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MEASURING AND MANAGING AGRICULTURAL IMPACTS ON  
WATER RESOURCES: A CASE STUDY OF THE PANGANI BASIN

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April 2004



## MEASURING AND MANAGING AGRICULTURAL IMPACTS ON WATER RESOURCES: A CASE STUDY OF THE PANGANI BASIN

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a four-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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## **ABSTRACT**

This paper considers the effects of agricultural trade liberalization on water resources in a developing country setting. Although a large body of research dealing with trade liberalization and the environment exists, little work has focused on how changing trade rules can affect water resources. We present a mechanism by which a trade-induced increase in agricultural prices stimulates crop production by farmers and leads to a rise in agricultural water demand. Changes in demand may strain water allocation and management regimes; unstable or inadequate systems may not be able to accommodate such changes without systematic or institutional modifications.

We apply this mechanism to rice production in the Pangani Basin, Tanzania. Incorporating GIS techniques, crop water requirements, and estimates of current water supply, we develop a model of agricultural water resource availability and consumption. To assess future water demand, we forecast agricultural production assuming an increase in world rice prices. Based on our findings, we offer a policy-relevant assessment of the current and alternative water management systems. Finally, we provide policymakers with a guide that outlines important lessons, considerations, and pitfalls associated with this type of analysis.

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## ACRONYMS AND ABBREVIATIONS

EU	European Union
FAO	Food and Agriculture Organization
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GIS	Geographic Information System
GNI	gross national income
GRDC	Global Runoff Data Center
HG	hectograms
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IR	infrared
ITCZ	Inter Tropical Convergence Zone
IWMI	International Water Management Institute
LDC	least developed countries
LMIS	Lower Moshi Irrigation Scheme
MCP	marginal cost pricing
MESM	Master's of Environmental Science and Management
MW	megawatts
MT	metric ton
NDVI	normalized difference vegetation index
NGO	non-governmental organization
PBWO	Pangani Basin Water Office
SMW	Soil Map of the World
TANESCO	Tanzania Electric Company
TPC	Tanganyika Planting Company
UNH	University of New Hampshire
USD	United States dollars
UNEP	United Nations Environment Programme
WDM	water demand management
WTO	World Trade Organization

## **EXECUTIVE SUMMARY**

This paper considers the effects of a trade-induced increase in world rice prices on crop production and the subsequent rise in agricultural water demand. Specifically the paper focuses on a case study of the rice sector in the Pangani Basin of Tanzania. The Pangani Basin is currently experiencing water stress and resource conflicts. This paper provides policy-relevant insights on the potential for the current allocation regime to adapt to increasing water demands in addition to alternative allocation mechanisms. The paper concludes with a guide to policymakers of the important lessons, considerations, and pitfalls associated with this type of analysis.

### **The Framing of the Paper**

Trade liberalization provides a means of increasing trade between nations. As markets have become more global, the effects of increased trade on local markets and the local environment have often been overlooked. These local effects can be significantly positive or negative. Trade liberalization of the agricultural sector has particularly large effects on the local scale due to the extent to which crops are grown on smallholder plots and the role agriculture plays in poverty alleviation. Water resources are an essential input for the production of agriculture and are particularly affected by changing demands through agricultural trade liberalization. However, not much research has examined the impacts agricultural trade liberalization on water resources. This paper provides a policy-relevant means of elucidating some of the effects of trade on local resources and explores mechanisms for solving the problem of water allocation.

### **The Importance of Rice to Tanzania**

Rice, which was introduced in Tanzania from 1890-1920, has become an important food staple with about 60% of the population eating rice. To meet growing demands, the total cultivated area for rice has increased substantially over the past several decades. Rice is one of the few irrigated crops in the Pangani Basin and the most water intensive. Rice is traditionally grown in river valleys using irrigation fed by springs and river diversion. Irrigated rice production potential for the Pangani Basin is estimated to be 150,000 Ha

### **The Current Situation in the Pangani**

The Pangani River Basin is located in the North East of Tanzania. This river is fed by runoff from Mt. Kilimanjaro, the highest mountain in Africa, and the basin encompasses an area of 42,000 square kilometers. The climate in the catchment varies considerably between the slopes of Mt. Meru and Kilimanjaro, which receive 1200-2000 mm of rainfall per year, and the rest of the catchment, which receives about 500 mm per year. This variation makes allocation of water within the basin a contentious issue of utmost importance. Irrigation was pioneered centuries ago by the Chaggas tribe in the upper Pangani Basin. As the population in the basin has increased, so has competition for water. It is predicted that the demand by urban users in the basin will double by 2015 further stressing the water supply. The Pangani River also provides 17% of the hydroelectric power for Tanzania requiring significant stream flows.

## **The Current Water Regime**

Currently Tanzania's water supply is legally governed by an administrative allocation system. Any abstraction from surface waters, other than minor water collection using buckets, or groundwater extraction of more than 22,700 L per day requires a permit. The cost of a right to water is significant for most users and includes yearly fees. Water rights currently do not expire and many were issued decades ago. The only means of transfer of rights between users is through the sale of land. The former water allocation system was an informal, user-based riparian system. Remnants of the old system still exist today.

## **Measuring the Impact**

A model is developed for the Pangani basin that takes the price pass-through (0.38) for rice to determine the impact a change in world price will have on local prices in Tanzania. Three supply response values (0.37, 1.33, 0.92) are used to determine the response of farmers to the change in local prices. Rice yield estimated for the basin converts projected production to projected area of rice cultivation. The area of cultivation and average water requirement - 156 m for an acre of rice within the Pangani Basin - are used to estimate the increase in water demand as world prices double. The water requirements for the production of rice in the basin are calculated using CROPWAT, a model developed by FAO. CROPWAT accounts for local precipitation, potential evapotranspiration, crop growth coefficients, and the growing period of the crop to determine crop water requirements. The crop water requirements are calculated using a grid, which divided the basin into 144 squares each 256 km<sup>2</sup>. A sensitivity analysis is conducted on the results by varying crop yield, supply response,

and average irrigation requirement.

A water balance for the Pangani Basin allows us to quantify the water demand for rice production relative to the available supply of water in the basin. A vertical water balance approach is applied to the same grid as used by CROPWAT to calculate the water supply for a smaller sub-catchments. The water balance indicates that the Pangani basin has an available water supply of approximately 315 million m<sup>3</sup> within the streams.

The results indicate that a doubling of the world price of rice would lead to an increase in rice production and an additional 1-8% percent increase in the demand for water from the available supply. While the values alone may not seem significant, when put into context of the current situation this increased demand may contribute to the larger problem of water allocation in the Pangani Basin.

### **Managing the Impact**

The current water allocation regime in the basin is evaluated to see if it can adjust to future changes in demand. The current regime appears to suffer problems due to a lack of enforcement in terms of abstractions. In addition, the regime may not have the flexibility to handle sudden shifts in demand since the water allocation permits are often provided for many years.

Four water allocation mechanisms, marginal cost pricing, public administrative water

allocation, water markets, and user-based allocation, are discussed. Marginal cost pricing seeks to price water based on the cost of the provision. Public administrative water allocation describes a commonly applied system in which a government structure provides permits or decides who and how much water is allocated to users. Water markets allow water use rights to be bought and sold. The fourth alternative, user-based allocation, describes community management comprised of collective action institutions, which determine the allocation of the water.

The strengths and weaknesses of the current regime, categorized as a mix between public administrative water allocation and user-based allocation, are evaluated. In addition, the advantages and disadvantages of the alternative mechanisms are described.

### **Lessons Learned**

The paper concludes with several insights into measuring and managing water demand at a basin level and some broader lessons on institutional behavior.

1. Data collection and monitoring relevant to demand evaluation and policy planning are often not available on a basin level, making it difficult to identify demands and prescribe good policy. For future watershed planning, it would be beneficial to have social, economic, and biophysical data on compatible scales with databases containing exploitation rates and land use.
2. The causal chain between world prices and local production contains complex

- variables, which should be understood with reasonable confidence in order to accurately predict the outcomes of a price change.
3. To understand the full effects of policies, the sector examined should be viewed in context of other affected institutions, ecological and economic entities, and supply availability.
  4. Institutions governing water resources should be flexible to change with the shifting demands and developments of the basin in order to effectively persist.
  5. For resource reallocation to be feasible, it must be compatible with other institutions, including property and use rights.

## **1 INTRODUCTION**

The United Nations Environment Programme (UNEP) initiative on *Capacity Building for Integrated Assessment and Planning for Sustainable Development* is designed to enhance capacities of countries, particularly those developing and with economies in transition, to use integrated assessment as a tool for balancing environmental, social, and economic objectives in national sectors of importance and relating them to the planning process in order to facilitate sustainable development. The initiative was designed to further the World Summit on Sustainable Development (WSSD) *Plan of Implementation*, which emphasized the importance of taking a “holistic and inter-sector approach” to implementing sustainable development and specifically calls upon countries to develop National Sustainable Development Strategies linked to poverty strategies. The current round of the UNEP initiative focuses on agriculture, poverty alleviation, environmental management, and trade.

This paper investigates the foci mentioned above by conducting a case study. This Pangani Basin Case Study complements the UNEP initiative by illustrating the linkages between trade, agriculture, and environmental management and encouraging good governance and institution building for sustainable development. The focus of the case study is a river basin in Tanzania with water as a crosscutting issue. The 2002 WSSD Plan of Implementation declared that “water is not only the most basic of needs but is also at the center of sustainable development and essential for poverty eradication”. The importance of water was recognized by the international community with the declaration of 2003 as the international year of fresh water (UNESCO, 2003). The case study examines the effects of a change in world price of rice on agricultural rice production and the subsequent change in water demand. The global importance of rice, specifically to developing countries that account for 83 to 85 percent of global rice imports and exports, is revealed by the declaration of 2004 as the International Year of Rice. Rice also uses more water than any other crop; in the 1990’s 89 percent of all rice grown was in water flooded systems (FAO, 2004). This study analyzes existing institutions governing water rights and forecasts the ability of these institutions to adjust to changing demands. The study concludes by exploring alternative water allocation mechanisms, which may be applicable to the basin.

The Pangani Study uses both quantitative and qualitative approaches. In the quantitative section, a modeling study is done with detailed analysis of critical issues, including the effects of changing prices on production of irrigated rice and the associated water demand. The



qualitative section is a descriptive case study and scenario analysis focused on relevant patterns and interrelations of affected water users and institutions in the basin. This paper also conveys the major lessons learned from the case study.

## **2 BACKGROUND**

A significant component of this project investigates the linkages between trade reform (represented by rising global agricultural prices), agricultural production, and water resources. While few studies have considered directly the effects of trade reform on regional water demand, the research community has thoroughly examined many of the intermediate issues. In this first portion of the paper we review a number of the fundamental relationships that link trade reform to water resource impacts. These relationships provide the theoretical underpinnings for our case study of Tanzania agricultural production; consequently, we use examples from Tanzania where appropriate. Three areas of the literature are summarized in this section: the relationship between agricultural prices and crop production, the change in water demand as a result of enhanced crop output, and allocation issues. We begin with a brief overview of agricultural trade liberalization, which serves as the motivation of the rest of our analysis.

### **2.1 The Current State of Agricultural Trade Reform**

The General Agreement on Tariffs and Trade (GATT) was established in 1947 to provide an international forum to encourage free trade between member states. The system was developed through a series of trade negotiations, or rounds. The Uruguay Round (1986-

1993) which led to the creation of the World Trade Organization (WTO), brought about the biggest reform to the world's trading system by discussing a wide variety of trading policy issues including reform of trade in the sensitive sector of agriculture. However, disagreements between member nations stalled any major agreements on agriculture until 1992 when the United States and the European Union (EU) reached a compromise known informally as the "Blair House Accord" (WTO, 2004b). Despite this progress, some countries demanded that negotiations be reopened. Beginning in 2000, negotiations on agriculture reconvened as part of the Doha Development Agenda. The objective of these negotiations is to limit policy distortions that adversely affect agriculture and trade in order to establish fair, market-oriented trading systems thereby helping to liberalize trade (WTO, 2004a).

The term "trade liberalization" encompasses a wide spectrum of policies; agreement upon a concrete definition has been difficult. Several studies have reviewed definitions of trade liberalization. Two such studies by Michaely, Papageorgiou, and Choski (1991) and Thomas and Nash (1991) concluded "liberalization encompasses not only a reduction in the anti-export bias of the trade regime, and an increase in reliance on the price mechanism, but also a reduction in level of intervention" (Dean, Desai, & Riedel, 1994). According to Metzel and Phillips, trade liberalization policies consist of five main principles: reforming exchange rate regimes, removing non-tariff barriers, harmonizing and reducing import taxation, removing export restrictions, and reducing subsidies (Metzel & Phillips, 1998).

If international reform efforts achieve some or all of these principles, the result could cause world crop prices to increase. According to the Canada Department of Foreign Affairs and International Trade, “reductions in tariffs, trade-distorting domestic support and export subsidies will likely lead to an increase in trade and in world prices for cereals and red meat” (Environment, 2003). Trade liberalization would likely raise world prices of products that receive significant support and protection. For example, the United States currently heavily subsidizes cotton. If the government reduced these subsidies American farmers would no longer be competitive on a world market. Consequently, as domestic cotton supply contracts, the US would reduce the amount of cotton it exports abroad. Should artificially low priced crops be removed from the market, the actual price of crops would be reflected in higher world prices (Gillson, Poulton, Balcombe, & Page, 2004).

## **2.2 Linkages Between Crop Prices and Production**

We assess how an increase in the world price of rice affects agricultural production. In response to increased prices, farmers are likely to increase production: “An extensive empirical literature confirms that farmers respond very significantly to government policies: when the prospects for farm profits are good, they innovate, adapt technologies, improve existing practices, and increase production” (Thomas, 1991). For example, Goreaux shows that between 1995-1997, when cotton prices were favorable, African “farmers received a greater share of the export price, payment was more timely, production of seed cotton increased and many private ginneries were built” (Goreux & Macrae, 2003).

Time series studies of agricultural supply response use either the Nerlove (1958) model devised for single commodities or the Griliches' (1960) method for aggregate supply response. The magnitude of the supply response to pricing incentives varies by crop, but research suggests that increased prices will likely affect agricultural production in the country of Tanzania. "For annual crops the response can be especially strong: Tanzania's cotton production doubled within a year when producer prices were substantially increased in 1986/87" (Thomas, 1991). McKay finds that within Tanzania "a 10 per cent increase in the relative price of food will lead to a 3.9 per cent increase in per capita food production in the short-run and a 9.2 per cent increase in the long-run" (McKay, 1998). These findings confirm that farmers respond to increases in world price by boosting crop output.

However, the extent to which farmers will respond to an increase in export crop prices will depend on several factors. First, local prices must reflect and respond to world prices. Dorward and Morrison argue that "improved price transmission of international prices to producers" is essential to ensure that farmers respond (Dorward & Morrison, 2000). Furthermore, if world and local prices increase, producers must be aware of this change and will "need to know whether they have an inherent comparative advantage in producing these products in relation to other potential suppliers" (Swanson, Sofranko, & Samy, 2001).

Another important factor is the ability of farmers to respond to increased prices; farmers must have the necessary inputs to expand production. These inputs include but are not limited to water, land quality, and labor. According to the Food and Agriculture

Organization (FAO 2001), “the most fundamental factor influencing the agricultural production potential of a country is the availability of arable land.” Moreover, the relative levels of cultivated land, available land, and projected population growth determine a country’s potential for agricultural expansion—for both domestic and export crops.

Additional factors that can inhibit agricultural supply response include the ability to transport crops to markets, access to credit to finance capital-intensive projects, and the availability of advanced technologies. Each of these needs, if not met, can diminish a farmer’s supply response in the face of rising export crop prices. Nevertheless, both general modeling techniques and Tanzania-specific studies suggest that, all other things being equal, farmers will respond to rising prices by producing more crops. The next three sections will consider the water resource consequences associated with increased agricultural production.

### **2.3 Crop Production and Agricultural Demand for Water**

Water has become a source of conflict and competition in areas of burgeoning population. Agricultural, industrial, and domestic users as well as ecosystem processes all vie for the same water resources. Globally, agriculture currently withdraws the largest share of water, approximately 70 percent. However, variation across continents is significant. In North America, 45 percent of withdrawn water is siphoned by industry, while Africans use nearly 90 percent for agriculture (FAO, 2002). Therefore, it is important to assess the amount of crop production that growing populations will need in the coming years. With this information we can consider how agricultural water demand will change as a result.

During the past century we have witnessed a doubling of the world’s population, and yet food production has exceeded demand, which can be attributed to the advances of the green revolution. From 1967 to 1995 the world’s population increased by 67 percent, while the production of cereals increased by 84 percent over the same period (IFPRI, 2003). The technological breakthroughs of the green revolution allowed immense growth in production; nevertheless, these breakthroughs may not be enough to meet future demands. Table 2.1 shows that the rate of food product consumption in developing countries increased substantially from 1971 to 1995 as compared to developed countries. Not only will demand for cereals increase with the projected population increases, but the demand for animal derived products will rise as well.

**Table 2.1: Increase in Food Consumption from 1971-1995**

Commodity	Consumption increase		Value of consumption increase		Caloric value of consumption increase	
	Developed	Developing	Developed	Developing	Developed	Developing
	(Million metric tons)		(Billion 1998 US\$)		(Trillion kilocalories)	
Meat	26	70	37	124	38	172
Milk	50	105	14	29	22	64
Fish	5	34	27	68	4	20
Major cereals	25	335	3	65	82	1064

Source: (Delgado, Rosegrant, Steinfeld, Ehui, & Courbois, 1999).

Due to increased demand for both cereals and livestock, the International Food Policy Research Institute (IFPRI) has formulated the International Model for Policy Analysis of

Agricultural Commodities and Trade (IMPACT), which takes into account agricultural production and economic indicators, such as prices and trade, to estimate the quantity and location of cereal crops and livestock production in order to meet forecasted demand. The IMPACT model predicts that cereal production in the developing world would increase by 51 percent between 1995 and 2020 while only increasing by 24 percent in the developed world (Pinstrup-Andersen, Pandya-Lorch, & Rosegrant, 1999). The Food and Agriculture Organization (FAO) forecasted in *World Agriculture: Toward 2015/2030* that global food production will have to increase by 60 percent in order to cope with population and diet changes and that water withdrawal due to agriculture will increase by 14 percent over the same time period (Bruinsma, 2003).

With the demand for cereal and livestock increasing it is beneficial to consider how and where the increases in production will occur. Crop production can increase in three ways: arable land expansion, enhanced cropping intensity, or yield increases (Bruinsma, 2003). Arable land expansion encompasses the development of new lands for agriculture. Increasing crop intensity consists of increasing the amount of crops grown per acre and the rotation of crops on the field to increase the amount produced. Yield increases can be met using new crop cultivars or increases in inputs such as fertilizers, pesticides, or even water. The IFPRI IMPACT model predicts that the greatest amount of growth in cereal production in terms of area expansion will be in sub-Saharan Africa at 2.9 percent per year (Pinstrup-Andersen et al., 1999).

The remainder of this section will discuss the impacts of increased agricultural production on the demand for water in agriculture with an emphasis on sub-Saharan Africa and East Africa regions. The majority of the paper will describe the effects that growing agricultural demands will have on the quantity of water. The paper cites examples and case studies and provides boxes with more detailed information on actual techniques and technologies. Then the management of agricultural water use is discussed as a means of reducing impacts and mitigating effects.

## **2.4 Effects of Meeting Growing Agricultural Demands on Water Resources**

We begin by assessing the impact on water resources of the three methods of increasing production: increasing arable land, enhancing crop intensity, and raising yields. As mentioned above, the expansion of arable land will continue to be the largest contributor to increased production in sub-Saharan Africa.

### *2.4.1 Increasing Arable Land*

In order to understand how land conversion affects water usage, it is important to review the management techniques that farmers use and the types of crops they plant. The impact of new cultivation on the quantity of water in the region is dependent on the source of the water supply. Cultivated fields that rely on rainfed irrigation rarely pose a significant impact to the natural conditions of an area. However, small irrigation projects that store rainwater may change the natural hydrography of a watershed and alter the natural water cycles. In



turn, this can impact the water available for surface and river flows and groundwater recharge (Gregory, 2002). For example, the Mount Meru Forest Reserve acts as a natural recharge basin for groundwater supplies to northern regions of Tanzania. The recharge area would have been diminished if the forested land had been converted to agriculture (Shechambo, 2001). The impact of bringing new land into cultivation depends on the amount of irrigation present at the fields and will be discussed in more detail in methods of increasing yields of crops. The parameter with perhaps the greatest power in determining the amount of water that will be devoted to a new agricultural area is the type of crops produced.

The amount of water consumed by crops differs widely not only in the species and cultivar of crop but in the region in which it is grown, due to its climate and rate of evapotranspiration. Crop water requirements can be determined by multiplying the reference crop evapotranspiration ( $ET_o$ ) by the crop coefficient ( $K_c$ ), where evaporation represents the amount of water turned to vapor by energy and transpiration is the amount of water consumed by a plant through its stomata. The ( $ET_o$ ) can be estimated using many methods depending on the amount of climatic data available. The Penman-Monteith method is suggested by the FAO as the best estimate (see Box 1) (Wallingford, 2003). The crop coefficient is based on the average amount of water a crop will evapotranspire throughout its growth. A tabular representation of the ( $K_c$ ) can be developed based on three reference growth stages, initial, middle, and end of season stage (Table 2.2). The difference between the values indicates the amount of water required by the different crops under ideal

conditions (Allen, Pereira, & Raes, 1998).

**Table 2.2: Time-Averaged Crop Coefficients (K<sub>c</sub>) for Three Stages of Development**

Crop	K <sub>c ini</sub>	K <sub>c mid</sub>	K <sub>c end</sub>
Cotton	0.35	1.15-1.20	0.70-0.50
Rice	1.05	1.20	0.90-0.60

Source: (Allen et al., 1998).

As shown in Table 2.2, rice will require more water than cotton under the same (ET<sub>o</sub>) conditions. To take into account the climate and location of growth we must calculate the crop water requirements as described above. FAO has developed a software package termed CROPWAT that calculates the crop water requirements for many agricultural commodities in any location around the globe (see Box 1) (Clarke, 1998).

#### 2.4.2 *Increasing Crop Intensity*

Another way to increase production of agricultural crops is to bolster the “intensity” of the crops grown. This is accomplished through increasing the amount grown per acre and the rotation of crops on the field. Enhanced crop intensity may raise demand for water on fields through irrigation—the effects of which are discussed in the *increasing yield* section below. In addition, the schedule and rotation of the crops can significantly affect the amount of water that a farmer demands. In many cases frequent crop rotation may be due to the fact that irrigation is already present. We will discuss this further in the next section.

#### BOX 1: MEASURING AGRICULTURAL WATER DEMAND: CROPWAT

CROPWAT was developed by FAO to assist water managers, agronomists, farmers, and irrigation engineers in order to improve performance and planning of irrigation schemes and can be used to determine agricultural water needs and demands for current or future schemes.

##### Data Input and Calculations:

The CROPWAT program has been updated since it was first produced in 1992. It allows users to select locations and crops—the windows version (4.2) allows users to input climate, precipitation, irrigation schedules, and soil type or use the preset values from CLIMWAT, a database consisting of climatic data from 144 countries distributed by FAO. The program uses the Penman-Monteith method to calculate the reference crop evapotranspiration based on climatic data provided by CLIMWAT. The Penman-Monteith method attempts to take into account climatic variables such as solar radiation, wind speed, relative humidity, and soil heat flux when calculating evapotranspiration for a grass at any location on Earth.

##### Outputs:

CROPWAT uses the reference crop evapotranspiration to determine crop water requirements used to determine the irrigation requirements for optimal growth. The program can display this result in either tabular or graphical formats.

Sources: Wallingford, H.R. 2003; Allen, Richard G. et al. 1998

### 2.4.3 *Increasing Yield*

Perhaps one of the most important methods of increasing crop production is to supplement the inputs plants require to grow. Increasing fertilizers, pesticides, and water all typically lead to larger yields. In addition, new crop cultivars can be used to reduce the amount of water consumed while increasing production. Because this paper emphasizes water quantity, we will not address the effects of fertilizers and pesticides on water quality. While it was once common to use new crop varieties to reduce water demand, this trend has begun to plateau; therefore, it is not reasonable to expect large decreases in crop water requirements from cultivars. The potential for genetically engineered crops to reduce the need for water, while achieving the same production, is small (Cassman, 1999). Conversely, the method with the largest impact on the quantity of water used for agriculture is irrigation. Irrigation can be

separated into small-scale projects, local single farmer or small community irrigation projects, and large-scale projects. This final category includes government funded or privately financed development schemes that irrigate large areas and may include large water diversions or hydroelectric generation.

Small-scale irrigation projects, also called small-holder irrigation schemes, impact water quantity differently than large-scale schemes. Small-holder irrigation schemes are popular in sub-Saharan Africa due to financing problems and associated challenges of large scale irrigation projects (Kay, 2001). The small-holder schemes found in sub-Saharan Africa consist of local farmers irrigating small plots for either subsistence food or export crops. Common irrigation techniques include small diversions from rivers, rainwater collection, or tapping groundwater (see Box 2 for a more thorough description of small-holder irrigation technologies). While it is true that newer technologies may be more efficient, diversion and tapping commonly used by these technologies may be unsustainable. Small-holder diversions have been known to decrease river flows and bore holes have reduced the amount of groundwater available to users. The water resources down river from the Upper Ewaso Ng'iro North Basin in Kenya have suffered from reduced river levels due to the diversion by small-holder irrigators upstream. The increased competition for water resources has become a source of conflict between population growth, agriculture, native wildlife, and livestock (Gichuki, 2002).

The impact of large-scale irrigation projects on water usage can be extreme even though the

theoretical benefits of such projects may seem immense. Large-scale irrigation schemes have been developed in many parts of sub-Saharan Africa and provide water to cultivate thousands of acres for food production. Dams constructed for these irrigation schemes also produce electricity for industrial growth. However, large-scale projects greatly alter the hydrologic cycles in the river basins in which they have been installed. Perhaps the most well-known and well-documented case is the loss of the Aral Sea after upstream users diverted the main feeder rivers to irrigate cotton-producing fields (FAO, 1997).

Similarly, the Great Ruaha Basin in Tanzania has attracted much study because of the competing water demands of large-scale irrigation schemes, wetlands areas, and the flow of the Great Ruaha River. The river flows not only into a game reserve and national park but provides the flow for a hydroelectric plant downstream. The effects of the large-scale rice irrigation program in the basin has caused all users to rethink and compete for resources once considered unlimited<sup>1</sup>. The loss of water to the wetlands can radically decrease biodiversity in the region due to the large number of species that depend on the wetlands. In addition, the fish species that thrive in the river—and upon which the local fishermen depend—may be lost due to reduced flows of the Great Ruaha River (SMUWC). The experience in the Ruaha Basin exemplifies the effects that large-scale irrigation projects can have on the natural environment—all in the name of increasing crop yield.

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<sup>1</sup> See *Talking About Usango* (SMUWC, 2002) for a general overview with references to many technical documents on the basin.

#### *2.4.4 Managing Agricultural Water Demand*

As agricultural production grows so too will the demand for water. As outlined above, land conversion and irrigation will provide vast increases in production; however, these advancements require that we have proper tools to manage water use. Management systems utilizing Geographic Information System (GIS) techniques to store data and provide analysis can provide a great advantage. In addition, data collection through methods that are less costly than standard, on-the-ground, labor-intensive sampling is critical. This makes remote sensing a great alternative. GIS systems have a huge advantage because they ensure that collected data has a spatial component that can be tracked, mapped, and analyzed for model construction and optimal efficiency (Bastiaanssen, Molden, & Makin, 2000). The development of a GIS in Kenya provides a good example of how these techniques can be used to manage smallholder irrigation and drainage projects. The project provides policy makers and farmers with a visual representation of the number of smallholder irrigation projects that surround certain watersheds in the Lake Victoria area (Mati, 2002). More recent studies have begun to use GISs to store data with a spatial feature such as economic and environmental variables with modeling techniques to optimize the economic use of water or its distribution amongst users. One example is of the Aral Sea region where the demand for water from the Kashkadarya River was analyzed including flow values to ensure that the management outcome would provide for continued river flow for environmental and species conservation (McKinney & Cai, 2002). The use of remote sensing instruments to measure such variables as precipitation and evaporation has been used for many years,

however, the use of the instruments for measuring irrigation performance has not been utilized to its full potential but may be in the future (see Box 3).

**BOX 3 AGRICULTURAL APPLICATION OF REMOTE SENSING: MEASURING IRRIGATION PERFORMANCE**

Remote Sensing can take the form of satellites in space sending out IR (Infra Red Wavelengths) to radio spectrums or the form of aircraft taking photographs. All of these processes can be analyzed using GIS so long as the spatial character of the data is preserved. Satellites are able to pick out distinct differences in spectrums received from areas which they fly over in order to determine the types of crops growing, the land use, the amount of photosynthesis occurring and the amount of evapotranspiration taking place just to name a few.

A study assessing the performance of the Sirsa Irrigation Circle in India was able to determine crop yield through the use of normalized difference vegetation index (NDVI) by means of satellites to determine the amount of yield of wheat just before harvesting of the crop. In addition, they were able to combine that information with water usage to determine the areas where water was being wasted by over use and areas not receiving enough water.

Source: Bastiaanssen, W.G.M. et al. 1999.

## 2.5 Water Allocation Mechanisms

Several water allocation mechanisms are currently used throughout the world. These can be broadly grouped into four categories: marginal cost pricing, administrative water allocation, water markets, and user-based allocation. While many countries, including Tanzania, use a combination of the above-mentioned mechanisms it is important to understand the basic concepts, including the advantages and disadvantages associated with them. This section will summarize the main principles of each of the four mechanisms and describe the mechanism currently used in Tanzania.

### 2.5.1 *Marginal Cost Pricing*

The marginal cost pricing (MCP) mechanism uses a fee structure and charges users based on a measurement of the volume of water consumed. The average price of the fee is set equal to the marginal cost of supplying the last unit of that water. The benefits of this mechanism include theoretical economic efficiency, avoidance of under-pricing water, and under conditions of scarcity, the MCP system averts overuse because water prices rise to reflect the relative scarcity of water supplied (Dinar, Meinzen-Dick, & Roesgrant, 1997). The disadvantages of MCP systems are associated with implementation and equity. Establishing a price with MCP is often problematic because of defining marginal cost is difficult. Once the price is determined, implementation costs are high because the central water authority or water user association must monitor use and collect fees. This system is susceptible to neglecting equity issues in periods of shortage or scarcity because lower income users may not be able to purchase water with higher marginal costs.

There are few clear examples of systems that strictly apply MCP principles to water management. One of the best examples is the irrigation system, *Societe du Canal de Provence et d'amenagement de la Region Provencale* in France, which was established in 1970 (Dinar et al., 1997). The central water authority supplies water to approximately 60,000 hectares of farmland. Fees are established every year and increase for a period of five months, from mid-May to mid-September to reflect an increase in the demand for limited supplies of water. “This scheme is thoroughly grounded in the theory of marginal cost pricing, with full recognition of the need to consider and reflect long-run costs if farmers are to make ‘correct’



investment decisions in terms of land, cultivation, crops, irrigation equipment, and storage” (Dinar et al., 1997).

### *2.5.2 Administrative Water Allocation*

Water allocation and pricing in an administrative water allocation system, is controlled by the state or government (public sector). The guiding principles in this system are water is perceived as a public good and the government is the proper authority to manage the resource because of the large capital requirements and long time horizons of water project investments. The main advantage of this mechanism is the promotion of equity in terms of supplying water to areas of insufficient quantity and protecting the poor. There are many disadvantages to this type of system. A major problem of this type of mechanism is the price of water does not represent the cost or value of water, which often promotes inefficient use and mis-allocation between users because a flat rate is often established. Another significant issue is implementation. Despite the state having responsibility for all water use, the implementing agencies have only sectoral responsibility (Karkkainen, 2001). Fragmentation of responsibility can prevent timely and rational decision-making, hinder coordination, and impede measuring performance (UN, 2003).

Administrative water allocation mechanisms are widely practiced throughout the world; the United States’ system provides a good example. The US Bureau of Reclamation, which was created in 1902, was created to help promote the development of the West by providing inexpensive water through the construction of various water projects. The Bureau is the

largest wholesaler of water in the US today by providing water to more than 31 million people (Reclamation, 2004). The Bureau provides water to domestic and irrigation users by charging fees based on the operating and maintenance costs necessary to maintain the water projects. Water is highly subsidized and as a result the resource is over used and development has occurred in areas naturally ill suited for irrigation.

### *2.5.3 Water Markets*

Water markets rely on spontaneous market pressures to determine the price for water. These systems allow water rights to be exchanged between different users and usually involve trading water among similar uses or sale of water (Perry, Rock, & Seckler, 1997). Water Markets provide a means to allocate water according to its opportunity cost, resulting in efficiency gains (Johansson, Tsur, Roe, Doukkali, & Dinar, 2002). Properly functioning water markets require a number of preconditions: 1) rights must be properly defined and transferable, 2) externalities and transaction costs should not be substantial, and 3) water transfers must be technically and hydraulically feasible. Water markets have several benefits, which include empowering of water users (reallocations of water have to be approved by them, and they have right for compensations if water is transferred), securing of water rights tenure (water users have an incentive to invest in water-saving technology), inducing water users to consider other uses, and encouraging water users to take into account external costs imposed by their water use (Karkkainen, 2001). The challenges of this mechanism are associated with marketing a commodity that is not like any other on a market. The commodity is difficult to measure and to define when flows are variable. Water systems

often require investment in basic infrastructure by governments to create necessary conditions for the water market to operate.

Chile provides a good example of a water market system. The mechanism was created in 1981 with the passage of Chile's National Water Code of 1981, which established water rights that are transferable and independent of land use and ownership (Dinar et al., 1997). This system creates several types of water rights including permanent or contingent, and consumptive or non-consumptive and defines these rights as a volume of flow per unit of time. Rights are obtained by petition to the government or by purchase from a rights owner. Once the rights are distributed from the government, the government rarely participates in the system.

#### *2.5.4 User-based Allocation*

User-based allocation mechanisms, often referred to as common pool resource managements, require collective action institutions with authority to make decisions on water rights. These types of systems often develop in places where a community shares the resource, such as a pond, lake or water pump. The biggest advantage of this system is that it is politically acceptable and feasible. Also, collective action institutions are closely tied to the community and are likely to have more information about local needs and demands. The disadvantages of this mechanism are the collective action institutions can be limited in their effectiveness for inter-sectoral allocation of water and are not always transparent (Dinar et al., 1997).

The Subaks of Bali provide an example of a user based allocation mechanism (Dinar et al., 1997). Irrigation associations have formed on the island and have, subsequently, developed and constructed an irrigation system with little external assistance. An important aspect of the system is the “tektek” principle of proportional water allocation to each individual member, which divides the water among the members of the community in equal shares based on the amount of water flow. The water can be traded among the individual members. Maintenance costs of the system are the responsibility of the entire group.

### **3 INTRODUCTION TO CASE STUDY**

This report employs a case study approach to examine water resource use in Tanzania, East Africa. The driving force behind our analysis is an assumption that, over time, the world price for rice will increase and Tanzania will adjust rice production accordingly. We focus on the Pangani River basin and analyze the effect of expanding agricultural production on water resources in the region. Given the competing demands between upstream and downstream users, as well as tension between domestic, agricultural, and industrial demands, we assume that water resources will become increasingly strained.

We begin with a brief overview of the country of Tanzania and provide pertinent background information on the Pangani river basin. In the next section we survey the historical and current water management systems in the Pangani basin. Section 5 outlines the modeling approach we use to calculate the impact of a change in world rice prices on

crop production and, in turn, agricultural water demand. While our quantitative model provides only rough estimates, it offers an empirical basis for the link between world rice price and water resources in the Pangani basin. Section 8 outlines possible alternative water management systems in terms of allocation methods and institutional changes. Finally, we offer policy-relevant recommendations for future management practices in light of the changing resource demands.

### **3.1 Setting: Country Background**

#### *3.1.1 Physical*

The United Republic of Tanzania is located in East Africa and borders Burundi, the Democratic Republic of the Congo, Kenya, Malawi, Mozambique, Rwanda, Uganda, Zambia, and the Indian Ocean (see Figure 3.1). It is composed of the mainland and three islands, Zanzibar, Pemba, and Mafia with a total area of 945,090 km<sup>2</sup> (roughly twice the size of California) ((FAO)). Elevation varies throughout the country from sea level near the Indian Ocean to the highest point in Africa, Mount Kilimanjaro at 5,895 m (CIA, 2003).

Figure 3.1: Map of Tanzania



Source: (CIA, 2003).

Tanzania's climate ranges from tropical in coastal zones to temperate in the highlands. Average temperatures range between 17°C and 27°C, depending on location (Agrawala et al., 2003). Average precipitation is 937 mm per year; however, 50% of the country receives less than 750 mm and 80% receives less than 1,000 mm ((FAO)). The two rainy seasons are from March to May and from November to December.

Tanzania's natural resources include hydropower, tin, phosphates, iron ore, coal, diamonds, gemstones, gold, natural gas, and nickel (CIA, 2003). Estimates suggest that renewable water resources are 80 km<sup>3</sup> per year, of which 30 km<sup>3</sup> are groundwater ((FAO)). These are largely inaccessible both because of poor soil quality, which makes for unsuitable cropland, and the vast distances between farmland and water resources. While Tanzania does not receive any

water from neighboring countries, it does share three major lakes with bordering nations: Lakes Victoria, Tanganyika, and Malawi. Tanzania also shares the Rovuma River with Mozambique.

### *3.1.2 Population Demographics*

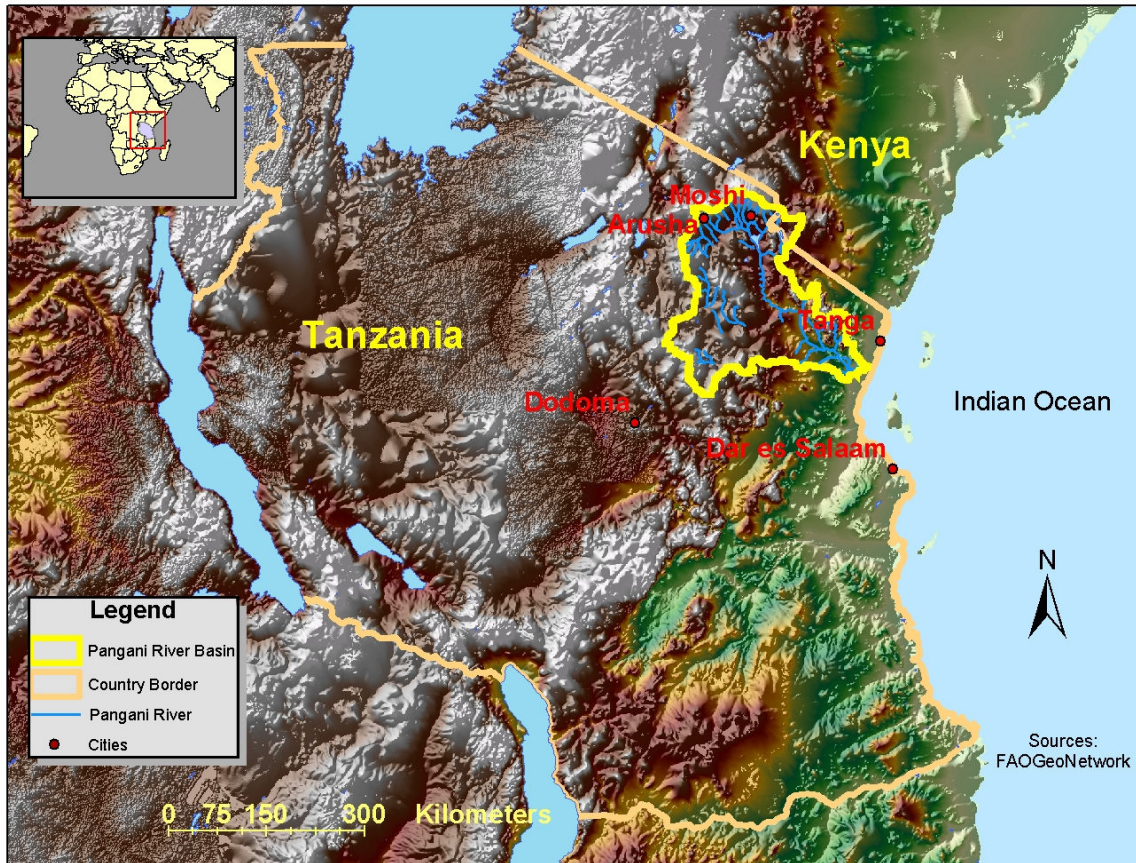
Tanzania's total population is approximately 36 million (2003) and growing at 1.72% per year (CIA, 2003). As is typical of Sub-Saharan African countries, 44.3 percent of the population is under the age of 14 with only 2.6% over the age of 65 (CIA, 2003). Average life expectancy is 44.56 years (CIA, 2003). An overwhelming proportion of the population lives in rural areas with only 23 percent living in urban areas (2002). The two official languages of Tanzania are English and Swahili.

Tanzania's citizens are some of the poorest in the world with a per capita gross national income (GNI) of US \$280. This is considerably less than the per capita GNI for Sub-Saharan Africa (US \$470) (Agrawala et al., 2003). As a result, the vast majority of people live on less than \$1 per day. The economy relies heavily on agriculture, which accounts for about one-half of Gross Domestic Product (GDP), provides 85% of exports, and employs 80% of the workforce (CIA, 2003). Topography and climatic conditions, however, limit cultivated land to only 4% of the total land area (CIA, 2003). Other important industries include diamond and gold mining, oil refining, shoes, cement, textiles, wood products, fertilizer, and salt.



## 3.2 Pangani Basin

Figure 3.2: Location of Pangani Basin

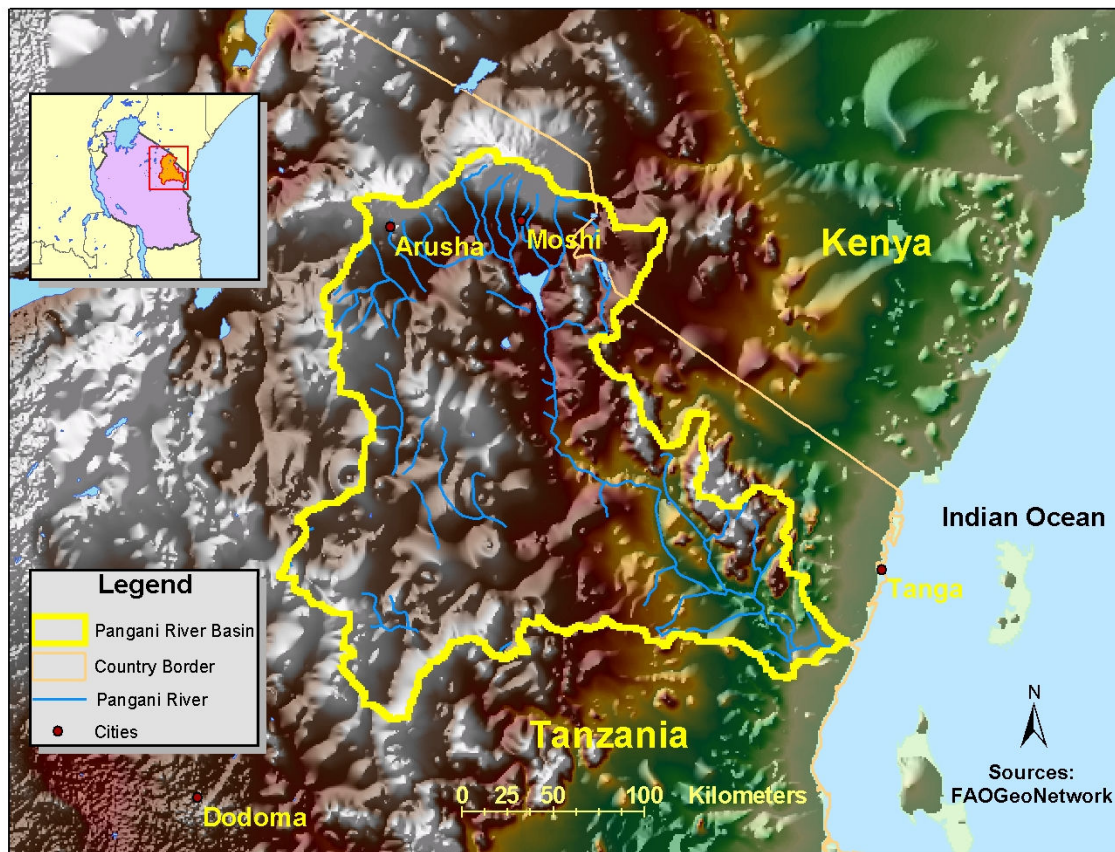


The Pangani River Basin (translation: “the place of enchantment”) is located in the northeastern part of Tanzania—with a small part of the catchment located in the southeastern part of Kenya—and lies between 1°S and 12°S latitude and 29°E to 41°E longitude. It stretches from the Arusha Region in the northwest to the Tanga Region in the southeast and has a total area of 42,000 km<sup>2</sup> (including 2,320 km<sup>2</sup> in Kenya) (Maganga, Butterworth, & Moriarty, 2001).



The basin contains four main rivers: Uмба, Sigi, Msangazi, and the Pangani River. The largest of these, the Pangani River, originates from the slopes of Mt. Meru (elevation 4,565 m) and Mt. Kilimanjaro (5,895 m) and extends south and southeast. It flows through Pangani Falls to the Indian Ocean covering 350 km from headwater to mouth. The Pangani River is the source of water for a large man-made lake, Nyumba ya Mungu, which the government constructed in 1965 for hydropower generation.

Figure 3.3: Map of Pangani Basin



The basin encompasses several climatic zones, which are generated by the Inter Tropical Convergence Zone (ITCZ) and the region's complex topography (Moges, 2002). These can be grouped into two broad zones: the wet highland zone and the dry, semi-arid lowland zone. The highland zones on the southeastern slopes of Mt. Meru and Mt. Kilimanjaro receive an average of 1,000-2,000mm of rain per year. In contrast, the dry and semi-arid lowland zones in the central portion of the basin experience only 500-600mm per year (Moges, 2002). There are two distinct rainy seasons within the basin including a short period from mid October to December and a longer episode from mid March to June.

### *3.2.1 Water Conflict in the Pangani Basin*

The Pangani Basin has many users competing for water, including domestic, agricultural, and hydroelectric. The two largest competitors for water are hydroelectric producers and irrigators and both sectors cannot expand without impacting the other. On a local scale, water conflicts usually arise between individual agricultural users. With 90 percent of Tanzania's workforce employed by agriculture and a rapidly growing population, increasing agricultural production is viewed as a critical step to ensure food security and reduce rural poverty (Røhr, Killingtveit, Nderingo, & Kigadye, 2000). This brings large-scale goals—those of food security, poverty reduction, and energy provision—into conflict at a local level.

Several factors contribute to water resource conflicts in the Pangani Basin. Since the 1980s a few large-scale irrigation schemes have been developed in the Pangani basin. The largest of

these is the Lower Moshi Irrigation Scheme (LMIS), which was completed in 1986 with assistance from a Japanese donor (Lein, 1998). The 2300 hectare LMIS catalyzed the expansion of rice cultivation on 3000 additional hectares through a system of 40 furrows that channel water to croplands. However, much of the water extracted for irrigation is taken by individuals or groups without water rights (Maganga et al., 2001). Furthermore, these irrigation schemes compete with hydropower plants and domestic users for limited water supplies.

### *3.2.2 Hydropower*

Currently, three main dams generate hydropower in the Pangani basin: Nyumba ya Mungu (8MW), Hale (21MW), and Pangani Falls (66MW); there are plans to construct two or three additional dams. The Nyumba ya Mungu reservoir is located near Moshi, near the top of the basin. The Hale and Pangani Falls plants are located downstream from irrigated agriculture. Domestic and industrial users also make abstractions above these two dams, but these withdrawals are small compared to irrigation usage levels (Mujwahuzi, 2001).

Upstream of the Nyumba ya Mungu Dam, in the upper part of the Pangani Basin, competition for irrigation water has intensified in recent years and is only expected to grow (Maganga et al., 2001). Increased water abstractions for irrigation have reduced September-to-February flows to watercourses that are upstream from Nyumba ya Mungu. The river that feeds the dam once flowed throughout the year (Mujwahuzi, 2001).

The Pangani Falls dam was funded bilaterally with Tanzania through grants from Norwegian, Finnish, and Swedish aid agencies at a cost of about \$100 million USD. Firms from these countries also provided the turbines and electrical equipment and did the consultant work and construction of the dam. The Nordic consultants spent significant resources studying small-scale irrigation in the Pangani Basin. The reports concluded that the traditional irrigation systems worked well with minimal ecological impact (Ek, 2000).

The Pangani Basin Water Office (PBWO) was formed in 1993 in accordance with the Nordic aid proposal. It is intended to resolve conflicts between irrigators and power generators by creating a management plan to decrease water use for irrigation (Ek, 2000). The PBWO facilitates the development of water user groups that purchase property rights, distribute water to individual farmers, and collect water rights fees.

### *3.2.3 Irrigation*

Although irrigation often competes directly with hydropower for water resources, the use of irrigation systems is widespread and part of the traditional practices of farmers in the Pangani Basin. The major irrigation projects in the basin are sugar estates owned by Tanganyika Planting Company (TPC), rice farms in the LMIS owned by Kilimanjaro Agricultural Development Programme, and the Burka Coffee Estate in Arusha.

In order to reduce agricultural water use by improving irrigation efficiency, the World Bank has coordinated the River Basin Management and Smallholder Irrigation Improvement

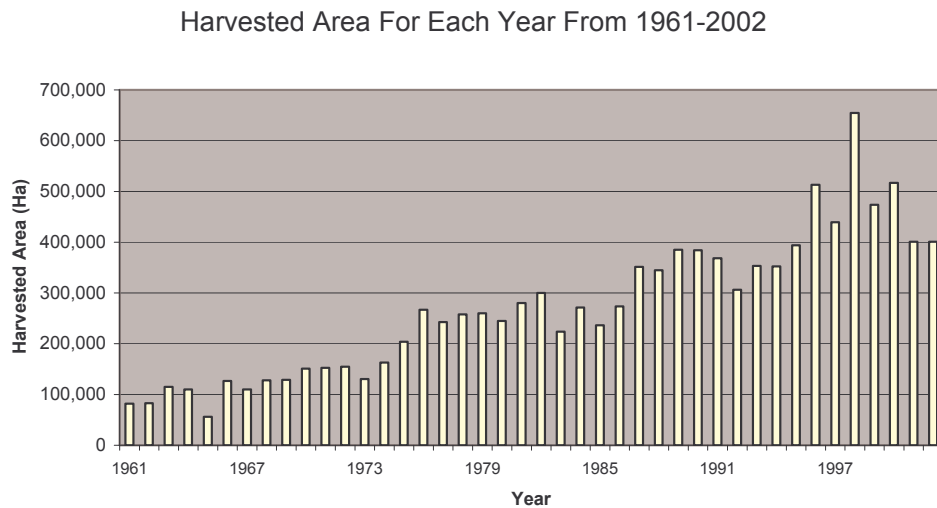
Project, which has already built 300 concrete regulators/slucice gates in the furrows along the slopes of Kilimanjaro. The sluice gates are intended to increase river flows by diverting excess water in the wet season into the main water reservoir. However, the design of the sluice gates is such that they have very little effect on the dry season flows. Although the gates were to be designed by local authorities, some contractors have been chased away by the local community. Other farmers have simply built bypass channels to augment water flow in the furrows (Lein, 1998).

### **3.3 The Importance of Rice in Tanzania**

Arab or Asian traders introduced rice in Tanzania during the German period from 1890 to 1920 (ICRA). Traditionally, rice has been grown in river valleys and areas fed by seepage or springs. It has become a major staple crop for the country of Tanzania with 60% of the population eating rice (Institute, October 2003). Rice consumption in Tanzania is estimated to be 232.7 kg per year per person compared to the United States' consumption, which is estimated to be 11.3 kg per year per person (FAO, 2001). The total cultivated area for rice in Tanzania has increased over time, and especially in the last several decades (see Figure 3.4).

Figure 3.4: Harvested Area for Rice in Tanzania, Each Year From 1961-2002

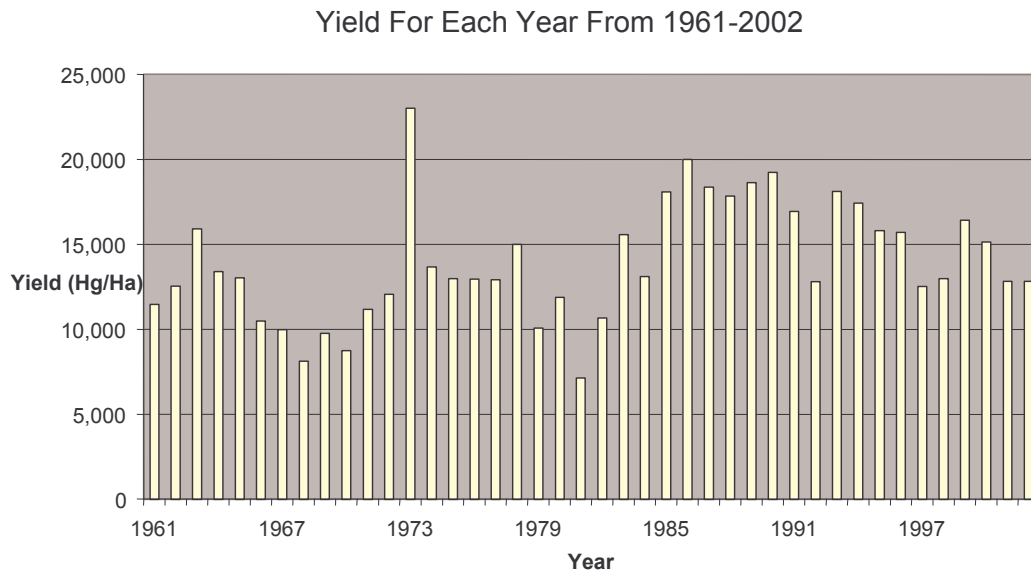
Source: FAO



Yield has also increased in the last forty-two years, although not as consistently as the total harvested area (see Figure 3.5). Rice production has fluctuated significantly over this time period due to several exogenous variables. The following is a summary of the main production constraints (FAO, 1998):

- Drought in upland areas and drought and flash flood in rainfed lowland (or inland swamp) areas due to irregular weather
- Infestation of red rice in the irrigated schemes
- Inadequate and irregular input supplies: seeds, fertilizer and credit
- Lack of small farm equipment especially for post harvest operations
- Lack of effective farmer organizations and cooperatives
- Poor maintenance of irrigation facilities
- Lack of a well-defined rice policy
- Poor road networks and marketing systems
- Labor shortage due to competition from other crops
- Weak research and extension support

Figure 3.5: Rice Yield in Hectograms per Hectare Each Year From 1961-2002



Source: FAO

#### 4 WATER MANAGEMENT IN THE PANGANI BASIN

In this section we discuss the traditional and current water management systems in the Pangani Basin. While Tanzania's water resource schemes have evolved over time, today's systems are deeply rooted in pre-colonial management practices. This poses both challenges and opportunities for policy makers as they work to design effective policies under the pressure of competing—and increasing—water demands. Section 4.1 reviews the history of water management in the Pangani Basin, while sections 4.2 and 4.3 evaluate the modern schemes and review some recent challenges in the region. Table 4.1 compares elements of the traditional and modern irrigation schemes.

## 4.1 Background of Traditional System

Pre-colonial water and land resources were governed by informal rules in Tanzania (Sokile, Kashaigili, & Kadigi, 2002). In the Pangani River Basin, the area along the southern slope of Mt. Meru, Mt Kilimanjaro, and the Pare and Usambara mountains is one of the most developed and well-known indigenous irrigation systems in the world (Lein, 1998). Traditional furrow irrigation developed by the Chaggas in the Kilimanjaro region can be dated back to pre-colonial times and was first described by European visitors in the nineteenth century. The Chaggas' irrigation system was based on an extensive network of channels, or "furrows", running across hill slopes. These furrows, which still exist today, were cut from streams and springs high up in the mountain and convey water along the steep river valleys to more low-lying inhabited areas. The furrows are several kilometers long, about one meter wide, and thirty centimeters deep. The water provided by these diversions was and is still used for both domestic and agricultural purposes.

Traditionally, construction and maintenance of the channel network was based on local irrigation associations organized around the Chaggas clan system. Some clans specialized in surveying and constructing furrows, while others were charged with upkeep and maintenance. Large furrows were constructed and maintained by communal effort and were controlled by local clan leaders. Smaller furrows were property of those who cut the furrow. For all furrows, water usage rights were inheritable. If a person claimed direct descent from the furrow's original builders, they were given access to water in that furrow (Lein, 1998). Other parties who wanted to use a furrow could join water associations or pay



a fee for use—payment in the form of local beer was common (Lein, 1998). Furrows were managed and maintained by diverse furrow committees: some led by clans, some controlled by furrow members, and others elected by village council.

Traditional usage furrow irrigation was halved between 1960 and 1986, largely as a result of public policy changes that mandated the construction of public pipelines for domestic water supply. While the furrow system is used primarily for domestic purposes in higher areas on Kilimanjaro, the furrows also provide a safeguard against agricultural water shortage at elevations of 1300 metres and lower. In the dry lowlands, the furrow system is still of vital importance for agriculture. There has been renewed interest by farmers in this area in rehabilitating and developing the furrow system to produce vegetables for growing urban markets (Lein, 1998).

Although the traditional water management system was long-lasting and deeply rooted in local culture and society, it has become inadequate as water demand has increased with population growth, development activities, and reduced stream flows from drought (Maganga et al., 2001). A principal drawback to the traditional system is that it is too localized and fragmented to adapt to rapidly changing economic and social conditions or increased competition among diverse users. Coordination problems between upstream and downstream users are compounded by a lack of mechanisms available for sorting out the problems. The traditional system is also criticized for not providing equitable or efficient use of water. Water was over-supplied to some areas and for particular uses, and some

groups have traditionally had better access to water than others (Lein, 1998).

## **4.2 Current Water Management Regime**

The current water management regime in Tanzania is rooted in colonial law, specifically the Water Ordinance of 1923. This ordinance introduced a water rights system that facilitated colonial settlers' access to water resources. It also established that all rights to surface water, groundwater, and land in Tanzania were vested in the state. Current laws maintain these principles. Some current water rights that were allocated during the pre-independence period allow for very high rates of abstraction. When these rights were allocated, the region's population was significantly smaller and industrial and urban areas were much less developed than they are today.

When Tanzania achieved its Independence in 1964, President Julius Nyerere's government moved toward socialist policies and pledged to prioritize basic needs and encourage equitable development. One of the products of these efforts, the Water Utilization Act of 1974, is the basis of modern water use law in Tanzania. This act required all users who extract water from a river or stream to have a water right.

The appropriative water rights prescribed by the Water Utilization Act of 1974 define the amount of water to be extracted, the purpose of the extraction, the source of the water, and the duration of the extraction. Under the 1974 Act, users could obtain water rights from the Water Officer—who dealt with all matters pertaining to the apportionment of water supplies

and had the authority to grant or refuse rights to anyone (Mwaka, 1999). These water rights can be transferred along with land but cannot be sold or traded on their own. However, the Water Utilization Act of 1974 does not contain any language that describes the role of traditional or customary water rights. Consequently, when this law came into effect, traditional furrows—which had been drawing water for hundreds of years—were not exempted from the law’s new restrictions on water use (Sokile et al., 2002).

The National Water Officer allocated water rights from the colonial period until 1981, when the national government transferred authority to basin-level water officers. At that time, the river basin was to become the decision-making unit for water policy and water rights allocation. The use of a basin system was intended to result in manageable and comprehensive water control. Although Tanzania designated nine water basins in 1981, water offices have thus far only been established in five basins: Pangani, Rufiji, Rumi/Wuvu, Lake Nyasa and Lake Victoria basins (Mutayoba, 2002). Basin Officers are appointed by the Minister of Water and are charged with approving water rights applications and addressing objections to proposed water rights.

A number of water use conflicts arose in the Pangani Basin in the 1990s as a result of population growth, development activities, and reduced river flows. The major water user conflicts in the basin were among individual irrigators and between irrigation use and hydropower production.

In 1991, the government launched a national water policy that focused on participatory planning, cost sharing in construction, and operation and maintenance of community based water supply (Mwaka, 1999:7). The Water Ordinance of 1948 affords the government the authority to prescribe the fees assessed for any water right application under the water ordinance. However, the government did not assume this authority until it issued a Government Notice in 1994. The Water Utilization Regulations of 1997 provided a schedule for application fees and annual rates that was amended in 2002 (see Table 4.2 and Table 4.3 below). For the first time in Tanzania's history, the government required registration and annual volume-based payment of water fees by all users who "divert, dam, store, abstract, and use" surface flows and groundwater in Tanzania. Now any abstraction from surface waters, other than minor water collection using buckets instead of pumps, requires a water right, as does groundwater pumping in excess of 22,700 liters per day, which effectively excludes hand pumps. The major difference between the 1997 schedule and the 2002 schedule is that charges in the 2002 schedule are not volume based for users who draw water at a rate less than 3.7 liters per second. Instead, these users pay a flat rate (van Koppen, 2004). The rationale behind this change was that smallholder irrigators constitute the majority of water users; hence, they could not be exempted from taxation.

River basin offices are responsible for allocating water rights. In areas without an office, the Regional Water Engineer, the District Executive Director, and the District Agricultural and Livestock Development Officer are authorized to allocate rights. The application fee for a water right for smallholders is the equivalent of \$40 USD and a \$35 USD minimum annual

fee—a non-trivial amount in Tanzania. These revenues are to be used to fund the operation of the water offices and a portion of excess revenues is to be used to develop offices in other basins. As the basin offices have yet to generate sufficient revenues to sustain their operations, Tanzania’s Central Ministry and donors, particularly the World Bank, currently finance the costs of the water regime (van Koppen, 2004).

Water rights do not expire with time as long as the yearly fees are paid. Consequently, there is often tension between changing water demands and water rights. In contrast, South Africa’s new water policy, which is regarded by many as a model of best practice, sets a 40 year maximum duration for water rights (Huggins, 2000).

**Table 4.1: Major Elements of Traditional and Modern Water Management Systems in Tanzania**

Traditional water management systems	‘Modern’ water management systems
Many small scale, local systems	Single river basin based system
Informal, unregistered water rights	Formal, registered water rights
Water for traditional agriculture and domestic purposes	Water for traditional agriculture, domestic purposes, hydropower, industries, agribusiness, urban areas
Water fee in kind/labor to the local irrigation committees	Water fee in cash to the central government
Informal furrow committees	Formal Water Users Associations

Source: adapted from (Lein, 1998).

**Table 4.2: Water User Fees**

Water User	Application Fee (\$US)	User fees in US \$ / year	
		Flat rate	Increment Rate
Domestic/Livestock	40	35	0.035 per 100m <sup>3</sup> above 3.7 l/s
Small Scale Irrigation	40	35	0.035 per 100m <sup>3</sup> above 3.7 l/s
Fish Farming	40	35	0.035 per 100m <sup>3</sup> above 3.7 l/s
Large Scale Irrigation	150	70	0.070 per 100m <sup>3</sup> above 3.7 l/s
Industrial	150	35	0.035 per 100m <sup>3</sup> above 1.11 l/s
Commercial	150	35	0.035 per 100m <sup>3</sup> above 0.94 l/s
Mining	150	none	0.017 per 100m <sup>3</sup>

Source: adapted from (van Koppen, 2004).

**Table 4.3: Non-Consumptive Water User Fees**

Non-consumptive Users	Charge (US\$)
TANESCO – Power Royalty	165,500
Power Royalty Fees per IMW installed capacity	300
Transport in Inland Water bodies (less than 5 tons)	10
Transport (above) for every additional Ton	2,2

Source: adapted from (van Koppen, 2004).

### 4.3 Implementation of Modern Water Regime in Pangani

The current water management regime in Tanzania has evolved from the traditional user-based system operated at a community scale to a publicly administrated pricing allocation system. The advantages and disadvantages of this system coincide with the strengths and weaknesses of user-based and publicly administrated pricing allocation systems described in Section 2.5. The qualities of the current system will be evaluated with criteria defined in

Section 6.1. For example, the current system experiences institutional fragmentation because there are so many institutions responsible for managing water in Tanzania but little coordination between them occurs. Table 4.4 identifies the most important institutions that are involved in water management in Tanzania. “Such predominance of isolated institutions locked up in a narrowly defined activities with no interactive learning is likely to continue to hamper national aspirations to manage water” (Sokile, Kashaigili et al., 2002). To change the current situation will require innovative reforms in national institutions and institutional learning.

**Table 4.4: Water Management in Tanzania**

Institution	Responsibility
Regional Water Engineers	Water Supply
Ministry of Agriculture and Food Security	Irrigation
Ministry of Natural Resources and Tourism	Hydropower
Planning Authority	Conversion of biodiversity in water bodies
Ministry of Industry and Commerce	Industrial discharge to water

Source: Adapted from (Sokile et al., 2002).

The modern water regime in the Pangani Basin has also suffered from a lack of monitoring and enforcement. In 2001, there were 1,028 legal abstractions in the Pangani Basin with a capacity to abstract more than 30 m<sup>3</sup> of water per second. In addition, there were 2,094 illegal abstractions with the capacity to abstract more than 40m<sup>3</sup> per second (Mujwahuzi, 2001:132). According to the World Bank (1997), farmers in both the Pangani and Rufiji Basins are suspicious of basin management and believe such efforts are designed merely to

safeguard the Tanzania Electric Company's (TANESCO) interests by preserving sufficient water for hydropower. This perception is reinforced by the fact that TANESCO provides most of the financial and material support for water management in the two basins (Maganga et al., 2001).

The current water rights regime allocates water based on four factors: geographical position in the basin, access to available infrastructure, sector of water use, and socio-political influence (van Koppen, 2004). And contrary to its objective, the new perception of water as an economic good for which one pays has actually led to increased water consumption. Those who buy water rights perceive themselves entitled to draw more water than they need or have rights allocated to them. Since monitoring and enforcement is minimal, these rights holders use water inefficiently and illegally abstract more water than they are permitted (Kashaigili, Kadigi, Sokile, & Mahoo, 2003).

Farmers who follow the traditional water rights systems still perceive their water use as legitimate, although they have no formal rights (Lein, 1998). This perceived legitimacy, coupled with costly application fees and suspicion of institutional motives, helps to explain why many farmers do not apply for water rights (Sokile et al., 2002).

## **5 MODELING WATER DEMAND AND SUPPLY**

This section models how an increase in world rice price affects water demand in the Pangani Basin, Tanzania. We develop a model to estimate the effect. The model assumes that rice

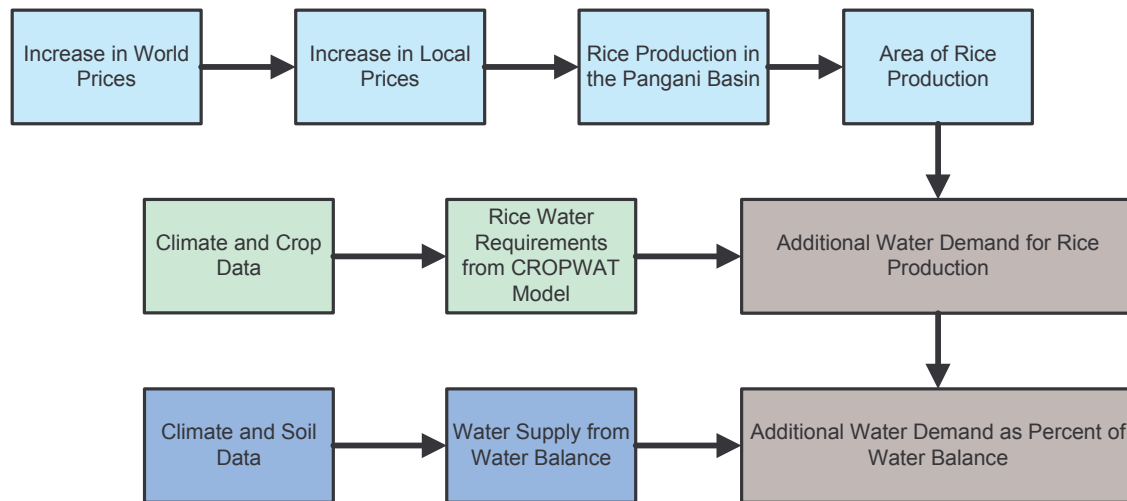


production by Tanzanian farmers will respond to increased world rice prices, and the demand for water will change within the basin. A similar approach is used by Rosegrant (2002) to predict the relationship between agricultural production and water demand at the global level.

Conceptually, the model uses world rice prices as the exogenous driving factor for increased water demand. As the world price of rice increases local farmers production of rice increases. To understand how the predicted change will affect water resources in the Pangani Basin, a water balance is calculated to provide a basis of the available water supply. The increased production demands more of the available water resources within the Pangani Basin.

The basic logic of the analytical model is as follows: 1) increases in world rice prices “pass through” to raise local rice prices, 2) a supply elasticity relates increased local prices to increased farmers production of rice, 3) production of rice is converted into area under rice cultivation using the average farmers yield of rice, and 4) the average water requirements per unit area determines the amount of water demand with a change in world price (see Figure 5.1). The data, steps and assumptions of the model will be discussed in the subsequent sections.

Figure 5.1: Flowchart of Analytical Model



## 5.1 Projected Increase in World Price

World rice prices vary from year to year; however, for a variety of reasons explained below, a permanent increase in world rice prices is likely to occur. Worldwide grain shortfalls have occurred in each of the past four years. A recent article by the Earth Policy Institute cites climate change and falling water tables as the cause of these shortfalls and predicts these reduced yields will lead to an increase in the world prices of rice and other grains (Brown, 2003). Similarly, a recently published World Bank report predicts that further trade liberalization will raise the price of rice between 33 and 90 percent with reduced crop tariffs and subsidies (World Bank, 2004). To model this projected increase in world rice prices we use a range of world prices based on a 0% to 100% increase relative to the 2003 world rice price of \$198/MT (World Bank, 2004a).

## **5.2 Projected Local Price Response**

In order for world rice prices to affect local water demand in Tanzania, world and local prices must be correlated. Despite the fact that rice is a food staple, it is a tradable good and local prices correlate with world prices. The World Bank (2000) found that the relationship between world rice prices and local prices, termed the pass through rate, is 38 percent. The pass through rate is the relationship between world and local prices and corresponds to a 38% increase in local prices with a 100% increase in world prices.

The model takes a “comparative static” approach by assessing how a change in a single parameter, the 0-100% increase in the world price of rice, affects the output of demand of water holding all other parameters of the model and the economy constant, including prices of other traded crops. Rice is a food staple in Tanzania and therefore can be assumed to have other cereal substitutes such as corn or wheat. However, a World Bank (2000) analysis performed in 2000 found that the price of maize, the largest food staple produced in Tanzania, is not a significant parameter in estimating the production of rice. The World Bank (2003) study also indicated that rice prices and production maybe independent of other food crop options or substitutes.

## **5.3 Projected Production Response**

The extent to which farmers will respond to rising local prices can be estimated using a production supply elasticity, which depends on relevant non-price factors including physical capital, human capital, technology, and biophysical conditions such as soil quality and the

intensity and rainfall variability (Thiele, 2003). Estimates of supply elasticity in Tanzania drawn from the literature are varied and range from 0.37 to 1.33. The first estimate, 0.37 is obtained from a 2002 study by Danielson who used four adapted Nerlove models with different regressors. This estimate provides a long-term supply response for rice in Tanzania. McKay (1998), who used a cointegration and error-correction model, provides an intermediate estimate of 0.92 as a long-term supply response for aggregate Tanzanian agriculture. The third estimate we obtained from a 2000 study by the World Bank provides a 1.33 long-term supply response for rice in Tanzania from a regression analysis.

#### **5.4 Projected Area Under Cultivation**

We assume that increased rice production will arise from a proportional increase in the amount of land and water used for rice production. The increase in land area may occur from either the expansion to previously uncultivated lands or the replacement of rice on agricultural lands previously growing other crops. We do not examine the alternate possibility that rice production increase via higher yields based on the following information.

Methods for increasing yield include applying optimal amounts of water to crops, using a new cultivar of rice that produces a higher yield with the same amount of water requirements, or applying fertilizer or pesticides. An increase in yield is not used in our model because the water requirements obtained from CROPWAT, a model developed by FAO, assume optimal water requirements; as a result our model cannot assume that yield can increase with increases in water application. In addition, a new cultivar of rice is not

assumed to increase yield because of the uncertainty in the success or discovery of new cultivars by those developing new cultivars (Cassman, 1999). Finally an increase in yield is not believed to occur due to the fact that few Tanzanian farmers have access to fertilizers and pesticides and these inputs are rarely used for growing rice. A World Bank (2000) study found that only about 15 percent of Tanzanian farmers use fertilizers and the majority of the uses were maize, coffee, and tobacco. In addition, the World Bank (2000) found that the majority of pesticide use in the country is limited to a few crops such as cotton, coffee, tobacco, and cashews.

It is unknown where in the Pangani River Basin the increase in the area of land used for rice will occur. Sub-Saharan Africa is estimated to have the largest potential for the expansion of land area for cereal production of any other portion of the developing world (Pinstrup-Andersen et al., 1999). Moreover, (Riceweb, 2004) estimates that the Pangani River Basin has the potential for 150,000 ha of rice production, which is much greater than the increase predicted by our analysis.

We determine the number of future acres of cultivated rice using yield. Tanzanian rice yields are variable from year to year (see Section 3.3) and therefore, three yield estimates are used. Using annual data from 1994-2001, we calculate a baseline yield estimate (2.06 MT/Ha) using a weighted average of yields in the three regions that comprise the Pangani River Basin: Arusha, Kilimanjaro, and Tanga; this yield data is obtained from the Tanzania Business Information Service (2004), additional weights are given by each regions share of

total Pangani rice production. Note that yield estimates for these regions vary from 1.00 MT/Ha to 5.35 MT/Ha.

## **5.5 Projected Water Requirements**

Agriculture in Tanzania is typically rainfed. Most crops, except rice, in the Pangani Basin are rainfed (Tanzania, 2004). Therefore, we assume that, if all the extra land necessary for producing rice came from displacing other crops or expansion to previously uncultivated land the additional amount of water needed to irrigate rice would not have previously been demanded for irrigating other crops or other uses.

We determine crop water requirements per unit area using CROPWAT. Crop water requirements are calculated by dividing the Pangani Basin into a grid of 144 squares each with 16 km sides. We use CROPWAT to determine the crop water requirements with in each square; the crop water requirement is the additional amount of water needed in excess of that available from precipitation (see Appendix 1 for CROPWAT equations). A mean value of water required to grow rice per unit area (156 mm) is calculated from those grids that grow agricultural products; the low (86 mm) and high (227 mm) water requirement estimates represent one standard deviation from the mean value.

## **5.6 Estimating Water Supply**

A water balance provides a simplified approach to budgeting the inflow and outflow of water in the basin; this is a valuable instrument that can be used to identify water supplies

and is a useful planning tool despite the fact that the results are approximations (Dunne, 1978). Accordingly, we calculate a water balance for the Pangani River Basin. It is calculated to determine the base-flow of the river. The base-flow corresponds to the amount of water available for use for irrigation or other demands via water diversion. The available supply is for the three-month period while rice is grown.

The water balance is conducted using the same grid of 144 squares used by the CROPWAT model to project crop water requirements. Within each square, the water balance is calculated by subtracting potential evapotranspiration from precipitation. To complete the water balance, we estimate the soil water holding capacity using the Digital Soil Map of the World, produced by FAO (1997), (see Appendix 1 for the water balance equations). For our analysis we use a 30-year average of water supply, we do not consider annual variability in our quantitative analysis but discuss its importance in section 5.7.

## **5.7 Results**

All of the results for water demand are for the three-month period when rice is grown in the Pangani Basin, March to June. The water balance indicates that for the three-month period the total supply of water available in the basin is 315,521,354 m<sup>3</sup>. The demand for this water is influenced by several factors in our model including world price, local price, production, pass-through, supply response, yield, and irrigation requirements. The initial world price is \$198/MT, the initial local price is \$197/MT, initial production is 20,800 MT, and the pass through is 38% (Table 5.1). The initial production is the median production for the

Kilimanjaro Region from 1994-2001, where most rice in the basin is sown.

We begin by calculating how a zero to one-hundred percent increase in the world price affects water demand when all parameters equal their baseline values; we will then conduct a sensitivity analysis using variation in the yield, supply response, and irrigation parameters. Finally the parameter estimates will be compared using the baseline, high and low estimates.

**Table 5.1: Baseline Values for Model**

Parameter	Value
Initial World Price \$/MT (Thailand 5% broken)(2003)	198
Initial Local Price \$/MT (2003)	197
Initial Production (MT)	20800
World Price-Pass Through (% change in local price with a 100% change in world price)	38%
Initial Yield (MT/Ha)	2.06
Production Supply Elasticity (% change in production with a 100% change in local price)	92%
Irrigation Requirement (mm)	156

**Table 5.2: Results of Model using Baseline Parameters with a doubling of the World Price of Rice**

Parameter	Value
Additional Rice Water Demand (m <sup>3</sup> )	5,554,452
Water Supply for Basin, Based on Water Balance (m <sup>3</sup> )	315,521,354
Additional Demand as Percent of Water Balance	2%

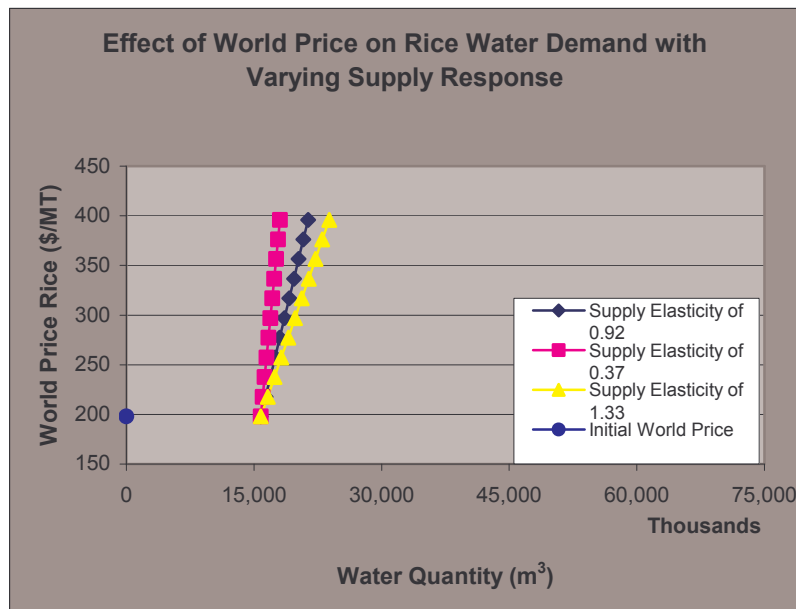
The results of the baseline estimate, see table 5.2, indicate that the additional demand for water as a percent of water supply is 2%. The implications of the results will be discussed further in the context of the results section.



### 5.7.1 Supply Response Sensitivity

To see the effect of the various parameters on the results of the model we analyze varying estimates of three of the parameters one at a time while holding all other values constant the using the baseline values. The first parameter of the model analyzed is supply elasticity. The three different supply responses, a baseline estimate of 0.92, a low estimate of 0.37, and a high estimate of 1.33 are used. Figure 5.2 indicates that changing the supply response will not greatly affect the amount of water demanded by rice production. Table 5.3 further illustrates that using the three estimates of supply response does not provide substantial differences in the results of additional water demanded for rice production as a percent of water supply as the world price doubles when compared to the other sensitivity analyses.

Figure 5.2: Results from Varying Supply Response



**Table 5.3: Results from Varying Supply Elasticity**

Additional Demand of Water by Rice with Doubling of World Price			
	Low Estimate	Baseline Estimate	High Estimate
Supply Elasticity	0.37	0.92	1.33
Additional Rice Water Demand (m <sup>3</sup> )	2,233,856	5,554,452	8,029,806
Water Supply for Basin, Based on Water Balance (m <sup>3</sup> )	315,521,354	315,521,354	315,521,354
Additional Demand as Percent of Water Balance	1%	2%	3%

### 5.7.2 *Initial Yield Sensitivity*

The second parameter analyzed is initial yield. Three different estimates are manipulated, a baseline estimate of 2.06 MT/Ha, a low estimate of 5.35 MT/Ha, and a high estimate of 1.00 MT/Ha. Figure 5.3 indicates that parameter values for yield provide the greatest variance in outcomes for the water demand by rice production. Based on the sensitivity analysis of yield shown in Table 5.4, the additional demand of water for rice production as a percent of water supply ranges from 1% to 4%. Therefore, obtaining more accurate estimates of yield from the basin would greatly increase the precision of our results. The difference in the starting point for the various estimates is due to the fact that the current amount of water demand for rice is unknown due to the various illegal abstractions within the basin.

Figure 5.3: Results with Varying Yield

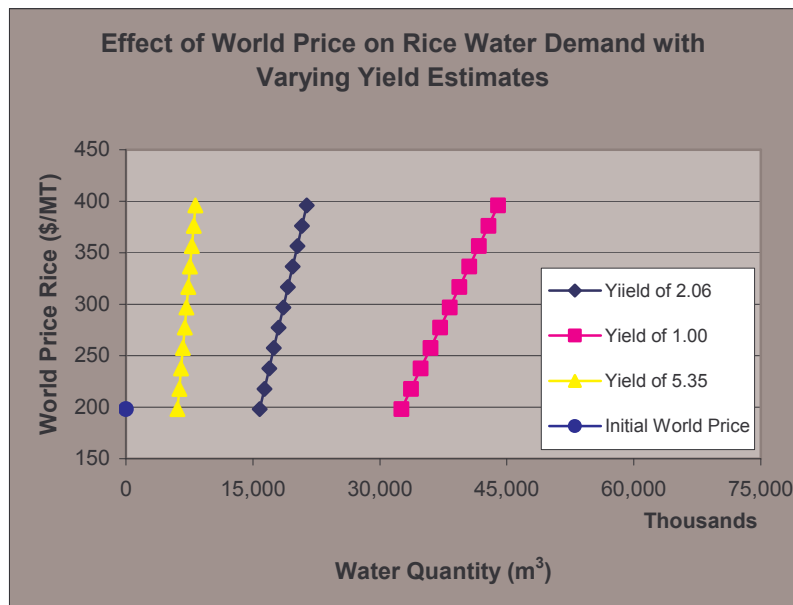


Table 5.4: Results with Varying Yield

Additional Demand of Water by Rice with Doubling of World Price			
	Low Estimate	Baseline Estimate	High Estimate
Initial Yield (MT/Ha)	5.35	2.06	1.00
Additional Rice Water Demand (m <sup>3</sup> )	2,137,171	5,554,452	11,433,862
Water Supply for Basin, Based on Water Balance (m <sup>3</sup> )	315,521,354	315,521,354	315,521,354
Additional Demand as Percent of Water Balance	1%	2%	4%

### 5.7.3 Irrigation Requirement Sensitivity

The third parameter analyzed is average irrigation requirements. Three different estimates are manipulated, a baseline estimate of 156 mm, a low estimate of 86 mm, and a high estimate of 227 mm. Figure 5.4 indicates the additional demand for water by rice using the three estimates of water requirements does not show as large a discrepancy as the three yield parameters. Table 5.5 further illustrates that changing the water irrigation requirements does

not greatly impact the results.

Figure 5.4: Results with Varying Water Requirements

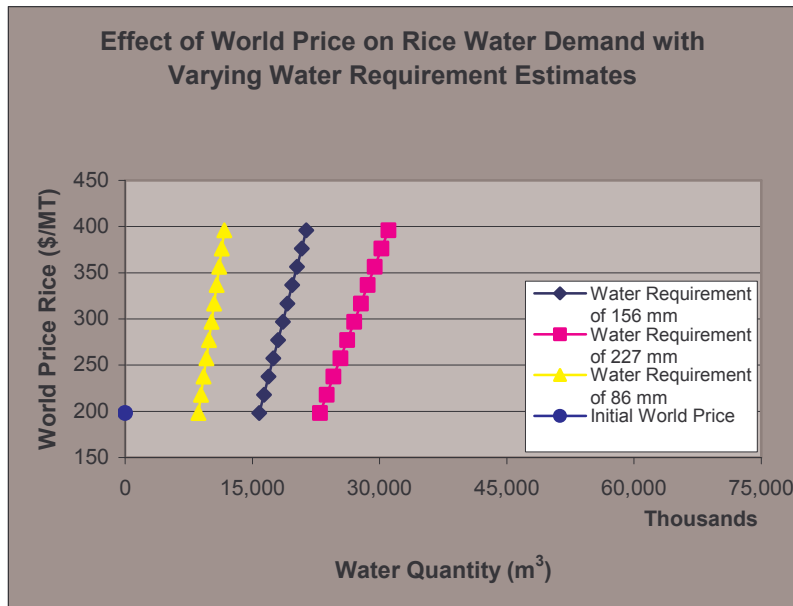


Table 5.5: Results with Varying Water Requirements

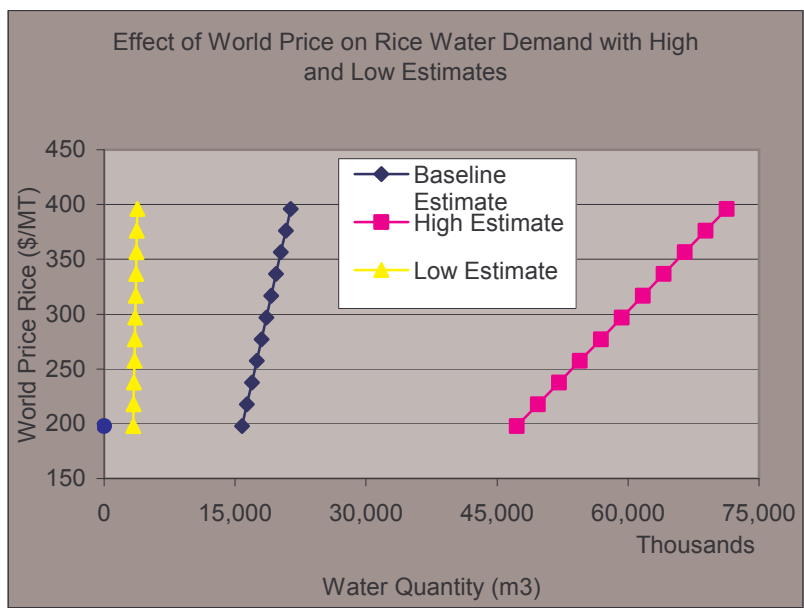
Additional Demand of Water by Rice with Doubling of World Price			
	Low Estimate	Baseline Estimate	High Estimate
Average Irrigation Requirements (mm H <sub>2</sub> O)	86	156	227
Additional Rice Water Demand (m <sup>3</sup> )	3,040,353	5,554,452	8,068,551
Water Supply for Basin, Based on Water Balance (m <sup>3</sup> )	315,521,354	315,521,354	315,521,354
Additional Demand as Percent of Water Balance	1%	2%	3%

#### 5.7.4 Sensitivity Analysis Across Many Factors

Finally, results for a baseline estimate, low estimate, and a high estimate are shown in Figure 5.5. As is shown the use of the high and low estimate provides a wide variation in water demand. The baseline estimate, with a doubling of world rice prices, will lead to a 2% additional demand of water for rice production as a percent of water supply, while the high

estimate indicates a value of 8% (Table 5.6). The large variation in the results indicates that while a small change may take place a large impact from a change in price may occur when the circumstances are unfavorable for the production of rice. A large impact may be due to low yields possibly from marginal lands or lack of inputs, while high irrigation requirements may be from low rainfall or the increase in cultivation in arid regions.

**Figure 5.5: Results of High and Low Estimates**



**Table 5.6: Results of High and Low Estimates**

Additional Demand of Water by Rice with Doubling of World Price			
	Low Estimate	Baseline Estimate	High Estimate
Initial World Price \$/MT (Thailand 5%broken)(2003)	198	198	198
Initial Local Price \$/MT (2003)	197	197	197
Initial Production (MT)	20800	20800	20800
Pass Through	38%	38%	38%
Supply Response	37%	92%	133%
Initial Yield (MT/Ha)	5.35	2.06	1.00
Average Irrigation Required (mm)	86	156	227
Additional Rice Water Demand (m <sup>3</sup> )	470,474	5,554,452	24,011,046
Water Supply for Basin, Based on Water Balance (m <sup>3</sup> )	315,521,354	315,521,354	315,521,354
Additional Demand as Percent of Water Balance	0.1%	2%	8%

## 5.8 Results in Context

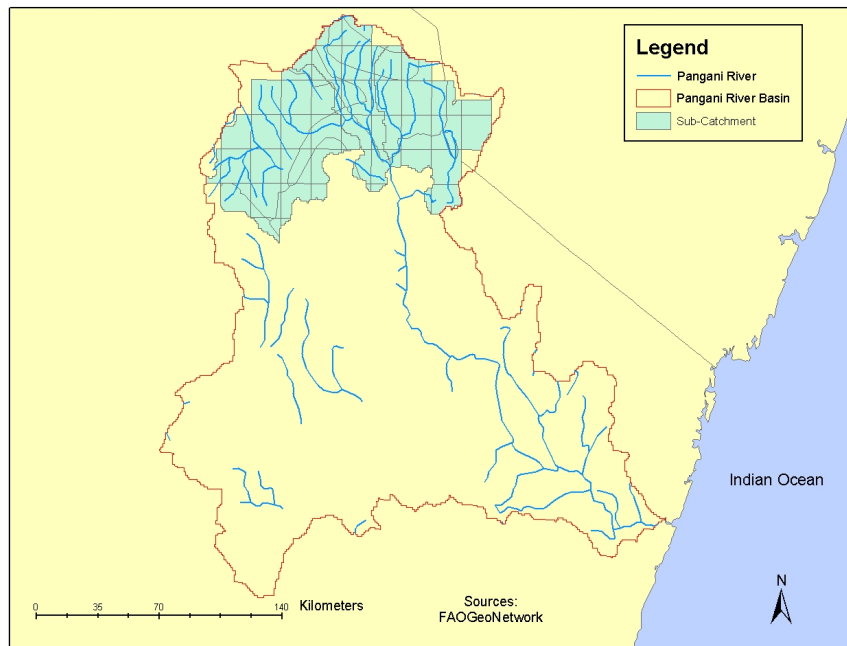
The results presented in our quantitative model only include the relationship between world price and water to meet the increased production of rice. The results exclude any additional impacts or circumstances that may compound the impacts of the predicted increase in water demand. Therefore, the results of the study must be put into context with other factors that may affect the quantity of water in the basin. This section will address additional issues that may compound the effects of a small change in water demand from increased rice production.

### 5.8.1 *Effects on Subcatchments*

The 2% value for increased water demand obtained using the baseline values was calculated based on the water supply for the entire basin. Therefore, the 2% value may be higher if the production of rice is concentrated in a sub-catchment of the Pangani Basin. A sub-

catchment refers to a smaller watershed within the Pangani Basin. As an example the water balance for a large sub-catchment in the upper Pangani Basin (see Figure 5.6: Subcatchment of Pangani Basin) indicated 208,219,819 m<sup>3</sup> of available water. Assuming that 50% of the rice production for the entire basin occurs in this large sub-catchment the water demand for rice is 1,626,127 m<sup>3</sup>, this represents approximately 1% of the total water supply of water in that sub-catchment for the three-month period when rice is grown when using the baseline values. Calculating the water balance for sub-catchments is critical to ensure that the amount of water available in the immediate watershed will be sufficient to meet the needs of rice production.

**Figure 5.6: Subcatchment of Pangani Basin**



### 5.8.2 Labor Adjustments

As the production of rice increases, as predicted by our model, the amount of labor required

will likely increase. Examining the rice sector in Tanzania (Yamada, 1997) found that as production increases, farmers increase their income and hire more workers. Therefore, as the number of workers increase in the Pangani Basin, the increase in rice production may have an indirect effect on the amount of water demanded for human use as families move into the basin. Water usage in Moshi, one of the largest cities in the Pangani River Basin, is estimated to be between 0.04 and 0.1 m<sup>3</sup> per day for houses with piped water and between 0.013 and 0.19 m<sup>3</sup> per day for houses with unpiped water (Mujwahuzi, 2002).

### *5.8.3 Environmental Flows*

An important issue that arises when assessing the ability to meet the increased demand for water in a sustainable manner is whether or not there is enough water to ensure that streams and wetlands are supported. The concept of environmental flow represents the amount of water in a river, wetland, or coastal zone required to maintain the ecosystem and the ecosystem benefits (Dyson, 2003). While no benchmark is currently available for the amount of environmental flow necessary to protect an aquatic ecosystem, estimates have been made that apply to specific regions. For example, in the United States, the Tennant method has been used as a guide in the Midwest for defining the quality of habitat; 10% of the mean annual flow is specified to provide poor quality habitat, while 60% will provide excellent habitat (Dyson, 2003). Using the mean annual flow for the Pangani River based on the monthly flows obtained from our water balance, a 60% mean annual flow translates into a stream flow of 18.6 m<sup>3</sup>. However, it should be stressed that assessments must be made on the ground to identify the specific requirements within each location. The IUCN Water and

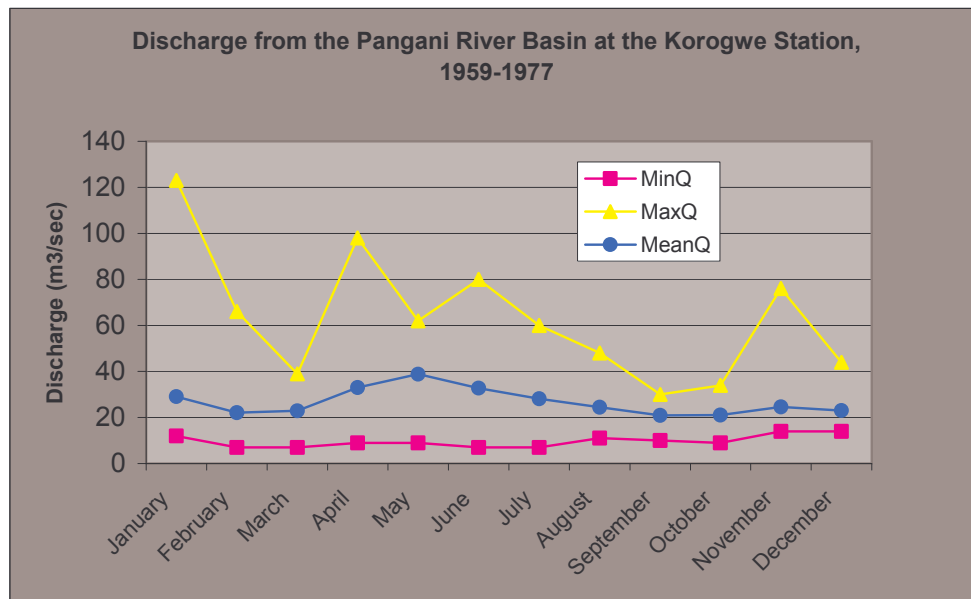


Nature Initiative has recently undertaken a project to investigate the environmental flows in the Pangani Basin. The IUCN Initiative will provide useful information to the Pangani Basin Water Office, which currently lacks information necessary to adequately estimate water needed to support the ecosystem (IUCN, 2003). The additional abstractions of water predicted by our study may further reduce the amount of water available to nature and therefore hinder the ability of the ecosystems within the basin to survive, making the IUCN Water and Nature Initiative crucial.

#### *5.8.4 Changes in Supply*

While the results predict that increased rice production, with a doubling of prices, will account for 1-8% increase in water demand, they are based on long-term average climate data during a 30-year period from 1961-1990. Therefore, the results do not reflect the extreme interannual variability in precipitation that is present in the Pangani River Basin. Stream flow data obtained from the University of New Hampshire (UNH) /Global Runoff Data Center (GRDC) for the Pangani River indicate that the maximum and minimum flows in the basin between 1959 and 1977 were highly variable (see Figure 5.7). The minimum values for stream flow shown in Figure 5.7 are smaller than the estimated stream flow from our water balance. This indicates that in certain years the projected 1-8% increase in the demand for water may be substantially higher if a drought were to occur.

Figure 5.7: Pangani Discharge at Korogwe Station



Not only is it important to take into account the interannual variability within the basin in terms of the amount of water available, but also it is essential to consider the effect of climate change on water supply. Climate change is projected to have both positive and negative consequences for Tanzania’s water-resources, including the Pangani River Basin. “For the Pangani River, there is some seasonal variation with runoff projected to increase in some months and decrease in others, with annual basin runoff decreasing by an estimated 6%. However, the Kikuletwa River, also within the Pangani Basin, is projected to decrease in all months, with annual reductions of 9%” (Agrawala et al., 2003).

Another issue closely related to climate change is the gradual decrease in supply as a result of Kilimanjaro’s melting ice cap. Between 1912 and 1989, the area of Kilimanjaro’s ice cap reduced by 75%, from 12.5 km<sup>2</sup> to 2.6 km<sup>2</sup> (IUCN, 2003). A conservative estimate predicts

the disappearance of the ice cap between 2010 and 2020 (Thompson, 2001). If the ice cap continues to decline, the Pangani River Basin will soon receive no water from glacial melt thereby amplifying our predicted small changes in water supply for rice production.

#### *5.8.5 Urbanization*

A rough approximation of the population within the Pangani River Basin based on the 2002 Tanzania Census is 3 million (Tanzania National Website, 2003). As with any developing country, migration to the cities is steadily increasing. It is predicted that by 2015 the urban water demand will be 163,600 m<sup>3</sup>/day (IUCN, 2003). This equates to an annual demand of approximately 59 million m<sup>3</sup>. Based on the results from the water balance, the projected urban demand represents 5% of the water supply for the entire basin. However, this value must be combined with the other users of water in the basin such as, livestock, agriculture, and hydroelectric.

#### *5.8.6 Hydroelectric*

Another growing sector of Tanzania's economy is electricity production, notably hydroelectric dams. The Pangani Basin generates up to 17% of Tanzania's electricity, and many of its hydropower units are designed with very specific water flows in mind (IUCN, 2003). If water abstractions from rice farmers were excessive, the hydroelectric plants would have to operate at less than optimal capacity. This could potentially cause conflicts between national interests and small-scale concerns. In fact, during the dry season, some hydropower stations below the Pangani Falls receive inadequate quantities of water to run turbines

contributing to the escalating numbers of water-related conflicts in the basin (IUCN, 2003).

## **6 EVALUATING MANAGEMENT SYSTEMS**

As water demand increases, mechanisms that manage the resource are challenged to adjust to cope with emerging challenges. A change in world price is only one of many possible drivers that can cause a shift in water demand. Other possible drivers of change include an increase in urban population and an increase in demand due to reduced water supply resulting from drought. To identify strengths, weaknesses, opportunities, and threats of the current system, an evaluation is necessary. In this section, evaluation criteria are developed and applied to the current Tanzanian water allocation system. The results of this type of analysis can be used to identify policy relevant issues in water management.

### **6.1 Evaluation Criteria**

Evaluation criteria are adapted from the Overseas Development Institute, World Bank, and several other sources. It should be noted that other criteria could be relevant to specific situations that should also be considered. Listed below is a useful but not exhaustive set of criteria. It should be stressed that using as many criteria as possible is advisable. Ensuring the set of criteria are exhaustive may allow unforeseen future problems to be considered, alleviating the need for a functional change in the mechanism chosen.

**Table 6.1: Evaluation Criteria**

Criteria Name	Definition
Adaptability	Ability to change in light of particular problems and circumstances. <sup>4</sup>
Administrative Feasibility	Capability of the institution to monitor and enforce the policy and communicate it to those affected. <sup>1</sup>
Compliance	Measure of how well management requirements are followed. <sup>2</sup>
Economic Efficiency	Ensuring the benefits of the mechanism out weigh the costs. <sup>1,2</sup>
Effectiveness	Needs to be defined in context of situation but includes a change in behavior. <sup>2</sup>
Efficacy	The management system changes the existing undesirable situation and helps achieve desired policy goals. <sup>1,4</sup>
Environmental Conservation	Promotes environmental integrity by mitigating negative effects of resource use. <sup>1</sup>
Equity	Users perceive system as fair. <sup>4</sup>
Flexibility	As demands change, the resource can be reallocated between different uses, users, and locations. <sup>3,4</sup>
Political and Public Acceptability	The system serves political and social values and objectives, and is accepted by various segments in society. <sup>1,2,4</sup>
Predictability	The outcome of the allocation process can be reasonably foreseen. <sup>4</sup>
Security	Securing tenure for established users, so that they will take necessary measures to use the resource efficiently. <sup>4</sup>

Notes: <sup>1</sup>Winpenny (1994), <sup>2</sup>Blomquist (1995), <sup>3</sup>Easter and Tsur (1995), <sup>4</sup>Dinar (1997)

## 6.2 Application of Criteria

To facilitate the use of criteria in evaluating regimes, the 12 criteria developed are applied to the current Tanzanian water allocation system, the results of which are presented in Table 6.2. If enough information was available, we scored each criterion a rating of low, medium or high, with low being undesirable. Note that some evaluation criteria could not be scored because of inadequate information. The scores represent estimates and are useful as guides but should be interpreted as a best judgment. The rationale for each score is given. In addition, suggestions are provided that may improve the system. Suggestions include: establishing clearly defined goals of the system, monitoring water availability, conducting studies to determine essential stream flows, creating incentives to purchase permits and or

penalties to discourage free-riders of the system, establishing permits that adjust in proportion to supply and that expire, allowing permits to be traded and retracted, and encouraging public participation by incorporating stakeholder involvement.

**Table 6.2: An Evaluation of the Current Management System**

Criteria Name	Score	Rationale	Suggestions
Adaptability	Low	1. Permits do not expire 2. Permits do not take into account variability of water supply	1. Monitor water availability 2. Permits should adjust in proportion to supply 3. Permits should be subject to reallocation
Administrative Feasibility	Low	1. Minimal monitoring and enforcement 2. Lack of knowledge of the law by those affected	1. Monitor and enforce permits 2. Public education
Compliance	Low	1. Lack essential information about quantities being used	1. Resources are needed to monitor available supply and use
Economic Efficiency		1. Information is needed on how much money it costs to run the system and how money is generated 2. Need clearly defined goals	
Effectiveness	Medium	1. Many non-permitted abstractions	1. Create incentives and or penalties for purchasing permits to discourage free-riders
Efficacy		1. Define the goal of the system	
Environmental Conservation	Medium	1. No provision for environmental flows	1. Incorporate environment into goals of the system 2. Conduct studies to determine the minimum water balance for streams
Equity	Low	1. High permit costs favor the rich 2. High permit costs encourage illegal abstractions 3. Upstream users are at an advantage compared to downstream users	1. Subsidize permits 2. Monitor use 3. Permits should be proportional to supply
Flexibility	Low	1. Cannot reallocate permits	1. Permits should be subject to reallocation 2. Permit rights should be retractable 3. Permits should be proportional to supply
Political and Public Acceptability	Medium	1. Users are not aware of the current law	1. Encourage public participation 2. Incorporation of stakeholders

Predictability	Low	<ol style="list-style-type: none"> <li>1. Amount of water currently being abstracted from the system is not known</li> <li>2. Lack essential information for predicting water supply</li> </ol>	<ol style="list-style-type: none"> <li>1. Monitor use to account for abstractions</li> <li>2. Model future water supply by increasing accuracy of supply models</li> </ol>
Security	Medium	<ol style="list-style-type: none"> <li>1. System is in place which establishes ownership</li> <li>2. No enforcement of permits</li> </ol>	<ol style="list-style-type: none"> <li>1. Enforce permits</li> <li>2. Permits should be proportional to supply</li> <li>3. Establish incremental pricing scheme</li> </ol>

## 7 INSIGHTS AND LESSONS LEARNED

This section concludes the paper with insights into measuring and managing water demand at a basin level and some broader lessons on institutional behavior

### 7.1 Importance of Data Compatibility

Although a river basin level analysis is optimal for evaluating competing water demands and relevant planning alternatives data collection and monitoring is often unavailable on a basin scale. The lack of correlation between river basin boundaries and the boundaries of government entities causes difficulty in allowing economic and social statistics to be applied to a specific river basin. Institutions based in various disciplines govern water users from multiple sectors. They perform many functions, which often conflict in water basins and it is often difficult to get discourse. In future planning, it would be useful to have social, economic, and biophysical data on compatible scales with databases containing rates of resource use.

## **7.2 Linkages Between World Price and Local Production**

The causal chain between world prices and local production must be understood in order to accurately predict the outcomes of a price change. For world prices to affect local markets, world price signals must be transmitted into domestic prices, this occurs through pass-through and supply response. Within a country, various crops can respond to world prices differently depending on tariffs, subsidies, and quotas. Supply response can be difficult to calculate due to data complexity and limitations. Most studies have therefore been conducted on long-term aggregate supply response by country or on long-term supply response by crop, but few studies have addressed a specific country and crop. Because estimates of the agricultural supply response display remarkably large variation across crops, regions, and time periods, it is essential that error bars be used based on the confidence of the estimate.

## **7.3 Putting Findings into Context**

To provide a better understanding of the effects of policies, the sector examined should be viewed in context of other affected institutions, ecological and economic entities and supply availability. In the case of water resources management, demand may be significantly affected by labor migration, and population increase. Supply is also affected by many factors, including evapotranspiration rates, hydrology, weather events, climate variability and climate change. Both the quality and quantity of water affect land and air systems, and associated ecosystem resources and services. Water use is directly linked to soil degradation from irrigation, water quality problems from discharge and ecosystem health from diversion.



## **7.4 Importance of Flexible Institutions**

Institutions must have an element of flexibility in order to remain stable and address changes in various social, economic and biophysical circumstances. Institutions governing water resources must be dynamic entities that change with the changing demands and developments of the basin, including flooding and droughts. To provide sustainable use of a watershed, water rights should be allocated in proportion to the actual water supply and reallocated when changing demands require reallocation.

## **7.5 Consideration of Feasibility**

In examining alternative policies and mechanisms, the feasibility of alternatives should be considered. For resource reallocation to be feasible, it must be compatible with other institutions, including property and use rights. The analysis of institutional interactions requires an interdisciplinary approach due to the complexity of these interactions. Changes to existing institutions should be done systematically, considering political feasibility, technological limitations and aspects of monitoring and enforcement. The considerations for the feasibility of a system may include such items as current property and use rights. If such rights are not in place certain alternative solutions may not be feasible without further political changes.

## APPENDIX: DETAILED PROCEDURE FOR CALCULATIONS OF WATER DEMAND AND WATER BALANCE

**Table A.1: Data Sources**

Data Type	Description	Sources
Economic	World Prices	World Bank (2004)
	Local Prices	Tanzania Business Information Services (2004)
	Supply Response	McKay et al. (1998), Danielson (2002), World Bank (2000)
Agronomic	Crop Yield	Tanzania Business Information Services (2004)
	Current Crop Production	Tanzania Business Information Services (2004)
	Local Crop Growth Values	Moges et al. (2002)
	Soil Types	FAO (1997)
Climatic	Precipitation	IWMI World Water and Climate Atlas (2004)
	Potential Evapotranspiration	IWMI World Water and Climate Atlas (2004)
Geographic	Rivers, Cities, Land Cover	Africover (2004)
	Political Boundaries, River Basin Boundaries, DEM,	FAO GeoNetwork (2004)

### CALCULATING WATER DEMAND BY RICE

To determine the amount of water required to grow rice, the following steps are taken: 1) the pass-through rate converts world prices to local prices; 2) the change in local price is converted to a change in production using the supply response; 3) the average yield value converts production of rice to acres of rice in production (see Box 1 for equations); 4) CROPWAT (see Box 2 for equations) determines the amount of water an acre of rice will require based on the crop coefficients (Table A.2) and the amount of precipitation and potential evapotranspiration.

### Box 1. Equations used in analytical model

Calculation for Total Water Demand

$$TWD = AWD * Area$$

Where:

TWD is Total Water Demand (m3)

AWD is Average Water Demand (m) calculated using CROPWAT

Calculation for Area of Rice Production

$$HA = NP * (1 / AvgYield)$$

Where:

HA is Harvested Area of Rice Production (m2)

NP is New Production (MT)

AvgYield is the Average Yield of Rice (MT/m2)

Calculation for Future Production of Rice

$$NP = [IP * SR * (NLP - ILP / ILP)] + IP$$

Where:

NP is New Production (MT)

IP is Initial Production (MT)

SR is Supply Response

NLP is New Local Price (\$)

ILP is Initial Local Price (\$)

Calculation for New Local Price

$$NLP = [IWP * PPT * (NWP - IWP / IWP)] + ILP$$

Where:

NLP is the New Local Price (\$)

IWP is the Old World Price (\$)

PPT is the Percent Price Pass Through

NWP is the New World Price (\$)

ILP is the Initial Local Price (\$)

## BOX 2. CROPWAT CALCULATIONS

### CALCULATION FOR AVERAGE WATER DEMAND (IRRIGATION REQUIREMENTS IN CROPWAT)

$$AWD = \frac{\sum_i CWR - ER}{n}$$

Where:

AWD is Irrigation Requirements (m)

CWR is Crop Water Requirement for rice (m)

ER is Effective Rain

n is # of grid cells

i is the grid cell #

Calculation for CWR

$$CWR = \sum_d ET_o * K_c$$

Where:

CWR is Crop Water Requirement for rice (m)

ET<sub>o</sub> is the Potential Evapotranspiration (m)

K<sub>c</sub> is the Crop Coefficient for rice

d is the time step in 10 day intervals

Calculation of Effective Rain

$$ER = 125 + 0.1 * TR, \text{ if } TR > 250mm$$

$$ER = \left( \frac{TR}{125} \right) * (125 - 0.2 * TR), \text{ if } TR < 250mm$$

Where:

ER is Effective Rain (m)

TR is Total Rain (m)

Estimation of Total Rain

TR is found by fitting a polynomial curve to the annual distribution based on monthly values, and assuming that rain fell in storms taking place every 5 days

Sources: Allen, Richard G. et al. 1998; Clarke, Derek, 1998

**Table A.2: Pangani River Basin Rice Growth Coefficients**

T.G.L. (Days)	Development Stages (days)				
	DEV 1	DEV 2	DEV 3	DEV 4	
102	20	20	32	30	
Root Depth (mm)	Crop Coefficients ( $K_c$ )				P
	DEV 1	DEV 2	DEV 3	DEV 4	
500	1.10	1.10	1.10	0.95	0.20

Source: Moges et al. 2002

In order to calculate the demand of water for rice, a boundary layer of the Pangani River Basin was divided into 144 squares, each 32 km<sup>2</sup> (see Figure A.1). Within each square the centroid is found for which climate data is obtained from the IWMI World Water Atlas. Land classification layers from Africover, a database of GIS data covering Africa, are used to determine by visible inspection the squares that contain agriculture in the Basin (see Figure A.2). Precipitation and evapotranspiration for the squares containing agriculture is inputted into CROPWAT to determine the amount of irrigation (in millimeters per hectare) that is necessary to grow rice during the growing season from March 1st to June 15. The mean irrigation requirement between cells is used to determine the average irrigation requirement for rice in the basin.

The total necessary irrigation value represents the amount of water required to support the growth of rice due to a deficit in available rain. The quantity of irrigation required by each cell is averaged to provide an estimate of the amount of water required for rice growth. The

average irrigation value is multiplied by the predicted hectares of future rice growth to provide the water demand by rice in the basin in cubic meters.

The predicted growth of rice is calculated by multiplying the predicted percent increase in world price by the supply response to obtain the increase in production for the next year. The predicted production divided by the yield (MT/Ha) determines the harvested area. The harvested area multiplied by the average water demand determines the Total Water Demand for rice production.

Figure A.1: Grids and Centroids Used for Climate Data

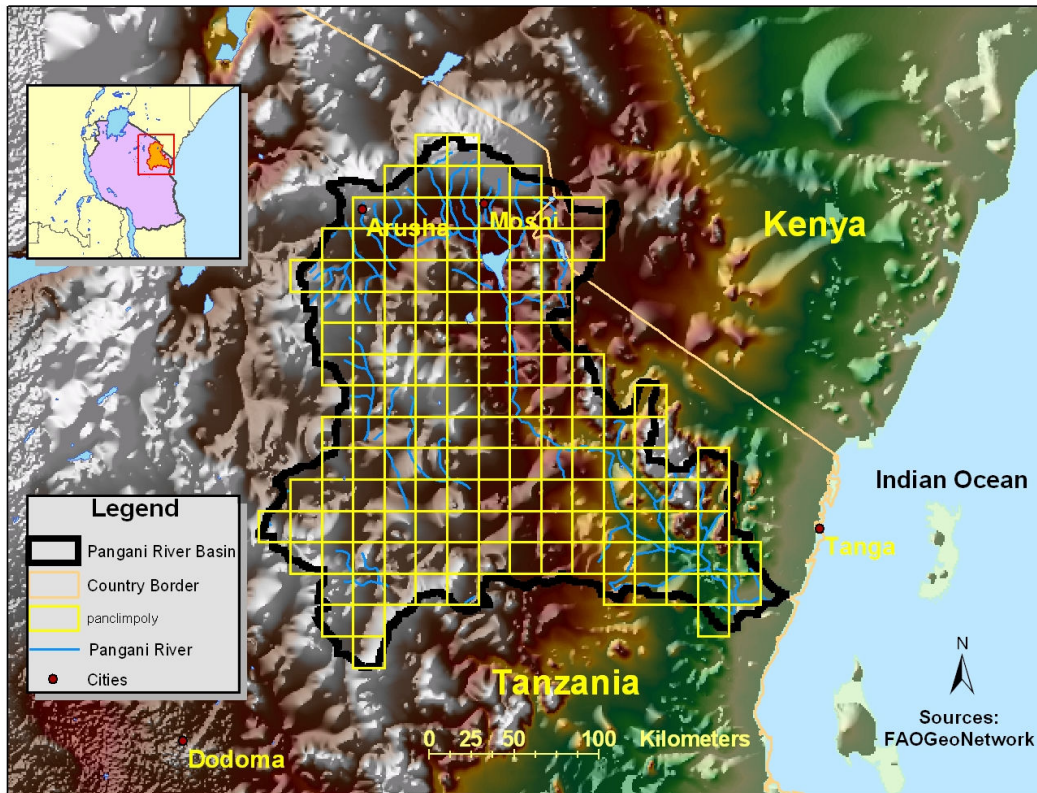
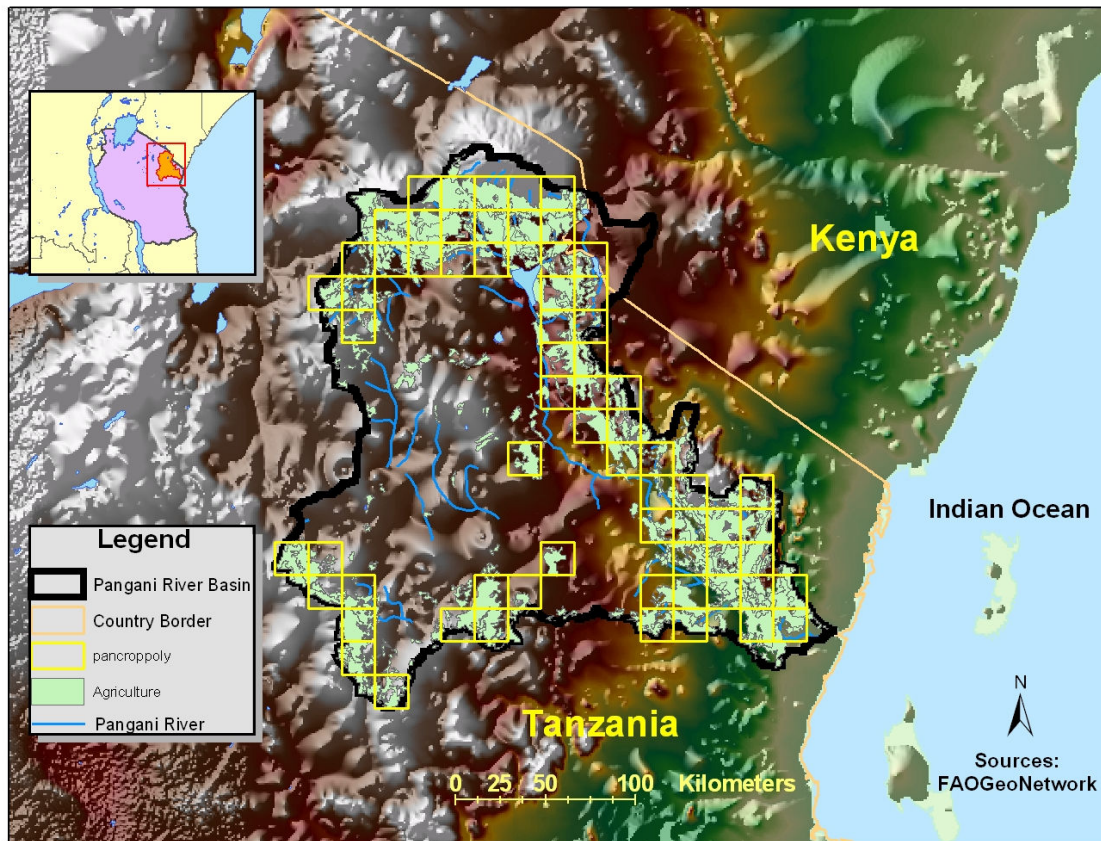


Figure A.2: Grid Cells Used for Calculating Average Water Demand and Agricultural Areas.



### Calculating Water Supply

The water supply for the Pangani River Basin and sub-basins was calculated using a water balance. A vertical water balance approach is taken in which the basin is divided into grid cells. Within each cell the equations (see Box 3) are solved on a monthly basis to obtain the monthly runoff.

The precipitation and Penman-Monteith potential evapotranspiration are obtained from the IWMI World Water and Climate Atlas. The FAO Digital Soil Map of the World (SMW) provides soil types and properties for the determination of soil water capacity. In some

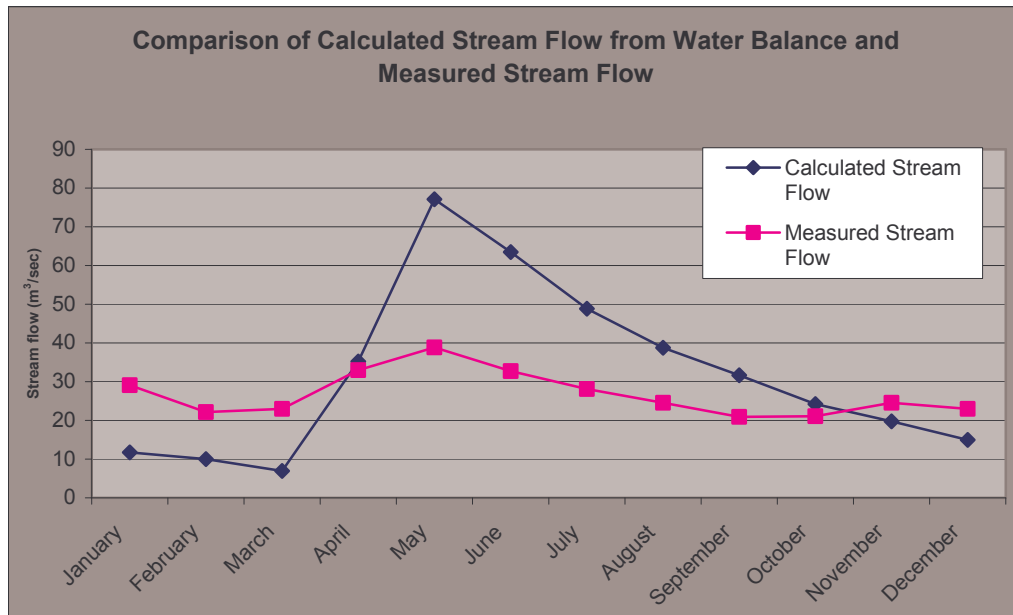


cases the total water storage capacity for 1 meter of soil from the SMW is not clear, or a specific soil unit had many possibilities. In such cases the storage class (e.g. 150-200mm) with the largest percentage is used, and where a tie existed the middle class is used. To include a more accurate representation of rooting depths within the basin, it is divided into three classes; 1) Agriculture, 2) Mixed (grassland and shrubs), and 3) Forests. After solving the equation for each month within each polygon, the discharge for the basin is found by multiplying the area of each polygon to generate a volume of water. The discharge at the outlet of the basin is found by adding the volume from each polygon that made up the basin. The discharge represents the water supply available at that point in the river basin.

The water balance was calibrated using stream flow data obtained from the University of New Hampshire/Global Runoff Data Center for the Pangani River Basin recorded from 1959 through 1977. The recorded monthly runoff was compared with the calculated monthly runoff to calibrate the percentage of runoff used for the equation. After changing the percent runoff, 20% runoff of the total available runoff was found to provide the most alignment with the recorded mean monthly stream flow (see Figure A.3).



Figure A.3: Calibration of Water Balance



### GIS Analysis

Geographic data is essential to performing this study. Political boundaries, the Pangani River Basin boundary is obtained from the FAO GeoNetwork. Classification of the land cover of the Pangani Basin is provided by the Africover database, in addition to rivers and cities layers. The land classification is essential to determining the rooting depth of the areas within the basin for the water balance. The division of the basin into a grid with spatial information is essential in determining the water requirements and the water balance within the basin.

### Box 3. Equations for Water Balance

Example of Water Balance for a specific grid cell used in analysis. Soil available water capacity of 150 mm/m and a rooting depth of 1.5 m. All values are in millimeters.

	Smax	P	PET	P-PET	SM	DSM	AET	Month's Deficit	ET	Month's Surplus	Total avail for runoff	RO	Detention
					25						0		20
Jan	225	56.69	137.33	-80.64	17	-8	64.69	72.64	0	20	6	14	
Feb	225	51.54	130.76	-79.22	11	-6	57.54	73.22	0	14	4.2	9.8	
Mar	225	112.67	133.92	-21.25	10	-1	113.67	20.25	0	9	2.7	6.3	
April	225	285.42	108.3	177.12	187	177	108.3	0	0	6	1.8	4.2	
May	225	235.9	97.34	138.56	225	38	97.34	0	100.56	104	31.2	72.8	
June	225	60.58	89.1	-28.52	198	-27	87.58	1.52	0	72	21.6	50.4	
July	225	36.02	95.79	-59.77	151	-47	83.02	12.77	0	50	15	35	
Aug	225	19.3	106.64	-87.34	102	-49	68.3	38.34	0	35	10.5	24.5	
Sept	225	11.48	127.8	-116.32	60	-42	53.48	74.32	0	24	7.2	16.8	
Oct	225	21.73	144.46	-122.73	34	-26	47.73	96.73	0	16	4.8	11.2	
Nov	225	100.46	125.1	-24.64	30	-4	104.46	20.64	0	11	3.3	7.7	
Dec	225	94.2	125.55	-31.35	26	-4	98.2	27.35	0	7	2.1	4.9	

#### Equations of Water Balance

Smax is the soil water holding capacity

P is Precipitation

PET is Potential Evapotranspiration

P-PET is the difference between Precipitation and Potential Evapotranspiration

SM is soil moisture, If  $P-PET \geq 0$ , then SM is the minimum value of either P-PET for that month plus SM for the previous month or Smax.

If  $P-PET < 0$ , then SM is equal to the Previous months value of SM( $\exp(P-PET/S_m$  from the previous month))

DSM is the deficit in soil moisture, based on the change in SM from month to month

AET is the actual evapotranspiration, when P exceeds PET AET equals PET, otherwise AET equals P-DSM

Month's ET Deficit is the PET-AET

Month's Surplus is equal to which ever is greater  $[(P-PET)+\text{previous months SM}]-S_{\text{max}}$  or zero

Total Available for Runoff is equal to the previous months detention plus the month's surplus

RO is the Runoff in terms of overland and groundwater runoff, it is equal to 30% of the Total Available for Runoff

Detention is equal to Total Available for Runoff-RO

Source: Dunne, T. and Leopold, L., 1978.

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