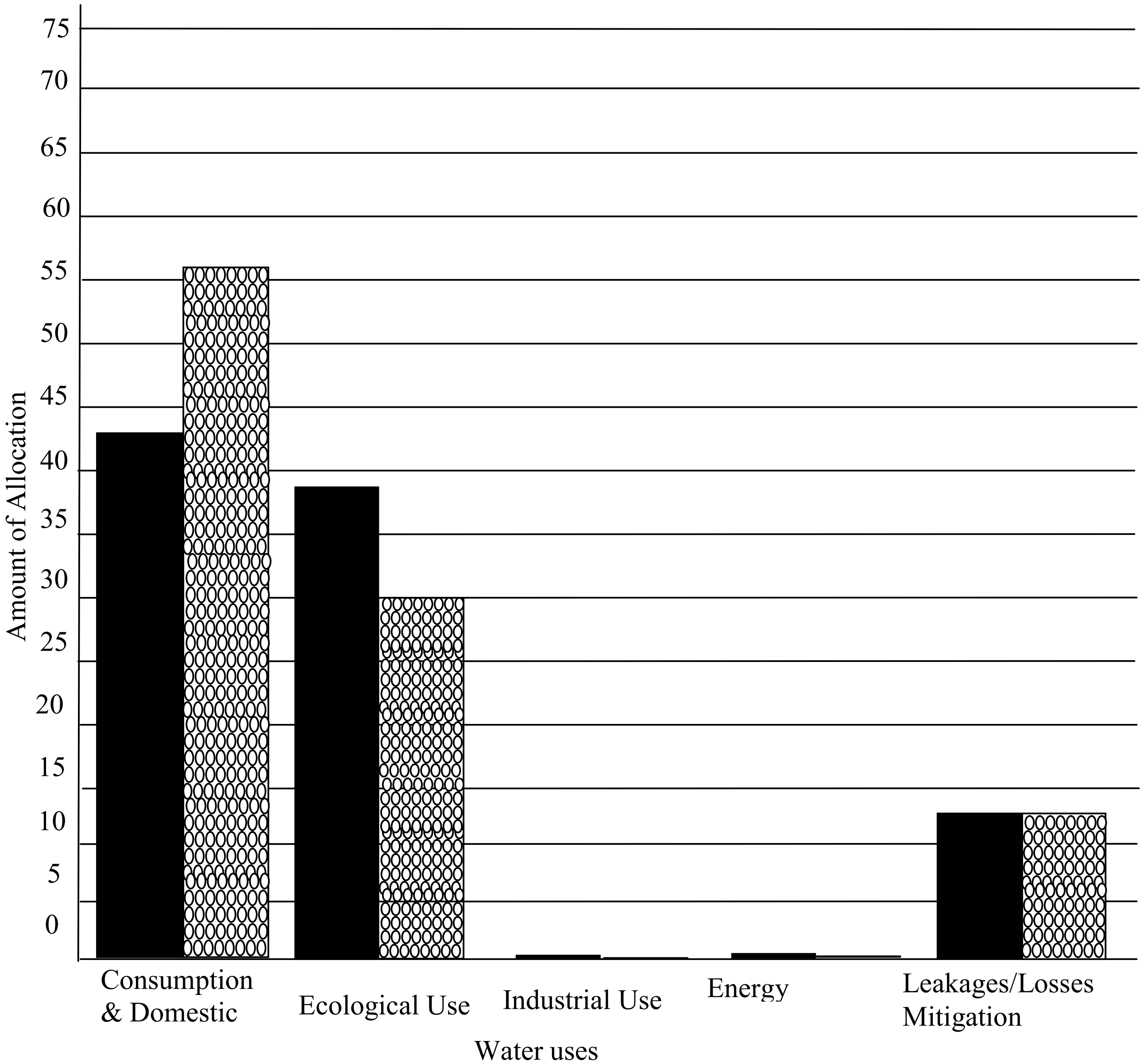

Fig. 4.2 *Allocations for Various Water Uses in Njaba River Basin*

Legend

Proposed Allocation (%)

Existing Allocation (%)

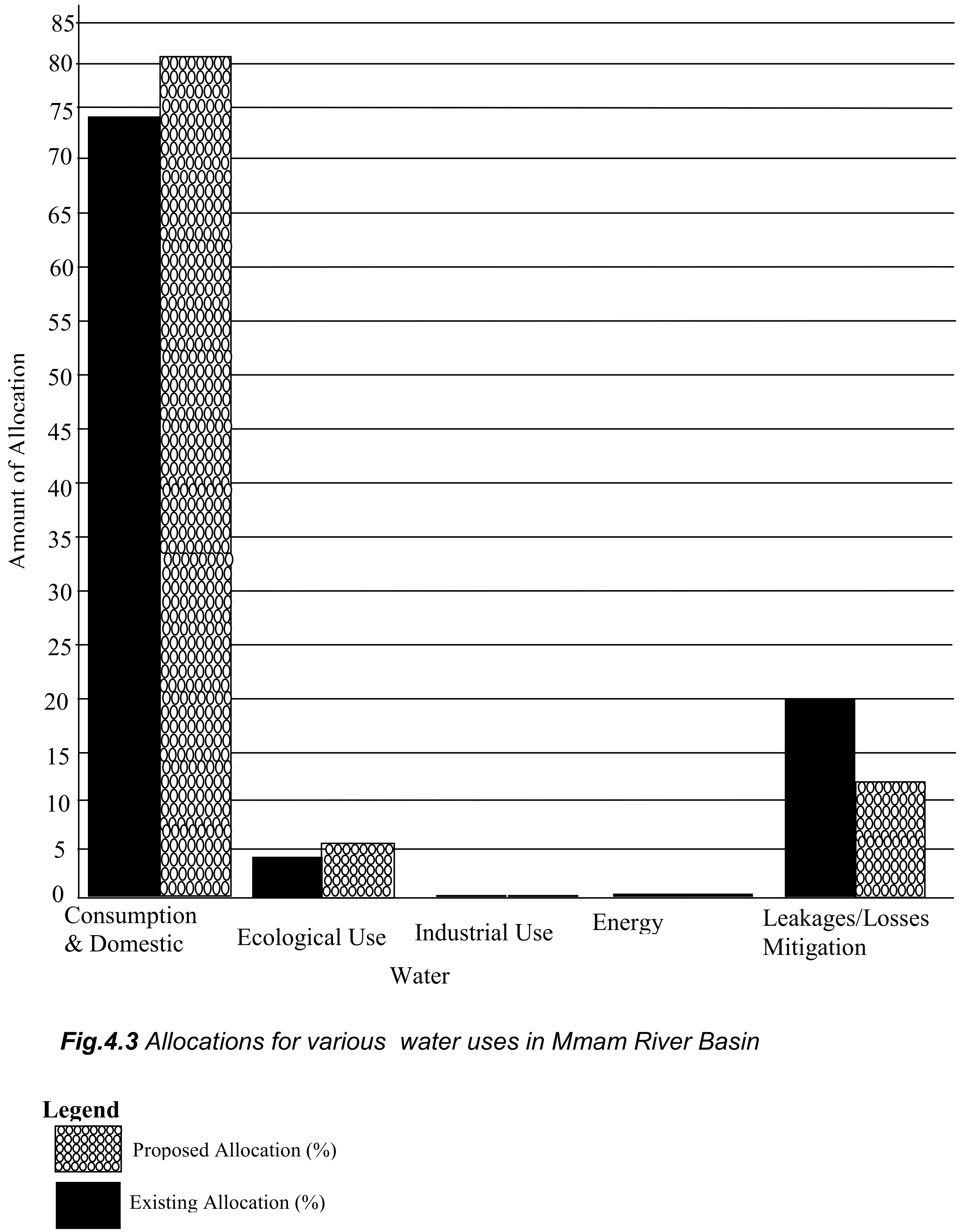

Fig.4.3 *Allocations for various water uses in Mmam River Basin*

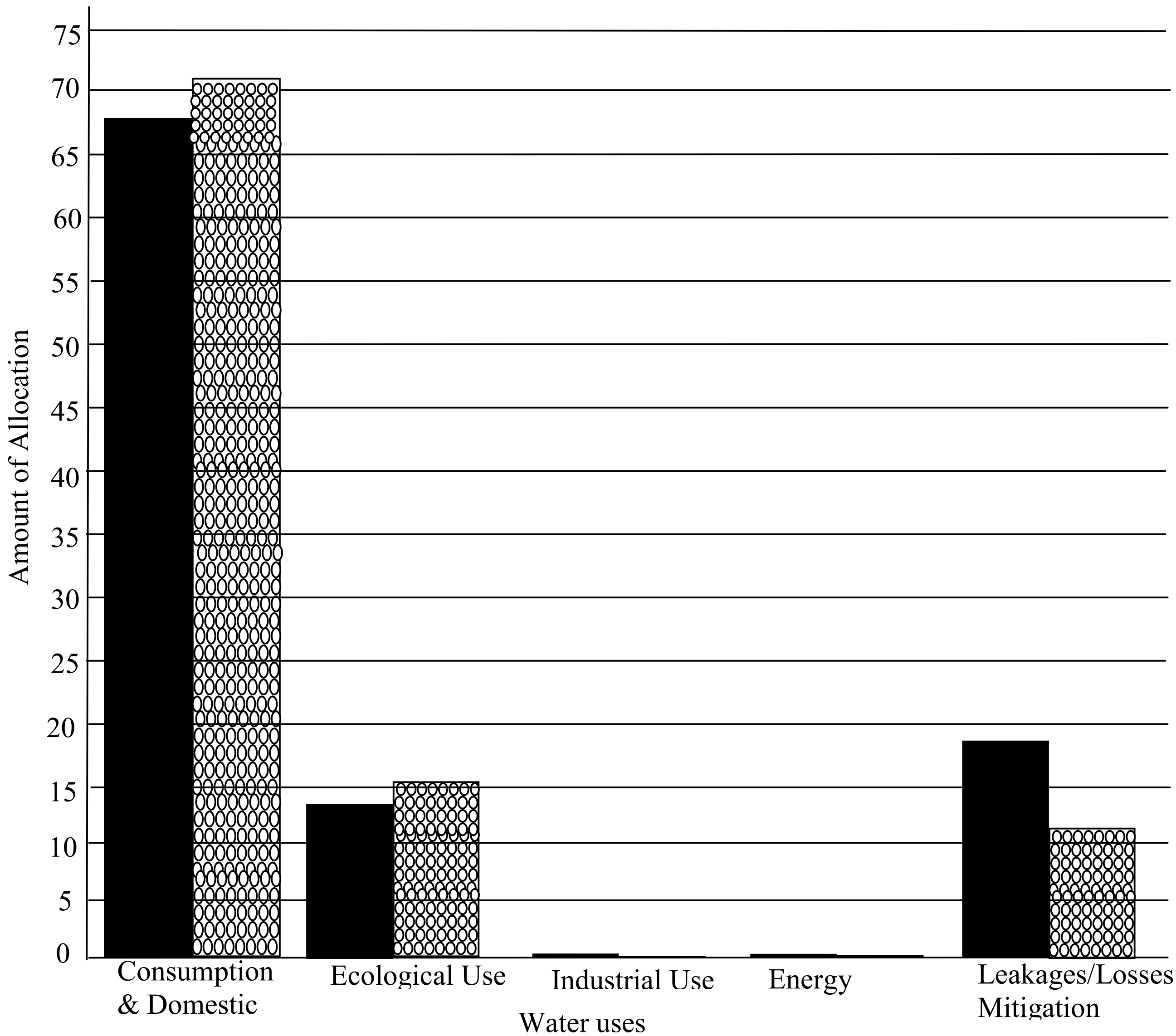

Fig. 4.4 *Allocations for various water uses in Otamiri River Basin*

Legend

Proposed Allocation (%)

Existing Allocation (%)

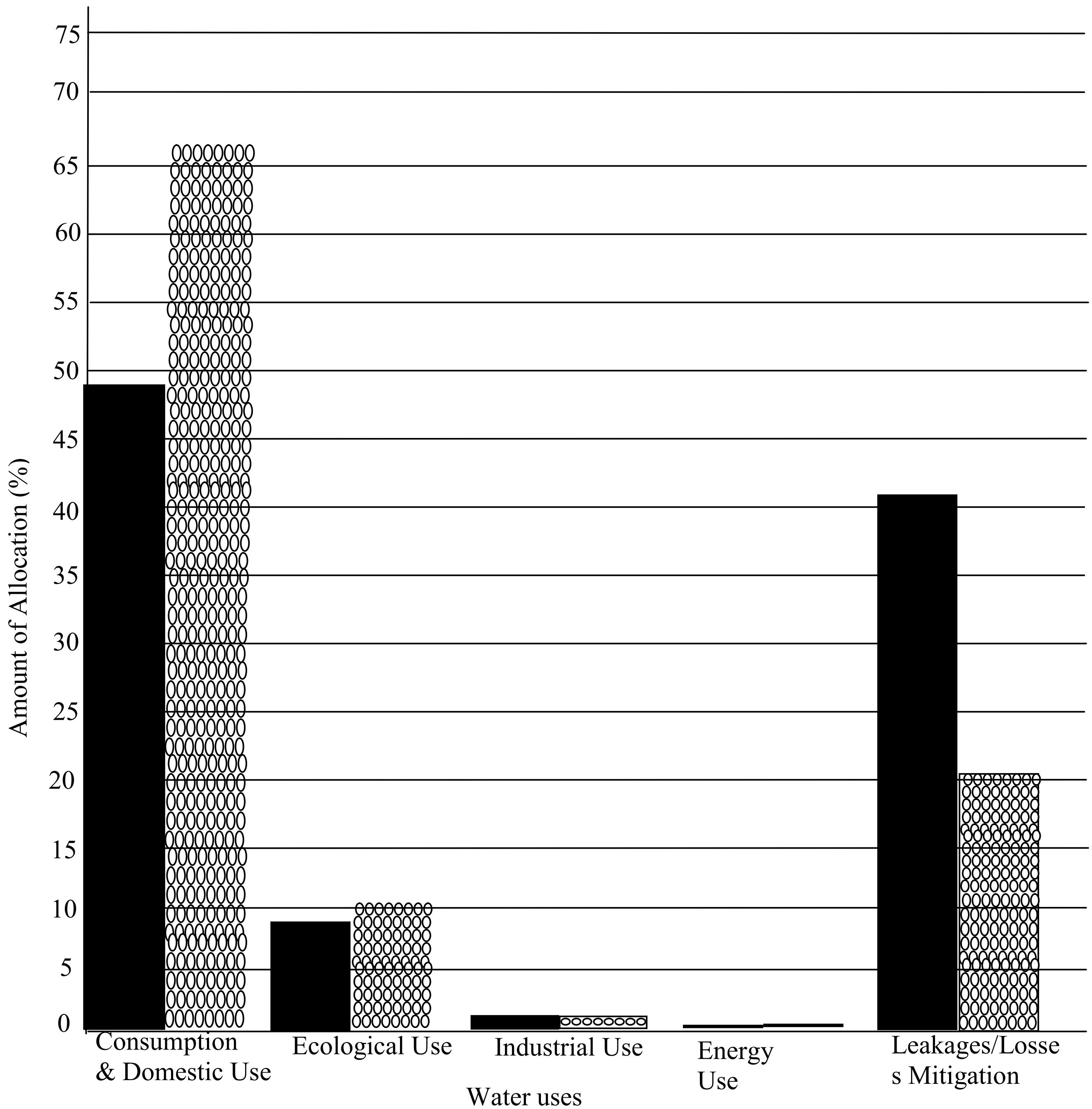

***Fig.4.5** Allocations for various water uses in Aboine River Basin*

Legend

Proposed Allocation (%)

Existing Allocation (%)

Having established the existing allocation and the allocation limits in the subareas of the river basins considered, the starting order for allocation of water is therefore decided. A priority regime establishes how water withdrawals from a river are to be restricted. A priority regime can be specified on a regional plan and implemented through consent conditions. Table.4.13 shows the available quantity of water in the basins, Tables 4.14 to 4.22 illustrate the order of allocation to the various usage areas in each river basin while Table 4.18 shows the population inclination in the usage of groundwater and surface water. The available water for allocation in the various sub-river basins was illustrated with hydrographs as shown in Fig. 4.1 while Figs. 4.2 to 4.5 show the allocation quantities graduated in percentages through bar charts.

4.5 Sensitivity of The Decision Variables

The computed rates provide a direct link between the model input or resources and its optimal output results. This means that a unit increase or decrease in capacity will increase or decrease by certain percentage or rate. In the section, the analysis is performed by varying some parameters in the model to find its effect on the optimum result. The various input data of population, land area, gross domestic product, electric power capacity and leakages/losses were varied by -5%, -2.5%, 0%, 2.5%, and 5% and the effects of each on the optimum solution determined. This analysis will show the relative importance of each to tne variable with respect to the optimal value of the objective function as well as help the River Basin Authority know the range of variability within which the optimal solution is valid. It should be noted that these changes will affect the model equations both on the Left Hand Side and Right Hand Side. The results of these changes and the resulting optimal solutions are shown on Tables 4.23 to 4.27

Table 4.23 Variation of Population Input Parameter and Optimal Output Allocations in the Basin

River Sub-basin	Population Input Value	Optimal Allocation ($x10^6m^3$)
Njaba	49,356	2.7814
	50,655	2.8303
	51,954	2.8633
	53,252	2.9786
	54,552	3.0245
Mmam	201,263	11.3461
	205,981	11.5135
	211,263	11.6263
	216,545	11.8379
	221,826	12.0001
Otamiri	92,804	7.4672
	95,246	7.5590
	97,688	7.5782
	100,130	7.5914
	102,572	7.6043
Aboine	180,035	11.1272
	184,773	11.2481
	189,511	11.4659
	194,249	11.4884
	198,987	11.5240

Table 4.24 Variation of Land Area Input Parameter and Optimal Output Allocations in the Basin

River Sub-basin	Area Input Capacity (x 10^3 ha)	Optimal Allocation (x$10^6 m^3$)
Njaba	182.400	2.2541
	187.200	2.5360
	192.000	2.8633
	196.800	2.1112
	201.600	3.4058
Mmam	256.500	11.58
	263.250	11.6038
	270.000	11.6263
	276.750	11.6511
	283.500	11.6923
Otamiri	147.250	6.4173
	151.125	6.9098
	155.000	7.5782
	158.875	8.1344
	162.750	8.1928
Aboine	98.800	10.8694
	101.400	11.1123
	104.000	11.4659
	106.600	11.7781
	109.200	12.0848

Table 4.25 Variation of Gross Domestic Product Input Parameter and Optimal Output Allocations in the Basin

River Sub-basin	Gross Domestic Product (x ₦10,000)	Optimal Allocation (x10^6m^3)
Njaba	96.90	2.4315
	99.45	2.6072
	102.00	2.8633
	104.55	3.0110
	107.10	3.2469
Mmam	45.60	11.4418
	46.80	11.5325
	48.00	11.6263
	49.20	11.7149
	50.40	11.8561
Otamiri	109.00	7.1941
	214.500	7.3569
	220.00	7.5782
	225.50	7.7609
	233.00	8.0418
Aboine	133.00	11.1243
	136.50	11.3872
	140.00	11.4659
	143.50	11.6181
	147.00	11.9267

Table 4.26 Variation of Electric Power Input Parameter and Optimal Output Allocations in the Basin

River Sub-basin	Electric Power Capacity (MW)	Optimal Allocation ($x10^6m^3$)
Njaba	41.80	1.8005
	42.90	2.3110
	44.00	2.8633
	45.10	3.3242
	46.20	3.8161
Mmam	45.60	10.8143
	46.80	11.2318
	48.00	11.6263
	49.20	12.0022
	50.40	12.4279
Otamiri	56.050	7.2461
	57.525	7.4318
	59.000	7.5782
	60.475	7.6744
	61.95	8.0029
Aboine	63.375	9.6263
	61.750	10.5817
	65.000	11.4659
	66.625	12.3721
	68.250	13.2466

Table 4.27 Variation of Leakages/Losses Per Capita Input Parameter and Optimal Output Allocations in the Basin

River Sub-basin	Leakages/Losses (m^3 per capita)	Optimal Allocation ($x10^6m^3$)
Njaba	53.20	1.2965
	54.60	2.2579
	56.00	2.8633
	57.40	3.4110
	58.80	4.0728
Mmam	25.650	10.64
	26.325	11.1388
	27.000	11.6263
	27.675	12.1118
	28.350	12.6040
Otamiri	48.450	6.0028
	49.725	6.2814
	51.000	7.5782
	52.275	7.8647
	53.550	8.1580
Aboine	29.450	5.7086
	30.225	7.0843
	31.000	11.4659
	31.775	12.8416
	32.550	14.22450

The plotting of the input resources against the output values enables the water allocation system to be calibrated. The graphs showing the input against the output resources in the five sectoral allocation areas of consumption, ecology, industry, power generation and leakages/losses mitigations for the various sub-basins of Njaba, Mmam, Otamiri, and Aboine are shown in Figures 4.6, 4.7, 4.8, 4.9 and 4.10 respectively.

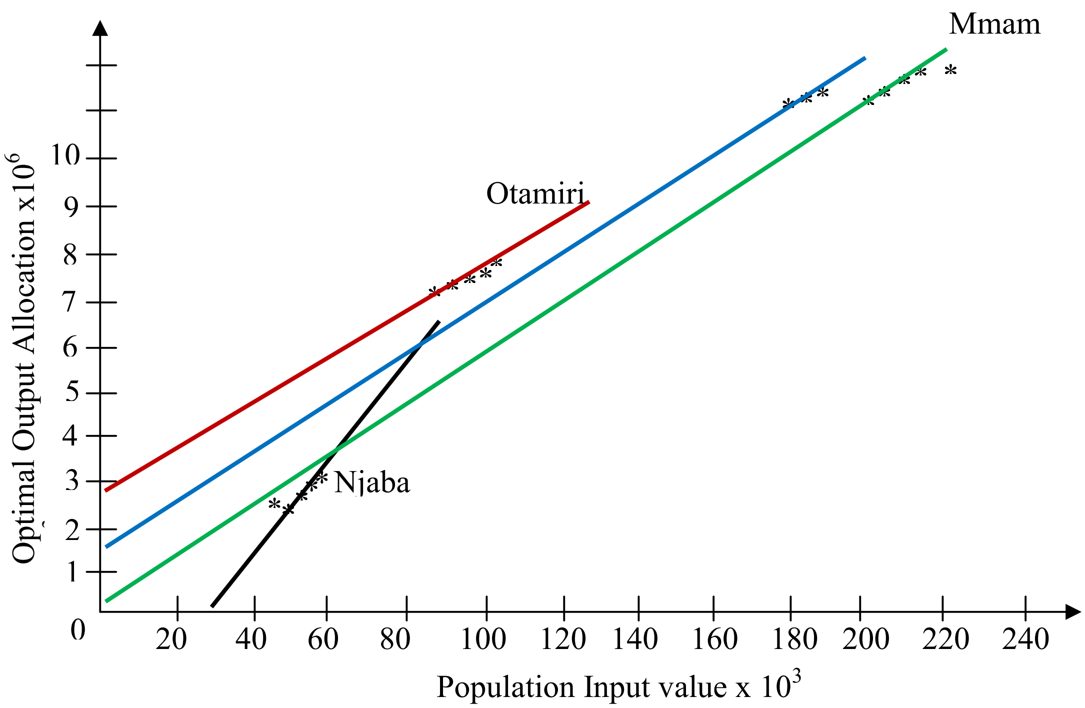

Fig. 4.6. Effect of Population Change on Optimal Output Allocation in the Basin

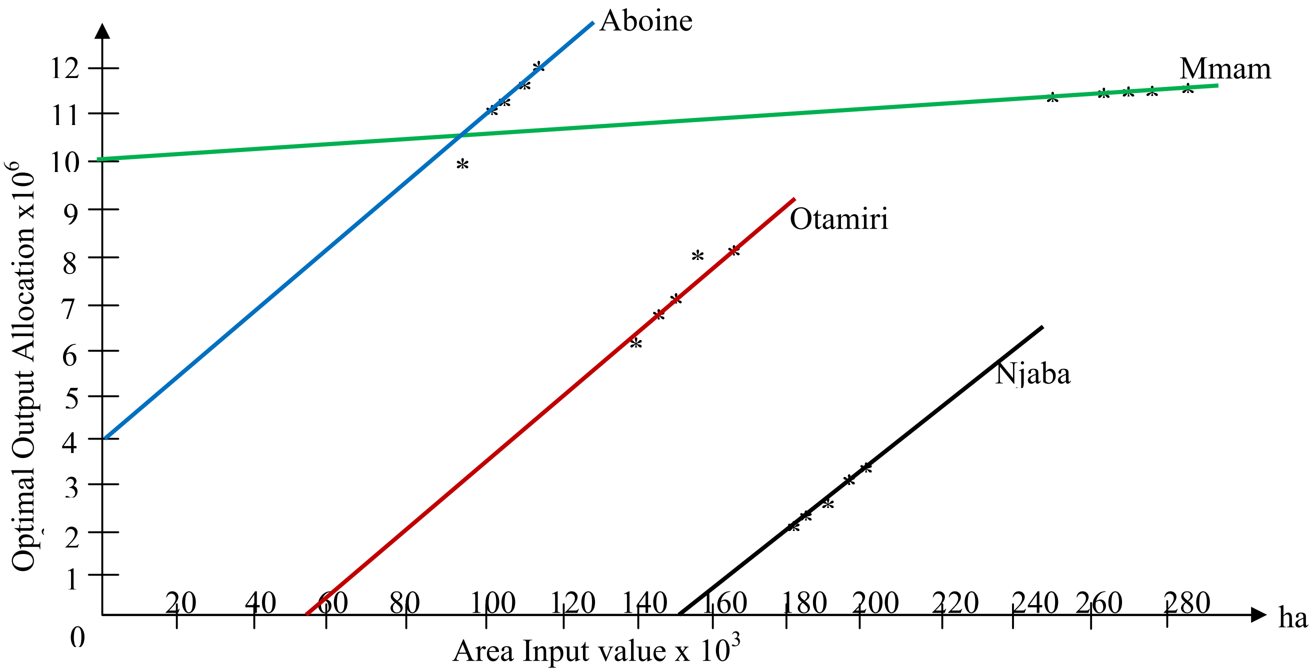

Fig. 4.7. Effect of Communal Land Area Change on Optimal Output Allocation in the Basin

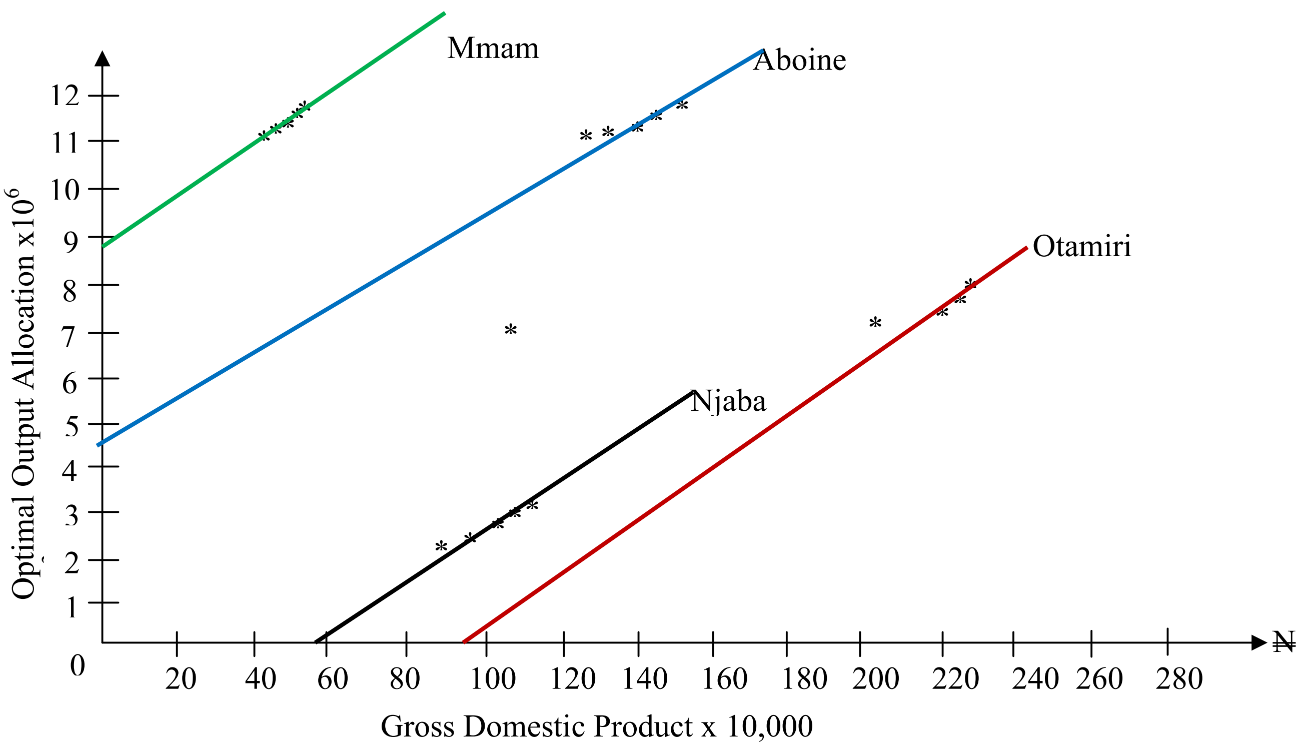

Fig. 4.8. Effect of Gross Domestic Product Change on Optimal Output Allocation in the Basin

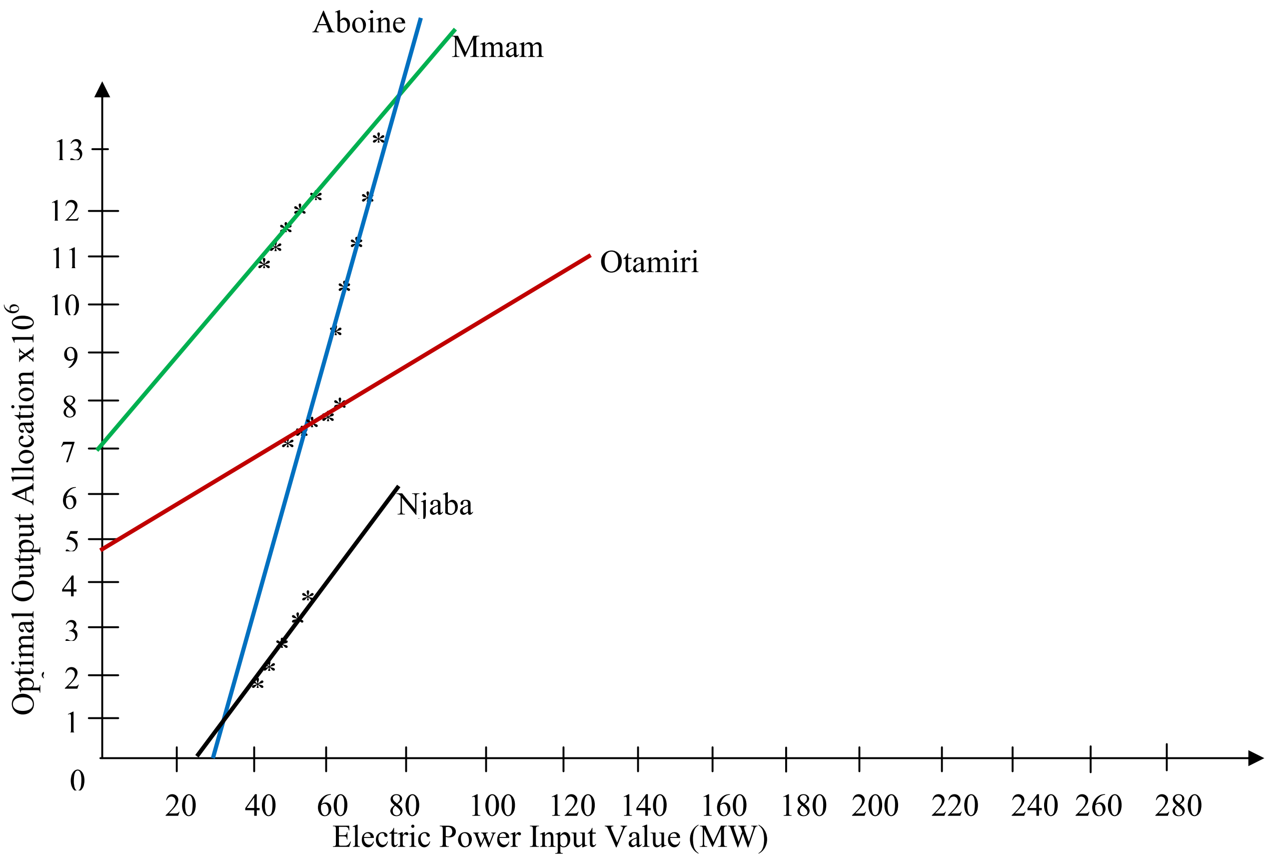

Fig. 4.9. Effect of Electric Power Capacity Change on Optimal Output Allocation in the Basin

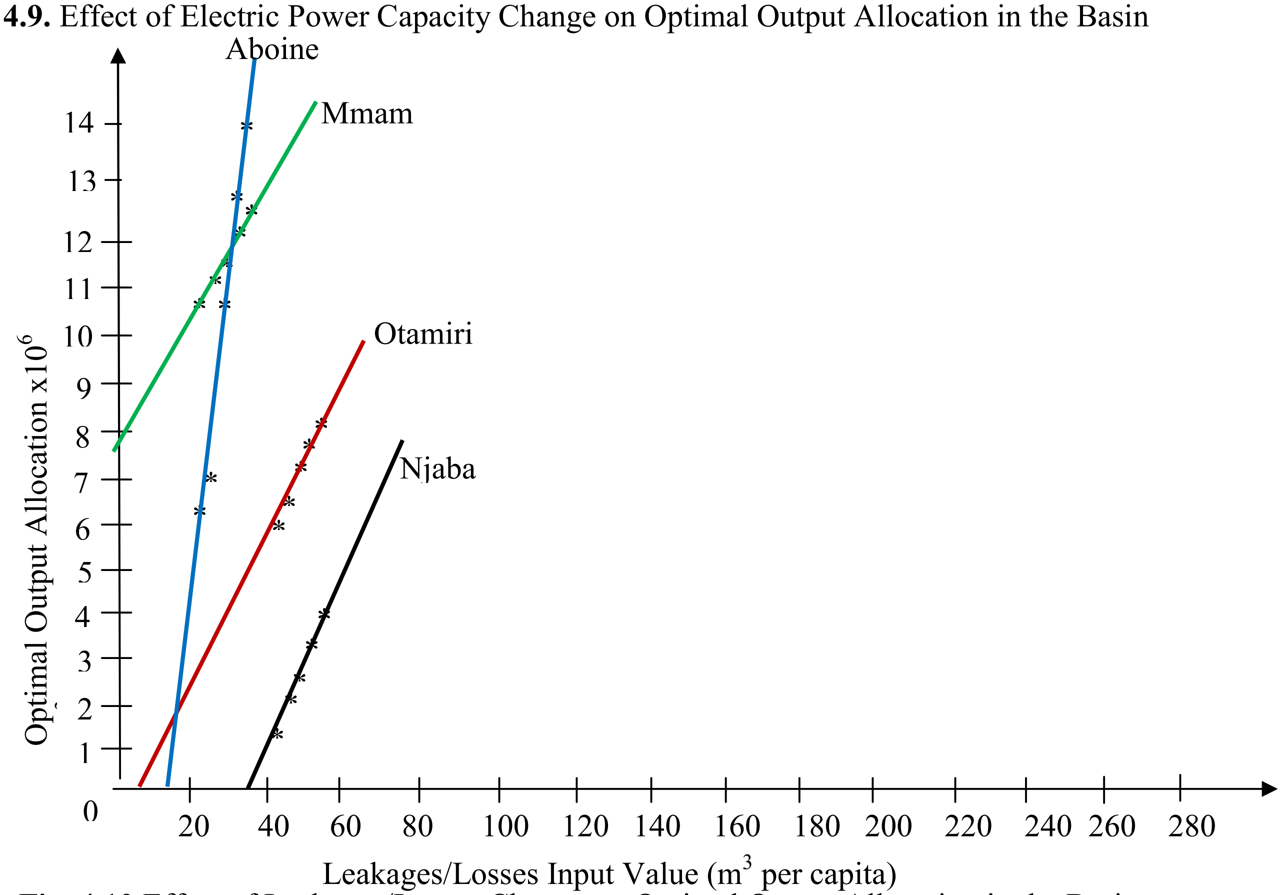

Fig. 4.10 Effect of Leakages/Losses Change on Optimal Output Allocation in the Basin

4.6 Verification of Solution By Optimization Software

The authenticity and accuracy of the solutions so far were verified manually through the application of the Simplex method in solving the LP allocation model equations for Aboine River Basin. The solution was done manually and the processes and the resulting tables are as presented below:

Objective function is given as in equation below:

Min $Z = 57X_1 + 64X_2 + 54X_3 + 65X_4$ …

Subject to these constraints:

$52422X_1 + 24568X_2 + 92787X_3 + 19734X_4 < 189,511$ … ………4.1

$27X_1 + 24X_2 + 30X_3 + 15X_4 < 96$

$75X_1 + 20X_2 + 30X_3 + 15X_4 < 140$…

$20X_1 + 10X_2 + 25X_3 + 10X_4 < 65$…

$7.5X_1 + 8.4X_2 + 7.2X_3 + 8.5X_4 < 31$…………………………………. 4.2

Transformation of the constraints into equations through the subtraction of slack variables and the addition of artificial variables;

$92422X_1 + 24568X_2 + 92787X_3 + 19734X_4 – S_1 + A_1 = 189,511$…

$27X_1 + 24X_2 + 30X_3 + 15X_4 – S_2 + A_2 = 96$ …

$75X_1 + 20X_2 + 30X_3 + 15X_4 – S_3 + A_3 = 140$…

$20X_1 + 10X_2 + 25X_3 + 10X_4 – S_4 + A_4 = 65$…

$7.5X_1 + 8.4X_2 + 7.2X_3 + 8.5X_4 – S_5 + A_5 = 31$…

The above transformations of the constraints with inequalities into equations will transform the objective function into the form;

Min Z = $57X_1 + 64X_2 + 54X_3 + 65X_4 + OS_1 + OS_2 + OS_3 + OS_4 + OS_5 +$

$MA_1 + MA_2 + MA_3 + MA_4 + MA_5$ …

Putting the above in tabular form we have Tables 4.28 to 4.37

Table 4.28: Initial Simplex Iteration Tableau

C_j			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
M	A_1	189511	52422	24568	92787	19734	0	0	0	0	0	1	0	0	0	0
M	A_2	96	27	24	30	15	0	1	0	0	0	0	1	0	0	0
M	A_3	140	75	20	30	15	0	0	1	0	0	0	0	1	0	0
M	A_4	65	20	10	25	10	0	0	0	1	0	0	0	0	1	0
M	A_5	31	7.5	8.4	7.2	8.5	0	0	0	0	1	0	0	0	0	1
Zj			52551.5m	24630.4m	92879.2m	19782.5m	M	M	M	M	M	M	M	M	M	M
Zj - Cj			52551.5m - 57	24630.4m - 64	92879.2m - 54	19782.5m - 65	M	M	M	M	M	O	O	O	O	O

Where Zj = ∑Cj x j

Table 4.29 2nd Simplex Iteration Tableau

C_j			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
M	A_1	2.04	0.56	0.26	1.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	A_2	34.8	10.2	16.2	0.0	8.7	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
M	A_3	78.8	58.2	12.2	0.00	8.7	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.0	0.00	0.00
M	A_4	14.0	6.0	3.5	0.00	4.75	0.00	0.00	0.00	1.0	0.00	0.00	0.00	0.00	1.0	0.00
M	A_5	16.31	3.47	6.53	0.00	6.99	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Zj			68.23m + 550.8	22.49m + 874.8	M	20.65m + 469.8	0.00	54	M	M	M	0.00	54	M	M	M
Zj - Cj			68.23m + 493.8	22.49m + 810.8	M - 54	20.65m + 404.8	0.00	54	M	M	M	- M	54-M	0.00	0.00	0.00

Table 4.30 3rd Simplex Iteration Tableau

C_j			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
M	X_1	1.28	0.00	0.14	1.00	0.13	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01	0.00	0.00
54	X_3	21.03	0.00	14.06	0.00	7.17	0.00	1.00	-0.20	0.00	0.00	0.00	1.00	-0.20	0.00	0.00
M	A_3	1.35	1.00	0.21	0.00	0.15	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00
M	A_4	5.9	0.00	2.24	0.00	3.85	0.00	0.00	-0.12	1.00	0.00	0.00	0.00	-0.12	1.00	0.00
M	A_5	11.63	0.00	5.80	0.00	6.47	0.00	0.00	-0.07	0.00	1.00	0.00	0.00	-0.07	0.00	0.00
Zj			M	8.25M + 67.22	57	10.47m + 394.59	0.00	54	-.17m -11.37	M	M	0.00	54	-0.17m -11.37	M	0.00
Zj – Cj			M - 57	8.25M + 703.22	3.00	10.47m + 329.59	0.00	54	-.17m -11.37	M	M	- M	54-M	-1.17 -11.37	0.00	-m

Table 4.31 4th Simplex Iteration Tableau

C_j			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
M	X_1	1.08	0.00	0.06	1.00	0.00	0.00	0.00	-0.01	-0.03	0.00	0.00	0.00	-0.01	-0.03	0.00
54	X_3	10.06	0.00	9.90	0.00	0.00	0.00	1.00	0. 02	-1.86	0.00	0.00	1.00	0. 02	-1.86	0.00
M	A_3	1.12	1.00	0.12	0.00	0.00	0.00	0.00	0.024	-0.039	0.00	0.00	0.00	0.024	-0.039	0.00
M	A_4	1.53	0.00	0.58	0.00	1.00	0.00	0.00	0.03	0.26	0.00	0.00	0.00	-0.03	0.26	0.00
M	A_5	1.73	0.00	2.05	0.00	0.00	0.00	0.00	0.124	1.68	1.00	0.00	0.00	0.124	-1.68	0.00
Z_j			M	2.17M + 575.72	57	65	0.00	54	0.148M – 1.44	-1.719M – 104.10	M	0.00	54	0.148M – 1.44	-1.719M - 85.25	0.00
Z_j - C_j			M - 57	2.17M + 511.72	3	0.00	0.00	54	0.148M – 1.44	-1.719M – 104.10	M	0.00	54-M	-0.852M – 1.44	-0.719M - 85.25	-M

Table 4.32 5th Simplex Iteration Tableau

C_j			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
57	X_1	1.029	0.00	0.00	1.00	0.00	0.00	0.00	-0.014	0.019	-0.03	0.00	0.00	-0.014	0.0192	0.00
54	X_3	2.344	0.00	0.00	0.00	0.00	0.00	0.00	-0.574	6.258	8.138	0.00	1.00	-0.574	6.258	0.00
M	A_3	1.019	0.88	0.00	0.00	0.00	0.00	0.00	0.017	0.059	-0.059	0.00	0.00	0.017	0.059	0.00
65	X_4	1.040	0.00	0.00	0.00	1.00	0.00	0.00	-0.038	0.736	-0.283	0.00	0.00	-0.065	0.736	0.00
64	X_2	0.844	0.00	1.00	0.00	0.00	0.00	0.00	0.060	-0.820	0.488	0.00	0.00	0.060	-0.820	0.00
Zj			0.88M	64	57	65	0.00	0.00	0.017M - 30.424	0.059M +334.375	-0.059M +388.115	0.00	54	-0.017M - 32.179	0.059M +334.386	0.00
Zj – Cj			0.88M - 57	0.00	3	0.00	0.00	0.00	0.017M - 30.424	0.059M +334.375	-0.059M +388.115	- M	54-M	-0.017M - 32.179	1.059M +334.386	-M

Table 4.33 6th Simplex Iteration Tableau

C_j			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
57	X_1	1.022	0.00	0.00	1.00	0.00	0.00	0.00	-0.001	0.00	-0.055	0.00	-0.003	-0.012	0.00	0.00
54	X_3	0.359	0.00	0.00	0.00	0.00	0.00	0.00	-0.092	1.00	1.300	0.00	0.160	-0.092	1.00	0.00
M	A_4	0.998	0.88	0.00	0.00	0.00	0.00	0.00	0.012	0.00	-0.136	0.00	-0.009	0.022	0.00	0.00
65	X_4	0.776	0.00	0.00	0.00	1.00	0.00	0.00	0.030	0.00	-1.240	0.00	-0.118	0.003	0.00	0.00
64	X_2	1.138	0.00	1.00	0.00	0.00	0.00	0.00	-0.015	0.00	1.554	0.00	0.131	-0.015	0.00	0.00
Zj			0.88M	64	57	65	0.00	0.00	0.012M -4.035	54	-0.136M +85.921	0.00	-0.009M +9.183	0.022M - 5.653	54	0.00
Zj - Cj			0.88M -57	0.00	3	0.00	0.00	0.00	0.012M -4.035	54	-0.136M +85.921	- M	-0.009M +9.183	-0.978M - 5.653	54 –M	-M

Table 4.34 7th Simplex Iteration Tableau

C_j			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
57	X_1	1.022	0.00	0.00	1.00	0.00	0.00	0.00	-0.001	0.00	-0.055	0.00	-0.003	-0.012	0.00	0.00
54	X_3	0.359	0.00	0.00	0.00	0.00	0.00	0.00	-0.092	1.00	1.300	0.00	0.160	-0.092	1.00	0.00
M	S_1	1.134	1.00	0.00	0.00	0.00	0.00	0.00	0.014	0.00	-0.155	0.00	-0.010	0.025	0.00	0.00
65	X_4	0.776	0.00	0.00	1.00	1.00	0.00	0.030	0.00	-1.240	0.00	-0.118	0.003	0.003	0.00	0.00
64	X_2	1.138	0.00	1.00	0.00	0.00	0.00	0.00	-0.015	0.00	1.554	0.00	0.131	-0.015	0.00	0.00
Zj			0.00	64	122	-65	0.00	1.95	-5.985	-26.6	166.521	-7.67	17.048	-6.417	54	0.00
Zj - Cj			-57	0.00	68	0.00	0.00	1.95	-5.985	-26.6	166.521	-7.67 - M	-17.048M	-6.417 -M	54 –M	-M

Table 4.35 8th Simplex Iteration Tableau

Cj			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
57	X_1	1.087	0.00	0.00	1.00	0.00	0.00	0.00	-0.005	0.042	0.00	0.00	0.004	-0.016	0.042	0.00
54	X_3	1.076	0.00	0.00	0.00	0.00	0.00	0.00	-0.071	0.769	1.00	0.00	0.123	-0.071	0.769	0.00
64	X_2	1.077	1.00	0.00	0.00	0.00	0.00	0.00	0.003	0.119	0.00	0.00	0.009	0.014	0.119	0.00
65	X_4	0.776	0.00	0.00	0.00	0.00	0.00	0.030	0.00	-1.240	0.00	-0.118	0.003	0.003	0.00	0.00
O	S_2	0.709	0.00	1.00	0.00	0.00	0.00	0.00	1.248	-1.195	0.00	0.00	-0.060	0.095	-1.195	0.00
Zj			64	64	54	0.00	0.00	1.95	75.753	-112.62	54	-7.65	1.529	1.529	-32.56	0.00
Zj-Cj			-3	0.00	-3	-65	0.00	1.95	75.753	-112.62	54	-7.67M	1.529 -M	1.529 -M	-32.56 -M	-M

Table 4.36 9th Simplex Iteration Tableau

Cj			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
57	X_1	1.040	0.00	0.004	1.00	0.00	0.00	0.00	0.00	0.037	0.00	0.00	0.004	-0.016	0.037	0.00
54	X_3	1.015	0.00	- 0.057	0.00	0.00	0.00	0.00	0.00	0.701	1.00	0.00	0.120	0.066	0.641	0.769
64	X_2	1.175	1.00	- 0.007	0.00	0.00	0.00	0.00	0.00	0.122	0.00	0.00	0.009	0.014	0.122	0.00
65	X_4	0.776	0.00	0.00	0.00	0.00	0.00	0.030	0.00	-1.240	0.00	-0.118	0.003	0.003	0.00	0.00
O	X_2	0.568	0.00	0.801	0.00	0.00	0.00	0.00	1.00	-0.957	0.00	0.00	-0.048	0.076	-0.958	0.00
Zj			0.00	57.57	1.14	0.00	0.00	1.95	64	-102.117	54	-7.67	-3.831	8.431	-24.591	41.526
Zj-Cj			-57	-6.43	60	-65	0.00	1.95	64	-102.117	54	7.67 - M	3.831 -M	8.431 -M	-24.591 -M	41.526 -M

Table 4.37 10th Simplex Iteration Tableau

Cj			57	64	54	65	0	0	0	0	0	M	M	M	M	M
	BV	Q	X_1	X_2	X_3	X_4	S_1	S_2	S_3	S_4	S_5	A_1	A_2	A_3	A_4	A_5
57	X_1	1.004	0.00	0.004	1.00	0.00	0.00	0.00	0.00	0.019	0.00	0.00	+0.004	-0.008	0.019	0.00
54	X_3	1.010	0.00	-0.057	0.00	0.00	0.00	0.00	0.00	0.701	0.00	0.00	-0.20	-0.066	-0.641	0.769
64	X_2	1.079	-1.00	-0.002	-0.080	0.00	0.00	0.00	0.00	0.122	0.00	0.00	-0.009	-0.014	0.122	0.00
65	X_4	0.776	0.00	0.00	0.00	0.00	0.00	0.030	0.00	-1.240	0.00	-0.118	-0.063	-0.003	0.00	0.00
0	S_2	0.568	0.00	0.801	0.00	0.00	0.00	0.00	1.00	-0.957	0.00	0.00	-0.048	0.076	-0.958	0.00
Zj			-64	-2.978	51.880	0.00	0.00	0.00	0.00	-33.86	-54.00	-7.670	-15.243	-5.111	-25.723	41.53
Zj-Cj			-7.00	-66.978	-2.120	-65.00	0.00	0.00	0.00	-33.86	-54.00	-7.670 -M	-15.24 -M	-5.111 -M	-25.72 -M	-41.53 -M

From the solutions obtained through the manual solution of the model for Aboine river basin, a comparative analysis of the solution results from the software and that of the manual method can be carried through as shown in Table 4.38.

Table 4.38 Comparison of Manual And Software Solutions.

Subarea X_n	**Manual Solution**	**Software Solution**
X_1	1.004	1.007
X_2	1.079	1.089
X_3	1.010	1.009
X_4	0.776	0.829

From Table 4.38, it can be observed that the differences between the software and manual solution are relatively minimal and can be neglected. The difference between the two solutions for subarea X_1 is 0.003 which amounted to 0.0029% degree of error while the degree of error arising from the solution for subarea X_4 is equal to 6.83%.

4.7 Comparison of The Existing System And The Proposed System

The comparisons of the existing system of allocation and that of the proposed system are done to evaluate comparatively the differences between the allocations made in the existing system and that of the proposed system. The comparative analysis was extended through the evaluation of the water allocations as it concerns existing allocation system and that of the optimality in the various allocation usage areas of consumption/domestic, ecology, industry, energy and leakage/losses mitigation in the various sub basins. The results obtained are shown in Tables 4.39 to 4.42.

Table 4.39 Comparison of the Existing and Optimal Allocation in Njaba River Basin

	Usage area	**Existing allocation(m^3)**	**Optimal Allocation(m^3)**	**Percentage Difference (%)**
1	Consumption and domestic use	1,417,467	1,607,831	13.43
2	Ecological use	862,900	866,761	0.50
3	Industrial use	3906	3950	1.13
4	Energy use	0.00	0.0748	7.48
5	Leakages/losses mitigation	372,902	378,517	1.51
6	Total Allocation	2,657,199	2,857,059.07	7.73

Table 4:40 Comparison of the Existing and Optimal Allocation in Mmam Sub-River Basin

	Usage area	Existing Allocation (m^3)	Optimal Allocation(m^3)	Percentage Difference (%)
1	Consumption and domestic use	8453340	9451166	11.8
2	Ecological use	679600	684951	0.80
3	Industrial use	2920	3862	32.26
4	Energy use	0.00	0.0822	8.22
5	Leakages/losses mitigation	1,290,849	1,485,456	15.50
6	Total Allocation	10,426,709	11,625,435.08	11.50

Table 4.41 Comparison of the Existing and Optimal Allocation in Otamiri Sub-River Basin

	Usage area	Existing Allocation (m^3)	Optimal Allocation (m^3)	Percentage Difference (%)
1	Consumption and domestic use	3,813,384	5,517,595	44.69
2	Ecological use	367,763	493,561	34.21
3	Industrial use	6,315	8,759	38.70
4	Energy use	0.00	0.1443	14.43
5	Leakages/losses mitigation	1,115,221	1,556,830	39.60
6	Total Allocation	5,302,683	7,576,745.14	42.89

Table 4.42 Comparison of the Existing and Optimal Allocation in Aboine Sub-River Basin

	Usage area	Existing Allocation (m^3)	Optimal Allocation(m^3)	Percentage Difference (%)
1	Consumption and domestic use	8,030,581	8,199,450	2.10
2	Ecological use	1,047,200	1,132,520	8.15
3	Industrial use	1251	2373	89.69
4	Energy use	0.00	0.1357	13.57
5	Leakages/losses mitigation	1,901,376	2,130,222	12.04
6	Total Allocation	10,980,408	11,464,565.14	4.41

From Tables 4.39 to 4.42, it can be observed that in the various sub-river basins, the quantity of water allocated by the model as reflected in the proposed system was greater than that of the existing system. For instance, the allocation made for consumption and domestic uses in Njaba, Mmam, Otamiri, and Aboine sub-river basins increased by 11,06%, 38.11%, 30.50% and 12.04% respectively. From Table 4.39, the existing system uses a small domestic ration of water supply, where quota and size are the parameters of consideration, with the population and land area comprising the size. It shows that 2,857,057.07m^3 of water is the desired optimal allocation to achieve fairness and efficiency in the usage areas and the subareas of the Njaba River Basin. The percentage difference of the existing allocation and that of the proposed is put at 7.5% and this shows that the optimal allocation is bigger by the stated percentage difference.

Table 4.40 shows that 11,625,435.08 m^3 of water is the value of the proposed system in Mmam river basin as against 10,426,709 of water that the existing system provides. The increased quantity is due to the more efficient and optimal application of the resource for improved water supply for various uses. The total allocation in the basin as offered by the existing allocation was increased through the optimization process by 10.50%.

From Table 4.41, the existing system provides an allocation of 5,303,694m^3 of water while the proposed system gives an allocation of 6757,785m^3 of water. The increased allocation of 42.89% by the proposed system will improve the sanitation and health conditions of the sub-basin citizenry.

4.8 Analysis of The Cost Implication of The Allocation System

Following the prevalence of epidemic outbreaks, increased incidences of diseases, abysmal sanitary conditions, high rate of mortality, inadequate power generation, hunger, poverty, and poor economic development, there are immense positive implications which the challenges of water allocations can impact on the cost of the water used for various purposes in the basin. It has been observed that the proposed model allocated more water than the existing system. The increment in the quantity of water as allocated by the proposed allocation system means an increase in the standard of healthy living and improvement in the sanitation condition of the basin. The inadequate quantity of water allocated by the existing system exposes the inadequacy of the water used which led to the persistent and high degree of water-related diseases existing within the basin. The research further investigated the degree of prevalence of diseases caused by water such as typhoid, cholera, dysentery, etc with information volunteered by health workers in the clinics, hospitals and health centers within the communities of the sample areas. The results of the data collected are shown on Table 4.43.

Table 4.43 Cost Effects of Poor Water Allocation System on Health

S/N	River Basin	Average Number of Patients Per Day	Annual Average Number of Patients	Cost of Treatment Per Patient (N)	Total Annual Cost of Treatment (N)
1	Njaba	53	19,345	6,900	1.335
2	Mmam	29	10,585	10,150	1.074
3	Otamiri	45	16,425	6,350	1.043
4	Aboine	16	5,840	7,900	0.461

On the cost of water sold within the sample communities, it was revealed that on the average, 20 liters of water were sold for ten naira (N10.00). From this current market price, it follows that one cubic meter of water should cost five hundred naira (N500.00). The cost implication for the effects of the changes resulting from the optimized water allocations is shown in Table 4.44

Table 4.44 Cost Implication of the Optimized Allocation System

River Sub-basin	Allocated Water (m^3)			Cost Implication x10^8 (₦)			
				Existing			Optimal
	Existing (1)	Optimal (2)	Rate (₦/m^3) (3)	Quantity Cost (4) = (1) x (3)	Hazard Cost (5)	Total Cost (6) = (4) + (5)	Quantity Cost (7) = (2) x (3)
Njaba	2,657,915	2,863,338	500	13.290	1.335	14.625	14.317
Mmam	10,427,524	11,626,257	500	57.138	1.074	58.202	58.131
Otamiri	6,503,694	6,657,785	500	32.518	1.043	33.561	33.289
Aboine	11,981,512	11,465,922	500	59.908	0.461	60.369	57.330

From Table 4.44, it was observed that there was a decrease in the cost of the optimally allocated water while the existing allocation was more costly. The reduction in cost by the optimized system is a total improvement of the entire sanitary condition, adequate potable water, agricultural boost, adequate power generation, high rate of industrialization and robust green economy which is what the allocation system is intended to achieve. For instance, in the Aboine River Basin the existing allocation gave 6.04 trillion naira while the optimal allocation cost was drastically reduced to 5.73 trillion naira representing cost reduction to the tune of 310 billion naira and this amounted to 5.33%.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

On the basis of the results obtained and the analysis that ensued therefrom, the following are the principal findings made

1 The optimization process has been able to establish an order for water allocation in the basin as against the previous situation where there was no order in allocating water and this disorderliness has resulted to poor appropriation of water.

2 There are abundant quantities of water in the sub-basins and the available water were enough to satisfy the allocations made by the optimization.

3 From the allocations made, the industrial and energy uses had the least quantity of water while the consumption and domestic uses were apportioned the greatest quantity.

4 The range at which optimal allocations could be attained was established through the sensitivity analysis done with input variables.

5 The proposed allocation system is more cost-effective as its optimized cost showed 5.33% cost reduction with improved sanitary, health, power generation, agriculture and industrialization.

The research has introduced an optimization model that can be used to allocate water resources optimally in Anambra-Imo River Basin of Nigeria. This research when fully applied in the basin will introduce water supply sustainability and affect positively the economic development of the basin. Conflicts over water allocations among communities and uses can be arbitrated based on facts and figures, as the allocation model will be able to provide modalities for such situations.

5.2 Recommendations

Following the analysis and the findings of this research, the following recommendations are made:

1) Groundwater is a major source of water that should be properly allocated and therefore it is suggested that a more specific work be carried out on modeling groundwater allocation in Anambra-Imo River Basin.
2) Integrated water resources management and/or any other holistic approach should be adopted in the river basin and more attention should be given to the development of rivers in the basin.
3) Water treatment plants should be established in the river basin with the various rivers as the major intake sources to enable potable water to be provided to the basin citizenry for domestic use so as to discourage over-exploitation of the groundwater which is known to cause land subsidence.
4) Economic activities which do not impact negatively on the rivers and its watershed such as sand dredging, fishery, etc. should be encouraged and allowed to thrive.

5) This optimization model should form part of the planning and management of water resources by the Anambra-Imo River Basin Development Authority to forestall further arbitrary allocation of water to communities in the basin.

6) Regular public enlightenment and awareness should be created to stress the importance of water losses reduction with appropriate laws which will stipulate penalty for defaulters.

7) The optimal allocation should be implemented in order to make adequate water available in all sectors that have been neglected in the existing water supply scheme. This will help to reduce some negative impacts which lack of water has created in these areas.

5.3 Contribution To Knowledge

The research has successfully contributed to knowledge by the

1. Developed and solved equations for optimal water resources allocation in the Anambra-Imo River Basin.
2. Successful application of the model to Anambra-Imo River Basin and a comparison with existing water resources allocation revealing reduction in cost of water resources allocation.
3. Provision of a range of variability of input variables and constraints within which the optimal solution is valid.

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APPENDIX I

LETTER FOR COLLECTION OF DATA

Department of Civil Engineering,

Post Graduate School,
Federal University of Technology,
Owerri.

27th July, 2009.

The Managing Director,
Anambra-Imo River Development Authority,
Agbala, Owerri.

Dear Sir,

APPLICATION FOR THE COLLECTION OF DATA

I humbly wish to apply for the collection of some relevant data from your agency to enable me prosecute my Ph.D. thesis titled " Modeling Water Resources Allocation In Anambra Imo River Basin "

I am a student of the Federal University of Technology, Owerri and your agency has been considered as a veritable source for the collection of some needed primary data.
I promise that all the data collected will be used only for the purposes of this research.

It will be a great delight if my application is favourably considered.

Yours faithfully,

Engr. Obi L.E. (MNSE, MNICE, MIWRE, MHAN)

LETTER OF INTRODUCTION

Department of Civil Engineering,
Post Graduate School,
Federal University of Technology,
Owerri.

7th December, 2010

Dear Respondent,

The researcher is a Post Graduate student of the Federal University of Technology, Owerri. Carrying out a research on the titled "**Modeling Water Resources Allocation In Anambra-Imo River Basin**".

Your maximum cooperation in completing this questionnaire is highly solicited as all information provided will be used for academic purposes only and will be treated with utmost and unreserved confidentiality. No identity of yours is required and as such, your responses cannot be used against you in any form. Hence, your honest response is highly anticipated.

The researcher will be grateful for your prompt compliance as this will facilitate the early completion of this research.

Thanks.

Yours faithfully,

Engr. Obi L.E.

QUESTIONNAIRE
WATER USAGE DATA COLLECTION WITHIN OTAMIRI AND NJABA RIVER SUB-BASINS

SECTION A
PERSONAL DATA

Read the following statements carefully and write down your responses in the blank spaces provided, where there are alternatives, put a check (√) against the responses that is best applicable to you. Please, check (√) as appropriated in the boxes provided or otherwise specify.

A. Which of these communities are you living in?
(i) Egbu ☐ (ii) Nekede ☐ (iii) Ihiagwa ☐ (iv) Eziobodo ☐
(v) Obinze ☐ (vi) Mgbirichi ☐ (vii) Umuagwo ☐ (viii) Amucha ☐
(x) Okwudor ☐ (xii) Umuaka ☐ (xiii) Awo-Omama ☐
(xiv) Nkwesi ☐

B. Educational Qualification
(i) FSLC (ii) SSCE/NECO ☐ (iii) NCE/OND ☐ (iv) HND/BSC ☐

(v) Others (specify) --

SECTION B

A. What is your main source of water supply?
(i) Otamiri River ☐ (ii) Njaba River ☐ (iii) Borehole ☐

B. State your use(s) of water,
(i) Drinking ☐ (ii) Washing ☐ (iii) Cooking ☐ (iv)Garden tendering ☐

(v) Other uses (specify) -----------------------------------

C. Which of these capacities of cans do you use for fetching water?
(i) 10 litres ☐ (ii) 20 litres ☐ (iii) 25 litres ☐ (iv) 30 litres ☐
(v) 40 litres ☐ (vi) 50 litres ☐ (vii) Others (specify) ---------------

D. Write down in the box the number of such cans you use in fetching water each day

(i) 10 litres ☐ (ii) 20 litres ☐ (iii) 25 litres ☐ (iv) 30 litres ☐
(v) 40 litres ☐ (vi) 50 litres ☐ (vii) Others (specify) -----------------

SECTION C

(FOR INDUSTRIES ONLY)

A. What is the main source of your industry's water supply?
(i) Otamiri ☐ (ii) Njaba ☐ (iii) Borehole ☐

B. Which of these towns is your industry located?
(i) Egbu ☐ (ii) Nekede ☐ (iii) Ihiagwa ☐ (iv) Obinze ☐
(v) Mgbirichi ☐ (vi) Umuagwo ☐ (vii) Eziobodo ☐ (viii) Amucha ☐
(ix) Okwudor ☐ (x) Umuaka ☐ (xi) Awo-omamma ☐ (xii) Nkwesi ☐

C. What is the name of your company?

D. What is the product of the industry?

E. What is the quantity of water used by the industry in a day?

G. Do you export your products Yes ☐ No ☐ (Tick approximately)

H. What is financial amount of your exports ----------------------------------

I. Estimate the cost of government assistant rendered to your company

----

SECTION D

(FOR HEALTH INSTITUTIONS)

(J) In which of these towns is your hospital/clinic located?
(i) Egbu ☐ (ii) Nekede ☐ (iii) Ihiagwa ☐ (iv) Obinze ☐
(v) Mgbirichi ☐ (vi) Umuagwo ☐ (vii) Eziobodo ☐ (viii)Amucha ☐
(ix) Okwudor ☐ (x) Umuaka ☐ (xi) Awo-Omamma ☐ (xii) Nkwesi ☐

(K) How many patients do you admit a day on water caused diseases? ☐

(L) How much on the average do you use to treat patients with water related diseases? ☐

(M) Has there been any outbreak of epidemic on water related diseases in your area? Yes ☐ No ☐ *Tick as appropriate*

(N) If M above is yes, state the number of patients in such cases ☐

QUESTIONNAIRE

WATER USAGE DATA COLLECTION WITHIN MMAM AND ABOINE RIVER SUB-BASINS

SECTION A

PERSONAL DATA

Read the following statements carefully and write down your responses in the blank spaces provided, where there are alternatives, put a check (√) against the responses that is best applicable to you. Please, check (√) as appropriated in the boxes provided or otherwise specify.

A. Which of these communities are you living in?

(i) Inyi ☐ (ii) Awlaw ☐ (iii) Akpugoeze ☐ (iv) Ufuma ☐

(v) Oboloafor ☐ (vi) Ikem ☐ (vii) Eha Amufu ☐ (viii) Nkalaha ☐

B. Educational Qualification

(i) FSLC ☐ (ii) SSCE/NECO ☐ (iii) NCE/OND ☐ (iv) HND/BSC ☐

(v) Others (specify) --

SECTION B

C. What is your main source of water supply?

(i) Mmam River ☐ (ii) Aboine River ☐ (iii) Borehole ☐

D. State your use(s)

(i) Drinking ☐ (ii) Washing ☐ (iii) Cooking ☐ (iv) Garden tendering ☐ (v) Other uses (specify) -----------------------------------

E. Which of these capacities of cans do you use for fetching water?

(i) 10 litres ☐ (ii) 20 litres ☐ (iii) 25 litres ☐ (iv) 30 litres ☐

(v) 40 litres ☐ (vi) 50 litres ☐ (vii) Others (specify) ------
----

F. Write down in the box the number of such cans you use in fetching water each day

(i) 10 litres ☐ (ii) 20 litres ☐ (iii) 25 litres ☐ (iv) 30 litres ☐

(v) 40 litres ☐ (vi) 50 litres ☐ (vii) Others (specify

SECTION C

(FOR INDUSTRIES ONLY)

G. What is the main source of your industry's water supply?

(i) Mmam ☐ (ii) Aboine ☐ (iii) Borehole ☐

H. In which of these towns is your industry located?

(i) Inyi ☐ (ii) Awlaw ☐ (iii) Akpugoeze ☐ (iv) Ufuma ☐

(v) Oboloafor ☐ (vi) Ikem ☐ (vii) Eha Amufu ☐

(viii) Nkalaha ☐

I. What is the name of your company?

J. What is the product of the industry?

K. What is the quantity of water used by the industry in a day?

M. Do you export your products Yes ☐ No ☐ (Tick appropriately)

N. What is financial amount of your exports --------------------------------

O. Estimate the cost of government assistant rendered to your company

----

SECTION D

(FOR HEALTH INSTITUTIONS)

(P) In which of these towns is your hospital/clinic located?

(i) Inyi ☐ (ii) Awlaw ☐ (iii) Akpugoeze ☐ (iv) Ufuma ☐ (v) Oboloafor ☐

(vi) Ikem ☐ (vii) Eha Amufu ☐ (viii) Nkalaha ☐

(Q) How many patients do you admit a day on water caused diseases? ☐

(R) How much on the average do you use to treat patients with water related diseases? ☐

(S) Has there been any outbreak of epidemic on water related diseases in your area? Yes ☐ No ☐ *Tick as appropriate*

(T) If S above is yes, state the number of patients in such cases ☐

APPENDIX II

DISCHARGE DATA

WATER DISCHARGE
(M^3/S)

RIVER SYSTEM: IMO STATION: NEKEDE
NAME OF RIVER / STREAM: OTAMIRI LOCATION" LAT: $05^0 26^1$N
LONG: 070 27^I
HYDROLOGICAL YEAR : 2007/2008

DAYS	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
1	7.70	7.10	7.10	7.34	8.12	9.24	8.96	8.54	7.98	7.84	7.70	7.58
2	7.70	7.34	6.98	7.22	8.26	9.10	8.96	8.54	7.98	7.84	7.70	7.58
3	7.46	7.34	7.70	7.70	8.32	9.24	9.10	8.54	7.98	7.84	7.70	7.58
4	7.34	7.22	7.10	7.58	8.54	9.24	9.38	8.40	7.98	7.84	7.70	7.58
5	7.46	.22	7.10	7.22	8.26	9.24	9.10	8.12	7.98	7.84	7.70	7.58
6	7.46	7.10	7.22	7.46	8.82	9.24	9.24	8.12	7.98	7.98	7.70	7.58
7	N.R	7.22	7.10	7.34	9.24	9.24	9.24	8.12	7.98	7.98	7.70	7.58
8	N.R	7.22	7.10	7.10	8.40	10.98	9.24	8.26	7.98	8.26	7.70	7.58
9	7.70	7.10	7.10	7.46	8.40	11.78	9.56	8.26	7.98	7.98	7.70	7.58
10	7.98	7.10	7.10	7.34	8.68	9.24	10.08	8.40	8.12	7.84	7.84	7.58
11	7.58	7.22	7.10	8.54	9.38	9.10	9.56	8.40	7.98	7.84	7.84	7.58
12	7.46	7.22	6.98	7.70	9.10	9.38	9.10	8.40	7.98	7.98	7.84	7.84
13	7.46	7.10	7.70	7.70	9.10	9.24	9.10	8.26	7.98	7.98	7.84	7.98
14	7.46	7.10	7.10	7.70	9.10	9.24	9.24	8.26	7.98	8.40	7.84	7.84
15	7.46	7.10	7.22	9.10	8.54	9.24	9.56	8.12	7.26	8.26	7.70	7.84
16	7.34	7.10	7.22	8.12	8.68	9.10	8.96	8.12	8.12	8.26	7.70	7.70
17	7.34	7.10	6.98	7.84	9.10	9.10	8.82	8.12	7.98	7.98	7.70	7.70
18	7.34	7.10	7.10	7.84	9.10	9.10	8.68	7.98	7.98	7.98	7.70	7.70
19	7.46	7.10	7.10	7.84	9.10	9.24	8.68	7.98	7.84	7.98	7.70	7.70
20	7.46	7.10	6.98	7.84	8.68	9.96	8.68	7.98	7.84	8.12	7.70	7.84
21	7.34	7.10	6.98	7.84	8.96	8.96	9.56	7.98	7.84	7.84	7.70	7.70
22	7.34	7.10	8.40	7.70	8.82	9.10	9.56	7.98	7.98	7.84	7.70	7.70
23	7.34	7.10	8.12	7.98	8.82	8.96	9.56	7.98	7.84	7.84	7.70	7.70
24	7.34	7.10	7.22	7.84	9.10	8.96	9.24	7.98	7.84	7.84	7.70	7.84
25	7.46	7.10	7.10	8.12	9.10	9.10	9.10	7.98	7.98	7.84	7.70	7.84
26	7.34	7.10	7.10	7.98	9.10	8.96	9.10	7.98	7.84	7.70	7.58	7.98
27	7.22	7.10	7.10	7.84	9.24	8.96	9.10	7.98	7.84	7.70	7.58	7.98
28	7.22	7.10	7.22	8.12	9.10	8.82	9.38	7.98	7.84	7.84	7.58	7.98
29	7.10	7.10	7.34	7.98	9.10	8.68	9.24	7.98	7.84	7.84	N.R	7.98
30	7.10	7.10	7.46	8.12	9.24	8.82	9.10	7.98	7.84	7.70	N.R	7.98
31	N.R	7.22	N.R	8.68	9.24	N.R	8.68	N.R	7.98	7.70	N.R	7.98
Max	7.98	7.34	8.40	9.10	9.38	11.78	10.08	8.54	8.26	8.40	7.84	7.98
Mean	7.43	7.13	7.24	7.79	8.88	9.25	9.20	8.16	7.95	7.91	7.66	7.73
Min	7.10	6.98	6.98	7.10	8.12	7.94	8.68	7.98	7.84	7.0	7.70	7.58

Source: Anambra Imo River Basin Development Authority,2007

WATER DISCHARGE
(M^3/S)

RIVER SYSTEM: ANAMBRA
STATION: OBOLLO AFOR
NAME OF RIVER / STREAM: ABOINE RIVER **LOCATION:**
LAT: 07^0 30^1N
LONG: $05^0 48^1$

HYDROLOGICAL YEAR: 2011/2012

DAYS	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
1	2.98	2.92	3.01	2.96	3.01	3.20	4.01	6.55	6.80	5.88	3.20	2.92
2	2.98	2.92	3.01	2.97	3.01	3.20	4.01	6.55	6.80	5.84	3.20	2.92
3	2.98	2.92	2.98	2.97	3.01	3.20	4.01	6.55	6.80	5.84	3.20	2.92
4	2.98	2.92	2.98	2.97	3.01	3.20	4.01	6.55	9.41	5.84	3.20	2.92
5	2.98	2.92	2.98	2.97	3.01	3.21	4.58	6.55	9.41	5.84	3.20	2.92
6	3.01	2.92	2.98	2.97	2.99	3.21	4.58	6.60	9.41	5.84	3.20	2.92
7	3.01	2.92	2.98	2.97	2.99	3.21	4.58	6.60	9.41	5.84	3.20	2.92
8	3.01	2.92	2.98	2.97	2.99	3.21	4.58	6.60	7.00	5.90	2.99	2.92
9	3.01	2.90	2.98	2.97	2.99	3.25	4.58	6.60	7.00	5.90	2.99	2.92
10	3.01	2.90	2.98	2.97	2.99	3.25	4.58	6.60	7.00	5.90	2.99	2.92
11	3.01	2.90	2.98	2.97	2.99	3.25	4.60	6.60	7.00	5.90	2.99	3.01
12	3.01	2.90	2.97	2.97	2.99	3.25	4.60	6.60	7.00	5.90	2.99	3.01
13	3.01	2.90	2.97	2.97	2.98	3.25	4.60	6.60	7.00	5.90	2.99	3.01
14	3.01	2.90	2.97	2.97	3.10	3.25	4.60	6.60	7.00	5.90	2.99	2.99
15	2.96	2.90	2.97	2.97	3.10	3.25	4.60	6.60	7.00	5.90	2.99	2.99
16	2.96	2.90	2.97	2.96	3.08	3.25	4.60	6.62	7.20	5.90	2.99	2.99
17	2.96	2.90	2.97	2.96	3.08	3.25	4.60	6.62	7.20	5.94	2.98	2.99
18	2.96	2.90	2.97	2.96	3.08	3.27	8.70	6.62	7.20	5.94	2.98	2.99
19	2.96	2.91	2.97	2.96	3.08	3.27	8.70	6.62	7.20	5.94	2.98	2.99
20	2.96	2.91	2.97	2.96	3.08	3.27	8.70	6.62	7.20	5.50	2.98	2.99
21	2.96	2.91	2.96	2.97	3.08	3.27	6.00	6.68	7.20	5.50	2.93	2.99
22	2.96	2.91	2.96	2.97	3.08	3.27	6.00	6.68	7.20	3.02	2.92	2.99
23	2.96	2.91	2.96	2.97	3.08	3.27	6.00	6.68	8.10	3.02	2.92	2.98
24	2.94	2.91	2.96	2.97	3.08	3.27	6.00	6.68	8.10	3.02	2.92	2.98
25	2.94	2.91	2.96	2.97	3.08	3.27	7.02	6.68	8.10	3.02	2.92	2.98
26	2.94	2.91	2.96	2.97	3.08	3.29	6.50	6.68	8.10	5.13	2.93	2.98
27	2.94	2.91	2.96	2.97	3.08	3.29	6.50	6.67	8.10	5.13	2.93	2.99
28	2.93	2.91	2.96	2.90	3.12	3.29	6.50	6.67	8.10	5.13	2.93	2.99
29	2.93	2.91	2.96	2.90	3.12	3.29	6.50	6.67	7.80	5.13	2.93	2.90
30	2.93		2.96	2.90	3.12	3.29	6.50	6.67	7.88	5.13	2.93	2.90
31	2.93		2.96		3.12	3.29	6.50	6.80	7.88	5.13	2.93	2.90
Max	2.01	2.92	3.01	2.97	3.12	3.29	8.70	6.80	9.41	5.90	3.20	3.01
Mean	2.77	2.84	2.97	2.91	3.05	3.25	5.32	5.77	7.16	5.35	3.02	3.15
Min	2.93	2.90	2.96	2,90	2.98	3.20	4.01	6.55	7.00	3.02	2.92	2.90

SOURCE: GAUGED BY THE RESEARCH STUDENT, 2011

WATER DISCHARGE
(M^3/S)

RIVER SYSTEM: IMO **STATION: AWO OMAMA**
NAME OF RIVER / STREAM: NJABA RIVER **LOCATION: Lat: 05^0 39 N,**
Long: 06^o 57^IE

HYDROLOGICAL YEARS 2007/2008

DAYS	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	JAN	FEB
1	0.98	1.93	2.17	3.11	3.32	3.13	2.17	4.21	2.93	4.21	2.93	0.98
2	1.15	1.85	2.61	3.19	3.43	4.02	2.17	4.11	3.05	4.21	2.93	0.98
3	1.09	1.91	2.61	3.17	3.74	4.13	2.17	3.91	3.19	4.21	2.93	0.98
4	1.09	1.93	2.45	3.19	4.02	4.21	2.17	3.91	3.37	3.00	2.93	0.98
5	1.13	1.95	2.50	3.19	4.30	4.21	2.17	4.02	4.21	3.26	2.93	0.98
6	0.98	1.93	2.61	3.19	4.30	4.21	2.17	4.02	4.21	2.93	2.93	0.98
7	0.85	1.93	2.61	3.21	4.30	4.21	2.17	4.02	4.21	4.21	2.93	0.98
8	0.85	1.93	2.67	3.30	3.78	4.21	2.17	4.02	4.21	4.21	2.93	0.98
9	0.85	1.98	2.69	3.37	3.24	4.21	2.17	4.02	4.02	4.21	2.93	0.98
10	0.98	1.95	2.74	3.34	2.93	4.21	4.21	2.93	3.08	4.21	2.93	0.98
11	0.98	1.95	2.76	3.37	2.93	4.28	4.21	2.93	3.50	2.93	2.93	0.98
12	0.98	1.98	2.65	3.39	2.82	4.28	4.21	3.17	2.93	2.93	2.93	0.98
13	1.19	1.93	2.69	3.24	2.85	4.21	4.21	3.69	2.65	2.93	2.93	0.98
14	1.32	2.02	2.67	2.93	2.91	4.21	4.21	4.21	2.85	2.93	2.93	0.98
15	1.46	2.04	2.69	2.93	3.02	4.21	4.21	3.91	2.93	2.93	2.93	0.98
16	1.09	2.04	3.04	2.82	3.30	4.21	4.21	3.08	2.93	2.93	2.93	0.98
17	1.00	2.09	3.08	2.82	4.21	4.21	4.21	2.93	2.93	2.93	2.93	0.98
18	0.98	2.00	3.15	2.91	4.21	4.21	2.17	2.92	2.93	2.93	2.93	0.98
19	0.98	2.09	3.11	3.02	4.21	4.21	2.17	2.93	2.93	2.93	2.93	0.98
20	1.15	2.09	3.19	3.30	4.13	4.21	2.17	3.00	2.93	2.93	2.93	0.98
21	1.09	2.04	3.17	4.21	4.00	4.21	4.21	3.11	2.93	2.93	2.93	0.98
22	1.13	2.06	3.19	4.21	4.28	4.21	4.21	3.11	2.93	2.93	2.93	0.98
23	1.15	2.09	3.19	4.21	2.17	2.17	4.21	2.98	2.93	2.93	2.93	0.98
24	1.41	0.15	3.19	3.24	2.17	2.17	4.21	2.91	4.21	2.93	2.93	0.98
25	1.41	2.17	3.21	2.93	2.17	4.21	4.21	2.93	4.21	2.93	2.93	0.98
26	1.48	2.17	3.30	2.93	2.17	4.21	4.21	2.93	4.21	2.93	2.93	0.98
27	1.41	2.17	3.37	2.82	4.28	4.21	4.21	2.93	4.21	2.93	2.93	0.98
28	1.37	2.13	3.34	2.85	4.21	2.17	4.21	2.93	4.21	2.93	2.93	0.98
29	1.37	22.15	3.37	2.91	3.19	2.17	4.21	2.93	4.21	2.93	2.93	0.98
30	1.37	2.17	3.39	3.02	3.15	2.17	4.21	2.93	4.21	2.93	0.98	
31	1.48		3.37	3.41	3.13	4.17		2.93		2.93	0.98	
Max	**1.48**	**2.17**	**3.39**	**4.21**	**4.20**	**4.21**	**4.21**	**4.21**	**4.21**	**4.21**	**2.93**	**0.98**
Mea	**1.15**	**2.03**	**3.10**	**3.33**	**3.45**	**3.90**	**3.39**	**3.37**	**3.20**	**3.23**	**2.77**	**0.98**
Min	**0.85**	**1.85**	**2.17**	**2.82**	**2.17**	**2.17**	**2.17**	**2.91**	**2.65**	**2.93**	**0.98**	**0.98**

SOURCE: ANAMBRA-IMO RIVER BASIN DEVELOPMENT AUTHORITY, 2007

WATER DISCHARGE

RIVER SYSTEM: ANAMBRA **(M^3/S)**

STATION: INYI

NAME OF RIVER / STREAM: MMAM RIVER **LOCATION: LAT:06º 15I**

LONG: 07º09I

HYDROLOGICAL YEAR: 2007/2008

DAYS	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
1.	0.48	0.52	1.11	1.22	2.54	4.11	5.28	3.17	1.24	0.83	0.56	0.48
2.	0.52	0.50	0.89	1.41	2.61	3.65	4.65	2.95	1.22	0.83	0.56	0.48
3.	0.65	0.54	0.85	1.28	2.16	4.06	4.39	2.58	1.19	0.83	0.56	0.48
4.	0.61	0.52	0.72	1.37	2.26	4.95	4.30	2.28	1.19	0.80	0.56	0.48
5.	0.54	0.67	0.83	1.15	1.93	4.78	4.24	2.11	1.22	0.77	0.56	0.43
6.	0.52	1.02	0.72	1.39	1.47	6.19	4.06	2.02	1.19	0.74	0.55	0.43
7.	0.59	0.89	0.61	1.50	1.30	6.06	3.74	1.89	1.18	0.73	0.55	0.43
8.	0.54	0.78	0.56	1.19	1.22	5.73	3.43	1.80	1.16	0.73	0.55	0.43
9.	0.65	0.78	0.61	1.69	1.17	5.39	3.69	1.74	1.15	0.71	0.55	0.43
10.	0.52	0.80	0.70	1.89	1.11	5.36	4.28	1.67	1.13	0.69	0.55	0.43
11.	0.52	0.76	0.65	1.87	1.04	4.84	4.34	1.62	1.09	0.69	0.52	0.43
12.	0.48	0.72	0.63	2.32	1.11	4.69	4.65	1.59	1.24	0.67	0.52	0.43
13.	0.50	0.95	0.61	2.67	1.15	4.15	4.63	1.54	1.41	0.65	0.52	0.43
14.	0.46	1.02	0.83	2.85	1.11	4.13	4.39	1.52	1.65	0.65	0.52	0.43
15.	0.43	1.22	1.02	3.26	1.09	4.11	4.37	1.69	1.78	0.65	0.52	0.43
16.	0.41	1.48	0.91	3.48	1.04	4.24	4.43	1.65	1.59	0.65	0.52	0.43
17.	0.41	0.83	1.11	3.08	1.09	4.19	4.37	1.62	1.30	0.65	0.52	0.43
18.	0.50	0.67	1.76	2.52	1.04	3.80	4.21	1.59	1.19	0.65	0.52	0.43
19.	0.48	0.67	2.09	2.09	1.15	3.76	3.71	1.37	1.12	0.62	0.51	0.43
20.	0.76	0.96	2.09	1.50	1.48	3.82	3.69	1.04	1.09	0.62	0.48	0.43
21.	1.11	1.09	2.13	1.26	1.61	3.69	4.17	1.32	1.00	0.62	0.48	0.43
22.	1.32	0.89	1.30	1.15	2.61	3.41	4.17	1.30	0.92	0.62	0.45	0.43
23.	1.89	0.72	0.98	1.06	2.85	3.65	3.76	1.26	0.99	0.59	0.42	0.43
24.	1.52	0.78	0.87	0.96	2.72	6.32	3.87	1.24	0.96	0.59	0.42	0.43
25.	1.48	0.63	0.78	0.85	3.02	6.36	3.78	1.22	0.94	0.59	0.42	0.43
26.	1.26	0.54	1.65	1.28	2.98	6.36	3.58	1.19	0.91	0.59	0.45	0.43
27.	0.85	0.59	1.61	1.50	2.54	6.54	3.26	1.17	0.91	0.59	0.45	0.43
28.	0.65	0.59	1.15	1.80	2.43	6.71	2.98	1.22	0.88	0.59	0.48	0.43
29.	0.59	0.63	0.96	1.82	2.48	6.36	2.85	1.19	0.88	0.59	0.48	0.43
30.	0.54	0.72	0.93	2.30	2.00	5.58	3.04	1.28	0.85	0.56		0.43
31.		1.06		2.67	2.80		3.02		0.85	0.56		0.43
MAX	**1.89**	**1.48**	**2.13**	**3.48**	**3.02**	**6.71**	**5.28**	**3.17**	**1.78**	**0.83**	**0.56**	**0.48**
MEAN	**0.73**	**0.79**	**1.06**	**1.83**	**1.82**	**4.90**	**3.98**	**1.66**	**1.11**	**0.67**	**0.51**	**0.44**
MIN	**0.41**	**0.50**	**0.56**	**1.85**	**1.04**	**3.41**	**2.85**	**1.04**	**0.85**	**0.56**	**0.42**	**0.43**

SOURCE: ANAMBRA-IMO RIVER BASIN DEVELPOMENT AUTHORITY, 2 002

APPENDIX III

Estimation of groundwater In Njaba River Using the above hdrograph

Determination of the area of the trapezium ABCD

$$\frac{1.2+0.55}{2}\ x\ \frac{366}{1}\ x\ \frac{24}{1}\ x\ \frac{60}{1}\ x\ \frac{60}{1}\ m^3 = 27{,}669{,}600m^3$$

Estimation of runoff

The estimation can be done by the determination of the area of the curve AEB.

This can be done by counting the squares under the curve thus;

Area of 1 square = 15 x 0.25m^3/s

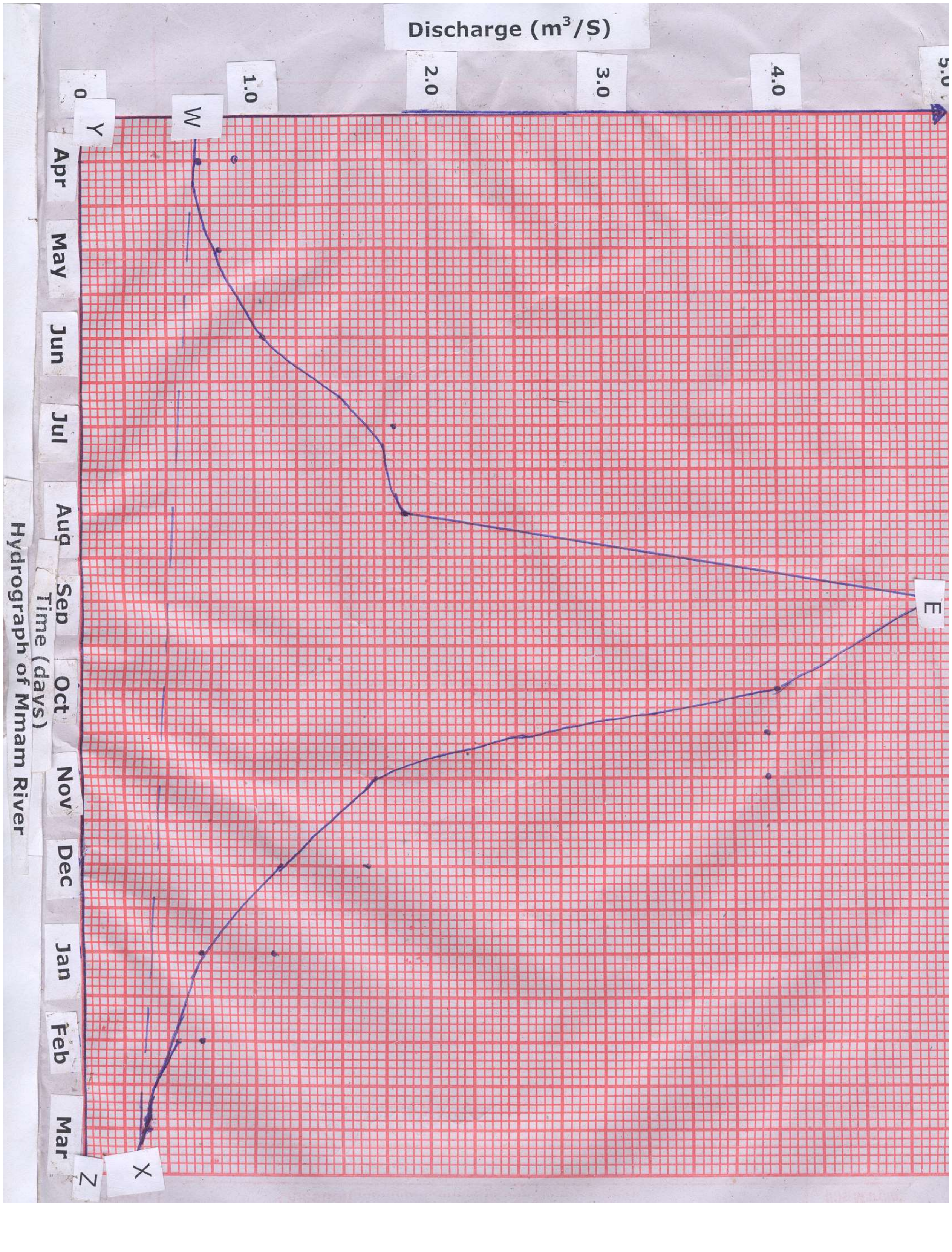
= 3.75dm^3/s

No of squares = 181

Area under curve AEB in m^3

= 3.75 x 24 x 60 x 60 x 181m^3

= 58,644,000m^3


Discharge (m3/S)
0
1.0
2.0
3.0
4.0
5.0
Y
W
E
X
Z
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Time (days)
Hydrograph of Mmam River

Estimation of groundwater in Mmam river basin using the above hydrograph

Determination of the area of the trapezium WXYZ

$$= \frac{0.75 + 0.40}{2} \, x \, 366 \, x \, 24 \, x \, 60 \, x \, 60m^2$$

= 18,182,880m^2

Estimation of runoff

Determination of area under the curve WEX by counting of squares:

Area of 1 square = 0.25 x 15m.d^3/s

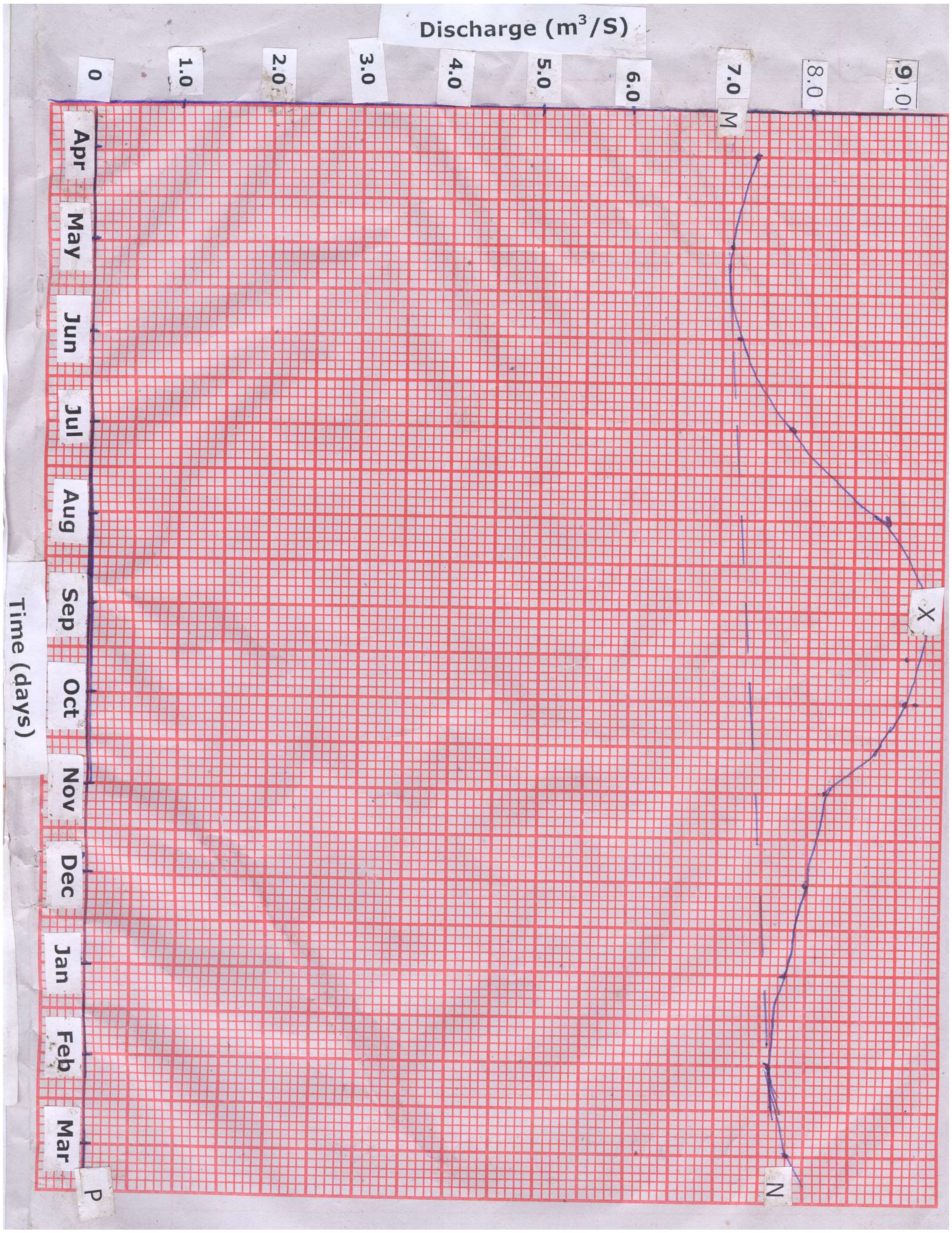
Number of square = 105

Area under the curve in m^3

= 0.25 x 15 x 24 x 60 x 60 x 105m^3

= 34,020,000m^3

Otamiri River Basin



Estimation of groundwater in Otamiri River using the above hydrograph

Determination of the area the trapezium MNOP in m^3

$$= \frac{7.0 + 7.3}{2}\ x\ 366\ x\ 24\ x\ 60\ x\ 60$$

= 226,100,160m^3

Groundwater quantity annually = 226,100,160m^3

Estimation of runoff

Determination of runoff by counting the squares under the curve MXN

Area of 1 square = 0.5 x 15days m^3/s = 7.5d.m^3/s

No of squares under the curve in m^3 = 30

0.75 x 24 x 60 x 60 x 30m^3

= 1,944,000m^3

Aboine River Basin

Estimation of Groundwater in Aboine river using the above hydrograph

Determination of the area of the trapezium STUV in m^3

$$= \frac{2.9 + 2.5}{2} \, x\, 366 \, x\, 24 \, x\, 60 \, x\, 60 \quad = 85{,}380{,}480 m^3$$

Estimation of the runoff can be done by determining the area of the curve SXT through the counting of the squares under the curve.

Area of 1 square = 0.5 x 15days m^3/s

= 7.5d.m^3s

No of squares = 51

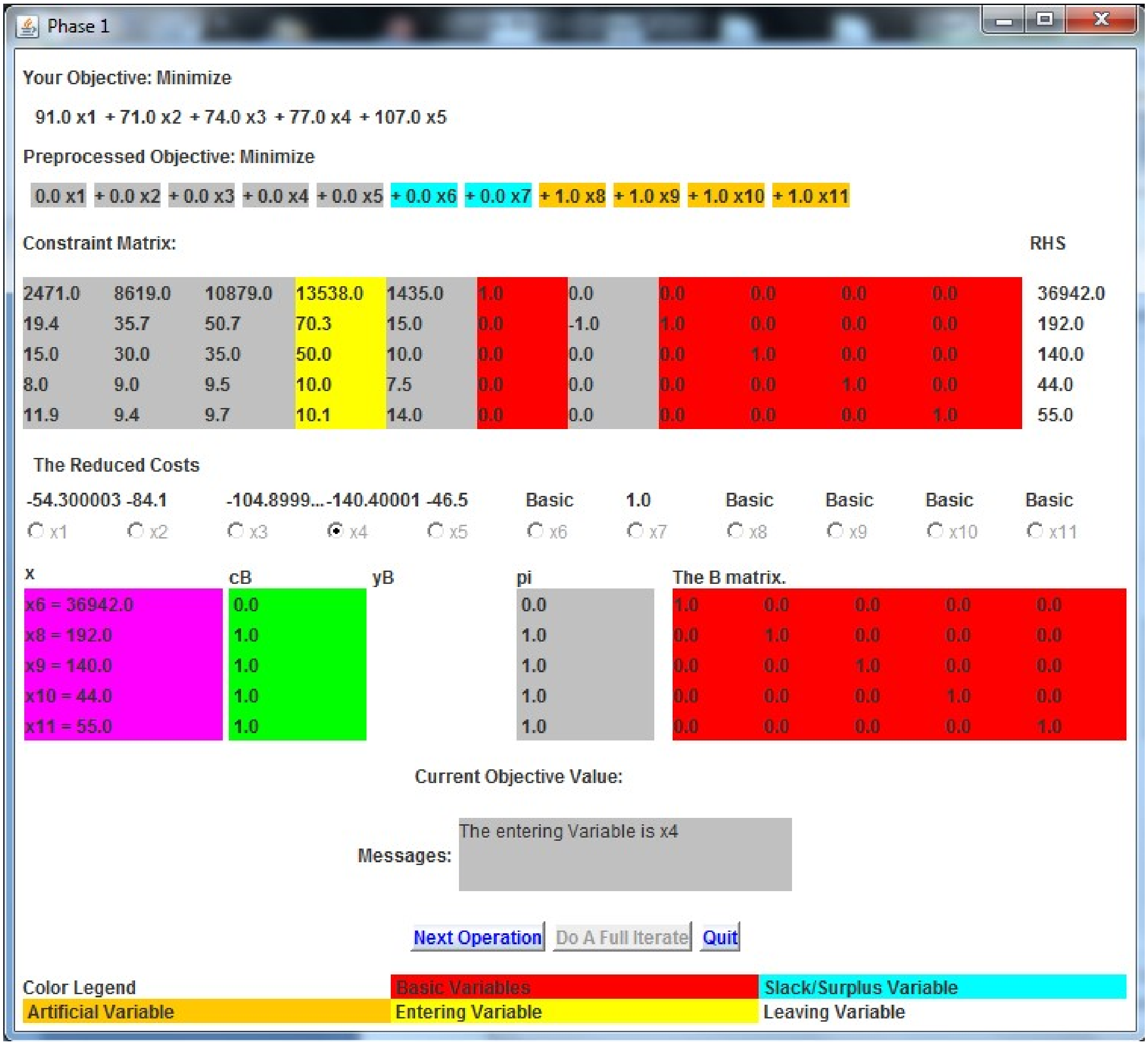
Area of the curve in m^3

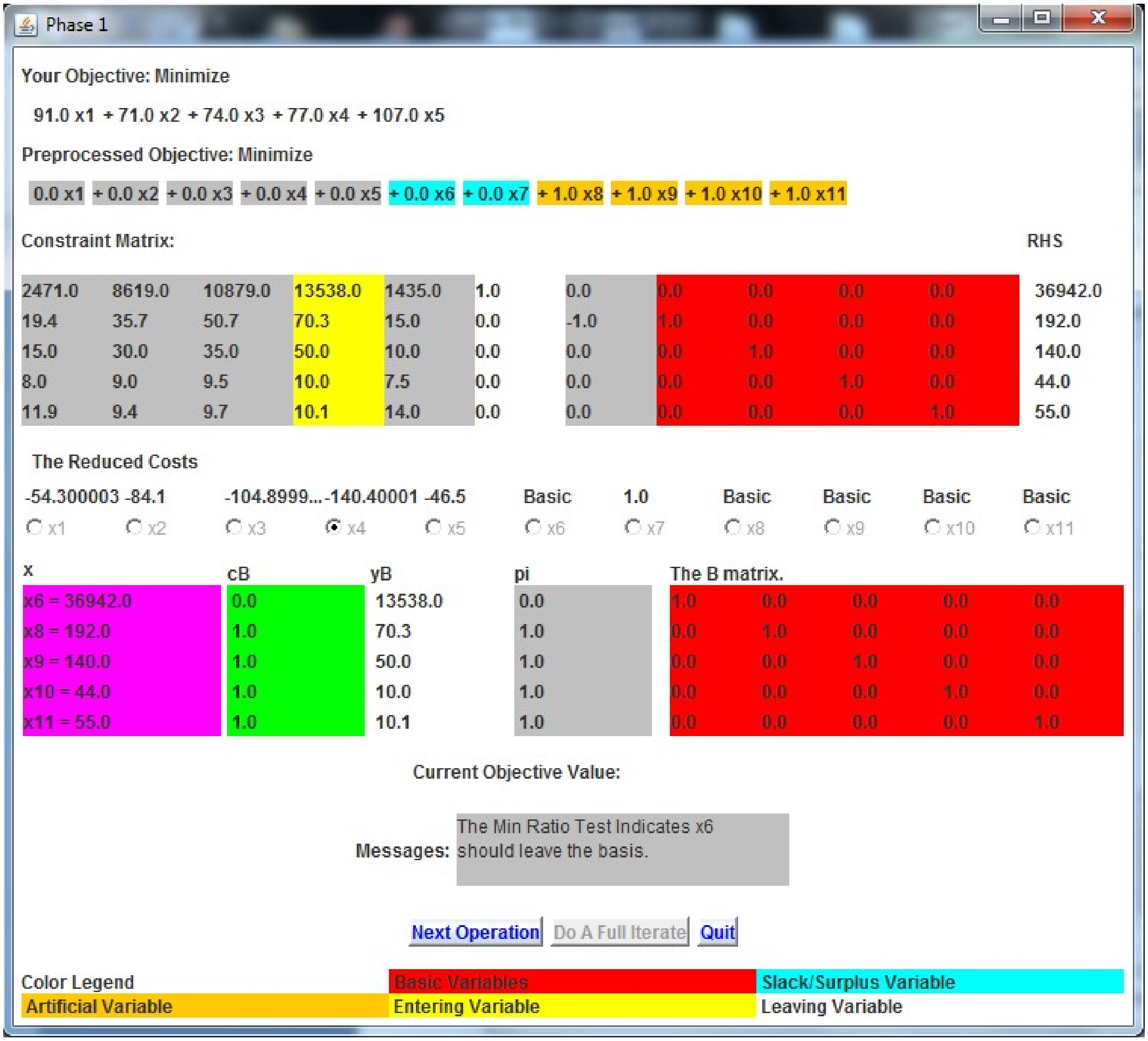
= 7.5 x 24 x 60 x 60 x 1 m^3

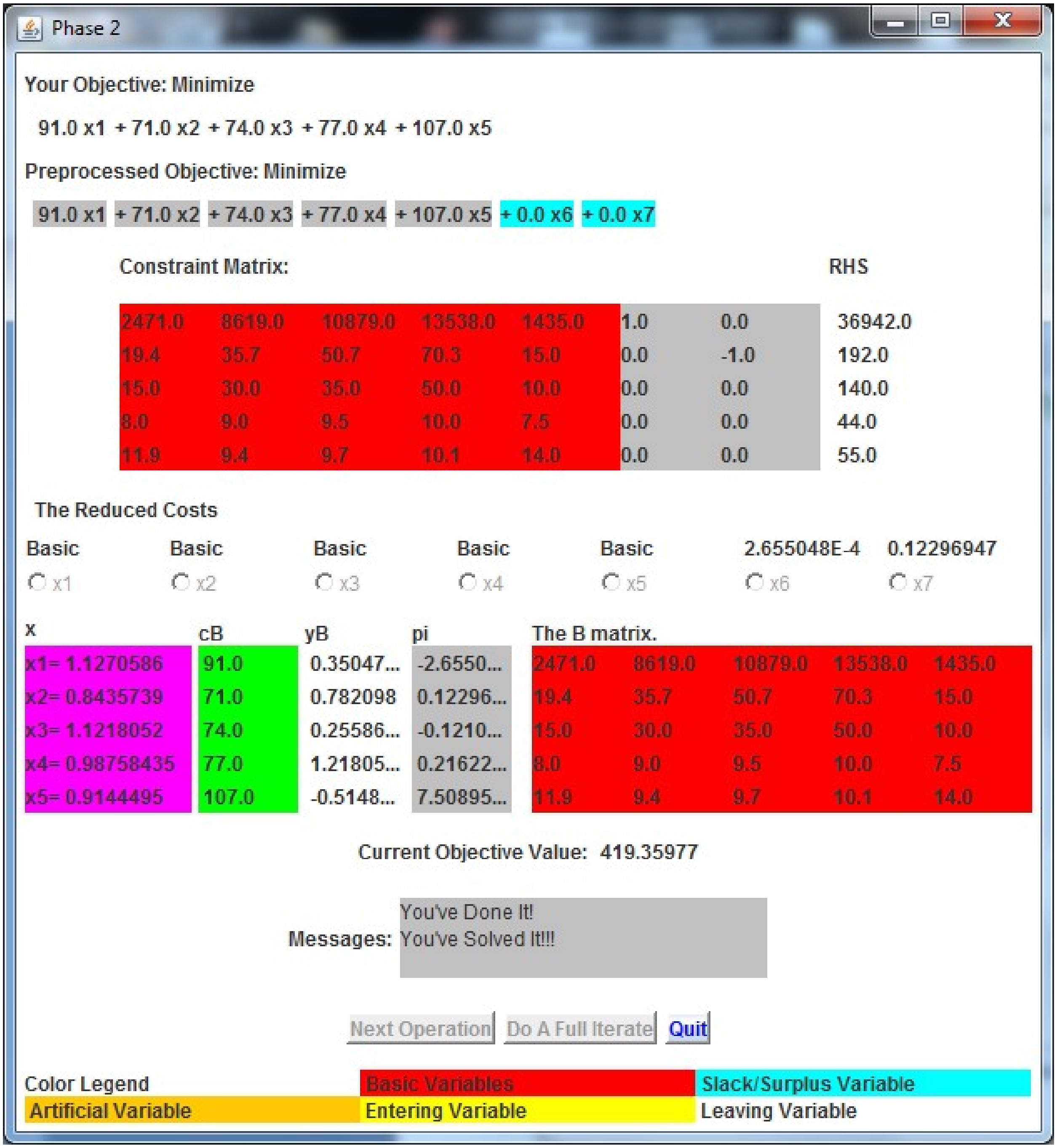
= 33,048,000m^3

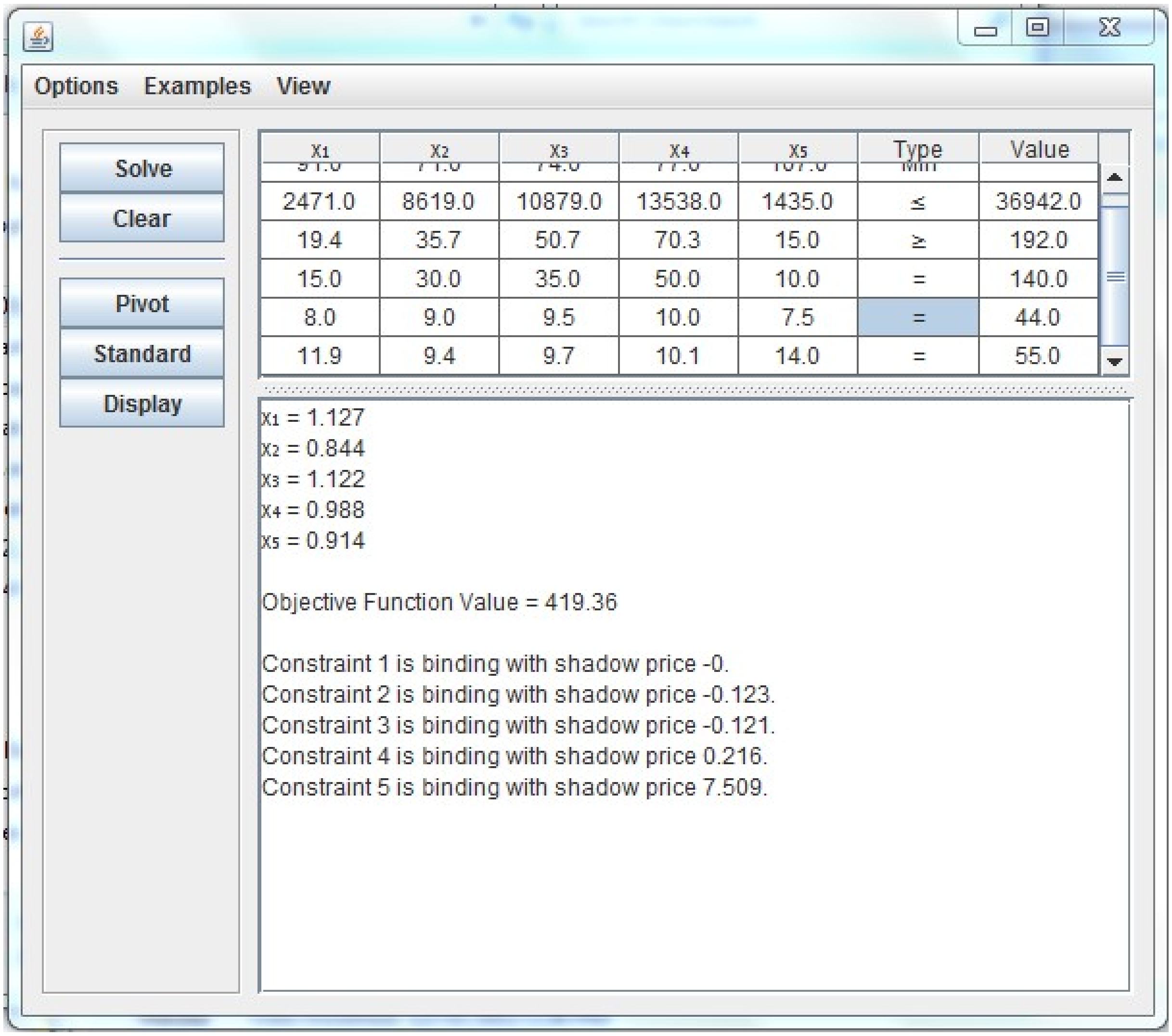
APPENDIX IV

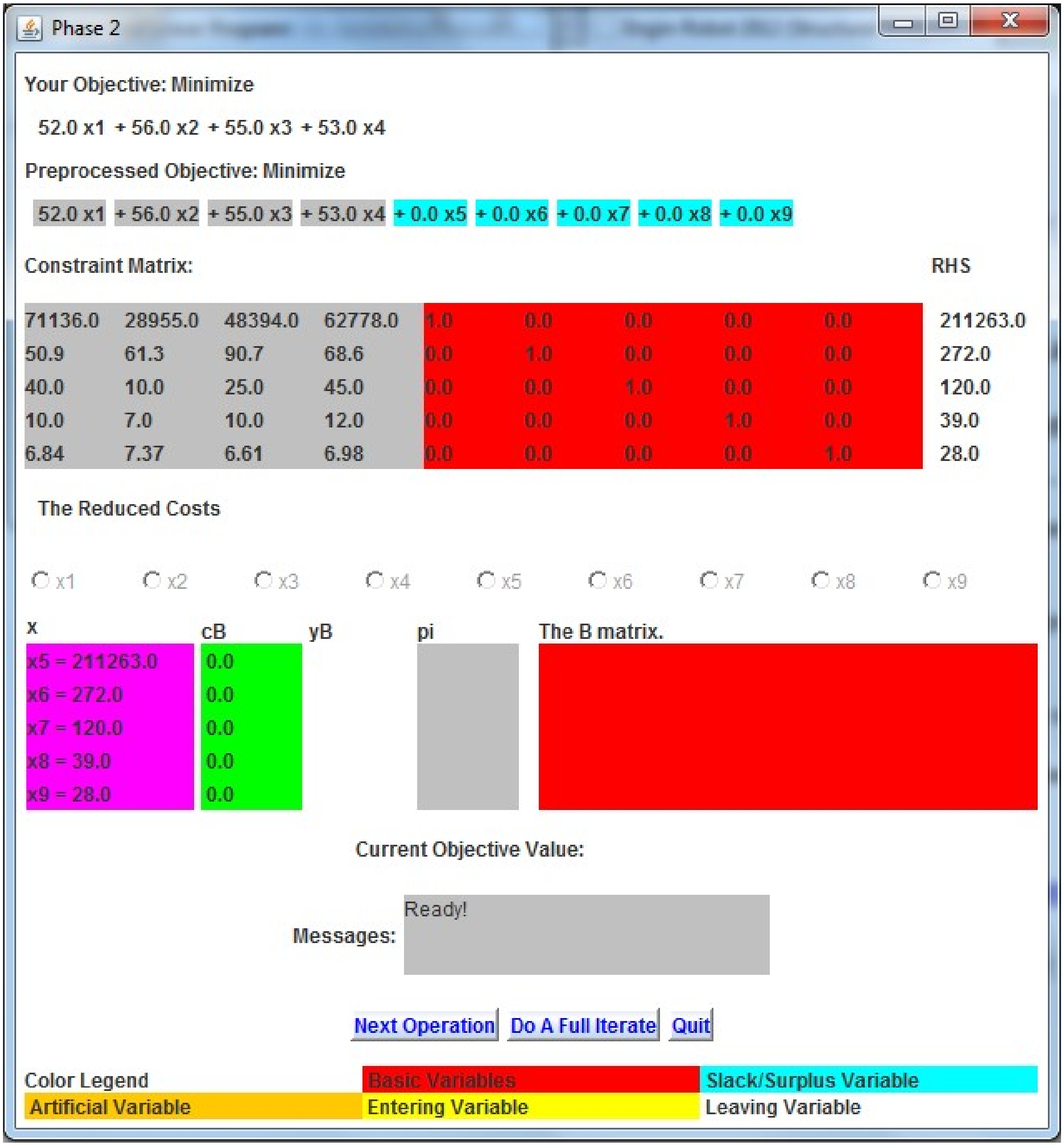
SCREEN SHOTS OF LINEAR PROGRAMMING SOFTWARE ITERATIONS FOR MODEL SOLUTIONS

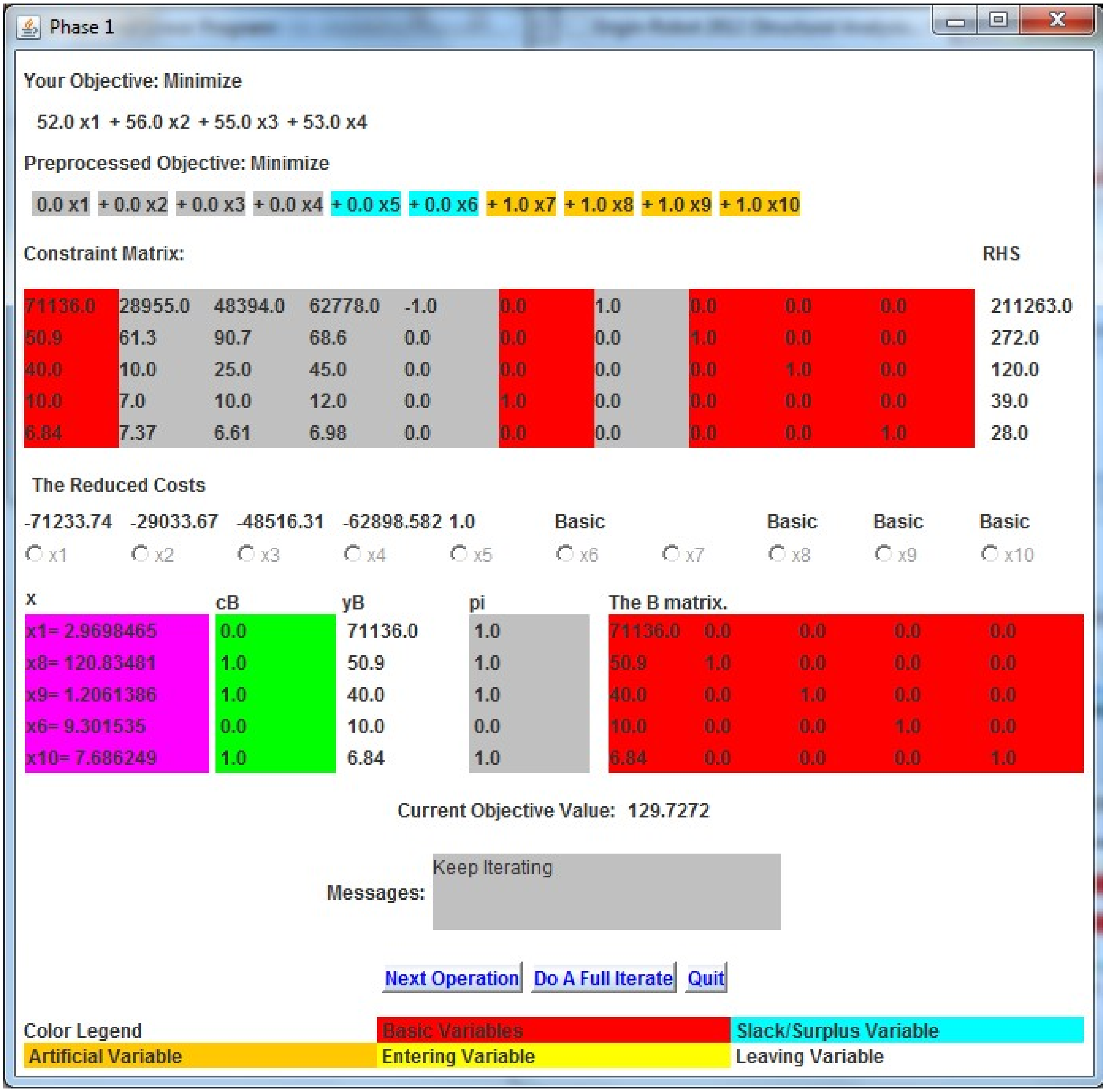


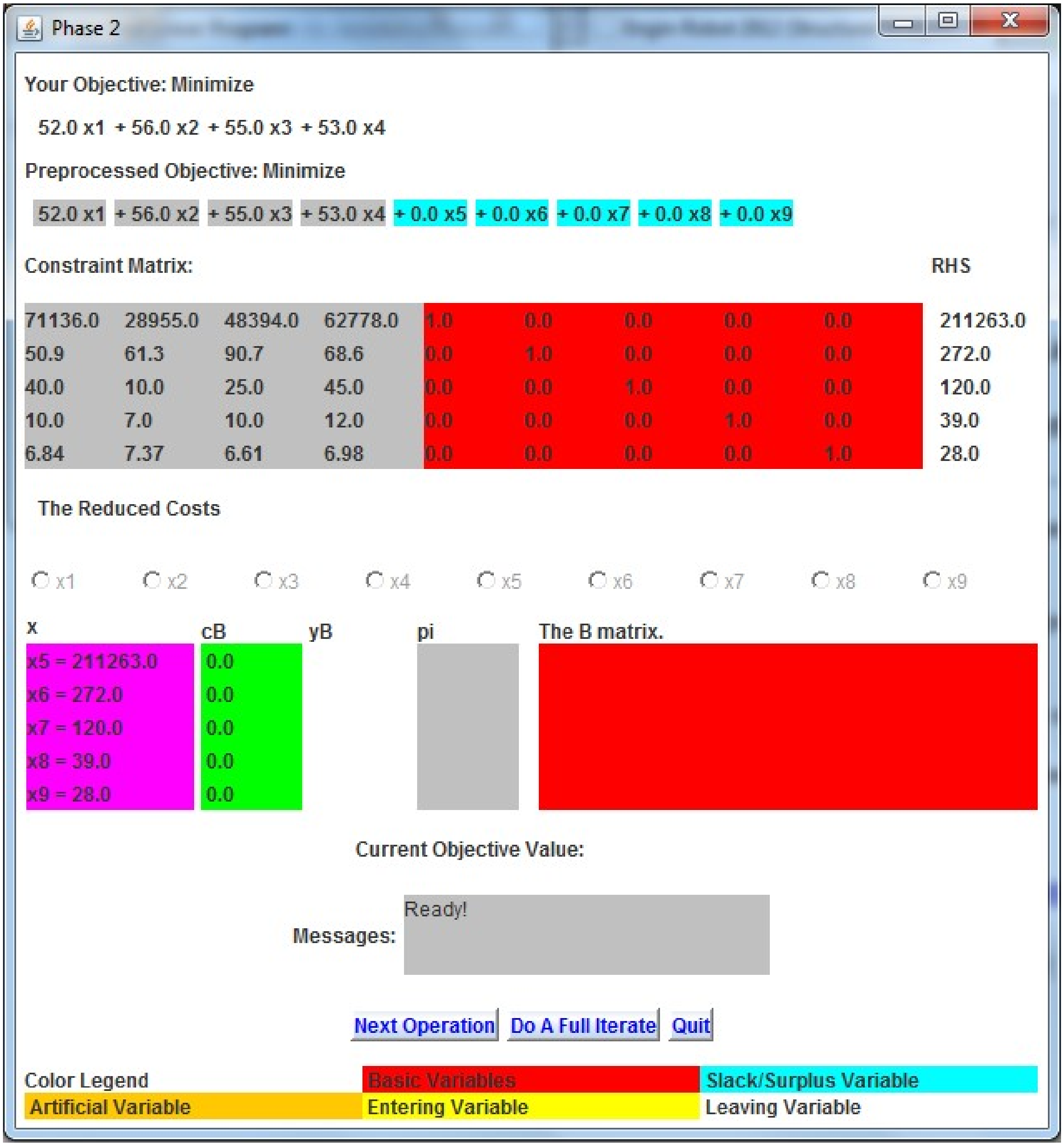

Phase 1
Your Objective: Minimize
91.0 x1 + 71.0 x2 + 74.0 x3 + 77.0 x4 + 107.0 x5
Preprocessed Objective: Minimize
0.0 x1 + 0.0 x2 + 0.0 x3 + 0.0 x4 + 0.0 x5 + 0.0 x6 + 0.0 x7 + 1.0 x8 + 1.0 x9 + 1.0 x10 + 1.0 x11
Constraint Matrix:
RHS
2471.0 8619.0 10879.0 13538.0 1435.0 1.0 0.0 0.0 0.0 0.0 0.0 36942.0
19.4 35.7 50.7 70.3 15.0 0.0 -1.0 1.0 0.0 0.0 0.0 192.0
15.0 30.0 35.0 50.0 10.0 0.0 0.0 0.0 1.0 0.0 0.0 140.0
8.0 9.0 9.5 10.0 7.5 0.0 0.0 0.0 0.0 1.0 0.0 44.0
11.9 9.4 9.7 10.1 14.0 0.0 0.0 0.0 0.0 0.0 1.0 55.0
The Reduced Costs
-54.300003 -84.1 -104.8999... -140.40001 -46.5 Basic 1.0 Basic Basic Basic Basic
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x11
x cB yB pi The B matrix.
x6 = 36942.0 0.0 13538.0 0.0 1.0 0.0 0.0 0.0 0.0
x8 = 192.0 1.0 70.3 1.0 0.0 1.0 0.0 0.0 0.0
x9 = 140.0 1.0 50.0 1.0 0.0 0.0 1.0 0.0 0.0
x10 = 44.0 1.0 10.0 1.0 0.0 0.0 0.0 1.0 0.0
x11 = 55.0 1.0 10.1 1.0 0.0 0.0 0.0 0.0 1.0
Current Objective Value:
Messages: The Min Ratio Test Indicates x6 should leave the basis.
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

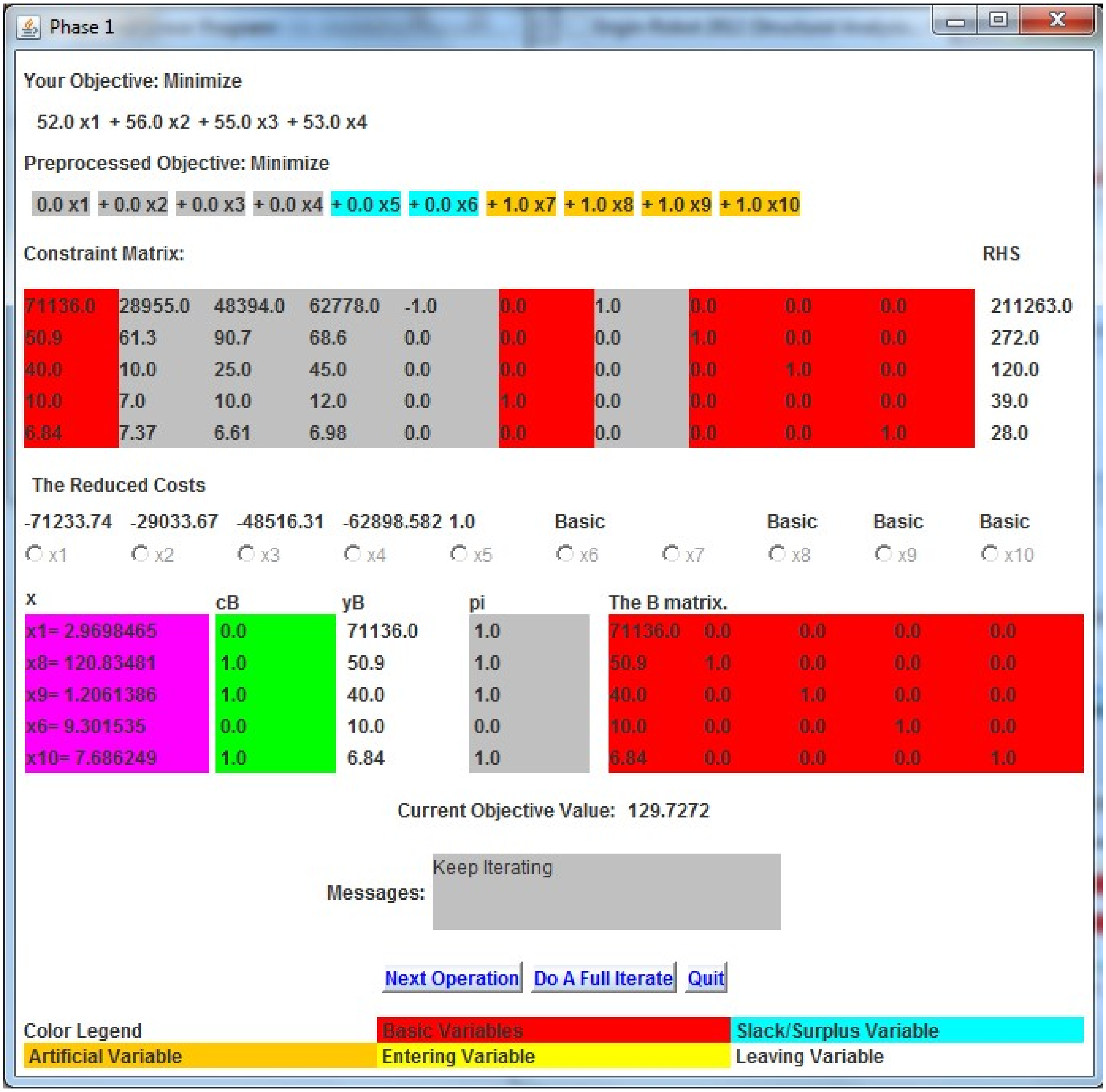

Phase 2
Your Objective: Minimize
91.0 x1 + 71.0 x2 + 74.0 x3 + 77.0 x4 + 107.0 x5
Preprocessed Objective: Minimize
91.0 x1 + 71.0 x2 + 74.0 x3 + 77.0 x4 + 107.0 x5 + 0.0 x6 + 0.0 x7
Constraint Matrix:
RHS
2471.0 8619.0 10879.0 13538.0 1435.0 1.0 0.0 36942.0
19.4 35.7 50.7 70.3 15.0 0.0 -1.0 192.0
15.0 30.0 35.0 50.0 10.0 0.0 0.0 140.0
8.0 9.0 9.5 10.0 7.5 0.0 0.0 44.0
11.9 9.4 9.7 10.1 14.0 0.0 0.0 55.0
The Reduced Costs
Basic Basic Basic Basic Basic 2.655048E-4 0.12296947
x1 x2 x3 x4 x5 x6 x7
x cB yB pi The B matrix.
x1= 1.1270586 91.0 0.35047... -2.6550... 2471.0 8619.0 10879.0 13538.0 1435.0
x2= 0.8435739 71.0 0.782098 0.12296... 19.4 35.7 50.7 70.3 15.0
x3= 1.1218052 74.0 0.25586... -0.1210... 15.0 30.0 35.0 50.0 10.0
x4= 0.98758435 77.0 1.21805... 0.21622... 8.0 9.0 9.5 10.0 7.5
x5= 0.9144495 107.0 -0.5148... 7.50895... 11.9 9.4 9.7 10.1 14.0
Current Objective Value: 419.35977
Messages: You've Done It! You've Solved It!!!
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

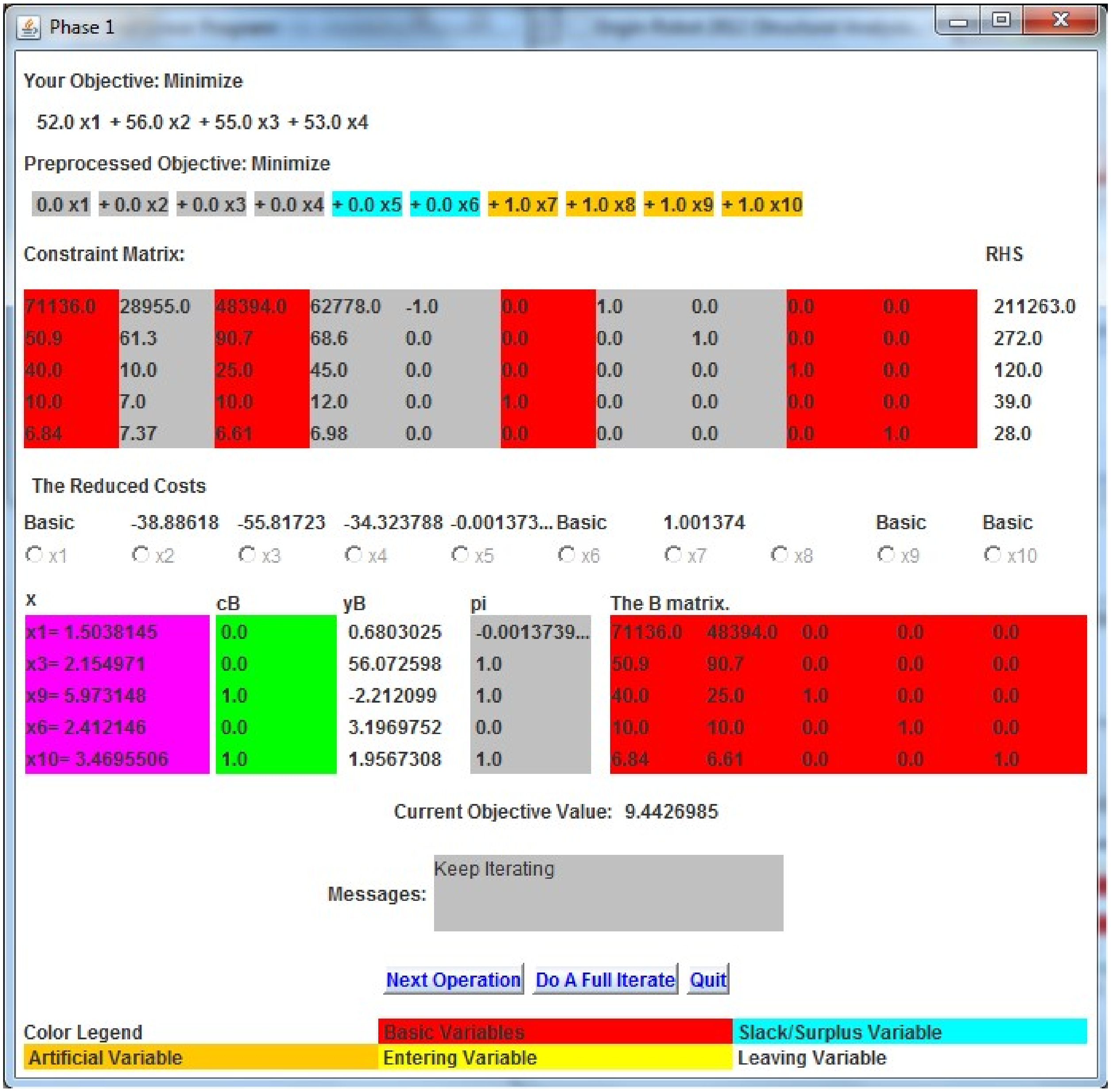

Options Examples View
Solve
Clear
Pivot
Standard
Display
X1 X2 X3 X4 X5 Type Value
2471.0 8619.0 10879.0 13538.0 1435.0 ≤ 36942.0
19.4 35.7 50.7 70.3 15.0 ≥ 192.0
15.0 30.0 35.0 50.0 10.0 = 140.0
8.0 9.0 9.5 10.0 7.5 = 44.0
11.9 9.4 9.7 10.1 14.0 = 55.0
X1 = 1.127
X2 = 0.844
X3 = 1.122
X4 = 0.988
X5 = 0.914
Objective Function Value = 419.36
Constraint 1 is binding with shadow price -0.
Constraint 2 is binding with shadow price -0.123.
Constraint 3 is binding with shadow price -0.121.
Constraint 4 is binding with shadow price 0.216.
Constraint 5 is binding with shadow price 7.509.

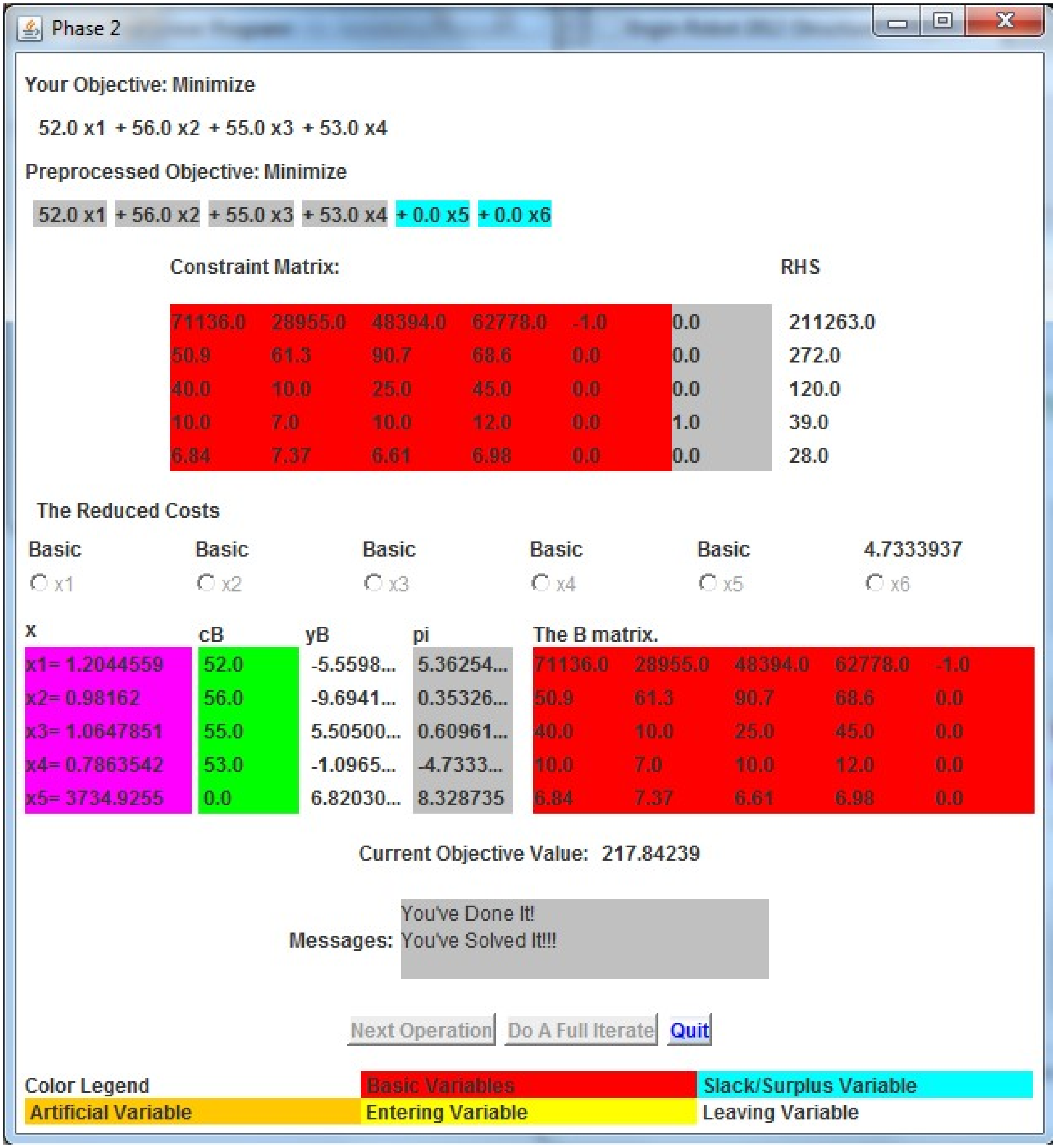

Phase 2
Your Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4
Preprocessed Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4 + 0.0 x5 + 0.0 x6 + 0.0 x7 + 0.0 x8 + 0.0 x9
Constraint Matrix:
RHS
71136.0 28955.0 48394.0 62778.0 1.0 0.0 0.0 0.0 0.0 211263.0
50.9 61.3 90.7 68.6 0.0 1.0 0.0 0.0 0.0 272.0
40.0 10.0 25.0 45.0 0.0 0.0 1.0 0.0 0.0 120.0
10.0 7.0 10.0 12.0 0.0 0.0 0.0 1.0 0.0 39.0
6.84 7.37 6.61 6.98 0.0 0.0 0.0 0.0 1.0 28.0
The Reduced Costs
x1 x2 x3 x4 x5 x6 x7 x8 x9
x
cB
yB
pi
The B matrix.
x5 = 211263.0 0.0
x6 = 272.0 0.0
x7 = 120.0 0.0
x8 = 39.0 0.0
x9 = 28.0 0.0
Current Objective Value:
Messages:
Ready!
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

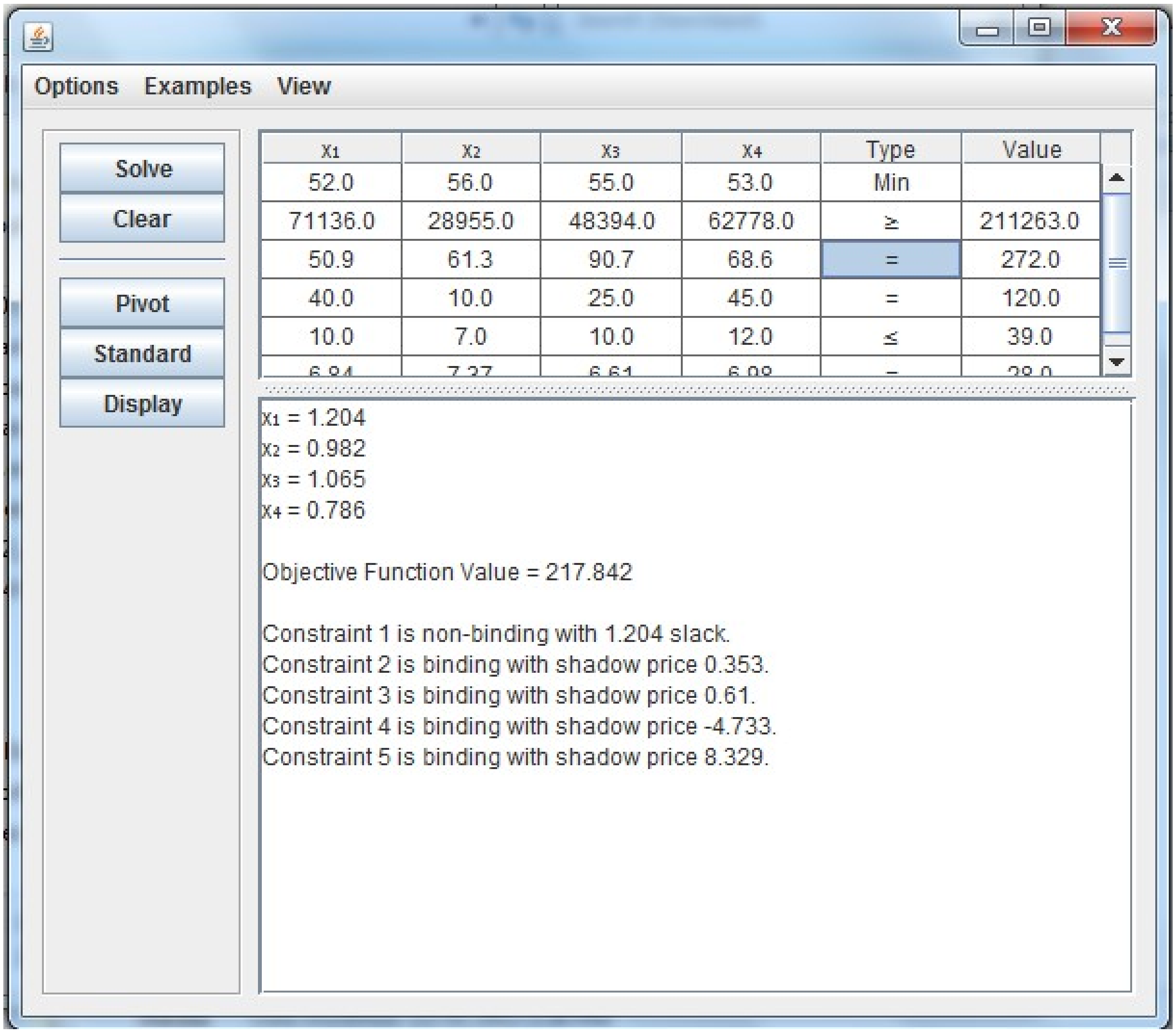

Phase 1
Your Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4
Preprocessed Objective: Minimize
0.0 x1 + 0.0 x2 + 0.0 x3 + 0.0 x4 + 0.0 x5 + 0.0 x6 + 1.0 x7 + 1.0 x8 + 1.0 x9 + 1.0 x10
Constraint Matrix:
RHS
71136.0 28955.0 48394.0 62778.0 -1.0 0.0 1.0 0.0 0.0 0.0 211263.0
50.9 61.3 90.7 68.6 0.0 0.0 0.0 1.0 0.0 0.0 272.0
40.0 10.0 25.0 45.0 0.0 0.0 0.0 0.0 1.0 0.0 120.0
10.0 7.0 10.0 12.0 0.0 1.0 0.0 0.0 0.0 0.0 39.0
6.84 7.37 6.61 6.98 0.0 0.0 0.0 0.0 0.0 1.0 28.0
The Reduced Costs
-71233.74 -29033.67 -48516.31 -62898.582 1.0 Basic Basic Basic Basic
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x
cB
yB
pi
The B matrix.
x1= 2.9698465 0.0 71136.0 1.0 71136.0 0.0 0.0 0.0 0.0
x8= 120.83481 1.0 50.9 1.0 50.9 1.0 0.0 0.0 0.0
x9= 1.2061386 1.0 40.0 1.0 40.0 0.0 1.0 0.0 0.0
x6= 9.301535 0.0 10.0 0.0 10.0 0.0 0.0 1.0 0.0
x10= 7.686249 1.0 6.84 1.0 6.84 0.0 0.0 0.0 1.0
Current Objective Value: 129.7272
Messages:
Keep Iterating
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

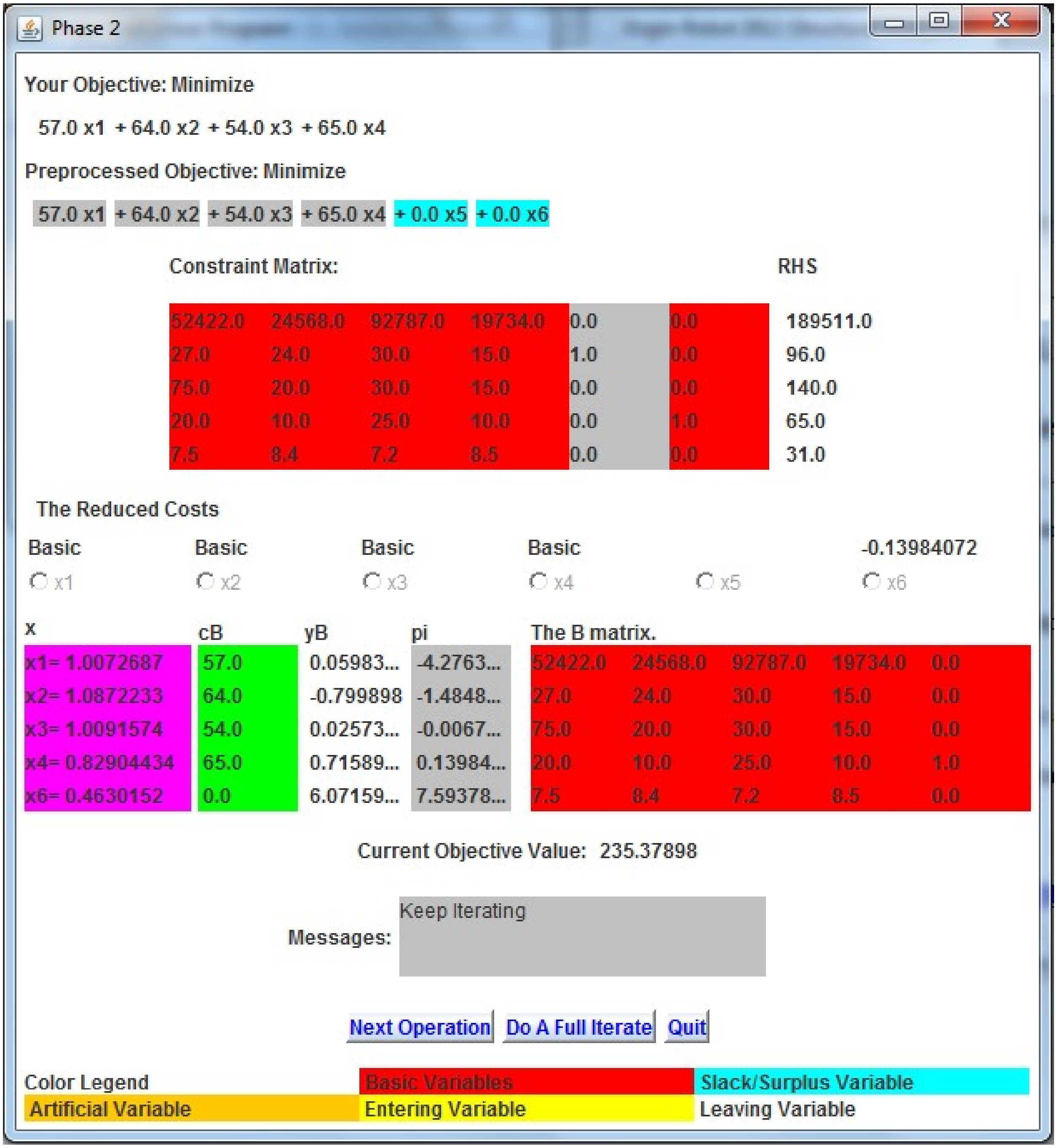

Phase 2
Your Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4
Preprocessed Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4 + 0.0 x5 + 0.0 x6 + 0.0 x7 + 0.0 x8 + 0.0 x9
Constraint Matrix:
RHS
71136.0 28955.0 48394.0 62778.0 1.0 0.0 0.0 0.0 0.0 211263.0
50.9 61.3 90.7 68.6 0.0 1.0 0.0 0.0 0.0 272.0
40.0 10.0 25.0 45.0 0.0 0.0 1.0 0.0 0.0 120.0
10.0 7.0 10.0 12.0 0.0 0.0 0.0 1.0 0.0 39.0
6.84 7.37 6.61 6.98 0.0 0.0 0.0 0.0 1.0 28.0
The Reduced Costs
x1 x2 x3 x4 x5 x6 x7 x8 x9
x
cB
yB
pi
The B matrix.
x5 = 211263.0 0.0
x6 = 272.0 0.0
x7 = 120.0 0.0
x8 = 39.0 0.0
x9 = 28.0 0.0
Current Objective Value:
Messages:
Ready!
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

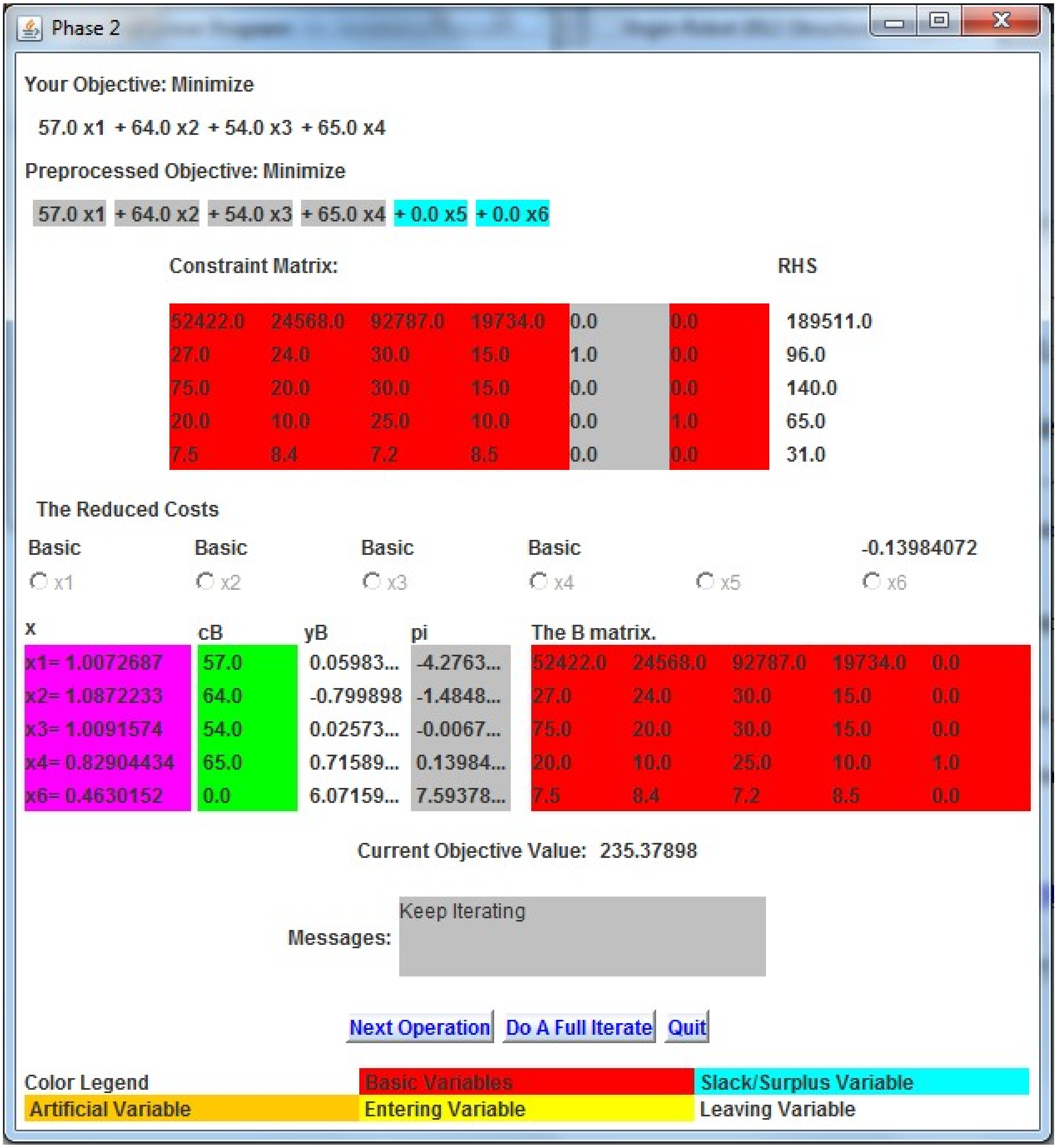

Phase 1
Your Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4
Preprocessed Objective: Minimize
0.0 x1 + 0.0 x2 + 0.0 x3 + 0.0 x4 + 0.0 x5 + 0.0 x6 + 1.0 x7 + 1.0 x8 + 1.0 x9 + 1.0 x10
Constraint Matrix:
RHS
71136.0 28955.0 48394.0 62778.0 -1.0 0.0 1.0 0.0 0.0 0.0 211263.0
50.9 61.3 90.7 68.6 0.0 0.0 0.0 1.0 0.0 0.0 272.0
40.0 10.0 25.0 45.0 0.0 0.0 0.0 0.0 1.0 0.0 120.0
10.0 7.0 10.0 12.0 0.0 1.0 0.0 0.0 0.0 0.0 39.0
6.84 7.37 6.61 6.98 0.0 0.0 0.0 0.0 0.0 1.0 28.0
The Reduced Costs
-71233.74 -29033.67 -48516.31 -62898.582 1.0 Basic Basic Basic Basic
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x cB yB pi The B matrix.
x1= 2.9698465 0.0 71136.0 1.0 71136.0 0.0 0.0 0.0 0.0
x8= 120.83481 1.0 50.9 1.0 50.9 1.0 0.0 0.0 0.0
x9= 1.2061386 1.0 40.0 1.0 40.0 0.0 1.0 0.0 0.0
x6= 9.301535 0.0 10.0 0.0 10.0 0.0 0.0 1.0 0.0
x10= 7.686249 1.0 6.84 1.0 6.84 0.0 0.0 0.0 1.0
Current Objective Value: 129.7272
Messages: Keep Iterating
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

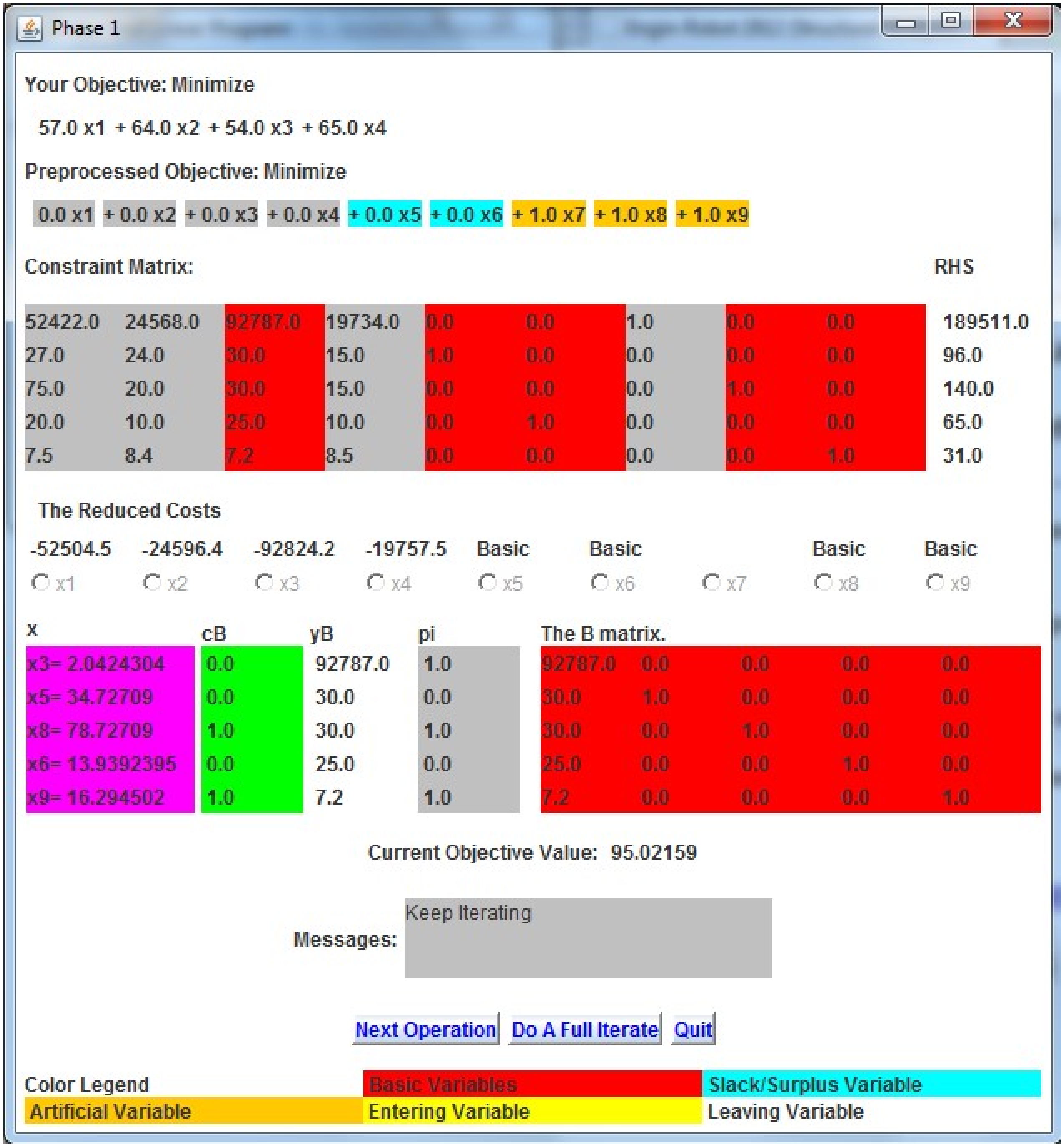

Phase 1
Your Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4
Preprocessed Objective: Minimize
0.0 x1 + 0.0 x2 + 0.0 x3 + 0.0 x4 + 0.0 x5 + 0.0 x6 + 1.0 x7 + 1.0 x8 + 1.0 x9 + 1.0 x10
Constraint Matrix:
RHS
71136.0 28955.0 48394.0 62778.0 -1.0 0.0 1.0 0.0 0.0 0.0 211263.0
50.9 61.3 90.7 68.6 0.0 0.0 0.0 1.0 0.0 0.0 272.0
40.0 10.0 25.0 45.0 0.0 0.0 0.0 0.0 1.0 0.0 120.0
10.0 7.0 10.0 12.0 0.0 1.0 0.0 0.0 0.0 0.0 39.0
6.84 7.37 6.61 6.98 0.0 0.0 0.0 0.0 0.0 1.0 28.0
The Reduced Costs
Basic -38.88618 -55.81723 -34.323788 -0.001373... Basic 1.001374 Basic Basic
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10
x cB yB pi The B matrix.
x1= 1.5038145 0.0 0.6803025 -0.0013739... 71136.0 48394.0 0.0 0.0 0.0
x3= 2.154971 0.0 56.072598 1.0 50.9 90.7 0.0 0.0 0.0
x9= 5.973148 1.0 -2.212099 1.0 40.0 25.0 1.0 0.0 0.0
x6= 2.412146 0.0 3.1969752 0.0 10.0 10.0 0.0 1.0 0.0
x10= 3.4695506 1.0 1.9567308 1.0 6.84 6.61 0.0 0.0 1.0
Current Objective Value: 9.4426985
Messages:
Keep Iterating
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

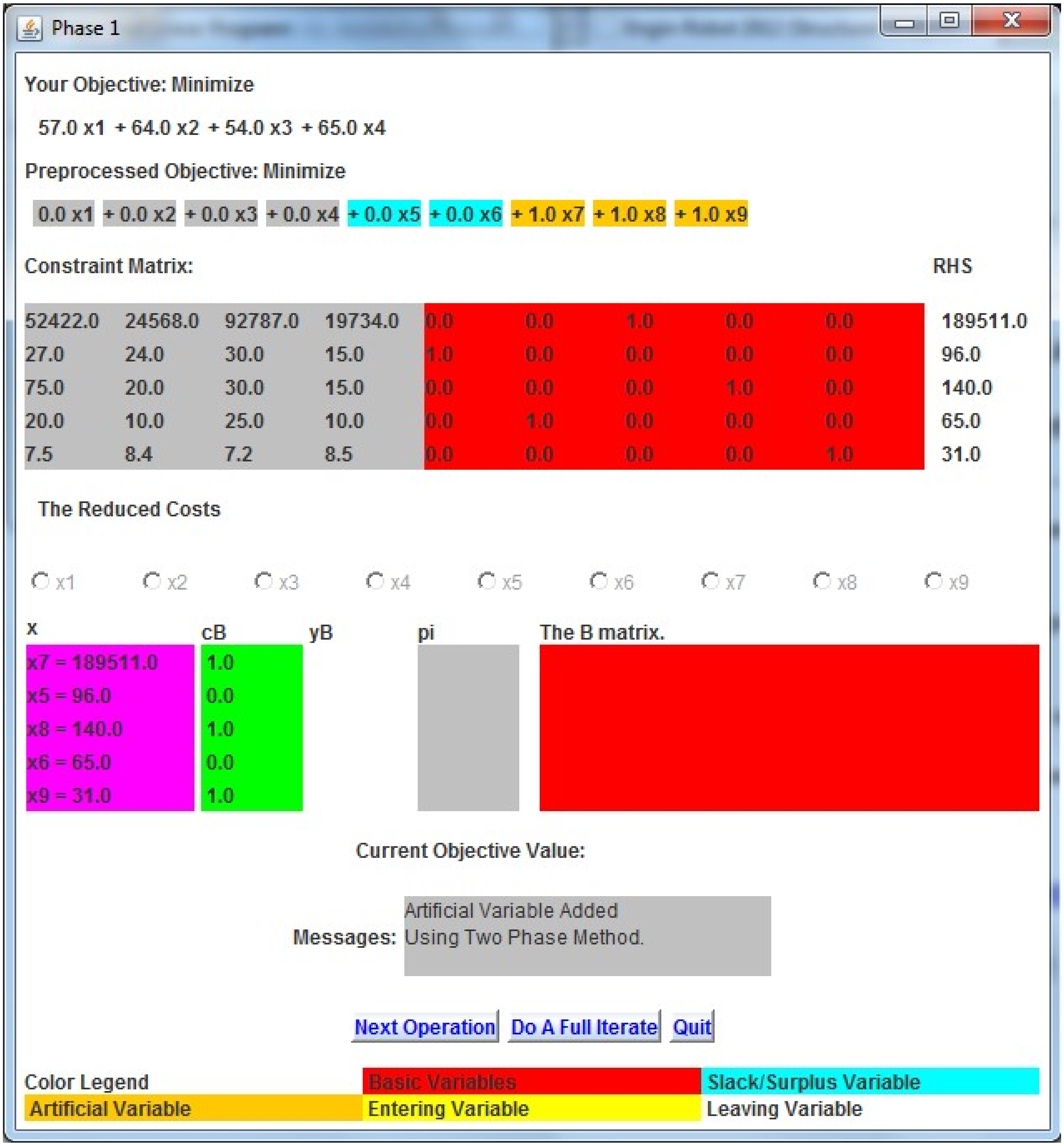

Phase 2
Your Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4
Preprocessed Objective: Minimize
52.0 x1 + 56.0 x2 + 55.0 x3 + 53.0 x4 + 0.0 x5 + 0.0 x6
Constraint Matrix:
RHS
71136.0 28955.0 48394.0 62778.0 -1.0 0.0 211263.0
50.9 61.3 90.7 68.6 0.0 0.0 272.0
40.0 10.0 25.0 45.0 0.0 0.0 120.0
10.0 7.0 10.0 12.0 0.0 1.0 39.0
6.84 7.37 6.61 6.98 0.0 0.0 28.0
The Reduced Costs
Basic Basic Basic Basic Basic 4.7333937
x1 x2 x3 x4 x5 x6
x cB yB pi
x1= 1.2044559 52.0 -5.5598... 5.36254...
x2= 0.98162 56.0 -9.6941... 0.35326...
x3= 1.0647851 55.0 5.50500... 0.60961...
x4= 0.7863542 53.0 -1.0965... -4.7333...
x5= 3734.9255 0.0 6.82030... 8.328735
The B matrix.
71136.0 28955.0 48394.0 62778.0 -1.0
50.9 61.3 90.7 68.6 0.0
40.0 10.0 25.0 45.0 0.0
10.0 7.0 10.0 12.0 0.0
6.84 7.37 6.61 6.98 0.0
Current Objective Value: 217.84239
Messages: You've Done It!
You've Solved It!!!
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

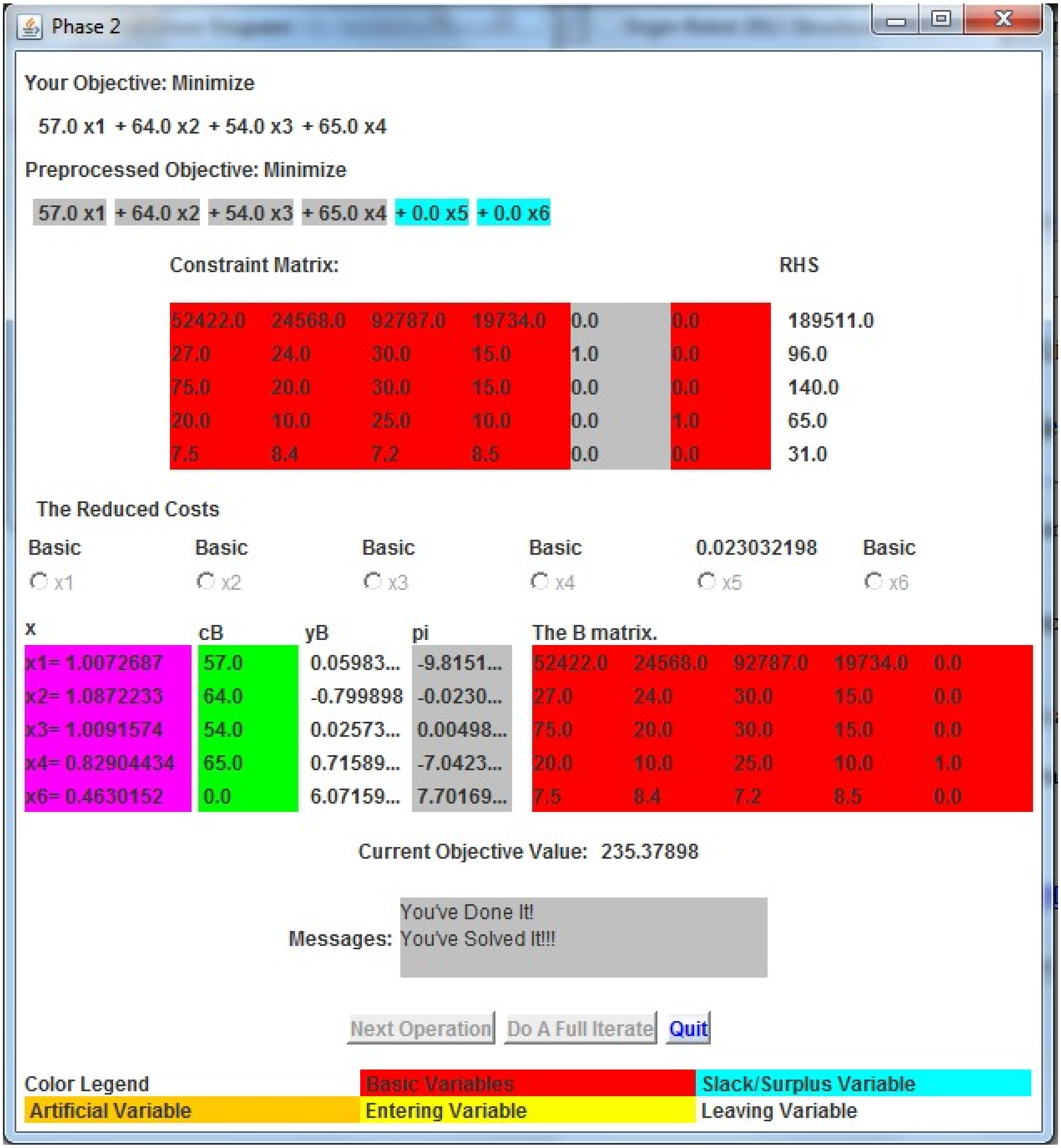

Options Examples View
Solve
Clear
Pivot
Standard
Display
x1 x2 x3 x4 Type Value
52.0 56.0 55.0 53.0 Min
71136.0 28955.0 48394.0 62778.0 ≥ 211263.0
50.9 61.3 90.7 68.6 = 272.0
40.0 10.0 25.0 45.0 = 120.0
10.0 7.0 10.0 12.0 ≤ 39.0
x1 = 1.204
x2 = 0.982
x3 = 1.065
x4 = 0.786
Objective Function Value = 217.842
Constraint 1 is non-binding with 1.204 slack.
Constraint 2 is binding with shadow price 0.353.
Constraint 3 is binding with shadow price 0.61.
Constraint 4 is binding with shadow price -4.733.
Constraint 5 is binding with shadow price 8.329.

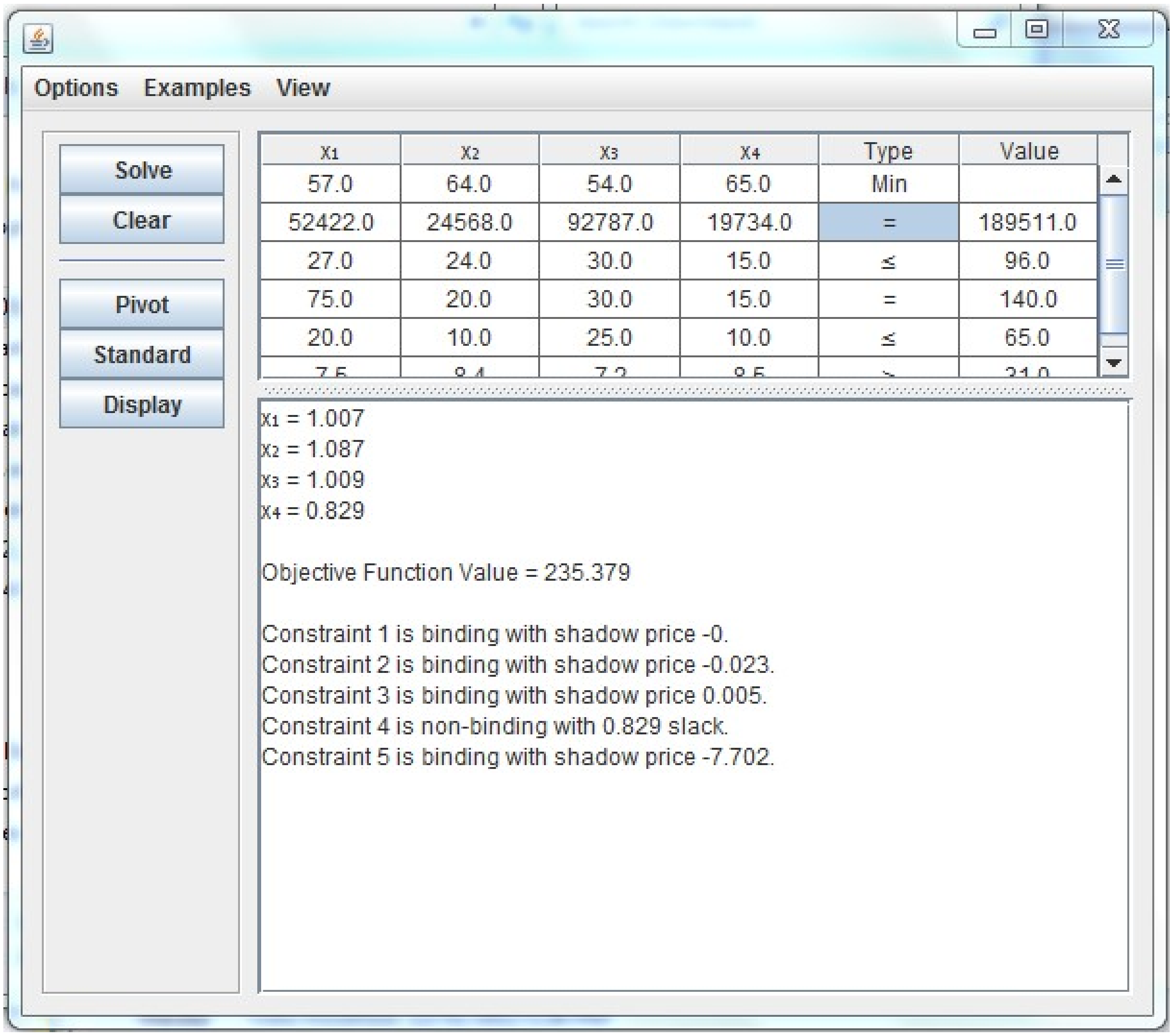

Phase 2
Your Objective: Minimize
57.0 x1 + 64.0 x2 + 54.0 x3 + 65.0 x4
Preprocessed Objective: Minimize
57.0 x1 + 64.0 x2 + 54.0 x3 + 65.0 x4 + 0.0 x5 + 0.0 x6
Constraint Matrix:
RHS
52422.0 24568.0 92787.0 19734.0 0.0 0.0 189511.0
27.0 24.0 30.0 15.0 1.0 0.0 96.0
75.0 20.0 30.0 15.0 0.0 0.0 140.0
20.0 10.0 25.0 10.0 0.0 1.0 65.0
7.5 8.4 7.2 8.5 0.0 0.0 31.0
The Reduced Costs
Basic Basic Basic Basic -0.13984072
x1 x2 x3 x4 x5 x6
x cB yB pi The B matrix.
x1= 1.0072687 57.0 0.05983... -4.2763... 52422.0 24568.0 92787.0 19734.0 0.0
x2= 1.0872233 64.0 -0.799898 -1.4848... 27.0 24.0 30.0 15.0 0.0
x3= 1.0091574 54.0 0.02573... -0.0067... 75.0 20.0 30.0 15.0 0.0
x4= 0.82904434 65.0 0.71589... 0.13984... 20.0 10.0 25.0 10.0 1.0
x6= 0.4630152 0.0 6.07159... 7.59378... 7.5 8.4 7.2 8.5 0.0
Current Objective Value: 235.37898
Messages: Keep Iterating
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

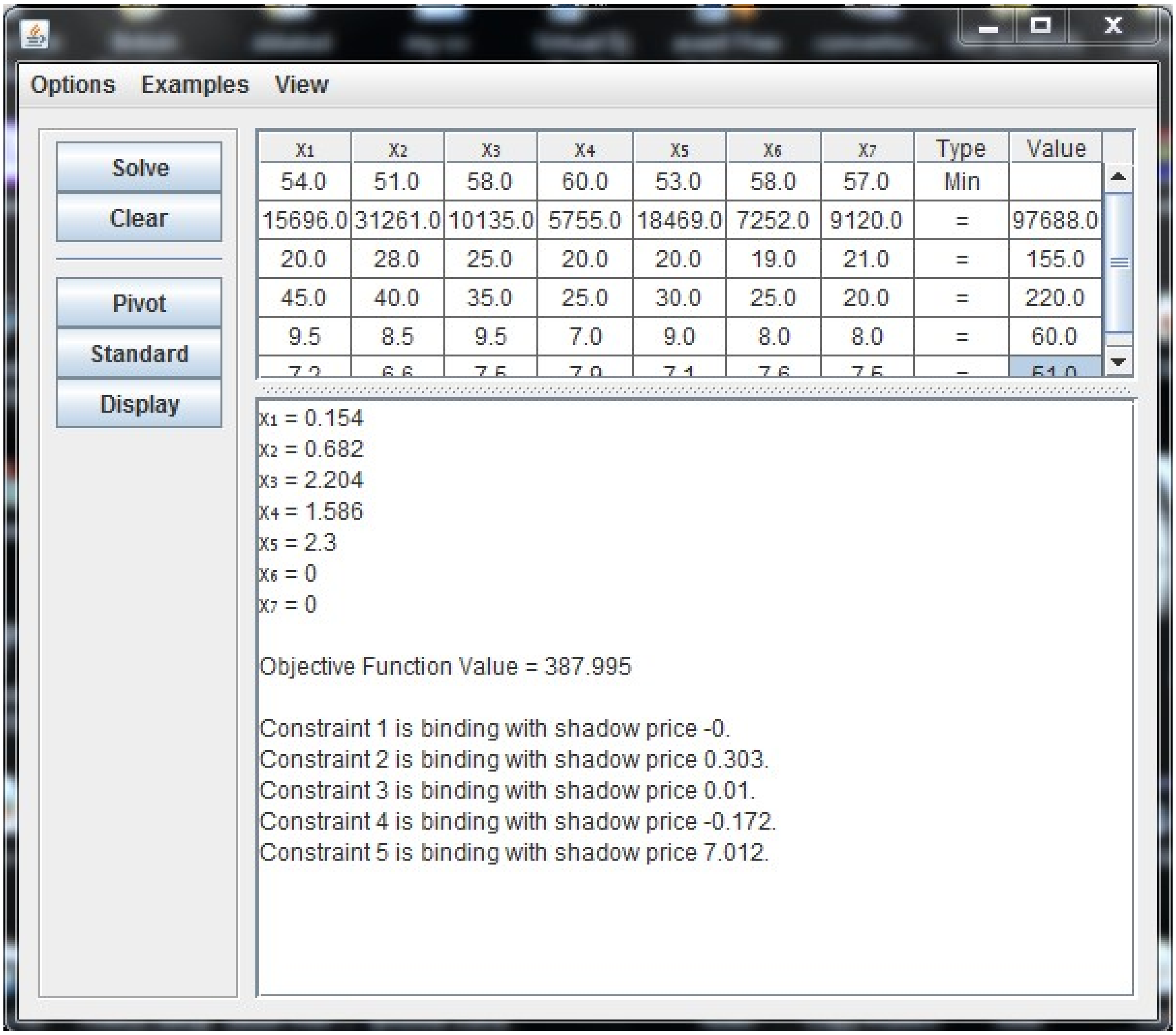

Phase 2
Your Objective: Minimize
57.0 x1 + 64.0 x2 + 54.0 x3 + 65.0 x4
Preprocessed Objective: Minimize
57.0 x1 + 64.0 x2 + 54.0 x3 + 65.0 x4 + 0.0 x5 + 0.0 x6
Constraint Matrix:
RHS
52422.0 24568.0 92787.0 19734.0 0.0 0.0 189511.0
27.0 24.0 30.0 15.0 1.0 0.0 96.0
75.0 20.0 30.0 15.0 0.0 0.0 140.0
20.0 10.0 25.0 10.0 0.0 1.0 65.0
7.5 8.4 7.2 8.5 0.0 0.0 31.0
The Reduced Costs
Basic Basic Basic Basic -0.13984072
x1 x2 x3 x4 x5 x6
x cB yB pi The B matrix.
x1= 1.0072687 57.0 0.05983... -4.2763... 52422.0 24568.0 92787.0 19734.0 0.0
x2= 1.0872233 64.0 -0.799898 -1.4848... 27.0 24.0 30.0 15.0 0.0
x3= 1.0091574 54.0 0.02573... -0.0067... 75.0 20.0 30.0 15.0 0.0
x4= 0.82904434 65.0 0.71589... 0.13984... 20.0 10.0 25.0 10.0 1.0
x6= 0.4630152 0.0 6.07159... 7.59378... 7.5 8.4 7.2 8.5 0.0
Current Objective Value: 235.37898
Messages: Keep Iterating
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

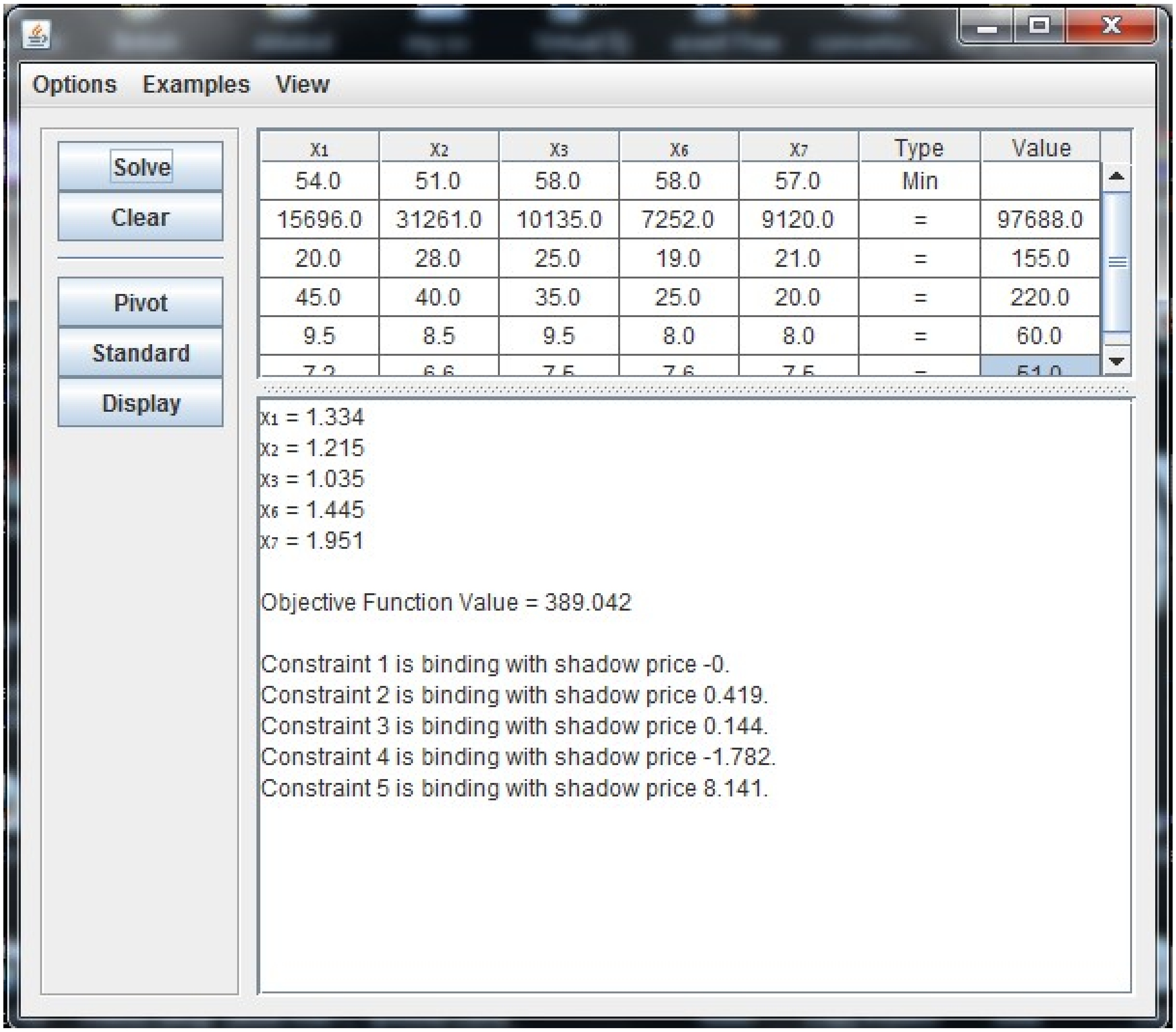

Phase 1
Your Objective: Minimize
57.0 x1 + 64.0 x2 + 54.0 x3 + 65.0 x4
Preprocessed Objective: Minimize
0.0 x1 + 0.0 x2 + 0.0 x3 + 0.0 x4 + 0.0 x5 + 0.0 x6 + 1.0 x7 + 1.0 x8 + 1.0 x9
Constraint Matrix:
RHS
52422.0 24568.0 92787.0 19734.0 0.0 0.0 1.0 0.0 0.0 189511.0
27.0 24.0 30.0 15.0 1.0 0.0 0.0 0.0 0.0 96.0
75.0 20.0 30.0 15.0 0.0 0.0 0.0 1.0 0.0 140.0
20.0 10.0 25.0 10.0 0.0 1.0 0.0 0.0 0.0 65.0
7.5 8.4 7.2 8.5 0.0 0.0 0.0 0.0 1.0 31.0
The Reduced Costs
-52504.5 -24596.4 -92824.2 -19757.5 Basic Basic Basic Basic
x1 x2 x3 x4 x5 x6 x7 x8 x9
x cB yB pi The B matrix.
x3= 2.0424304 0.0 92787.0 1.0 92787.0 0.0 0.0 0.0 0.0
x5= 34.72709 0.0 30.0 0.0 30.0 1.0 0.0 0.0 0.0
x8= 78.72709 1.0 30.0 1.0 30.0 0.0 1.0 0.0 0.0
x6= 13.9392395 0.0 25.0 0.0 25.0 0.0 0.0 1.0 0.0
x9= 16.294502 1.0 7.2 1.0 7.2 0.0 0.0 0.0 1.0
Current Objective Value: 95.02159
Messages:
Keep Iterating
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable


Phase 1
Your Objective: Minimize
57.0 x1 + 64.0 x2 + 54.0 x3 + 65.0 x4
Preprocessed Objective: Minimize
0.0 x1 + 0.0 x2 + 0.0 x3 + 0.0 x4 + 0.0 x5 + 0.0 x6 + 1.0 x7 + 1.0 x8 + 1.0 x9
Constraint Matrix:
RHS
52422.0 24568.0 92787.0 19734.0 0.0 0.0 1.0 0.0 0.0 189511.0
27.0 24.0 30.0 15.0 1.0 0.0 0.0 0.0 0.0 96.0
75.0 20.0 30.0 15.0 0.0 0.0 0.0 1.0 0.0 140.0
20.0 10.0 25.0 10.0 0.0 1.0 0.0 0.0 0.0 65.0
7.5 8.4 7.2 8.5 0.0 0.0 0.0 0.0 1.0 31.0
The Reduced Costs
x1 x2 x3 x4 x5 x6 x7 x8 x9
x
cB
yB
pi
The B matrix.
x7 = 189511.0 1.0
x5 = 96.0 0.0
x8 = 140.0 1.0
x6 = 65.0 0.0
x9 = 31.0 1.0
Current Objective Value:
Messages:
Artificial Variable Added
Using Two Phase Method.
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable

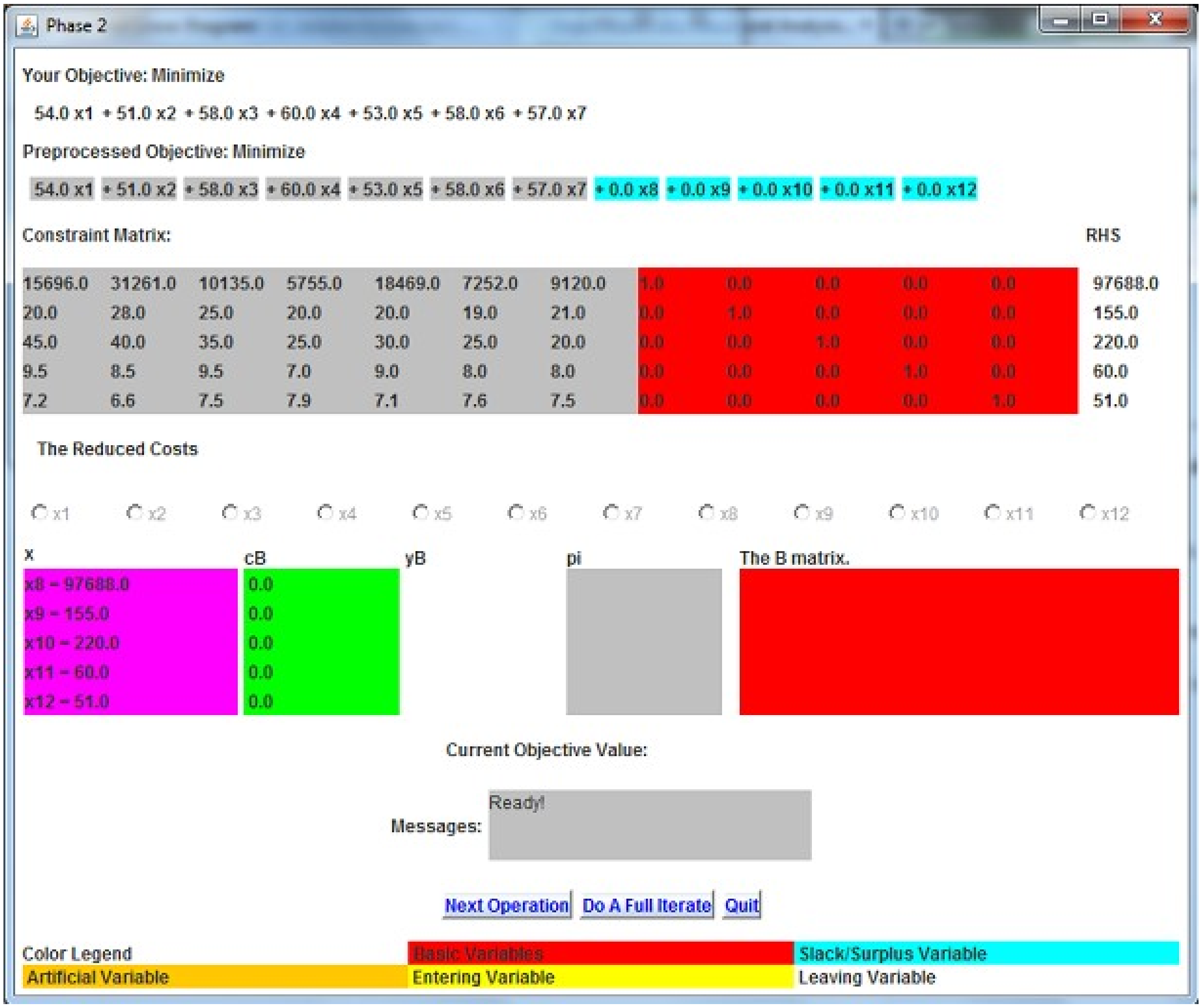

Phase 2
Your Objective: Minimize
57.0 x1 + 64.0 x2 + 54.0 x3 + 65.0 x4
Preprocessed Objective: Minimize
57.0 x1 + 64.0 x2 + 54.0 x3 + 65.0 x4 + 0.0 x5 + 0.0 x6
Constraint Matrix:
RHS
52422.0 24568.0 92787.0 19734.0 0.0 0.0 189511.0
27.0 24.0 30.0 15.0 1.0 0.0 96.0
75.0 20.0 30.0 15.0 0.0 0.0 140.0
20.0 10.0 25.0 10.0 0.0 1.0 65.0
7.5 8.4 7.2 8.5 0.0 0.0 31.0
The Reduced Costs
Basic Basic Basic Basic 0.023032198 Basic
x1 x2 x3 x4 x5 x6
x cB yB pi
The B matrix.
x1= 1.0072687 57.0 0.05983... -9.8151... 52422.0 24568.0 92787.0 19734.0 0.0
x2= 1.0872233 64.0 -0.799898 -0.0230... 27.0 24.0 30.0 15.0 0.0
x3= 1.0091574 54.0 0.02573... 0.00498... 75.0 20.0 30.0 15.0 0.0
x4= 0.82904434 65.0 0.71589... -7.0423... 20.0 10.0 25.0 10.0 1.0
x6= 0.4630152 0.0 6.07159... 7.70169... 7.5 8.4 7.2 8.5 0.0
Current Objective Value: 235.37898
Messages:
You've Done It!
You've Solved It!!!
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable


Options
Examples
View
Solve
Clear
Pivot
Standard
Display
x1 x2 x3 x4 Type Value
57.0 64.0 54.0 65.0 Min
52422.0 24568.0 92787.0 19734.0 = 189511.0
27.0 24.0 30.0 15.0 ≤ 96.0
75.0 20.0 30.0 15.0 = 140.0
20.0 10.0 25.0 10.0 ≤ 65.0
x1 = 1.007
x2 = 1.087
x3 = 1.009
x4 = 0.829
Objective Function Value = 235.379
Constraint 1 is binding with shadow price -0.
Constraint 2 is binding with shadow price -0.023.
Constraint 3 is binding with shadow price 0.005.
Constraint 4 is non-binding with 0.829 slack.
Constraint 5 is binding with shadow price -7.702.


Options Examples View
Solve
Clear
Pivot
Standard
Display
x1 x2 x3 x4 x5 x6 x7 Type Value
54.0 51.0 58.0 60.0 53.0 58.0 57.0 Min
15696.0 31261.0 10135.0 5755.0 18469.0 7252.0 9120.0 = 97688.0
20.0 28.0 25.0 20.0 20.0 19.0 21.0 = 155.0
45.0 40.0 35.0 25.0 30.0 25.0 20.0 = 220.0
9.5 8.5 9.5 7.0 9.0 8.0 8.0 = 60.0
x1 = 0.154
x2 = 0.682
x3 = 2.204
x4 = 1.586
x5 = 2.3
x6 = 0
x7 = 0
Objective Function Value = 387.995
Constraint 1 is binding with shadow price -0.
Constraint 2 is binding with shadow price 0.303.
Constraint 3 is binding with shadow price 0.01.
Constraint 4 is binding with shadow price -0.172.
Constraint 5 is binding with shadow price 7.012.



Options Examples View
Solve
Clear
Pivot
Standard
Display
x1 x2 x3 x6 x7 Type Value
54.0 51.0 58.0 58.0 57.0 Min
15696.0 31261.0 10135.0 7252.0 9120.0 = 97688.0
20.0 28.0 25.0 19.0 21.0 = 155.0
45.0 40.0 35.0 25.0 20.0 = 220.0
9.5 8.5 9.5 8.0 8.0 = 60.0
x1 = 1.334
x2 = 1.215
x3 = 1.035
x6 = 1.445
x7 = 1.951
Objective Function Value = 389.042
Constraint 1 is binding with shadow price -0.
Constraint 2 is binding with shadow price 0.419.
Constraint 3 is binding with shadow price 0.144.
Constraint 4 is binding with shadow price -1.782.
Constraint 5 is binding with shadow price 8.141.


Phase 2
Your Objective: Minimize
54.0 x1 + 51.0 x2 + 58.0 x3 + 60.0 x4 + 53.0 x5 + 58.0 x6 + 57.0 x7
Preprocessed Objective: Minimize
54.0 x1 + 51.0 x2 + 58.0 x3 + 60.0 x4 + 53.0 x5 + 58.0 x6 + 57.0 x7 + 0.0 x8 + 0.0 x9 + 0.0 x10 + 0.0 x11 + 0.0 x12
Constraint Matrix:
RHS
15696.0 31261.0 10135.0 5755.0 18469.0 7252.0 9120.0 1.0 0.0 0.0 0.0 0.0 97688.0
20.0 28.0 25.0 20.0 20.0 19.0 21.0 0.0 1.0 0.0 0.0 0.0 155.0
45.0 40.0 35.0 25.0 30.0 25.0 20.0 0.0 0.0 1.0 0.0 0.0 220.0
9.5 8.5 9.5 7.0 9.0 8.0 8.0 0.0 0.0 0.0 1.0 0.0 60.0
7.2 6.6 7.5 7.9 7.1 7.6 7.5 0.0 0.0 0.0 0.0 1.0 51.0
The Reduced Costs
x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x11 x12
x
cB
yB
pi
The B matrix.
x8 = 97688.0
x9 = 155.0
x10 = 220.0
x11 = 60.0
x12 = 51.0
0.0
0.0
0.0
0.0
0.0
Current Objective Value:
Messages:
Ready!
Next Operation
Do A Full Iterate
Quit
Color Legend
Basic Variables
Slack/Surplus Variable
Artificial Variable
Entering Variable
Leaving Variable