UNIVERSITY OF ÇUKUROVA
INSTITUTE OF NATURAL AND APPLIED SCIENCES

Ph.D. THESIS

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COMPUTER SIMULATION MODELS FOR SUSTAINABLE GROUNDWATER USE IN AGRICULTURE IN SYRIA

DEPARTMENT OF AGRICULTURAL ECONOMICS

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ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

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Bu tez 10/03/2003 Tarihinde Aşağıdaki Jüri Üyeleri Tarafından Oybirliği ile Kabul Edilmiştir.

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ÖZ

DOKTORA TEZİ

SURİYE'DE TARIMDA SÜRDÜRÜLEBİLİR YERALTI SULARI KULLANIMI İÇİN BİLGİSAYARLI SİMÜLASYON MODELLERİ

FADIL RIDA

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
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Danışman : Doç.Dr. Aykut GÜL
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: Yrd. Doç. Dr. Cuma AKBAY

Bu çalışma, Suriye'de yeraltı suyu kullanımının yayılmasına neden olan faktörleri belirlemek ve dört bölgede altı ilde, kritik su alanlarında sulu tarımın karlılığını değerlendirmek için yürütülmüştür. Ayrıca, yeraltı suları için talep ve sulama maliyet fonksiyonu analiz edilmiştir. Çiftçilerin yeraltı su yatırımları modellenmiş, kuyu açma başarısının ihtimali belirlenmiş ve dinamik sistem simülasyonu geliştirilmiştir.

Geleneksel önerilere zıt olarak, bu alanda yeraltı suyu kullanımının sürdürülebilir geleneksel canlı hayvan-arpa tarım sistemini sürdürülemez sisteme dönüştürdüğü ve orta vadede göçe neden olduğu bulunmuştur. Ürün alım fiyatları, düşük yakıt masrafi ve yeraltısuyu kullanma hakkının açık olması, yeraltısuyu kullanımının genişlemesini zorunlu kılmıştır. Aynı zamanda yüksek su tüketen ürünler için su talebinin elastik ve bu yüzden fiyatlarının sürdürülebilir şekilde su kullanımında önemli rol oynayabileceği bulunmuştur.

Yeraltısuyu sulamasındaki yatırımın telafisi güçtür, risklidir ve kuyu açma başarı ihtimali yanlızca 0.07'tür. Diğer yatırım seçeneklerinin yokluğu çiftçilerin tükenmekte olan yeraltısuyu stoklarında yatırım yapmalarına neden olmaktadır. Pamuk gibi yüksek su tüketen ürünler aşırı su tüketimine neden olmakta ayrıca mevcut yakıt masraflarının %50'den fazla artması karlılığı ortadan kaldırmaktadır. Buğdayla birlikte kısa ömürlü sebzelerin yüksek su tüketen ürünler ile yer değiştirmesi sürdürülebilir seçenek olabililecektir.

Anahtar Kelimeler: Karlılık, Yeraltısuyu Yatırımı, Talep Fonksiyonu, Maliyet Fonksiyonu, Simulasyon Modelleri, Sürdürülebilirlik.

ABSTRACT

Ph.D. THESIS

COMPUTER SIMULATION MODELS FOR SUSTAINABLE GROUNDWATER USE IN AGRICULTURE IN SYRIA

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This study was conducted to determine the deriving factors of groundwater use expansion, to evaluate the profitability of irrigated cropping in water-scarce areas in five villages in four stability zones in Syria. Further, demand for groundwater and irrigation cost function was analyzed. Farmers' groundwater investment was modeled, the probability of drilling success was determined, and system dynamic simulation model was developed.

Contrary to the conventional proposition, it was found that groundwater use in these areas has transformed sustainable traditional livestock-barley farming system to non-sustainable system and led to migration in the medium run. Procurement prices of wheat and cotton, low fuel cost, and open access to groundwater constituted the driving forces for expansion. It was also found that, demand for water for high water consuming crops was elastic and hence irrigation cost and crop prices can play an important role in the water use sustainability.

Investment in groundwater irrigation was unrecoverable and risky where the probability of drilling success was only 0.07. It was also evident that due to the absence of other investment options, farmers invest in depleted natural resource. Expansion in areas allocated to high water consuming crops such as cotton have led to water depletion and are not profitable at 50% higher fuel cost than the current cost. Crops such as vegetable in combination with wheat can be sustainable option to replace high water consuming crops.

Keywords: Profitability, Groundwater Investment, Demand Function, Cost Function, Simulation Models, Sustainability.

To my late father and to my mother whose only aspiration was to pursue our education.

To my family who has borne with me all the difficulties and the time I spent at work or at the University.

FOREWORD

Groundwater use in agriculture in Syria has contributed to the expansion of irrigated agriculture and to the self-sufficiency policy. The short-run analysis of this expansion concluded that groundwater has curbed migration and stabilize income in the areas where expansion took place. Given the low level of rainfall and recharge, groundwater aquifers in most of the Syrian basin can not sustain rapid expansion. Hence, the intensive use of groundwater has led to aquifer depletion and poses a major threat to the sustainability of an importance natural resource in the country.

This study is an attempt to contribute to the knowledge base of groundwater research and analyze the factors that have led to the existing situation. This study analyzed the demand for water and the response of water application to different cost level. Farmer investment was analyzed to evaluate the return on investment in well drilling. Computer simulation model was developed to evaluate allocation decisions under different scenarios. Farmer groundwater use profitability under different set of crop area allocation was analyzed to assess the sustainable options that farmer can adopt. Further research has been suggested to deal with basin level demand for groundwater and investment analysis.

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I would also like to sincerely thank my principle advisor Assoc.Prof.Dr.Aykut Gül for his ideas and questions and his endless enthusiasm which was contagious. His encouragement as well as his recognition to the importance of the subject has made this dissertation a reality. He is also always eager to see the results of the dissertation has relevance and application on the farm level and at the policy issues.

Being a staff member at ICARDA, I would like to place on record the uniqueness of ICARDA. The Center is generous in providing the time and resources to the employees to continuously improve their skills and compete for any position available at the Center. Further, the Center always encourages the staff members to further pursue their higher education and hence my situation implies to both cases. In that, I would sincerely like to thank Professor Dr. Adel El-Beltagy, the Director General of the Center for his continuous support to the staff members who wish to pursue their education. I would also like to thank Dr. William Erskine the Center Assistant Director General for Research for supporting me to complete this dissertation.

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I would like also to thank Professor Dr. Rolf Mueller of Kiel University, Germany, the research project collaborator for accepting my application to be part of the research project on groundwater sustainability. His ideas of the importance of the institutions in the issue of groundwater sustainability were valuable in this research project. He and research staff has introduced the System Dynamics approach and that adopted and further developed by the research team.

The financial support for this study was provided by German Ministry of Economic Cooperation (BMZ) through the German Agency for Technical Cooperation (GTZ) through the Kiel University.

Finally, I must thank the farmers of all the surveyed villages. Those farmers provided us with great insight to the problem. Their patience and keen interest in the subject assisted us to understand the problem. We also enjoyed their hospitality, which they are well known of.

CONTENTS

ABBREVIATONS

ICARDA	International Center for Agricultural Research in the Dry Area
MC	Marginal Cost
AC	Average Cost
TC	Total Cost
t	t-test
F	F-test
P	Probability level
MAAR	Ministry of Agriculture and Agrarian Reform, Syria
SMAAR	Statistical Year Book of MAAR
JICA	Japan International Cooperation Agency, Japan
FAO	Food and Agriculture Organization of the United Nations
BMZ	German Ministry of Economic Cooperation, Germany
GTZ	German Agency for Technical Cooperation, Germany
SI	Supplemental Irrigation
SYP	Syrian Pound
m^3	Cubic meter
BIM	Base Irrigation Model
WIM	Well Interference Model
PGM	Policy Global Model
ha	Hectare
EPC	Effective Protection Coefficient

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1. INTRODUCTION

1.1 Background

Increasing inefficient groundwater utilization which exhibits several common property features and the consequent water resource scarcity and the externalities associated with groundwater-irrigated agriculture have raised a serious question on the capability of this resource base to sustain productivity and provide the basic food for ever increasing population. Groundwater-based agriculture in Syria, contributes a considerable proportion of agricultural production. Groundwater use in irrigation is estimated to constitute more than 50% of the total volume of irrigation water used (JICA, 1997, Jumaa, 1998). Groundwater in most of the five stability zones excluding Euphrates basin is the primary resource of any farming system and determines the sustainability of agricultural production. These zones are characterized by highly varied and poorly distributed rainfall (Perrier and Salkini, 1991). Groundwater based agriculture has proliferated since the 1950s. Expansion in irrigated areas is officially considered as the basis of economic growth (Wakil, 1993). Expansion has taken place not only in the areas where surface irrigation were available but also in areas where groundwater is the main source of irrigation and associated with low rainfall. It is estimated that the cultivated area under groundwater was more than doubled during the period of 1986 to 1996 (from 311740 to 643773 ha) (SMAAR, 1997). Irrigation efficiency coefficient is estimated to be between .25 and .55 (Wakil, 1993) which has also added to worsening the situation. Concerns of government, research institutions and international research centers such as ICARDA have been growing regarding the sustainability of groundwater.

It is apparent that economic aspects of groundwater based farming range from macro policies at the national level to micro policies and at the farm or project levels. Further, groundwater extraction is based on "use it or loose it" principle which is certainly incompatible with the objective of sustainable use of a scarce natural resource as depicted the schematic Figure 1.1. This figure clearly represents groundwater condition and aquifer depletion.

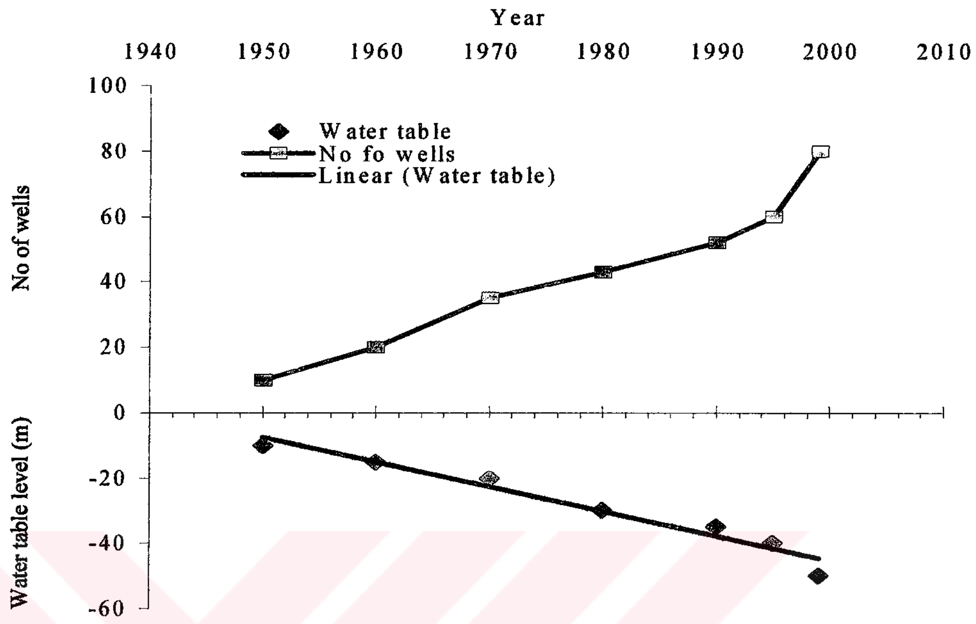

Figure 1.1 Change in Water Table Due to Continuous Increase in Drilled Wells in Fafin Village in Zone 1 in Syria.

With annual low recharge and the continued overdraft of groundwater will lead inevitably to further decline in the groundwater table and, other things being equal, to increase in lifting cost and reduction in the profitability and viability of groundwater-irrigated crop production. It is estimated that the annual groundwater table decline is over 1 m/year (JICA, 1997; Rodriguez 1998). Eventually, it will be uneconomic and unsustainable practice to lift water for irrigation purposes. Further, resources that committed to irrigated agriculture will revert to dry land farming.

The above conditions might require adjustment from irrigated agriculture to dry land farming in areas where expansion has taken place. Such adjustment may result in a serious primary and secondary reduction in agriculture production and in farmer income.

Thus, the issue of groundwater use is characterized by the existence of a set of complex interactions and linkages of many factors. For economic policy to be meaningful, it has to take into consideration issues such as hydrology, biology, agronomy, law and sociology.

In recent years, increase in irrigated crop production and hectare-feet of water withdrawn from aquifer have been dramatic. Studies on the annual average recharge differ in their estimate. However, given the low rainfall level and the expansion of groundwater irrigated agriculture, the ground water table budget will always be in deficit. Mining the precious groundwater is unsustainable and will have adverse economic repercussions on agriculture and farmer income.

1.2 Proposition

This study will be based on the proposition that the existing institutional and regulatory arrangements, if any, may have unintentionally led to an inefficient allocation of groundwater to crop production and diminishing scarce natural resource. Further, such arrangements reflect the open and usually subsidized access to natural resource.

The management of a groundwater resource has the following characteristics, which adds to its complexity. There are location-specific physical and infrastructure constraints that impinge the current and future resource use. There are also institutional arrangements that generate constraints. The impact of use decision on the future availability of the resources is highly uncertain because of the variability in both seasonal conditions and individual users ignore the social cost of their action.

1.3 Objectives

In water critical dry areas, groundwater constitutes an important factor in determining farm income and stability of food availability on the national level. There has been little detailed scientific knowledge on the various aspect of groundwater use in agriculture in Syria. This study is an attempt to contribute to the economics research activities related to groundwater use in agriculture. The primary objectives of the study:

a) to provide quantitative description and analysis of factors contributed to the rapid depletion of groundwater in the study area and to propose a policy recommendation that take into account the natural resource base.

b) analyse the demand for groundwater and determine the price elasticity of demand for groundwater in the study area in order to understand the farmer response to different level of water cost and consequent effect on irrigated crop area allocation decision.

c) to model farmer groundwater investment and evaluate the return on investment, an attempt is made to quantify the rate of well drilling success which has a major implication of the farmer return on investment in groundwater and hence the utilization of available groundwater resource. Given the uncertainty that associated with groundwater investment and consequent chains of well drilling undertaken by most farmers, this study aims to layout a recommendation based on the result of the investment analysis.

d) an attempt to analyse groundwater irrigated crops' profitability in terms of present value of gross margin in different villages across the four stability zones in Syria under different fuel cost scenarios, in order to demonstrate the viable and more sustainable options.

e) to evaluate the effect of different sets of crop allocation scenarios on groundwater aquifer by developing system dynamics models. Different crop area allocation scenarios were used to assess the likely long terms outcome of such allocations strategies on the aquifer. Different discount rates were used to assess the present values of total gross margin under different area allocation strategies for fourty years. The objective is to present a tool to farmers, researcher and policy officials to review their outcome of their decision on a virtual world.

This study will contribute to the knowledge base of groundwater use in Syria. It will provide a general tool for resource allocation policy maker to select between alternatives related to groundwater use. Groundwater investment can be evaluated and simulated on different set of parameters. This study may form a basis for further refined studies.

2. LITERATURE REVIEW

2.1 Water Use and Productivity Research

The foremost concern in the arid and semiarid areas is water availability and research effort is directed towards finding ways to optimize its use. Water use efficiency has been one of the key issues on the research agenda for ICARDA and other research institutions. During the 1980s and early 1990s research focused on the efficient use of water in agriculture to meet the increasing demand and attain food security objectives. In rain-fed farming systems, where lack of moisture limits crop production, agronomists and water management specialists frequently assess innovative management practices in terms of water use efficiency (WUE)[1] (Cooper 1983, Cooper and Gregory, 1987). Improved production from a limited water supply can result from both an increase in the total amount of water used by the crop, and improved efficiency of water use. Cooper et al., (1987) stressed the need to consider the variation in rainfall between season and its interaction with crop growth and crop management strategies in terms of the probability of its occurrence to assess the long-term suitability of genotypes and management strategies.

Salkini and Ansell (1987) estimated wheat response to supplementary irrigation (SI) at 80%, 125% and 390% for high, normal and low rainfall respectively. This has led to the suggestion that the introduction of supplemental irrigation into rain-fed agriculture can increase productivity, reduce rural poverty and, lead to greater private capital and labor investment and decrease rural-urban migration (Perrier and Salkini ,1991). This research did not consider the resource base carrying capacity to sustain the production of high water consuming crops in some parts of Syria where water resources are scarce.

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[1] Water use efficiency is defined as a ratio of dry matter production kg ha^{-1} to evapotranspiration (mm). It is used as index to evaluate the efficiency of crop water use and the practices amid to improve it. This definition must be distinguished from irrigation efficiency. IE is defined as the ratio of crop water use to the total water delivered to the field. However, this definition implicitly constitutes the conveyance and distribution efficiency.

Oweis and Zhang (1998), refined the SI technology, and recommended combined technology package that include different water application and N levels that can optimize plant water use efficiency by using supplementary irrigation (SI) at critical stages of growth. The study suggested a strategy based on applying restricted amount of water on wheat crop in the winter season based on available soil moister. The study suggested that by 1/3 of full irrigation combined with 100 kg of N the yield loss would be only 10-15% while the water is conserved by 50%.

Other studies estimated that available groundwater resource can sustain the irrigation of additional 400-500 thousands hectare and the economic return will have considerable impact on the food security (Almair and Somi, 1993). These estimates did not consider the long term effects of continuous over-drafting of the aquifers. Rapid expansion in groundwater-based farming lasted only for very short period of time in many communities where most of the wells have now dried up with negative effects on rural communities. Hence, the food security objective based on uncontrolled exploitation of groundwater resources and expansion of irrigated agriculture has become self-defeating.

The key element in these studies is monitoring soil moisture content and hence determining the timing of water application. In contrast, farmers' water application is based on their knowledge and judgment of plant soil relationships and water availability. It is, therefore, questionable how easily can farmers apply this technology, without other external factors that influence their behavior. One of the determining factors that affect WUE is the distribution of rainfall. Since the expected rainfall is subject to wide variation, the suggested technology may be difficult to apply to farm conditions. Furthermore, farmers' application of water is not influenced only by the understanding or assessing plant soil relationship, and knowledge of critical stages that crop requires irrigation; rather it is affected by many economic and institutional factors.

2.2 Suggested Scenarios

In further studies on SI of wheat in winter season, Owies and Zhang (1998) and Zhang and Oweis (1999) suggested different scenarios based on yield, profit and cost relationships. Both studies suggested that profit maximization scenarios are preferred to yield maximization. Yield maximization leads to excessive water use whereas profit maximization is more water conserving with a target yield of 4-5 tons per hectare. Although these studies have introduced prices and costs in their water use analysis, it is confined to a single crop at the plot level using experimental data. Further, energy cost is not considered as a constraint to farmers because fuel prices are subsidized. Given the existing fuel price levels, the primary constraint is water availability.

It is evident that studies on groundwater capacity as to sustain the expanding irrigated agriculture were not carried out in parallel with the agronomic studies. However, there were few studies in this area though limited in scope. Wakil (1993) estimated Syria water demand for different sectors and concluded that agriculture consumed 90% of total water use and water deficit will be experienced after 2010. Smith (1993), however, stated that groundwater studies are difficult and require information on the properties of aquifers which are difficult to estimate. Furthermore, water level in aquifers has a random walk element plus the net effect of recharge and discharge. It is also subject to feedback process during drought seasons, i.e. drought induces intensive abstraction as well as expansion in well installations. This study stressed that local institution should be combined with policy option in combating groundwater resource use.

2.3 Farmer Perception, Aquifer Condition and Policy Studies

Smith (1993) recognized the importance of interaction between science and action through changing agents. This process allows that understanding of users' perceptions of possible water conservation measures and policies. Although, this study raised a crucial element related to the importance of understanding farmer perception, it would be false assertion to postulate that farmers do not perceive groundwater depletion. Most farmers understand the source of depletion but their objectives are to achieve the maximum benefits from available water and recover their investment in wells and in other irrigation technologies.

Ward and Smith (1993), considered aquifer modeling necessary for groundwater studies, but cautioned that any predictions that do not take into account of the difficulty of groundwater parameter estimates may provide misleading parameters that could be used in policy options.

As policy options affect the resource use and hence the long-term production sustainability, ESCWA (1995) undertook a study aimed at evaluating agricultural policy in Syria. The study used policy matrix analysis in an attempt to evaluate the impact of agricultural policy on resource use. Government price and input support as well as rates of protection were estimated. Effective Protection Coefficient (EPC) indicates that effective price of cotton received by farmers has decreased from 1.03 of the world price to 0.98 of the world prices during the period 1989-1993. While EPC increased from 1.32 to 1.64 of the world prices in the case of wheat for the same period.

On-farm water use efficiency was studied by ESCWA and ICARDA (2000) in Syria and Iraq. The study shows that farmers over-irrigate most of the crops studied. An econometric model involves multi-crop producers of irrigated agriculture. It was shown that output prices appeared to be the strong determinant for short-run decision on allocating water among competing crops. The study shows that an increase of 1 m^3 in water availability 0.77 m^3 to cotton followed by wheat 0.20 m^3 and negligible volume of 0.03 m^3 diverted to barley. This study confirmed that farmers of both countries over-irrigated cotton and contradict with other studies (Rodriguez et al., 1999), where cotton was found as to be under irrigated. In over study it was found that cotton was also over irrigated except in few cases where the wells water yield fails to provide sufficient water to the crop.

Rodriguez et al. (1999) concluded that open access and sprinkler technology have contributed to the decline of groundwater table in the first stability zone of Syria and confirmed as other studies that SI irrigation benefit farmers by increasing yield. The study has also shown that large areas were allocated to crops with lower gross margin per water unit. The study did not determine levels of input subsidy or price support to farmers and their influence on crop area allocation.

2.4 Technology, Irrigation Efficiency and Policy

Farmers' behavior in adopting more water use efficient practices is influenced by many factors. Hence, sustainable groundwater use is affected by many factors beyond the farmer plot boundaries. These include government policy, local and official institutions, rules and regulations that govern access, price support, input subsidy, competition and price expectation. Although technology on efficient water use at plot level is necessary component of water management strategy, it is not sufficient for achieving sustainable groundwater use.

Technology that makes irrigated agriculture more profitable may actually accelerate ground water depletion, increase conflict, and in the long-run have negative effect on rural communities. This occurs because it provides incentives to pump more water and expansion of irrigation, which eventually leads to drop in water table levels and abandonment of irrigation. Hence, to be effective, technology package have to be an integral part of a strategy addressing all these factors. It was found that farmers in Colorado (USA) with high-cost water can conserve water and increase profit by applying profit-rather than yield maximizing water quantities (Hoyt, 1984). In a study on adoption of irrigation technologies by farmers in California, Caswell and Zilberman (1985) found that the use of water prices policies can induce adoption of modern technologies and lead to substantial water saving as these modern technologies have high efficiency and may reach 95% for drip irrigation as an example. To explain the reason of the intensive use of groundwater use by farmers in Oklahoma, Thomas and Mapp (1986) concluded that low pumping cost relative to the benefit from irrigation seem a more plausible explanation than risk aversion.

Market and institutional options could be part of ground water management strategy that aims to achieve more efficient allocation of water resources. Strengthening local and formal institutions in enforcing rules and regulation that govern access to water, reversing agricultural policies that provide incentives to inefficient allocation of water within the agricultural sector and removing subsidies on irrigation could be of that strategy.

Water markets have also been used elsewhere. Water market provides incentives to transfer water from low valued to high valued uses and improves water use efficiency through the introduction of an opportunity cost. For example, research has shown that gain in trade from water sales in Texas ranges from $3000 to $16000 per 1000 m^3. In a similar situation trade in water within the agricultural sector, that moves water from northern to southern part of Central Valley, would produce gains of $10 million annually based on 1980 figures (William et al., 1994).

2.5 Water Prices, Quota and Taxes

In a study on demand for water at different price charges, Amir and Fisher (1999) found that at lower prices all the available area is used hence the demand for water will not increase. Conversely, when prices of water are high water allocated to high consuming crops shrinks. Mallawaarachchi, Hall and Philips (1992) found that water price policies and tax incentives are important determinants of water saving technologies. Further, Fienerman and Mapp (1983) found that the net benefit from groundwater management in Kern County (USA) represented 14% increase compared to no regulation and 6% increase in the net benefit from both ground and surface water.

Above review on water research indicate that most studies focus on the technical efficiency of irrigation water use, recommend technological solutions and highlight their potential yield gains. Several studies have stressed that expansion in SI and full irrigation will stabilize income, raise the productivity of land allocated to rain-fed crops and promote rural development, thus curbing migration. This was supported by the evidence, from experimental research, that crop production under SI was higher than that under rain-fed production by many folds, and water saving was achieved using supplementary irrigation technology.

2.6 Summary on Previous Research

The limitations of previous results and recommendations include:

a) practical difficulty in the application of precision technological solutions in terms of the agronomic practices, timing of water application and water level applied.
b) inadequate consideration of the capacity of ground water resources and their dynamics in space and time,
c) failure to consider the effects of technology and irrigation expansion on ground water depletion. It is difficult to prove technology can contribute to sustainability.
d) inadequate treatment of the effects of agricultural policy on ground water,
e) lack of consideration of the role of formal and informal institutions.

3. MATERIAL AND METHODS

3.1 Introduction

The objective of this study is to determine the factors that contributed to groundwater depletion, to analyse water demand, investment in groundwater and groundwater allocation profitability under different sets of allocation decisions. This chapter lays out the conceptual framework and the methods used for analysis.

Village, farm and enterprise level data was acquired. Well investment data was also essential to capture farmer investment in well drilling and irrigation layout costs. Secondary data was also compiled to analyse the expansion in irrigated area and well drilling. The following are the material and method in the data collection and analysis:

3.2 Material

3.2.1 Village Resource Profile

In order to understand water management and use, it was essential to capture physical and socio-economic condition of the village surveyed. Village level data was used to describe the resource profile for each village in the study area as described in the sampling frame. The resource profile includes data on each village in terms of location, area, population, water resources, well conditions, irrigation infrastructure, income and type of energy. Descriptive data on cropping patterns and water use over time was compiled through interviews with farmers.

3.2.2 Crop Enterprise Data

Primary data on crop area allocation, yield, crop prices, land preparation cost, fertilizer quantity and cost, pesticides and herbicides quantity and prices, irrigation cost, weeding, harvesting and transportation was collected to be used in the analysis of irrigated crop profitability and scenario analysis. Average yield, prices and cost were fed in the simulation models. Records on cropping for two seasons were kept for all surveyed farmers in the all the research area.

3.2.3 Well Water Flow Data

One of the difficulties that face water use studies is the available data on water allocation to different crops at the farm level. The lack of water use data requires the use of monitoring schemes to capture water allocation levels to different crops. It was essential to measure well water flow data at farmer field in each village. Quantity of water allocated to different crops was required for the analysis of water use productivity. Total average quantity of water abstracted and allocated to different crops was used in the simulation scenarios.

3.2.4 Crop Water Requirement Data

Crop water requirement data was estimated for different crops for each village. Hydrology group participating in the research projects estimated crops water requirement to compare farmer actual water allocation with crop water requirement across the surveyed villages. Crop water requirement also can be used to estimate water productivity under different fuel cost scenarios.

3.2.5 Groundwater Investment Data

Data on well investment and water distribution cost was used in groundwater investment analysis. Well depth, well age, pumping engine cost, water distribution pipes cost, horizontal drilling, maintenance data was essential to evaluate farmer investment in groundwater. Data on drilling failure was collected to estimate the probability drilling success.

3.2.6 Secondary Data

Secondary aggregate data from the Ministry of Agricultural and Agrarian Reform abstract was used in the analysis of groundwater irrigation expansion, price support and input subsidy. This data includes number of drilled wells, total area irrigated and total groundwater-irrigated area for the period 1960-1999. Drilled wells data for the period 1986-1999 was used to model well and irrigated area expansion.

It also includes wheat and cotton price for the period 1960-1999. For fertilizers and fuel, international prices were used. Local fuel prices data was compiled from different sources.

3.3 Methods

Several methods have been used in the data collection and analysis. Data collection includes surveys, well monitoring, rainfall gauging and water use measurement. Farmer participation in the research was also included. For the economic analysis, the analysis scheme was based on the standard economic theory as is explained shortly.

3.3.1 Sampling Frame and Selection Criteria

Enterprise level unit was the base of the survey. Given the depletion situation in the Northeast part of Aleppo region across four stability zones. The selection of these villages was based on preliminary visit to the villages in order to decide on the extent of water depletion in these villages. The absence of data availability, requires a scheme of well monitoring and water use measurement. To collect data on wells' condition and changes in aquifer over time, we decided to select five villages across the four stability zones. Five farmers were selected in each village as participating farmers in the study. The farmers were chosen as actual irrigators and full time farmers. The reason was that there has been no well monitoring scheme, so in order to conduct reliable water use and well monitoring scheme farmers have to be selected to participate in the scheme. It would be impossible to monitor large number of farmers in terms of cost and effectiveness.

However, 50 farmers were randomly selected from the village of Bershaya based on their cropping system. Since the research is concerned with water use it was essential to select irrigators randomly from Bershaya village. Those farmers should represent the defined group of farmers in the domain under study. The domain is defined as the group of farmers whose farms are similar and use similar practices.

As there is a relationship between the sample size and the result precision, the cost of well monitoring may not justify the precision achieved. If there are no large difference among farmers in the study domain, 20-25 farmers from each domain will be enough (Perrin et al., 1974). This village was chosen because it represents groundwater depletion problem. Further, the preliminary visits show homogeneous irrigation practices in all villages. Hence, surveyed farmers highly reflect the water use and depletion condition.

3.3.2 Surveys

3.3.2.1 Crop Budget Survey

Crop budget is a method used to record farmer cropping activities and to compare between different activities. In order to generate crop budget for different cropping activity for farmers in the study area, a farm survey was conducted which contains detailed questionnaire (Appendix A). Cropping patterns and farmer allocation of land to different crops at each season were included in the survey. This part of the survey also includes crop input quantity and cost. Yields and prices for different summer and winter crops were also compiled.

Water use and water cost were also included to capture the allocation of water to different crops. Irrigation cost associated with allocation of water allocation was also compiled.

3.3.2.2 Farmer Groundwater Investment Survey

Survey on well investment was conducted for the farmer in the selected villages. The survey includes questionnaire on the cost vertical and horizontal drilling, cost of pumping engine and distribution equipment costs. Data related to investment risk was also conducted. To depict the cropping pattern changes as a response to water scarcity, separate survey items were included in the survey to determine how return on investment changes due to change of cropping patterns. The investment survey covered the participating farmers in all study area villages as well as the randomly selected farmer in Bershaya village

3.3.2.3 Well Monitoring Scheme

Well monitoring scheme was an important element in the study. Precipitation was measured with a plastic rain gauge by a farmer in the village. In the Hobs and Harbakieh area, precipitation was monitored with an automated rain gauge. To compute the amount of water used for irrigation, the farmer was asked to record the number of times he irrigated a given crop, the time it takes to irrigate his field, and the size of the field. Well discharges were measured with a 98.7 liter barrel at different times throughout the season. The water use for each crop was computed from the total irrigation time and the measured well discharges. If no well discharge was measured, the water use was estimated from the median irrigation depth for that particular crop in the village. Back-computation of the well discharge from the irrigation water depth for different crops sometimes resulted in different discharges for a specific well. The results indicated that the irrigation estimates of the farmers were less reliable for small areas of land.

3.3.3 Analysis Methods

3.3.3.1 Trend Analysis

Logistic model was fitted to the aggregate irrigated area in Syria of the following form (Ross 1990; NAG, 2002):

$$Y = A + C/(1 + Te^{-B(X-M)})^{1/T}$$

where Y is the total irrigated area, *A* is lower asymptote indicates to the initial irrigated area, *C* parameter controls the upper asymptote which indicates the level where the growth is saturated, *T* is a shape parameter which controls the maximum growth near the upper or lower asymptote, *B* is the rate of growth, *M* is the time at which maximum growth occurs and *x* is time in years.

The same model was used to fit the drilled wells aggregate data and also groundwater irrigated data. This model is used to analyse a natural resource phenomenon where growth is saturated as result of resource capacity limit. This model demonstrates the linkage between a natural resource capacity and the policy decision. That is the policy was aimed at irrigation expansion based on groundwater which is constrained by capacity of groundwater aquifers to sustain crop water requirement under such expansion (see section of trend analysis).

3.3.3.2 Crop Water Use Profitability Analysis

Crop budget analysis was used to determine the profitability of different water allocation decisions. Gross margin (gross production value-variable cost) and per cubic meter productivity were estimated. Gross margin is defined as the difference between gross production value variable cost. Water related contribution was also calculated. Water related contribution is defined as the difference between total revenue and variable cost other than water cost. It reflects the ability of a given activity to pay for water cost. Farm survey was used to collect data on yield, prices, water cost and all other variable costs. Irrigation cost was calculated on the basis of the number of irrigation applied and the cost per irrigation. Irrigation labour cost was based on the total number of hour required for irrigating one hectare of a given crop (see crop budgets in Appendix A). Gross margin per cubic meter was calculated as water productivity indicator for different level of allocation.

3.3.3.3 Sensitivity Analysis and Ranking

Based on the crop budget analysis, sensitivity analysis was conducted to reflect the change of ranking of the gross margin of different crops under different fuel cost scenarios. The sensitivity analysis reflects the changes of cropping patterns due to different policy decisions.

3.3.3.4 Production Function and Demand for Groundwater Function

Crop production function was fitted to experimental durum wheat data to measure the response of wheat crop to different levels of water application. The function was of the following form(Hoyt, 1984; Zhang and Oweis, 1999):

$$y = a + bw + cw^2 \qquad (3.1)$$

where y is the yield, *b* is the coefficient of the linear segment of the function and , *c* the coefficient of the quadratic segment and *w* is the water level applied to the crop. Marginal physical product is calculated as the first derivative of equation 3.1

$$\frac{dy}{dw} = b + 2cw \qquad (3.2)$$

Equation (3.2) estimates the marginal physical product of water (MPP_w). MPP is the additional per hectare yield measured in tons due to the application of one additional hectare-mm. of water.

To estimate the additional revenue from an incremental unit of water which is represented by the marginal value product, the following may be used:

$$MRP = (MP_w)(MR) = MRP = (MP_w)(P) \qquad (3.3)$$

where the MP is the marginal physical product, MR is the marginal revenue and P is the price of the product.

Demand for groundwater function was used to calculate the elasticity of demand and determine equilibrium water price level.

$$w^d = f(p, x) \qquad (3.4)$$

where w^d is the volume of water demanded in cubic meter per hectare, *P* is the cost of cubic meter of water, and *X* is a vector of variables that characterize the production possibilities of particular farmer, for example soil type, slope, hilliness, whether, the prices of inputs other than water, and the prices of agriculture output. It is reasonable to assume that farmers in the selected villages face the same price for inputs other that the water and for their outputs. Soil type did not show in all villages where the research has been done is correlated with water cost. Linear relation of the following form is considered to estimate water quantity used:

$$Q_w = \alpha + \beta P_w + \varepsilon. \qquad (3.5)$$

where Q_w is water quantity, *a* is constant which is the rainfall level and *P* is the crop prices was used to fit the groundwater supply and β is the slope of the line.

The elasticity of demand for water indicates the percentage change in the quantity of water used to grow a crop resulting from 1 percent change in the cost of water which can be estimated by the following relationship:

$$\eta = \frac{dQ_W}{Q_W} / \frac{dp_W}{p_W}$$
$$\eta = \frac{dQ_W}{dP_W} . \frac{P}{Q} \qquad (3.6)$$

where η is the price elasticity of demand for water, dQ_w is the change in water quantity, *dP* is the change in water price and Q_w,, P_w are quantity and price of water respectively. It was also possible to fit an inverse demand function of the following form to demonstrate the price elasticity of demand for different crops.

$$Q_W = \alpha - (\beta P^{-1}) + \varepsilon \qquad (3.7)$$

P is the water cost and *a* is constant indicates to water cost at which farmers irrigate all available land. The coefficient β refers to the rate of changes in Q_w due to change of the inverse of water cost, Q_w is quantity of water applied and *P* is the price of water in terms of the cost of abstraction and ε is the error term. Well monitoring data and quantity of water applied to each individual crop was used. Diesel prices and irrigation labour cost for different crops at each village was used to estimate water demand equation.

3.3.3.5 Water Application Cost Function

Research literature and official work show limited direct information on the water abstraction cost. Engineering data on pumping efficiency was also absent. Hence, it makes it difficult to acquire accurate information on water use or the precise cost of application. As it is mentioned in the previous sections, we took two approaches to acquire the data:

The first approach was to ask the farmer to record the number of pumping hours on daily basis. The hydrology team measured the water flow at each monitored well. The second is to cross check the farmers' daily record by introducing an item in the questionnaire that to ask the farmers on the number of irrigation he applied to each crop and the number of hours he used to extract water. We have also calculated the fuel use by engine for water extraction by engine to come up with cost of water use applied to different crop.

Quadratic cost function was fitted to the data in order to calculate the marginal cost which is the first derivative of the cost function. The groundwater marginal cost represents the change in total cost due to change in additional water unit used. The analysis is represented by the following equations:
The model fitted was quadratic and may be represented by the following quadratic cost function:

$$TC_w = \alpha + \beta_1 I_c + \beta_2 I_c^2 + \varepsilon \qquad (3.8)$$

where TC_w is the total irrigation cost, α represent intercept, the coefficient β_1 indicates to the slope of the linear segment of the cost function , I_c is the groundwater cost and β_2 is the slope of the quadratic segment of the cost function where the marginal cost is greater than the average cost.

The marginal cost of groundwater is derived as the first derivative of the cost function of equation (3.8):

$$MC_I = \frac{\delta TC}{\delta Ic} = \beta_1 + 2\beta_2 I_c \qquad (3.9)$$

where MC_w is the marginal cost of irrigation water, β_1 *and* β_2 are the intercept and the slope of the linear marginal cost.

3.3.3.6 Groundwater Investment Analysis

One of the distinguishing features in groundwater investment, particularly in water critical dry areas, is that farmers are investing in depleting assets. Depleting assets is a natural resource such as wells, mines or oil wells or other minerals, that may be considered as exhaustible when productive operations terminates. Groundwater is no exception, particularly in the dry areas. Further, well drilling is subject to high risk. It is either success or failure activity. Return on groundwater investment is also uncertain and the time horizon usually not known. Farmers invest large amounts of capital in drilling, deepening wells or horizontal drilling in the speculation of high return. To capture these relationships and evaluate the return on investment several methods have been used:

3.3.3.6.1 Regression Analysis

Well age is an important factor that determines the return on investment. Regression model has been used to estimate the relationship between depth and productive wells age. The computed estimate indicates the marginal productive age changes due to well deepening. Such relationship is then linked to the productive age of the well to calculate the number of payment generated over the productive life of the well. Simple regression was also used to estimate the relationship between depth and cost of the drilling. This relationship captures the marginal depth cost of drilling for different areas. Simple linear regression was also fitted to capture the relationship between depth and well cost of the following form:

$$DC_v = \alpha + \beta Depth_w \qquad (3.10)$$

where DC_v is vertical drilling cost, a is the intercept and β is slope of the line which indicate the marginal cost of drilling due to one additional meter added to the depth of the well. This relationship depicts the contribution of depth to the cost of well drilling. To test the hypothesis that deepening wells can increase the productive age of the well, the following relationship was fitted the data of well depths and age of wells :

$$A_w = \alpha + \beta V_d + \varepsilon \qquad (3.11)$$

where A_w refers to the well productive age, a is constant which represents the average well productive age in the research area, β refers to the contribution of additional vertical drilling (V) unit to the productive age of the well. This relationship has important implications on the total investment cost where farmers tend to deepen their wells in shallow aquifers in the expectation that their productive life will increase.

3.3.3.6.2 Probability of Drilling Success

Well drilling is either success or failure operation. When successful the expected water yield sufficient to irrigate 2-3 hectares deepening on the water yield or failure and nothing is obtained. So the cumulative density function (CDF) for finding water for is modest for area A = 0 and continuous for A > 0. The CDF can be estimated by applying the sparse data rule as outlined by Anderson (1997).

$$\begin{aligned} P(A) &= 0.5e^{-.05A} \ldots\ldots\ldots A > 0 \\ P(A) &= 0.5 \ldots\ldots\ldots\ldots\ldots\ldots A = 0 \end{aligned} \qquad (3.12)$$

To estimate the expected irrigated area which resulted from a successful drilling is done through the following procedure:

$$f(x) = Ae^{-kx} \qquad (3.13)$$

where A is expected irrigated area from successful drilling, K is a positive constant. A is determined by the requirement that the total area under the graph of f is equal to 1. Thus,

$$\int_{-\infty}^{\infty} f(x)dx = \int_{0}^{\infty} Ae^{-kx}dx = \lim_{N\to 0} \int_{0}^{N} Ae^{-kx}dx \qquad (3.14)$$

$$= \lim_{N\to\infty}\left(-\frac{A}{K}e^{-kx}\Big|_{0}^{\infty}\right) = \frac{A}{K} \qquad (3.15)$$

This calculation leads to the following formula of an exponential density function and hence figure 4.16 follows exponential density function of the following

$$f(x) = \begin{cases} ke^{-kx} if \ x & \geq 0 \\ 0 \quad otherise \end{cases} \qquad (3.16)$$

To illustrate the use of equation 3.16, we calculate the probability of drilling success for irrigating 2- 3 hectares.

3.3.3.6.3 Return on Investment Analysis

Investment in groundwater is not a single time investment and return on investment is assured for some time periods. Capital recovery and sinking fund factors were estimated to calculate the return on investment over time. Net present value was also used to calculate the net worth of future returns. Classic method for evaluating investment in depleting stock is represented by the following formulae (Kurtz, 1984):

$$R - B_0 r = (B_0 - L)(A / F_u, n, i) \qquad (3.17)$$

solving for B_0

$$B_0 = \frac{R + L(A/F_u, n, i)}{r + (A/F_u, n, i)} \qquad (3.18)$$

where B_0 ,R, L , A , F_u ,n, r, i are the capital investment, annual income, period payment, present worth of a series, number of payments, speculative rate of return and the interest rate, respectively. F_u can be calculated as follows:

$$F_u = A\frac{(1+i)^n - 1}{i} \qquad (3.19)$$

Similarly we can compute the present value of a future series of payments P_u as

$$P_u = A\frac{1-(1+i)^{-n}}{i} \qquad (3.20)$$

We can solve for A in equation (3.19) and (3.20) as follows:

$$A = \frac{P_u i}{1-(1+i)^{-n}} \qquad (3.21)$$

and similarly in equation (3.21)

$$A = \frac{F_u i}{(1+i)^n - 1} \qquad (3.22)$$

The factors $(A/P_u, n, i)$ and $(A/F_u, n, i)$ are known as the capital-recovery and sinking fund factors, respectively. They can be expressed as:

$$(A/P_u, n, i) = \frac{i}{1-(1+i)^{-n}} \qquad (3.23)$$

and

$$(A/F_u, n, i) = \frac{i}{(1+i)^n - 1} \qquad (3.24)$$

From the above relationships we obtain :

$$F_u / P_u = (1+i)^n \qquad (3.25)$$

and hence the term:

$$\frac{(A/P_u,n,i)}{(A/F_u,n,i)}=(1+i)^n \qquad (3.26)$$

3.3.3.7 System Dynamics

System dynamics model based on differential equation is developed to estimate the likelyhood of groundwater depletion based on several cropping allocation scenario. Stella software (Richmond and Peterson, 1992) was programmed to generate an interactive tool that can be used by planners, farmers or researchers as learning tool. It can be used to simulate different strategies and their effect on the resource and farmer income. The purpose of modeling the dynamics of natural resource use in economic system is to develop quantitative and integrated models that effectively deal with inherent uncertainty in these very complex systems (Ruth and Hannon, 1997). Stock, flow and converters are the building blocks of system dynamics models (Ford, 1999). Stocks are often called levels and flows usually represent rates. The relationship between the building blocks is represented by equations. The sequence of calculation depends on the time step used in the model. The numerical solution is based on Euler method (Ford, 1999). The use of Euler method can be summarized as follows:

In order to use Euler's Method to generate a numerical solution to an initial value problem of the form:

$$\begin{aligned} y' &= f(x,y) \\ y(x_0) &= y_0 \end{aligned} \qquad (3.27)$$

we decide upon what interval, starting at the initial condition, we desire to find the solution. We divide this interval into small subdivisions of length *h*. Then, using the initial condition as our starting point, we generate the rest of the solution by using the iterative formulas (Francis, 1968):

$$\begin{aligned} x_{n+1} &= x_n + h \\ x_{n+1} &= y_n + hf(x_n, y_n) \end{aligned} \qquad (3.28)$$

In order to find the coordinates of the points in our numerical solution. We terminate this process when we have reached the right end of the desired interval.

Stella Software is programmed to find the solution for the equation linked to the stock and flow variables of the model. The main stock flow equation is presented by the following:

$$AQUIFER_{(t)} = AQUIFER_{(t-dt)} + (inflow - water\ extraction) * dt \qquad (3.29)$$

Where

$AQUIFER_{(t)}$ = Aquifer condition at time t which is the state variable at

t = Current point in time during the simulation time.

$AQUIFER_{(t-dt)}$= Aquifer condition at *t-dt* at the initial time of simulation

dt = delta t which is the step of time throughout the duration of the model.

inflow = Rainfall recharge

water extraction= Water discharge from the wells.

The model equations full listing is presented in (Appendix C).

4. DESCRIPTION OF STUDY AREA

The study area covers four different agroecological stabilization zones in northern Syria. Field research was done in five sites that receive different amounts of annual rainfall (see the map in Appendix D). In this study, the sites are referred to as villages, but actually two of the five sites are composed of two neighboring villages. All the five villages (see Table 4.1 in chapter 4) have experienced intensive irrigation based on groundwater and expansion on well drilling as well as fall in water table level (see Figure 1.1 presented in chapter 1). Observations were collected for the 1998-1999 and 1999-2000 crop season during regular field visits and survey questionnaire. In two of the villages (Barshaya and Baggat and Rabia'a) the survey covered almost all the farmers in the villages. At two of the five villages complete irrigation water use of the village was monitored and crop budget and institutional survey were conducted. The results of the research include estimates of the irrigation water use and practices, comparisons of actual water use with standard crop water requirements, an assessment of available water resources, and suggestions for the sustainable use of water resources for the five villages, profitability, alternatives and option available to farmers.

4.1 Location

Syria is located in the western part of the Mediterranean basin. The country has a surface area of 185,180 km^2. In 1997, the cultivated area was 55,212 km^2. Approximately 21% of the cultivated land is irrigated, 60% with groundwater and 40% with surface water (SMAAR, 1997). Although Syria's per capita water availability is less than 1000 m^3 (World Resources Institute, 1999), 90% of Syria's current water withdrawal is used for irrigation (Wakil, 1993).

4.2 Climate

Syria's climate is Mediterranean with continental influence: cool rainy winters and warm dry summers, with relatively short spring and autumn seasons. The average annual rainfall in the country is 252 mm (FAO, 1993). The country is divided into five stabilization zones, which are used for agricultural planning. These zones are based on average annual rainfall (Soumi 1991), as follows;

Zone 1, average annual rainfall exceeds 350 mm, with a 33% probability to be less than 300 mm;

Zone 2, average annual rainfall exceeds 250 mm, with a 33% probability to be less than 250 mm;

Zone 3, average annual rainfall exceeds 250 mm, with a 50% probability to be less than 250 mm;

Zone 4, average annual rainfall exceeds 200 mm, with a 50% probability to be less than 200 mm;

Zone 5, average annual rainfall is less than 200 mm.

Although some 50% of Syria's area is located in zone 5, there is no rain-fed cultivation in this zone. The study area covers zones 1 to 4 in northern Syria. Five villages in Aleppo province were selected for the field research, one village from for zone 1 to 2 and two sites for zone 3 and 4. However, two adjacent villages in both zone 3 considered one village and similarly for zone 4. The five sites and their climatic characteristics are listed in Table 4.1. The average annual climate data were obtained from Corbett et al. (2000). The villages are located between 362 m above sea level (asl) (Baggat and Rabia'a) and 461 m asl (Barshaya). Precipitation varies from 349 mm in Fafin to 225 mm in Seyaleh. The average annual potential evapotranspiration varies from 1493 mm for Barshaya to 1576 mm for Hobs and Harbakieh (Table 4.1). The precipitation exceeds the potential evapotranspiration only during the months of December, January, and February. The average potential evapotranspiration of the five villages is at its lowest in December (0.6 mm/day) and reaches a maximum of 9.1 mm/day in July.

Table 4.1 Long Term Annual Precipitation and Potential Evapotranspiration for Village in the Study Areas.

Village	Zone	Elevation	Average Precipitation	Average Potential Evapotranspiration
		m	(mm/yr)	(mm/yr)
Fafin	1	416	349	1500
Barshaya	2	461	309	1493
Baggat and Rabia'a	3	362	264	1544
Hobs and Harbakieh	4	416	237	1576
Seyaleh	4	390	225	1571

4.3 Well and Groundwater Characteristics

4.3.1 Fafin

The village of Fafin is located next to the Qweiq River. Observations and farmers' information regarding the wells indicate that the wells on the west bank of the Qweiq draw water from the Helvetian aquifer.. Well depths range between 60 to 300 m. The groundwater level in May 1999 was approximately 74 m below the surface. In the summer of 2000, a 100m well fell dry and another farmer deepened his well from 180 to 200 m. The wells on the west side of the Qweiq have more water than those on the east side.

Wells fall dry later during the summer. Water levels increase during the winter, indicating recharge from distant locations. The water quality is good (< 1 dS/m). The two wells on the east side of the river have depths of 55 and 104 m and the water level in May 1999 were approximately 34 m below the surface. Water levels observed in September 1999 were 24 and 72 m. These observed water levels are most likely not static water level, but affected by pumping.

This village experienced severe shortage in water availability during both 1999 and 2000 season. During 2000 summer season there was only very few irrigated plots in summer.

4.3.2 Barshaya

Similar to Fafin, the wells in Barshaya draw water from both the Eocene and Helvatian aquifers. The field research indicated that the groundwater resources in the southern part of the village are limited. This is confirmed by the geologic map, which shows Helvatian formations to the north and Eocene formations to the south of Barshaya (Technoexport, 1967). There are 59 wells in the village, with depths varying between 60 and 100 m. The observed ground water level is between 33 and 50 m below the surface. The water quality is good (< 1 dS/m).

4.3.3 Baggat and Rabia'a

The Eocene is overlain by Upper Miocene Basalts. There are 4 wells in Baggat, 100-135 m depth. Average groundwater depth is 100 m below surface.

One well is used for irrigation in summer (7 hectares cotton) and winter; the other three wells are only used in winter. The Eocene is locally known not to hold water. Water is abstracted from a baked clay layer (approximately 4 m thick) and the overlaying basalt layer, observed between 25 and 100 below the surface. The basalt is covered by a layer of red soil of approximately 25-35 m thick. The observed water quality is good (EC < 2 dS/m).

In Rabia'a there are approximately 15 wells, depths vary between 70 and 120 m. Observed water levels vary between 48 and 80 m below the ground surface. Some of the wells are dry. The quality of the water is good (EC < 2 dS/m).

4.3.4 Hobs and Harbakieh

The hydrogeology in the area of Hobs and Harbakieh is similar to Baggat and Rabia'a. Water is abstracted from the Eocene aquifers. There are six irrigation wells in Al Hobs and four in Harbakieh. The water level is approximately 30 to 40 m below the surface. Not all wells are used for summer irrigation. The quality of the water is good (EC < 1 dS/m).

4.3.5 Seyaleh

The hydrogeology in Seyaleh is similar to Baggat and Rabia'a. However, the Eocene formations start at a depth of approximately 35 m. There are 100 well in Seyaleh, but most of them do not yield water any more. Approximately 10 wells are still working. Well depths are 50-60 m (combined haffara-arabic wells) or 90-100 m (haffara wells). The water level is approximately 35 to 40 m. The quality of the water is good.

4.4 Water Use

Observations were collected for the 1999-2000 crop season during regular field visits from four to six selected farmers in each village. In Barshaya (zone 2) and Hobs and Harbakieh (zone 4), the irrigation water use of the complete village was monitored. Land use maps of Barshaya were prepared for the 1998-1999 season.

Precipitation was measured with a plastic rain gauge by a farmer in the village. In the Hobs and Harbakieh area, precipitation was monitored with an automated rain gauge. To compute the amount of water used for irrigation, the farmer was asked about the number of times he irrigated, the time it takes to irrigate his field, and the size of the field. Well discharges were measured with a 98.7 liter barrel at different times throughout the season. The water use for each crop was computed from the total irrigation time and the measured well discharges. If no well discharge was measured, the water use was estimated from the median irrigation depth for that particular crop in the village. Back-computation of the well discharge from the irrigation water depth for different crops sometimes resulted in different discharges for a specific well. The results indicated that the irrigation estimates of the farmers were less reliable for small areas of land.

The water requirements of the crops planted by the selected farmers was computed using CROPWAT (Smith, 1992), the long-term potential evapotranspiration averages (Corbett et al., 2000), and the observed rainfall. Additional information on crop water use was obtained from Allen et al. (1998) and Doorenbos and Kassam (1979). The computations are based on planting and harvesting dates, collected during the meetings with the farmers.

4.4.1 Rainfall

The observed precipitation for Barshaya was 173 mm, which is 56% of the average annual rainfall. Automated rain gages in the Hobs and Harbakieh area and at Breda on the Jebel Al Hoss mountain range adjacent to the three dry villages received 63 and 72% respectively of the long-term annual rainfall. For the estimation of the irrigation water requirements of the winter crops, rainfall was assumed to be 65% of the average annual rainfall.

4.4.2 Irrigation

The irrigation water requirements, median irrigation water use for each crop, total summer and winter irrigation use of the participating farmers in all five sites is presented in Table 4.2. Farmers in zone 1 have wider crop selection than those in zone 3 and 4. Vegetables are grown by some farmers as alternative to cotton and other high water consuming crops. However, this village has been experiencing groundwater and crops may be abandoned or irrigation was discontinued.

Table 4.2 Water Use and Requirements for the Villages in the Study Area.

Village		Crop	Farmer (No.)	Area (ha)	Total Irrigation (m3)	Median Irrigation (m)	Water Requirement (mm)
Fafin	Winter	Wheat	4	20.0	90660	0.38	0.21
	Summer	Beans	1	0.4	2659	0.66	0.34
		Cotton	1	1.2	20160	1.68	1.20
		Eggplant	3	0.3	3601	1.20	0.39
		Onions	2	2.0	10676	0.53	0.58
		Potatoes	4	13.0	43370	0.38	0.40
		Tomato	3	1.5	18005	1.20	0.39
		Watermelon	1	0.5	1101	0.06	0.42
Barshaya	Winter	Barley	1	1.2	3751	0.32	0.11

Village		Crop	Farmer (No.)	Area (ha)	Total Irrigation (m3)	Median Irrigation (m)	Water Requirement (mm)
		Faba bean	23	39.7	133847	0.36	0.06
		Garlic	14	5.7	28896	0.49	0.13
		Wheat	33	91.1	470702	0.54	0.17
		Winter Crop	1	1.5	1818	0.12	0.00
	Summer	Beans	25	25.3	219486	0.64	0.38
		Cucumber	30	16.8	110020	0.64	0.36
		Cotton	2	2.1	23627	1.43	1.20
		Melon	1	1.0	12599	1.28	1.05
		Onion	1	0.4	1135	0.20	1.25
		Fruit Trees	3	2.8	6234	0.39	0.75
		Potato	1	0.3	956	0.32	0.69
		Sugarbeet	1	1.0	7738	0.78	0.96
		Summer Crop	1	0.3	81	0.03	0.58
		Tomato	1	0.2	1507	0.76	0.89
		Vegetables	2	1.0	10811	1.10	0.58
Baggat	Winter	Barley	2	2.8	3323	0.18	0.13
		Wheat	5	31.5	204888	0.51	0.32
	Summer	Cotton	5	17.6	281972	1.44	1.13
		Corn	1	0.6	2492	0.42	0.43
		Vegetables	1	0.6	9029	1.50	0.57
Hobs	Winter	Barley	10	11.5	29632	0.31	0.13
		Garlic	1	0.1	702	0.70	0.24
		Faba bean	2	0.8	4841	1.00	0.09
		Wheat	8	8.2	65956	0.83	0.26
	Summer	Cotton	1	1.2	12458	1.04	1.12
		Olive	5	5.3	5843	0.10	0.64
Seyaleh	Winter	Barley	1	2.0	2867	0.14	0.28
		Wheat	4	8.0	52757	0.51	0.46
	Summer	Cotton	3	3.3	55155	0.87	1.15

4.4.2.1 Fafin

Farmers irrigate cotton, wheat, and vegetables such as beans, cucumber and tomatoes. Beans and cucumber are grown from April to October. The two vegetable crops are grown on separate plots in April then again in July in other plots.

4.4.2.2 Barshaya

This village represents the high intensity of irrigated cropping. The village has two segments in regard to water availability. In the Northern part, farmer can irrigate cotton and wheat while in the southern part water was depleted and wheat only is grown on small plots.

4.4.2.3 Baggat and Rabia'a

In winter, irrigation for the six farmers was limited to 1.8 ha barley and 0.6 ha faba bean. The barley plots received a total of 180 mm water, divided over two irrigations, in November and February. This should be sufficient for the crop water requirements. The faba beans received 350 mm water, whereas water requirements after the precipitation should be approximately 100 mm.

4.4.3 Village Resources Profile

Table 4.3 and 4.4 list the villages' resource profile in terms of land, population, water use and social structure. Most of the villages in the study area share common characteristics that they experienced intensive use of groundwater in the past and aquifer depletion. While the farming system was transformed from traditional barley livestock to irrigated crops farming system, the reversibility seems to be of high social consequence in terms of migration and affect on income and livelihood of the farmers.

Table 4.3 Study Area Villages Resource Profile

	Village				
Profile	Fafin Zone 1	Barshaya Zone2	Rubia & Bagat Zone 3	Harbakieh & Hobs Zone 4	Seyaleh Zone 4
Affiliation	Izzaz	Al-Bab	Jabal Saman	Sfira	Khanaser
Population	3000	1000	500	700	1300
Literacy %	60	70	50	30	40
Social Structure /Family 1,Tribal 2, Heterogeneous 3	3	1	2	2	2
Number of Households (no)	300	70	50	70	120
Total Geographical Area (ha)	3000	1000	3000	800	1100
Total Cultivated Land (ha)	2500	600	1500	600	600
Net Cropped land/ Winter (ha)	2300	500	250	200	100
Net Cropped Land /Summer (ha)	1200	100	50	10	10
Average Size of Holding (ha)	13	15	30	10	17
Type of Land Holding (private) %	100	95	100	100	100
Type of Ownership (rent) %	0	5	0	0	0
Off-farm Income (%)	30	40	60	70	60

	Village				
	Fafin	Barshaya	Rubia & Bagat	Harbakieh & Hobs	Seyaleh
Profile	Zone 1	Zone2	Zone 3	Zone 4	Zone 4
Share Cropping	0	0	0	0	0
Irrigated Area (% of cultivated)	40	30	10	3	10
Wells /Artesian (no)	70	10	80	20	15
Wells /Arabic (no)	3	1	4	4	5
Shared Wells (no)	0	0	0	0	0
Abandoned Wells (no)	100	200	73	15	70
Direct Well Irrigation (%)	90	60	60	50	50
Water Transfer (PVC pipes) %	10	30	40	50	50
Water Transfer (open Canal) %	0	10	0	0	0
Land Rent to dig well (year)	0	150	0	0	0
Average Transfer Distance (m)	150	1000	200	500	500
Water Sales (number of farmers)	0	0	0	1	0
Distance between Wells (m)	150-200	70	50	200	100
Beginning of Well Irrigation (years)	35	50	50	20	30
Initial Well Depth (m)	15	7	25	15	40
Current Well Depth (m)	55- 120	50	100	50	90
Well Head (m)	45 –90	35	90	40	80
Well Average Yield (inch)	3.5	3	3.5	2.5	3
Water Lifting Average/Hours/Day	12	12	10	5	5
Average Annual Rainfall (mm)	349	309	264	237	225
Cropping Intensity	65	85	65	45	50
Farmers Organization	1	1	1	1	1
Irrigation Energy Used (Diesel) %	100	100	100	100	90
Irrigation Energy Used (Electricity) %	0	0	0	0	5

Irrigation in these villages began in early 1950s. Water was abundant and drilling technology was primitive and associated with modest demand for cereals as population growth far less than the current growth which is estimated at 3.5%. During the 1960s and 1970 farmer began to explore other alternative method for drilling and government began to support major crops. Hence, expansion in area based on groundwater showed rapid increase which affected the farming system in these villages and as shown in Table 5.4.

Table 4.4 Cropping Patterns Change in The Research Site Villages for the Period 1950-1999.

	Fafin	Barshaya	Rubia & Bagat	Harbakieh & Hobs	Seyaleh
Total Geographical Area (ha)	3000	1300	3000	800	1100
Initial stage of groundwater use (1950-70s)					
Net Cropped Land Winter (ha)	2000	1000	1200	300	300
Major Winter Crops	Wheat, Barley, Chickpea	Wheat, Barley, Chickpea	Wheat, Barley	Wheat, Barley	Wheat, Barley
Net Cropped Land Summer (ha)	300	100	150	10	10
Number of Productive Wells	15	15	10	5	5
Major Summer Crops	Maize, Cotton, Vegetable	Maize, Cotton	Maize, Cotton	Maize	Maize
Peak groundwater use (1970s-1985)					
Net Cropped Land Winter	2000	600	2000	500	600
Major Winter Crops	Wheat, Barley, Faba bean, Vegetables, Onions, Garlic	Wheat, Barley, Faba bean, Vegetables	Wheat, Barley, Faba bean, Vegetables	Wheat, Barley	Wheat, Barley
Net Cropped Land Summer	1200	300	1200	200	150
Major Summer Crops	Maize, Cotton, Vegetable, Sugar beat, Potato	Maize, Cotton, Vegetable, Sugar beat, Potato	Maize, Cotton, Vegetable, Sugar beat.	Cotton	Cotton
Number of Productive Wells	120	230	100	50	80
Major Winter Crops					
Current groundwater use (1985-1999)					
Net Cropped Land Winter	1500	500	250	200	100
Major Winter Crops	Wheat, Barley, Faba bean	Wheat, Barley	Wheat, Barley	Wheat, Barley	Wheat, Barley
Net Cropped Land Summer	100	50	30	10	10
Major Summer Crops	Cotton, Vegetable	Vegetable	Maize, Cotton, Vegetable	Maize, Cotton, Vegetable	Cotton
Abandoned Wells	100	160	73	45	70
Productive Wells	25	40	6	3	6

5. RESEARCH FINDINGS

5.1 The Role of Agriculture

5.1.1 The Role of Groundwater in Agricultural Production

The expansion of irrigated land in the World has contributed considerably towards averting the Malthusian curse and today irrigated agriculture accounts for between 30 and 40 percent of world food production although only 16 percent of total cultivated land is irrigated (FAO, 1993). Due to continued population growth and growing market demand for food and fiber, much is expected from irrigated agriculture for the foreseeable future. According to Serageldin (1995), half of the growth in food supply in the past thirty years had come from the expansion of irrigated agriculture, and an estimated half to two-thirds of the increment in food production in the future will have to come from irrigated land. Similarly, FAO (1993) expected that, Food security in the next century will be closely allied to success in irrigation " because about 80 percent of the additional food required during the next 30 years will have to be produced on irrigated land. In addition to the considerable contribution to food supplies, irrigated agriculture also provides employment opportunities for rural community and an estimated 2.4 billion people are employed in irrigated agriculture".

Agriculture is by far the largest consumer of the world's scarce water resources and irrigation accounts for more than two-thirds of all water consumption (FAO, 1993). Despite the considerable importance of water for providing income opportunities for rural people and for assuring food supplies for an increasing world population, agriculture is considered a low-value user of water (FAO, 1993) and only about 45 percent of the water withdrawn from its source is effectively used by the crop (Serageldin, 1995). As agriculture has to compete with water demands from industry and from households for increasingly scarce freshwater supplies, irrigation practices that are characterized by high water losses, low water use effectiveness, and low economic returns to water resources employed in production are not only unsustainable but also make little economic sense. Such ineffective use is particularly deplorable in regions where annual internal renewable water resources are less than 1000 m^3 per capita and where the lack of water constrains social and economic development, as is the case in the Near East, North Africa, and Sub-Saharan Africa (FAO, 1993).

5.1.2 The Contribution of Groundwater to the Economy

The contribution of irrigated agriculture to total agricultural output is approximately mirrored in Syria, whose renewable internal water resources amount to only some 430 m^3 per capita and year (FAO, 1993), far below the 1000 m^3 per capita threshold below which social and economic development, is deemed to be water-constrained. Irrespective of the shortage of water, 50 percent of Syria's total value of agricultural production is produced on the 15 percent of total cultivated area that is irrigated (FAO, 1993).

Groundwater is estimated to constitute more than 50% of the total volume of irrigation water in Syria (JICA, 1997). The estimated volume used for irrigation was 8,109 m^3 of groundwater and annually irrigated 60 percent of the country's total irrigated area. Of this water only small proportion is rechargeable (Ahmed, 1998). In spite of that, current irrigation practices are deemed to have low water use effectiveness. Irrigation efficiency coefficient, defined as the ratio of crop water use to the total water delivered to the field, was estimated to be between 0.25-0.55 (Wakil, 1993). Hence, irrigated agriculture in Syria to a large extend depends on mining the country's groundwater heritage and this is likely to be unsustainable. Signs of unsustainable groundwater use for irrigation are evident in some parts of Syria where groundwater irrigation has been practiced for some time. Water tables are reported to be in decline as more farmers have installed wells, and in some areas water quality is deteriorating rapidly as groundwater is pumped from increasing depth. Farmers in these areas are well aware of the threat to groundwater-irrigated agriculture but appear to be resigned to the prospect of having to revert to rain-fed cropping systems. In other areas, where groundwater irrigated agriculture is a more recent development; farmers appear to be, as yet, unaware that the new development will not be sustainable. Whatever the state of the groundwater resource, in many parts of Syria, however, the race for tapping groundwater continues unabated, much to the pleasure of well-drilling contractors

Various conditions in Syria set the stage for ineffective and unsustainable groundwater use by rational farmers, who equate marginal costs of water extraction and provision with marginal returns to water. As long as water is treated as a ubiquitous common property resource with unconstrained access, economically rational farmers will always extract more, and not less water, when the costs of water extraction are reduced or the returns to water are increased. In Syria, product prices have been supported at above world market levels, inputs have been subsidized, research and technology development are aimed at increasing water productivity, and, to top it up, the construction of well has been encouraged with subsidized loans from the late 1980s into the early 1990s. The aggregate impact of these policies has been summarized by (FAO, 1993). These policies are contributing to the proliferation of wells in the Syrian Arab Republic. Digging wells to pump groundwater accounts for 80 percent of the newly irrigated land since 1987. With irrigation, farmers obtain higher yields, more stable production and greater profit. Since water is free, the only investment expense required is the well and the pumping gear - a one-time fixed cost. Farmers obtain subsidized credit to purchase subsidized fuel for operating imported pumps purchased with overvalued currency (an implicit subsidy). With these economic opportunities, most farmers want to dig wells or pump surface water.

The trend remains untrammeled and in some areas of Syria it is possible to observe contiguous wells every 50-80 meters. Supplemental irrigation of winter crops, which is considered as an important innovation to increase productivity, is deemed to be wiser sue of groundwater than full irrigation of summer crops. Farmers once invested in wells and pumping equipment, however, will irrigate winter as well as summer crops and there is no reason to do otherwise as long as they have the incentives. The problem of groundwater-based irrigation is clear: The trend toward more wells and its twin trend of growth in irrigated area, are not sustainable because the volume of groundwater extracted already exceeds by far the volume of groundwater recharged.

5.1.3 Complexity of Governing Common Access Resource Use and Institutional Issues

Groundwater use in water critical area is inefficient in spite of its scarcity. The most important factor contributing to low effectiveness of water use is its common access nature. Common access resource are resources which are mobile and must be captured (reduced to possession) before they can be allocated to groups and individuals. The fugitive nature of water makes it difficult to establish and enforce private and exclusive property rights to water. In the absence of effective property rights, markets for water cannot develop and less effective means of allocating water to alternative uses have to be employed. Often, no allocation mechanism is in place and water is treated as a ubiquitous resource which, from the point of view of the individual user, is not scarce.

The difficulties that derive from the fugitive nature of the resource are exacerbated in some cultures and societies that attribute to water special religious and social values. In Islam, for example, such norms militate against the allocation of water through market prices and may prevent the establishment of water markets. In Syria, water is sometimes sold in villages that are poorly endowed with drinking water. Our own rapid appraisals of such transactions indicate that no less than 50% and up to 80% of the price paid is pure rent to the seller. About 15% of the price covers the variable cost of water extraction from a depth of 70-80 m and the rest is accounted for by fixed costs. If this information were indicative for drinking water transactions in rural Syria, one would have to conclude that cultural norms and market forces have co-evolved to a new symbiosis.

Finally, the effectiveness of water use is often strongly influenced by many intricate interactions between water and site-specific factors of production, such as climate or soils. Information of the site-specific interactions between water and its complementary factors of production is rarely made explicit and recorded, and even where such information would be available, it could easily exceed the information handling capacities of boundedly rational water users. Hence, water users often have little or no incentive to use water effectively, and even where such incentives exist, water users may be overwhelmed by the difficulty of the task to allocate water rationally.

Supplemental irrigation with groundwater extracted from an aquifer is prone to be affected by additional obstacles to a more effective use of water. Most aquifers are large enough to provide sufficient groundwater for more than one irrigator but aquifers often are too small to supply adequate volumes of water at all times to all irrigators. Groundwater in an aquifer can therefore be regarded as a common property resource in of the farmers of the land overlying the aquifer. Access to the water is limited to this group but no member of the group can prevent another group member from extracting groundwater. Hence, each group member has an incentive to capture groundwater before it is captured by some neighbor and no individual farmer has an incentive to conserve water, because water not extracted by him may be extracted by some other irrigator. In short, where and when water demand from supplemental irrigation exceeds available groundwater supplies from an aquifer, a tragedy of the commons may unfold (Hardin, 1968).

Finally, the effectiveness of groundwater use is impaired by the difficulty to monitor the resource. In contrast to water flowing in rivers or canals, where changes in the availability of water can be readily monitored, water tables of aquifers are hidden from view and the impact of water use extraction by individual irrigators may be imperceptible. Hence, the tragedy of the commons may unfold without the players noticing that they are the cause and the victims of a tragedy.

The diffusion and intensity of SI in Syria has, in many regions, reached levels where it has become unsustainable. The development is the result of many interacting factors of which two are of primary interest. For one, the development is to some extend the unintended consequence of economic policies and of current priorities in agricultural research. Both, policies and research encourage farmers to invest in and apply modern water extraction technologies. The other factor is the absence of rules governing access to and use of groundwater.

Given the increasing scarcity of water resources available for agriculture and the low effectiveness of water use in agriculture, more attention is now given to ways of influencing the behaviour of water users at the expense of approaches that are focused on capturing more water (FAO, 1993).

This perception of the problem of unsustainability of SI in Syria suggests two strategies for approaching the solution of the problem:

to demonstrate to policy makers, researchers and extension agents the unintended consequences for groundwater exploitation of their actions and to provide them with means that enable them to take into account in the second-order effects on the groundwater resource of their decisions;

to design or encourage the emergence of suitable institutions regulating access to groundwater and coordinating its use.

Given the complexity of the causes of unsustainable water extraction, it is unlikely that neither the learning-focused strategy nor the governance strategy, when applied in isolation, will be able to bring about the change necessary to break the trend toward unsustainable groundwater use and a mixed strategy will have to be found.

5.1.4 Groundwater Use in Supplemental Irrigation

An aquifer is an underground geological formation that, actually or potentially, contains water in its pores and voids and which transmits water readily. Water contained in aquifers is called groundwater (FAO, 1993). Groundwater use is sustainable if the groundwater withdrawn from an aquifer is recharged from lateral groundwater flows, or from rainfall, or both. Such sustainable groundwater use leaves the aquifer intact so that future generations can continuously use the renewable portion of the groundwater resource.

If groundwater extraction exceeds recharge the aquifer is depleted and water use is unsustainable if the aquifer does not recover from depletion. Symptoms of unsustainable groundwater use are increasing water extraction costs, wells falling dry, intrusion into the aquifer of groundwater of low quality, or subsidence of overlying lands. Such symptoms of overuse are a common in the drier parts of India and China, but have also become common in the Near East and North Africa (FAO ,1993).

Supplemental irrigation (SI) has been defined as "the application of small amounts of irrigation to essentially rain-fed crops normally grown at that location, to increase and stabilize yield levels" (ICARDA, 1995). Characteristically, the decision to supplement rainfall with irrigation water depends purely on the estimated profitability of providing additional water (Perrier and Salkini, 1991). SI is distinguished from full irrigation which is the "application of irrigation water to crops that would not normally be grown at that location, in quantities sufficient to ensure satisfactory economic yields" (ICARDA, 1995).

In Syria, SI is applied mainly in the areas with more than 200 mm annual rainfall and less than 350 mm. In very dry areas with less than 200 mm annual rainfall, however, farmers also claim to use SI for their cereal crops. Even farmers in relatively wet areas with more than 250 mm annual rainfall use up to 500 mm ha^{-1} of supplemental irrigation (Rodriguez and Pala, 1999).

SI increases water productivity of crops. In Syria water productivity of wheat production increases from about 0.7 kg of grain per cubic meter of rainfall to about 3 kg of grain per cubic meter of supplemental irrigation. In addition to increasing the water productivity of individual crops SI also affects farmers' choice of cropping systems because the improved and more assured water supply from a well allows cropping systems based on crops that would not be grown in the absence of irrigation. For instance, the emergence of modern irrigation systems in Syria during the 1970s made possible the cultivation of wheat and summer crops where barley and livestock production systems had been customary. These traditional systems have been displaced to the driest areas of the agricultural frontier with subsequent erosion of genetic and other resource of the fragile dryland. Furthermore, cereal-based cropping systems are replaced by systems based on more profitable summer vegetables or irrigated fruit that find a ready market in the sprawling cities. The replacement of crops of low market value by high-value crops is accompanied in Syria by increasing cropping intensities that typically increase from 85% in rainfed crops to 150% in irrigated systems, irrespective of whether irrigation is supplementary or full.

5.2 Evolution of Groundwater Use in Syria –Trend Analysis

5.2.1 Modeling Well Drilling and Groundwater-Irrigated Area Expansion

Irrigated agriculture has proliferated in Syria since the 1950s. During the 1966-1999 period irrigated area also increased from 0.4 to1.2 million ha.[1] Rapid increase was started during 1980s and 1990 Table 5.1 Irrigated area growth is depicted by Figure 4.1 where the rapid growth occurred during the last 15 years. This expansion is associated with similar rapid increase in the groundwater irrigated are (Table 5.2). It was also associated with similar high expansion in well drilling Table 5.3.

Table 5.1 Total Cultivated Area and Irrigated Area for the Period 1966-1999 in Syria.

Year	Total Area(ha)	Irrigated Area (ha)	Irrigated /Total%	Year	Total Area(ha)	Irrigated Area (ha)	Irrigated /Total(%)
1966	2,039,352	416,739	20	1983	4,070,076	579,847	14
1967	2,248,272	407,281	18	1984	3,733,945	616,862	16
1968	2,562,202	446,019	17	1985	3,970,256	651,903	16
1969	2,899,809	465,099	16	1986	3,903,128	652,380	16
1970	3,395,113	467,517	13	1987	4,040,172	654,709	16
1971	2,801,552	474,872	16	1988	4,297,437	650,298	15
1972	2,995,285	484,839	16	1989	5,395,824	670,134	12
1973	3,374,518	505,972	14	1990	5,466,031	692,977	12
1974	3,338,554	550,384	16	1991	4,853,374	788,331	16

[1] Total cultivated area also increased from 2.03 to 4.50 million ha during the same period.

Year	Total Area(ha)	Irrigated Area (ha)	Irrigated /Total%	Year	Total Area(ha)	Irrigated Area (ha)	Irrigated /Total(%)
1976	4,063,957	620,590	15	1993	4,938,670	1,013,273	20
1977	3,891,428	620,821	15	1994	4,869,287	1,082,107	22
1978	3,896,594	632,574	16	1995	4,981,621	1,088,891	21
1979	3,712,475	605,383	16	1996	4,642,059	1,126,096	24
1980	3,993,967	646,628	16	1997	4,803,119	1,167,633	24
1981	3,937,698	653,173	16	1998	4,868,179	1,213,108	24
1982	3,988,120	555,116	13	1999	4,540,588	1,185,679	26

Source: SMAAR (1962-1999).

This expansion is an economic phenomenon which is based on a policy option and farmer level decision but it is linked to a natural resource base (Figure 5.1). How far the existing resource base can uphold this option is under question.

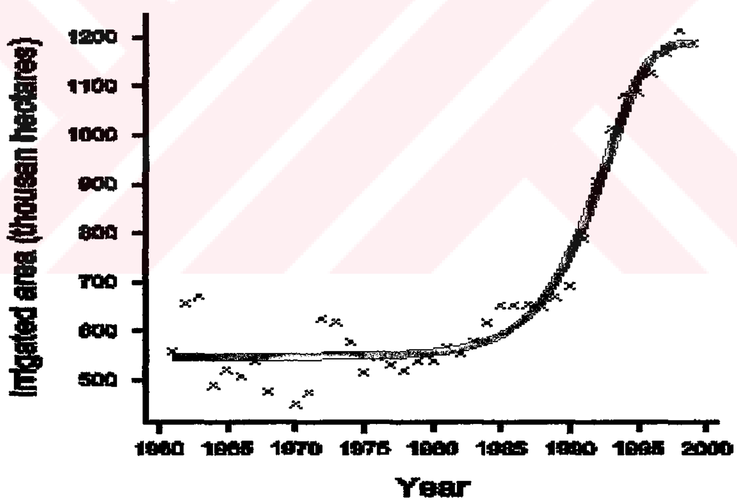

Figure 5.1 Irrigated Area Trend for the Period of 1961-1999 in Syria.

It is interesting to observe the trend of the growth in total irrigated area and groundwater-based areas both follow a logistic model. The groundwater irrigated area reached 705 thousands ha (Table 5.1) with an absolute increase estimated 184%, and constituted 60% of the total irrigated area. It is estimated that 80% of the newly irrigated land during the period 1983-1993 was based on ground water and supported by government subsidies on fuel for operating pumps (FAO ,1993).

To model the three trends, we have fitted the following equation to the data in Tables 5.1, 5.2 and 5.3

$$Y = A + C/1 + e^{-B(X-M)} \qquad (5.1)$$

where Y is the area or number of wells , A is lower asymptote indicates to the initial irrigated area, C parameter controls the upper asymptote which indicates the level of saturation.

Logistic models are applied to natural phenomena where there is a factor that limits growth rate in variety of contexts. This model introduces the concept of saturation where there is a factor, in this case the carrying capacity of the aquifer limits growth of groundwater irrigated agriculture or of the number of drilled wells as shown in Figures 5.1, 5.2 and 5.3

Table 5.2 Groundwater Irrigated Area for the Period 1981-1999 in Syria.

Year	Groundwater-Irrigated(ha)	Year	Groundwater-Irrigated(ha)
1981	248061	1990	341951
1982	259485	1991	420802
1983	266210	1992	530884
1984	294676	1993	610057
1985	318306	1994	693621
1986	315987	1995	685497
1987	311740	1996	683773
1988	309930	1997	701634
1989	313925	1998	723696
1990	341951	1999	704905

Source: SMAAR (1981-1999).

Figure 5.1 demonstrated a situation of rapid growth in irrigated area which represents interaction of several factors that will be discussed later in this chapter. It shows that the highest growth we experienced during late 1980s and early 1990s. Given the condition of the affect of the rapid growth, the expansion has reached the upper limit of the natural resource to sustain such expansion and hence policy changes has to take place. This could also be reflected in cropping patterns changes on the country level on the farm level. This model shows high fit (R^2= 92%). The power of predicting the trend of irrigated area would help in the policy analysis and control can be introduced to change the depletion or degradation of the natural resource. The model shows also growth rate was 0.15 and the groundwater irrigated area was constrained at the level of 1.4 million ha. The model shows rapid growth followed by decline and saturation. The saturation of the expansion explains the limitation of groundwater resource to support such expansion.

Table 5.3 Number of Wells and Groundwater-irrigated Area in Syria for 1986-1999.

Year	Drilled Wells (No)	Irrigated Area (ha)
1986	63836	315987
1990	89991	341951
1991	100086	420802
1992	105734	530884
1993	117099	610057
1994	124092	693621
1995	125669	685497
1996	134988	683773
1997	138358	701634
1998	139899	723696
1999	135089	704905

Source: SMAAR (1986-1999).

Number of wells showed similar growth trend. In the case of total irrigated area the equation exhibits the variability in irrigated area growth over time which is depicted by (Figure 5.2). The equation showed highly significant fit and R^2 was or 0.98.

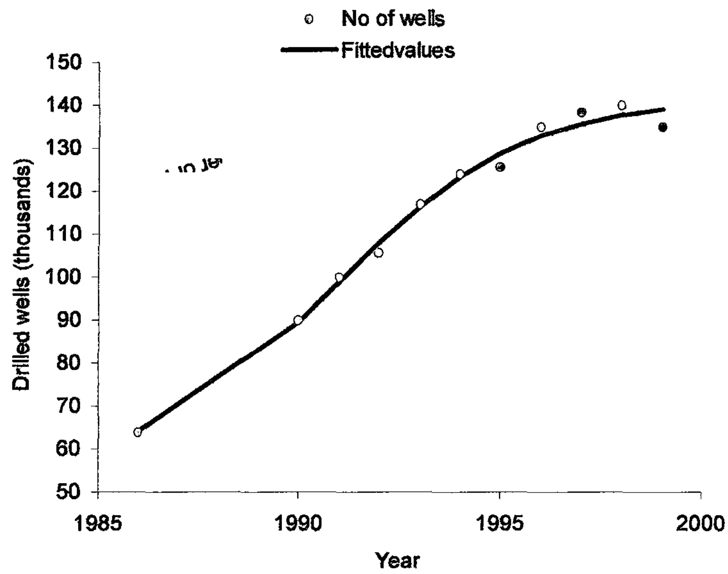

Figure 5.2 Number of Drilled Wells Trend for 1961-1999 in Syria.

The maximum growth occurred during 1994 and the capacity of groundwater level was reached in 1998 which made the curves to plateau. This implies that the capacity of the irrigation infrastructure has been reached.

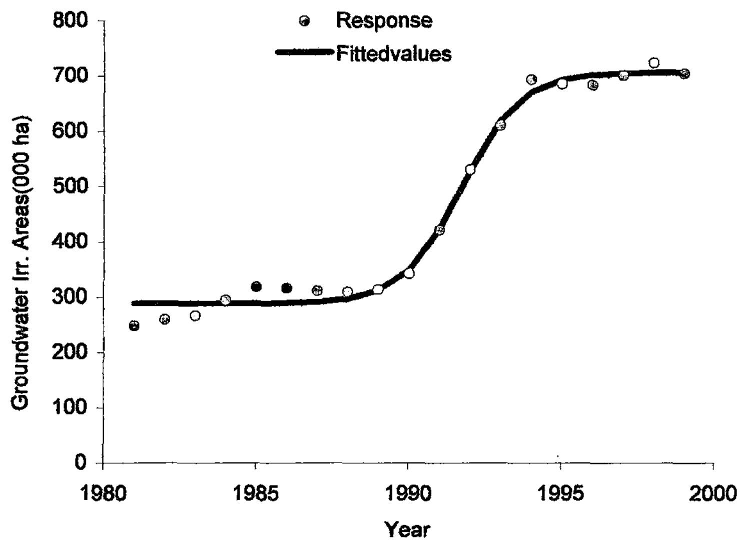

Figure 5.3 Trend of Groundwater Irrigated Area for 1986-1999 in Syria.

The growth in well-irrigated area was paralleled with similar logistic growth pattern in the number of wells (Figure 5.2). Number of wells increased during 1980s and 1990. The maximum growth rate occurred during 1992 followed by slow growth during late 1990s. The slow down in the growth of wells is reflected in the decline in the growth of groundwater irrigated areas and the total irrigated areas. The growth in number of wells and irrigated areas declined in 1998 and reached a plateau.

Logistic model was also fitted to groundwater- irrigated area growth (Figure 5.3) for the period 1981-1999. It showed highly significant fit with R^2 was 99%. The maximum growth was in 1991. This was associated with high level of increase in number of wells during the 1990s preceded by a stable growth during the 1970s and 1980s. Expansions reached a plateau during 1998. These trends demonstrate the importance of groundwater-based agriculture in attaining the policy objectives and show the vulnerability of groundwater resource to depletion as abstraction levels exceed the recharge.

5.2.2 Driving Forces for Groundwater Use

Expansion in irrigated areas has officially been considered as the basis of economic growth (Wakil, 1993). Growth in irrigated areas during 1986-1998 reflects nation wide economic policy objectives and government policies aimed to achieve those objectives (Soumi et al., 2000). Population growth and food self-sufficiency strategy constituted the driving forces that induced economic policy makers to expand irrigated areas. Major policy objectives during that period included the achievement of self-sufficiency on major food crops, particularly cereals, increased agricultural production to increase rural employment and foreign exchange earnings, and to provide supply of row materials to domestic industries as part of overall strategy of economic development.

Government policy instruments to achieve the objective of food self-sufficiency included: credit subsidy, input subsidies, exchange rate adjustment and price support. Plans were undertaken to expand the irrigated area through large irrigation projects and conversion of rain-fed areas to groundwater based areas (Soumi et al., 2000). Government devoted 60-70% of the agricultural budget to irrigation projects (ESCWA, 1994), which provided subsidies for well drilling. Irrigation with surface water from government irrigation projects was supported by relatively low fees charges and subsidized diesel fuel. Irrigation fees charged for Euphrates projects, for example, comprise only 50% of the real cost. Groundwater abstraction has also been supported through highly subsidized fuel.

Farmers registered in the government agricultural plan have access to low interest loans and input purchase credit represented by 5% lower interest rate compared with 9% as the official interest rate. This is in contrast with annual interest rate ranging from 25% to 40% charged by local money lenders in the informal financial sector (Saade, 1991). Direct input subsidies cover farm inputs such as diesel fuel, seeds, farm equipment and, fertilizers, bags and so forth. Fertilizer support was estimated to range from $100/ton to $200/ton for N and P_2O_5 respectively (Saade, 1991). However, during the 1990s, the major subsidy is confined with diesel fuel. Fuel subsidy is estimated to be as high as 80% of the purchase prices (Table 5.4).

Table 5.4 Major Production Input Support Calculated on Year 1999 Exchange Rate in Syria.

Commodity	Unit	Local Prices (SYP)	Intl. Prices $US	Border Prices (SYP)	Input Price Subsidy (SYP)
Diesel	Liter	6.1	0.23	11.54	5.44
N Fertilizer	Kg	8.3	0.18	9.00	0.70
P Fertilizer	Kg	8.3	0.23	10.72	2.42

Border prices (Int. FOB Prices + Transport)*Exchange rate)

Further, the major irrigation cost component is fuel cost and, hence, fuel subsidy has wide implication on groundwater use. Profitability provided additional stimuli for expansion and acceleration in groundwater based farming. Government procurement price policy for strategic crops set high profit margin for the main crops. It ranges from 37-79% for wheat and 31-66% for cotton during 1987-1992 period. Prices have increased by more than 30% for the period 1996-1999 (Figure 5.4).

Owies (1999) found that the average wheat yield under rain-fed conditions was 1.25 tons/ha compared to 3 tons/ha for supplementary Irrigation in Syria.

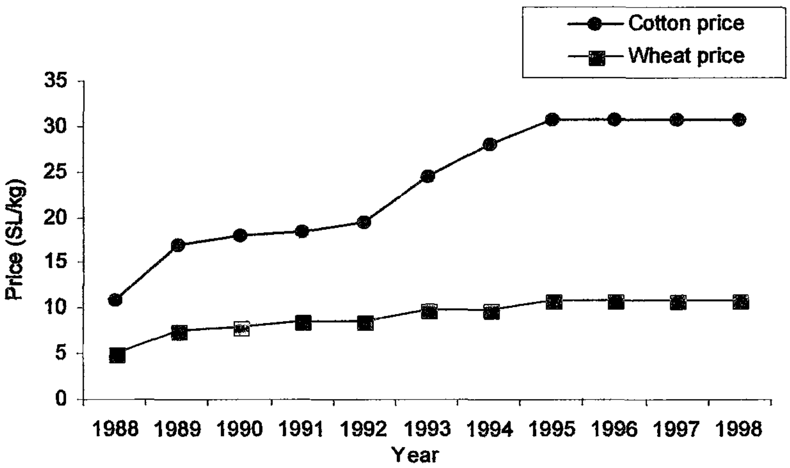

Figure 5.4 Wheat and Cotton Prices Trend for 1988-1999.

The average wheat yield is estimated at 4 t/ha (MAARS, 1999). Using current price for wheat (11 SYP/kg), the difference in gross return is 30,000 SYP/ha. Cotton, root beat and other irrigated crops contribute to the profitability of irrigated agriculture.

In addition to the government guaranteed procurement price, strategic crops prices have been supported. However, government has relaxed these support price. Table 5.5 presents major crop prices support where calculation was based on 1999 exchange rate.

Table 5.5 Major Crops Prices Support Based on the Year 1999 Exchange Rate.

Crop	ER	SYP/ton	Border Price US$	NPR	RD	Price Support (SYP/Kg)
Wheat (Soft)	50.2	10800	134	1.6	0.6	4.06
Wheat (Durum)	50.2	11800	138	1.7	0.7	4.87
Maize	50.2	8000	68	2.3	1.3	4.57
Cotton	50.2	30750	502	1.2	0.2	5.53
Barley	50.2	7500	124	1.2	0.2	1.28

ER = Exchange rate
NPR = Nominal protection rate
RD= Rate of distortion

Although diesel prices have increased, the level still does not constitute a major constraint on the production of groundwater based crops. The consumer price of diesel is only 14 cents. However, diesel prices have been increased by 16% in year 2002. Figure 5.5 depicts the change in diesel nominal prices.

The expansion due to these factors is limited by decreasing returns to investment in groundwater irrigated agriculture and increased risk as the rate of well drilling success has substantially decreased. As the number of irrigators has increased, wells started to dry up and irrigated areas per farm have decreased in the surveyed villages. Given these trends, there will be a decline in groundwater- based

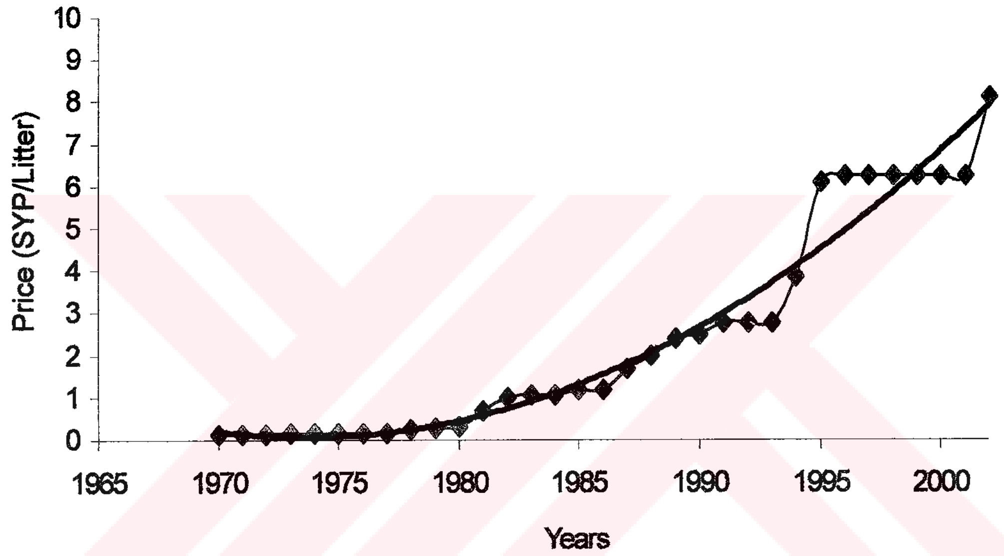

Figure 5.5 Diesel Nominal Prices Trend in Syria for 1965-2000.

The legal and regulatory framework governing resource management is generally weak (ESCWA, 1994). Effectively ground water access is unrestricted. Rodriguez et al. (1999) found that declining groundwater levels were the result of economic incentives, unrestricted access to groundwater, tube well technology and sprinkler irrigation systems. Unrestricted access to groundwater, given groundwater being fugitive resource, led to high rate of investment in well drilling and hence farmers have to expand their irrigated area to increase their income, and if they face water shortage they search for more water. Sprinkler irrigation is used to conserve water in order to expand the irrigated areas, but inevitably increases abstraction intensity.

The combination of agricultural price support, effectively unrestricted access, and improved technologies that raised profitability of irrigated agriculture has contributed to the expansion of ground water pumping and led to rapid groundwater depletion. This condition is characterized by over-exploitation and low efficiency of groundwater use.

The fitted curves indicate that population growth and economic incentives have exponentially increased both drilled wells and irrigated areas. The growth patterns show the combined effects of population growth in terms of growing demand for agricultural products, agricultural policy, and lack of regulation or ineffective enforcement of regulations. The expansion due to these factors is limited by decreasing returns to investment in groundwater irrigated agriculture and increased risk as the rate of well drilling success has substantially decreased. As the number of irrigators has increased, wells started to dry up and irrigated areas per farm have decreased in may villages. Given these trends, there will be a decline in groundwater-based areas due to increase in abandoned wells and decline in water tables. Thus it will have negative effects on farm income, rural employment and rural out-migration. This raises questions about the long-term sustainability of policies aimed at achieving high performance of the agricultural secretor and increased rural development based on the exploitation of ground water resources with out careful consideration of the long-term effects of such policies on the resource base. The combination of technological, policy and institutional measures can bring the system to equilibrium. The participation of the users is essential for such measures to have the socially desired effects.

5.3 Groundwater Irrigation in Syria

5.3.1 Governance Strategies

Governance of groundwater resources rests on two foundations. The regulation of access to the groundwater resource and the coordination of its use. The introduction of laws and regulations governing access to groundwater amounts to a major change in policy in countries with far-reaching distributional consequences. Such policies are therefore highly sensitive issues in countries that are short of water but where access to groundwater is unconstrained in spite of evident water scarcity. The coordinated use of a resource can be achieved under either of three regimes. That may be imposition of hierarchical command or submission to market forces, and observance of local institutions conducive for cooperative resource use.

Many governments have endeavored to achieve coordinated groundwater use by attempting to impose the will of government on the will of irrigators. Various rules and regulations governing the extraction of groundwater have been tried to this end. Examples of such attempts are regulating minimum distances between wells, specifying maximum permissible power of motors used for pumping, constraining access to electricity, limiting the amount of water that may be extracted by all irrigators from an aquifer, or allocating pumping quotas to individual irrigators (FAO 1993; Saleth at al., 1999). Most of these measures require considerable administrative effort and determined enforcement in the face of often strong opposition from irrigators. Furthermore, some of the measures, e.g. spacing regulations, effectively transform some part of the water rents into rents for administrative acts and thereby expose government servants to considerable moral hazards.

In spite of certain limitations of government regulations as a means for achieving coordination among groundwater users, the approach is feasible as the experience from some countries indicates

Markets for irrigation water extracted from aquifers have emerged in some countries, e.g. in Chile, India and Mexico (Saleth et al., 1999). However, as long as the implicit common property rights of all farmers of an aquifer have not been replaced by secure private property rights to groundwater, such markets are not truly markets for groundwater and may be better characterized as markets for water extraction services. At this time, private property rights to groundwater have not been defined in Syria and the coordination of groundwater use through water markets is the exception rather than the rule. Furthermore, there is no indication that the government of Syria has the desire to establish the requisite rights.

With markets and hierarchical command being unrealistic options for achieving coordinated, sustainable groundwater use in Syria, research must be focused on the establishment of local institutions conducive for cooperative water use. Such arrangements are currently not in use among farmers practicing supplemental irrigation and the proposed research is a first step towards the implementation of such institutions either through deliberate design or through their spontaneous emergence.

5.4 Economic Modeling of Groundwater Use

5.4.1 Water Demand Analysis

It is generally assumed that groundwater extraction by farmers is characterized by being myopic in which users set private marginal benefit of water applied equal to private marginal cost. The present discounted net benefits generated by this behaviour using social discount rate are then compared with the present discounted net benefit in the collusion in which aquifer rent is maximized. The difference is called common-pool inefficiency. In the groundwater use literature, the period marginal benefit function is usually taken to be the inverse derived demand of water (Kindler et al., 1984; Carlson et al., 1993 ; Dixon, 1989). The derived demand for water estimates the amount of water a farmer will allocate to different crops in a given period at a given water price to maximize profit. This is based on the assumption that all other input variables are fixed and quadratic production function. The assumptions can be justified in that input prices, product prices are similar and policy issues for those villages are also the same.

The assumption of quadratic production function is based on the work of (Zhang and Oweis, 1999). The function was estimated for durum wheat under Syria weather condition. The estimated relationship is depicted by the following equation:

$$y = -5.855 + 0.0329w - 0.00002164w^2 \qquad (5.2)$$

where y is wheat production measured in ton per hectare and w is the water applied. w has tow component that is rainfall and supplementary irrigation measured in mm (Figure 5.6) . Under this production function the maximum yield is achieved when water level applied reaches 760 mm. Hence, in order to achieve the target of 6.5 tons/ha farmer has to apply 510 m^3 ha^{-1} of groundwater in addition to 250 mm ha^{-1} of rainfall. This production function is assumed to work under unconstrained access to irrigation water and fixed product prices. Given groundwater depletion condition in Syria this assumption would be questionable

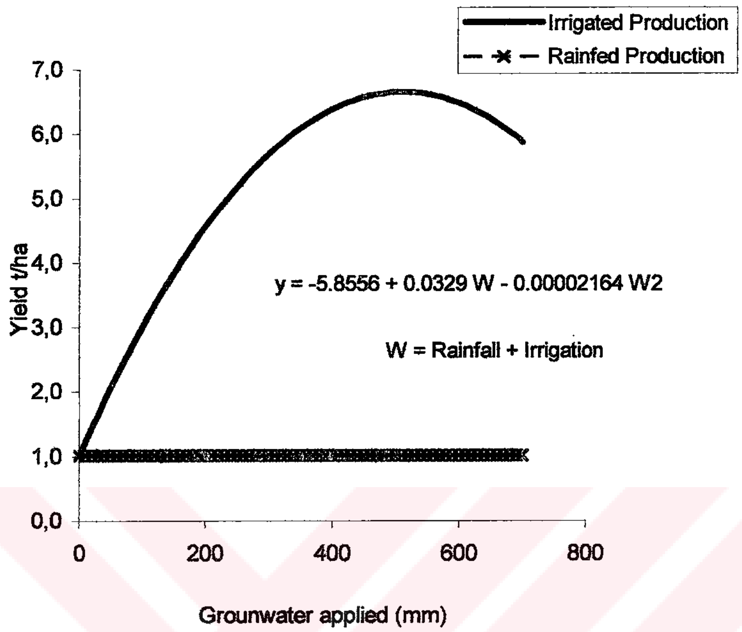

Figure 5.6 Wheat Production Function and Water Application

However, wheat procurement prices maintain stability of prices. This condition may applicable to other crops since the response to irrigation water is quadratic in most cases. We also shall assume a linear functional form and estimate

$$w^d = f(p,Q) \qquad (5.3)$$

where w^d is the volume of water demanded in cubic meter per hectare, p is the cost per cubic meter, and Q is a vector of variables that characterize the production possibilities of the particular farmer. For example soil type, slope, hilliness, whether, and the prices of inputs other than water, and the prices of agriculture output. It is reasonable to assume that farmers in the selected villages face the same price for inputs other that the water and for their outputs. Soil type did not show in all villages where the research has been done is correlated with water cost.

In the groundwater literature linear function for of the following form is fitted and estimated using the following linear equation:

$$p_w = \alpha + \beta Q_W + \varepsilon. \quad (5.4)$$

where Q and P are water quantities and average price respectively; α and β are the intercept and the slope of the demand schedule. Water prices in such situation are based on the irrigation cost since there is no price charging or taxes on groundwater extraction. Fitting the relation using ordinary least squares method shows weak linear relationship. The price coefficient was not statistically significant although it has the expected negative sign. However, the intercept is highly significant, the following equation represent the fitted line :

$$P_W = 3.972 - 1.33Q_W \quad R^2 = 0.085 \quad (5.5)$$

(.677) (.089)

Figure in parentheses is the standard errors of the estimates.

The low R^2 demonstrate that not only water cost determines the demand for water and accordingly only 9% of the variation in water prices is explained by water quantities. Evidence in the villages shows that farmers do not consider water cost as a constraint when applying water to crops. This stems from the fact that fuel prices are highly subsidized and hence the availability of water may the key determinant of the demand for water in water scarce areas. Farmer were asked whether fuel cost affect their decision on the allocation of water to crops, 99% of the 80 farmers surveyed do not consider fuel cost as a major factor when allocating areas to irrigated crops. The demand schedule also shows that demand is elastic for high water consuming crops as shown in Figure 5.7. The low percentage of explained variation by the fitted model is represented by the low R^2. If the estimated relationship was strong it should allow us to predict how an individual farmer will adjust to the changes in prices in the short or long run, given externals condition.

These external condition include other farmers action that may influence input an output prices. Farmers, in the research area cannot influence the prices of input or output prices. However, if prices of fuel increase, farmers will have to adjust their crop allocations (see section 5.10). However, there other factors influence farmer's water allocation decision including crop prices, risk and water availability.

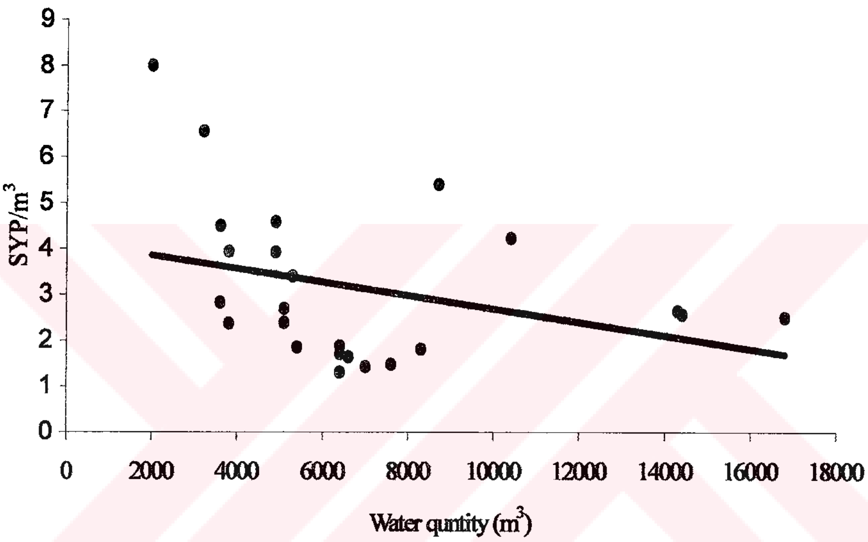

Figure 5.7 Water Demand Schedule in the Research Site Villages.

The water demand elasticity coefficient was calculated by:

$$\eta = \frac{dQ_W}{Q_W} / \frac{dp_W}{p_W}$$

$$\eta = \frac{dQ_W}{dP_W} \cdot \frac{P}{Q} \qquad (5.6)$$

The elasticity of demand was only (- 0.1%) and this supports the hypothesis that farmers under low fuel price are less responsive to price changes. However, because of the absence of water charges or water market, these elacticities can be used for short run analysis. The demand for groundwater is an elastic demand for crops such as cotton where water requirement is high. While it is inelastic for low water requirement crops such as wheat in zone 1 and other crops such as faba bean which is depicted by figure 5.6. One may expect that any government fuel prices change will have major effect on the groundwater use by farmers and consequently will be reflected in cropping patterns changes.

When trying to fit an inverse demand functions as the following relationship:

$$P = \alpha - (\beta Q_W^{-1}) + \varepsilon \qquad (5.7)$$

α and β are unknown constants and Q is quantity of water applied and P is the price of water in terms of the cost of abstracted water. This equation demonstrates strong relationship between groundwater demand and the marginal cost of groundwater. Equation (5.7) was estimated using Ordinary Least Square Method (OLS) shows highly significant coefficient and the variation accounted for was represented by high R^2 of 63%. The following coefficients resulted when equation (5.8) is estimated using marginal cost:

$$P_W = .925 - (11.427Q^{-1}) \qquad R^2 = 0.63 \qquad (5.8)$$

(.5956) (2.8473)

Figures in parentheses are standard errors of the estimates.

This model shows clearly the down ward sloping demand schedule as depicted in Figure 5.8. It demonstrates that when water requirement is very high farmer will not irrigate because the cost of irrigation might be prohibited. Hence, farmer in the research site villages, switch irrigation decision between crops rather than abandoning irrigation. This is particularly true in most of the research site villages where farmer switch from cotton to short-lived crops. Further, although farmer in the research site villages place high priority to cotton cultivation, it is likely that change in price of fuel will certainly affect their allocation decision. For high consuming crops farmers can only irrigate these crops if the average cost within 3 SYP/m^3. This function can assist in predicting cropping patterns adjustment when prices changes. If water prices increases, farmer may switch to low consuming crops.

However, few farmers in zone III and IV still grow cotton because it is the only profitable crop they can grow, given the low diesel cost.

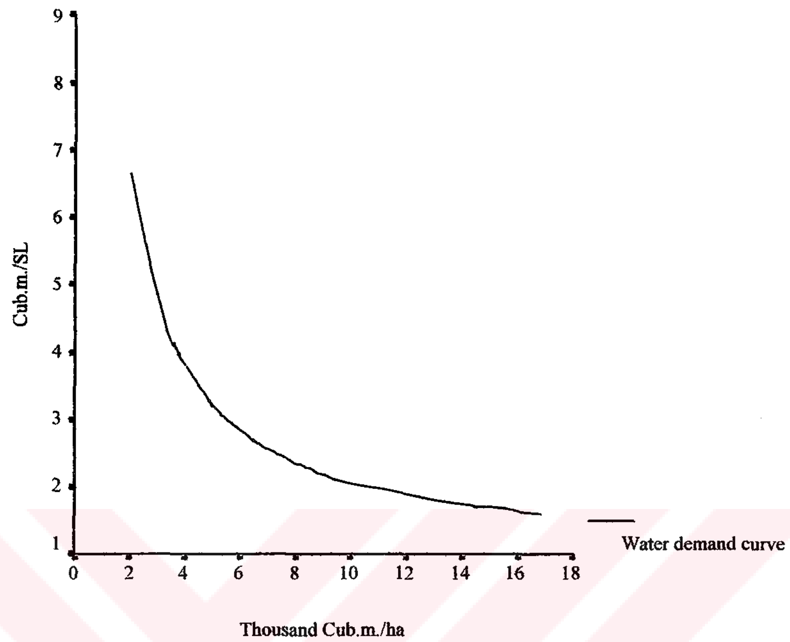

Figure 5.8 Inverse Demand for Groundwater Schedule for Different Crops in 1999 Season.

Demand for water use is a derived function in that it reflects the value of the agricultural product produced. In the sense that the value of irrigation water is partially a function of the price of the crop produced (Carlson et al., 1993). It is essential to estimate the relationship between the irrigated crop prices and the allocated quantity to different crops. The following equation has been fitted to estimate the contribution of product price level to the variation of water use:

$$p = 7.8038 + .0001W + .000001W^2 \qquad (5.9)$$

This relation explains the farmer water allocation decision to different crops. Farmers allocate high volume of groundwater to high price crops such as cotton. Since irrigation value is partially determined by product price then equation 7 sketches the water supply function. This relationship can be depicted from figure 5.9. The figure shows that at low product prices, farmer allocates very low quantity of water. Farmer allocated low quantity of water to vegetable crops since these crops

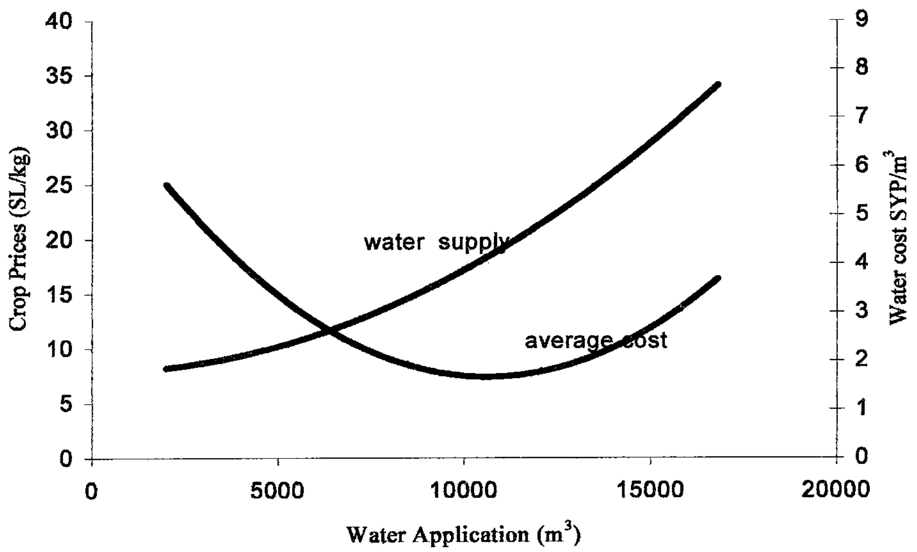

Figure 5.9 Water Supply and Average Cost for Different Crops in the Study Area.

are short lived and price-volatile. However, in Syria condition it is unlikely this situation remains if the price of diesel increases.

Joining the demand for groundwater schedule presented in Figure 5.7 and groundwater supply schedule presented in Figure 5.9, demonstrates that clearing price of water is 3 SYP/m^3 and the quantity of water farmers willing to apply is 8,000 m^3 and product prices would be 13 SYP/kg as depicted in Figure 5.10. Survey evidence shows that farmer in all villages grow wheat and apply 4500-6000 m^3/ha and the selling prices of wheat at 10-11 SYP/kg. Given the water depletion condition in all the villages surveyed, few farmers opt for high value crops because of high water requirement. However, farmers can only grow high water requirement crops provided their prices are high. This is supported by the evidence shown in Figure 5.7 where cotton price is high at 29-30 SYP/kg and water requirement between 12000-16000 m^3.

Although water demand electricity coefficient is low -0.1 for all crops and all zones, it is likely to be responsive for high consuming crops (see section 5.10).

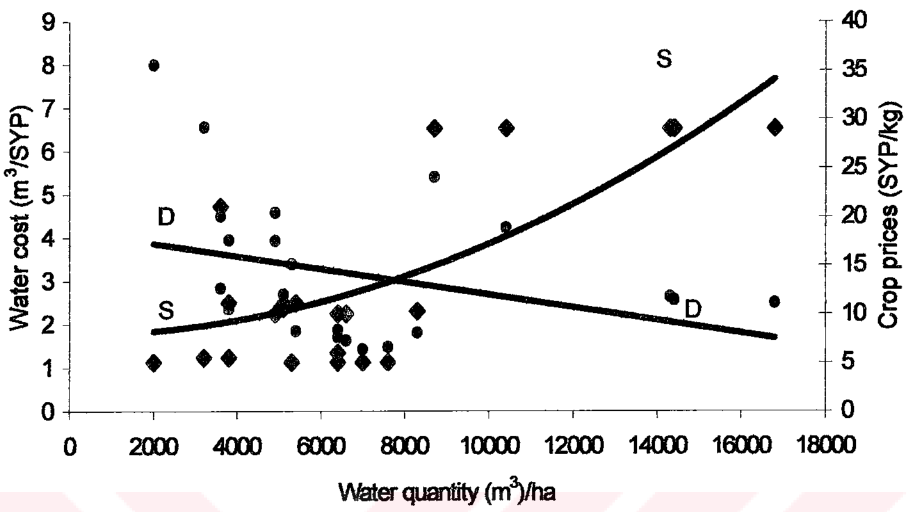

Figure 5.10 Demand and Supply for Groundwater for Different Crops in the Study Area.

Product price contribution in the variability of water application is also modeled in combination with water cost and represented by the following equation:

$$w^d = \alpha + \beta_1 P_w + \beta_2 P_c + \varepsilon \qquad (5.10)$$

where w^d is the demand for groundwater, α, β_1, β_2 are constants and P_w and P_c are price of water and crop product prices respectively. This equation was estimated using water application across villages and prices for all irrigated crops and the estimated coefficients as follows:

$$w = 14.187 - .233 P_W - 1.340 P_C \qquad (5.11)$$

(2.316) (0.084) (0.451)

The model shows relatively high fit with 54% R^2 and coefficient are highly significant at 5% probability level. This clearly explains that demand for water is a derived demand and it is necessary to include product price when modeling demand for water. From policy prospective, in the case of groundwater use in Syria, crop price and water price can play an important role if the water market is developed and procurement prices relaxed.

One of the main factors which contributed to depletion of groundwater has been procurement prices where sale of the product is guaranteed before harvesting. Hence, high price crops can compensate the energy cost incurred from cultivated high consuming crops. Cotton in the 1970s and 1980s was supported crop and farmers who participated in the government plan receive incentive through low interest loans and subsidized inputs.

5.4.2 Water Extraction Cost Function

Research literature and official work show limited direct information on the water abstraction cost. Engineering data on pumping efficiency was also absent. Hence, it make difficult to acquire accurate information on water use or the precise cost of application. As it is mentioned in the previous sections, we took two approaches to acquire the data:

The first approach was to ask the farmer to record the number of pumping hours on daily basis. The hydrology team measured the water flow at each monitored well. The second is to cross check the farmer's daily record by introducing an item in the questionnaire that to ask the farmers on the number of irrigation he has applied to each crop and the number of hours he used to extract water. We have also calculated the fuel use by engine for water extraction to compute the cost of water applied to different crops.

The groundwater cost function was fitted to the data collected on quantity of water applied and the cost of pumped water. The fitted model was quadratic and may be represented by the following equation:

$$TC = \alpha + \beta_1 I_c + \beta_2 I_c^2 + \varepsilon \qquad (5.12)$$

From this equation we can derive the marginal cost of ground water use as the first derivative as follows:

$$MC_I = \frac{\delta TC}{\delta Ic} = \beta_1 + 2\beta_2 I_c \qquad (5.13)$$

Equation (5.12) was fitted to the irrigation total cost and the quantity of water applied to different crops . The model has relatively high R^2 of 0.54%.

$$MC_I = 0.535 + .0002 I_C \qquad (4.14)$$

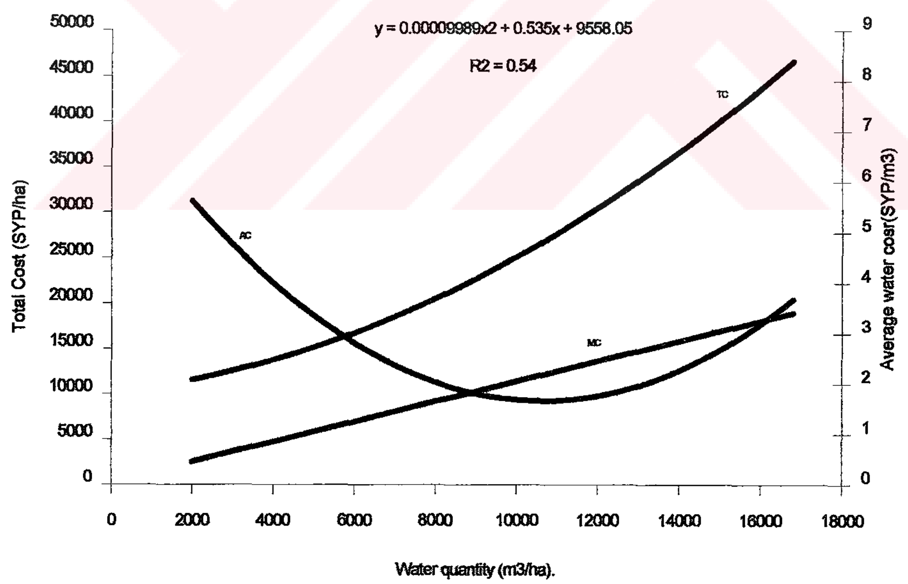

Figure 5.11 Total Cost, Average and Marginal Cost of Irrigation Water Cost for Different Crops in the Village in Zone 1-4 in the Study Area.

Figure 5.11 depicts the relationship between total irrigation cost, marginal irrigation cost and average irrigation cost. The model is very well bounded by the economic theory. Marginal irrigation cost pulls the average irrigation cost downward when marginal cost below the average cost and conversely pulls it upward when it is higher than average cost. This support the hypothesis that farmers whose marginal irrigation cost is lower than the irrigation price will still expand irrigation by allocating area to high water consuming crops. However, high water consuming crops responsible for the quadratic shape of the total cost curve since the high cost is reflect by reflect to upward slopping total cost. This model shows that farmers growing cotton entail high cost and hence their profitability is associated with price support. Any increase in fuel cost will make the slope of the total cost is even more steeper and hence such farmers will abandon cotton crops due to higher marginal cost and hence the average cost will be higher. The fuel cost can be a policy instrument to control the water depletion. Since fuel is highly subsidized, farmer in depleted aquifers will continue growing cotton and high water consuming crops. The marginal cost for high consuming cross is estimated at 3.2 SYP/m^3 while it is less than two SYP/m^3 for other crops like cotton and vegetable crops. For crops such and vegetable can be more profitable since the irrigation marginal cost intersect with average cost at the lower segment of the average cost. Accordingly, these crops can attain a maximum profit (see discussion on farmer profitability option for further details).

Groundwater literature postulate that positive correlation between depth and cost water abstracted. Most wells in the research site villages are shallow wells and hence the variations in depths was considerable (Table 5.6). Contradictory to the literature, particularly in shallow aquifers, the depth and water shows very week correlation of -.03. This low correlation is clearly demonstrated by Figure 5.12. This is due to the fact that the aquifer condition in the research site visit was fractured. However, this relationship can only proved by detailed hydrological studies.

Further, in such aquifers, abstracting water from deeper wells may be characterized by lower cost than shallow wells

Table 5.6 demonstrates that marginal cost for high consuming crops is relatively high compared with other crops. Further, the table also shows that water marginal cost is associated with high crop price. Hence, high crop prices operates as an incentive for allocating water to high water consuming crops. The table also shows that the average cost for cotton was relatively high in a situation where quantity of water abstracted is low. This explains that when aquifer is depleted the average cost will be higher because number of pumping hours will increase.

Table 5.6 Water Costs, Crop Price, Depth ad Marginal Cost for Different Crops Across the Village in 1-4 Stability Zones .

Crop	Water Quantity (m^3)	Total Cost (SYP)	Marginal Cost SYP	Average Cost SYP	Depth m	Crop Prices SYP	Gross Margin SYP
Cotton	16800	42000	3.41	2.50	50	29	42251
	14300	37800	2.91	2.64	63	29	35596
	14400	37000	2.93	2.57	96	29	29256
	10400	44000	2.13	4.23	51	29	17318
	8700	47000	1.79	5.40	62	29	10845
Wheat	3800	9000	0.81	2.37	50	11.1	17212
	5400	10000	1.13	1.85	63	11.2	10388
	5100	12200	1.07	2.39	96	10.6	1550
	8300	15000	1.71	1.81	51	10.3	5435
	5100	13750	1.07	2.70	62	11	12771
Faba bean	3600	16215	0.77	4.50	50	21	14504
	3600	10200	0.77	2.83	63	21	55365
Cucumber	6400	12000	1.33	1.88	50	6	70307
	6400	8400	1.33	1.31	63	5	59374
Beans	6400	10925	1.33	1.71	50	10	41775
	6600	10800	1.37	1.64	63	10	28680
Tomato	7000	10000	1.45	1.43	50	5	23195
	7600	11250	1.57	1.48	63	5	92860
Potato	3800	15000	0.81	3.95	50	5.5	43850
	3200	21000	0.69	6.56	63	5.5	34361
Onions	5300	18000	1.11	3.40	50	5	16250
	2000	16000	0.45	8.00	63	5	29261
Garlic	4900	22500	1.03	4.59	50	10	26800
	4900	19250	1.03	3.93	63	10	29261

5.5 Investment in Groundwater Irrigation

5.5.1 An Overview

"Investment arises when sum of money is expended in the expectation of receiving a larger sum in return" (Kurtz, 1984). Investment analysis lies into two categories, those in which it is necessary 1) to appraise an individual investment and 2) to identify the most desirable investment or set of investments. The recovery of capital invested and the receipt of interest or profit characterize every successful investment. Many investments require substantial expenditure beyond the initial capital. For example, a well is currently under exploitation may require major expenditure to deepen or to drill additional bore holes to increase the water yield. These expenditures are capital payments and they increase invested capital.

One of the distinguishing features of groundwater investment enterprise, particularly in water scarce dry areas, is that farmers are investing in a depleting asset. Depleting assets is a natural resource such as wells, mines or oil these are considered as exhaustible when productive operations terminates. Further, returns from groundwater use are uncertain. Groundwater extraction in Syria especially in zones 1-B, 2, 3 and 4 is a typical example of such investments. Farmers investing large amounts of capital in speculation of high return may receive low accumulated return or abandon the project. Assets such as the wells are abandoned and machines and pipes may be scrapped rather than sold on second-hand market. Econometric studies suggest that firms can only expect to get back 20-50% of initial prices of new machines once installed (Asplund, 1999).

Many investments in groundwater irrigation require sunk cost[2] that are not easily recovered. This condition is represented by a situation when wells are depleted. There will be irreversible component and that is the well investment, the distribution layout and sunk value represented by the lifting engine.

[2] Sunk cost is the difference between acquisition cost and salvage value of an asset of capital investment.

5.5.2 Groundwater Investment Component

The development of groundwater-irrigated cropping requires large investment that individual farmers have to initiate. Construction of groundwater irrigation system comprises well drilling and distribution schemes. In Syria, investment in groundwater-based irrigation systems is conducted entirely by individual farmers. It is characterized by absence of government or community-shared investment. Hence, the cost of investment entails large sums of funds for individual farmers.

5.5.3 Type of Wells

5.5.3.1 Arabi Well

Arabi wells were constructed by manual drilling during the early years of groundwater use in farming. Such a well is an opening up to 90 cm at the ground surface and the cone diameter increases and reaches 300 cm at the chamber. This type of wells is constructed in soft soil type. Farmers assume that a well with large diameter can have larger flow capacity. In hard-rock type soil such construction requires large capital investment. These wells may perform well in the initial period of construction only and require lateral drilling to supplement their water yield capacity and hence require reinvestment.

5.5.3.2 Horizontal Drilling

Horizontal drilling is constructed to increase the number of boreholes leading to the existing wells. Horizontal drilling is initiated at depth between 40-60 meters. The diameters of these holes are 1.5 - 2.0 inches. The maximum distance of lateral drilling is up to 200 m. While the total distance in all direction may reach more than 1000 meters in all distances.

5.5.3.3 Artesian Well

An artesian well is vertically drilled and begins with an opening of 10 inches and decreases by 1 inch every 100-meter depth. Artesian wells are the most common wells in the study area

5.5.3.4 Dual Well Type (Arabi-Artesian)

In order to increase the Arabi well water flow farmers drill an artesian well adjacent to it. The artesian well is joined with Arabi well by using a hole to transfer water from the artesian to the Arabi well.

5.5.3.5 Well Depths

Depth of artesian wells depends on water availability in the aquifer. In shallow aquifer, the average depth is 50 m. While in other areas it reaches 180 m as summarized by Figure 5.12 shows the frequency of well depths in the study area villages.

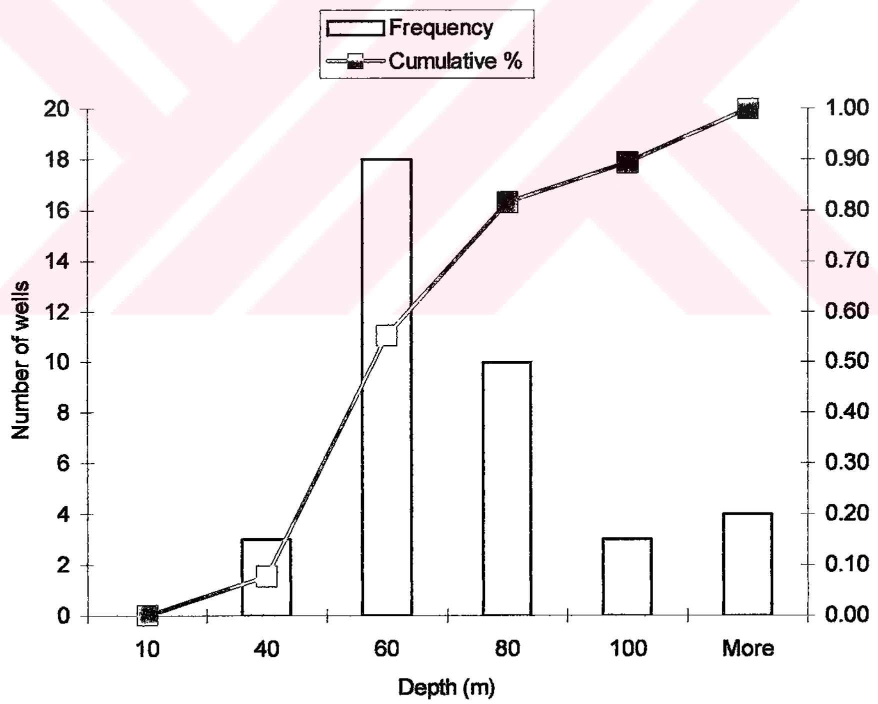

Figure 5.12 Frequency Distribution of the Depths of the Wells in the Research Site Villages.

5.5.4 Lifting Equipment

The second component of the groundwater irrigation investment is lifting and distribution equipment. This equipment comprises rotary pumps driven by diesel engine and rarely by electric motor, lifting engine, pump and distribution pipes. The power outfit varies from 40-70 horse power and also depends on the on the expected water flow and command area

5.5.5 Distribution Equipment

In most of the surveyed villages, water has to be transported to crops not at the head of the pump but rather to crops grown in plots away from the command area of the well. In certain cases, water is transported as far as 2.5 km. Farmers use plastic pipes to transport water to the irrigated plots. During 1999 and 2000 seasons 90% of the farmers used furrow irrigation only

5.5.6 Installation

Installation is usually done by hiring technical personnel from town or conduct by the farmers themselves. Installation also depends on the type of lifting devices and size of these devices. Farmers estimated the installation cost at 15,000 SYP.

5.5.7 Well Investment Analysis

5.5.7.1 The Relationship Between Depth and Vertical Drilling Cost

Considering above points for construction of the wells, it is evident that investment cost involves many factors including not only the physical factors but also the farmer decision options available and expected return.

Given the variation in drilling depth one might expect that there is a positive relationship between depth and well drilling cost. Shallow wells should cost less than the deeper wells. Evidence from the survey data did not show strong relationship between depth and vertical drilling cost. Although it shows a linear relationship but the variation in well depths explains only 20% of the variation of vertical drilling cost and represented by the following equation:

$$DC_v = 2894 + 404 Depth \qquad (5.15)$$

(± 405) (± 145)

$R^2 = 0.15$

where quantities in parenthesis are estimated standard error and R^2 is the percentage variation accounted for. The estimated regression model was significant at (1%). When setting the intercept to origin the relationship did not show any large differences from equation (5.15) and represented as:

$$DC_v = 440 Depth \qquad (5.16)$$

(± 55.6)

Estimate is highly significant (P <.001) and the coefficient magnitude almost identical in both equation and similarly for R^2 (20%) as shown in Figure 5.16.

In a well inventory study in Khanaser area conducted by ICARDA hydrology team, a linear model was fitted to the data, showed equivalent R^2 value at 20%. However, when set the regression set to pass through the origin the R^2 is reduced to 9%. Wells depth in the study villages differ depending on the aquifer properties and ranged from 60-80m for a large number of the surveyed wells as shown in Figure 5.13. Khanaser is located in zone 3 an zone 4. The aquifer strata also vary from one location to the other.

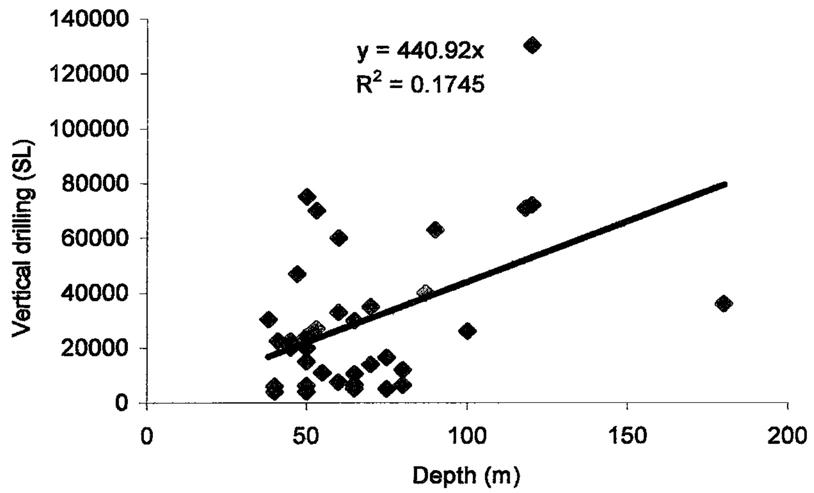

Figure 5.13 The Relationship between Cost of Drilling and Well Depth in the Villages in the Study Area.

This implies that it is necessary to study the rock structure of the aquifer to determine the contribution of the rock type to the cost of well drilling which is beyond the scope of this study. The wide variation exists in the cost of drilling and hence investment is a site specific. Caution should be made when generalization is extrapolated.

5.5.7.2 Relationship Between Depth and Well Productive Years

Natural resource exploitation is a function of investment incurred during an initial phase, reinvestment and the returns over time. Hence, the number of productive years of a well is crucial component of successful investment and sustainability of the natural resource. Further, the decision of investment would also be based on the present value of future returns. Given the common access condition of groundwater use, farmers will use competing decision options. Farmers either decide to extract as much groundwater in a shorter time or sustain the resource for a longer time period. In a perfectly competitive market, farmer may operate under the condition that sets the marginal cost equal to the marginal revenue. However, policy issues such as price support, input subsidy and credit facilities may influence the farmer behavior and hence water use efficiency will be low. Hence the user scarcity rent will be high thus the social cost of exploiting the resource would be higher than the private resource use cost.

Wells in shallow aquifer varies in their production life and water yield. Contradictory to the farmer perceptions that in such aquifers deepening wells increase the water yield capacity of the well, the lack of association in Figure 5.14 and the following equation shows that such relation hardly exists. Consider

$$A_w = \alpha + \beta V_d + \varepsilon \qquad (5.17)$$

where A_w and V_d are productive well age and vertical depth respectively. α refers to the average productive number of years in the study area and β refers to increase or decrease in the number of productive years of the wells with respect to the vertical drilling. Estimating equation 5.17 using Ordinary Least Square (OLS), it was found that the slope of the vertical drilling insignificant and the linear model was inappropriate to explain this relationship. The sign of the estimate was not as expected and was negative and shown:

$$A_W = 10.48 - 0.0242 V_d \qquad (5.18)$$

$$(\pm 2.6) \ (\pm 0.035)$$

Quantities between parentheses are the standard errors of the estimates.

The residual variance exceeds the error variance ratio. And hence the linear relation is inappropriate method to explain the variations in well productive years at the research area villages with respect to depth. The correlation between both variables was also low and estimated at -.011. The intercept was as expected and comparable to the average productive life of the well in the research sites villages and was approximately 10 years.

The result contradicts with farmer conventional perception that in order to increase well productivity and increase the number of productive years it was necessary to deepen the wells (see Figure 5.14). In shallow aquifer this does not necessarily happen. During the visits, we noticed that farmers attempt to deepen their wells on the expectation for increasing the flow. In most cases the well runs reasonably well for one season and returns to the original condition in the previous season. In most cases, the deepening was not successful in increasing the productive life of the well. Hence, the return on these additional investments is negative. Similar finding was reported by Engelhardt (1984) in India, where high yielding wells do not necessarily indicate potential increase in water yield through further drilling.

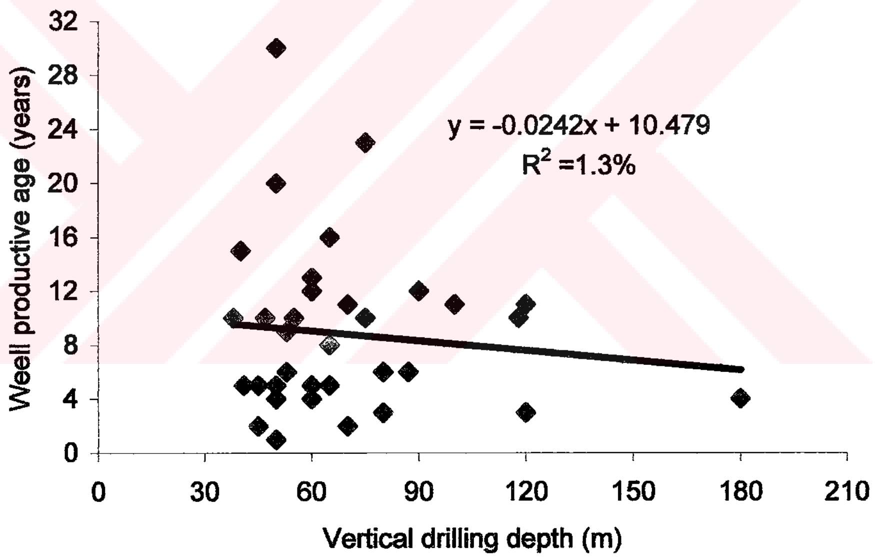

Figure 5.14 The Relationship Between Well Depth And Productive Age of Wells in the Research Site Villages.

Hence, it is difficult to predict the likely success of supplementing depleted wells through deepening wells. Evidence in the research site villages, shows that all farmers have conducted chain of investment and reinvestment in deepening wells or drilling new wells. Farmers lack the information on the aquifer structure and often base their decision of drilling on lack.

5.5.7.3 Rate of Drilling Success and Return on Investment

A question was asked in the survey that, what was the probability of success when drilling the last well? Histogram in Figure 5.15 shows the result of the response of 45 farmers to this question. It indicates that farmers are not risk avers since the average probability of expected success was only 0.29. However, farmers still proceed with drilling with low expected success. Discussion with farmer on the reason of drilling with low probability explains a situation such a decision is influenced by many elements. The lack of other investment options constitutes an important factor, which entail investment in risky project. Further, low fuel prices operate as incentive to farmer to expand irrigation. Farmers are also driven by their previous investment where they have covered the cost incurred through the construction of wells and the purchase of distribution equipment.

Well drilling is a risky investment activity operation. When successful, the expected water yield sufficient to irrigate 2-3 hectares. When failed nothing is obtained. Thus cumulative probability distribution function (CDF) for finding water for is modest for area A = 0 and continuous for A > 0. The CDF can be estimated by applying the sparse data rule outlined by Anderson (1979).

$$P(A) = 0.5e^{-.05A} ....A > 0 \qquad (5.19)$$

To estimate the expected irrigated area which resulted from a successful drilling is done through the following procedure:

$$f(x) = Ae^{-kx} \qquad (5.20)$$

where A is expected irrigated area from successful drilling, K is a positive constant. A is determined by the requirement that the total area under the graph of the probability density function $f(.)$ is equal to 1. Thus, the calculation leads to the following formula of an exponential density function and hence Figure 5.15 follows exponential density function. To illustrate the use of equation 5.20 that is to calculate the probability of drilling success for irrigating 2 to 3 hectare as follows:

$$p(2 \le x \le 3) = \int_2^3 0.5e^{-0.5x}dx = -0.5e^{-0.5x}\Big|_2^3 \quad (5.21)$$

$$= -e^{-1.5} + e^{-1} = 0.07 \quad (5.22)$$

Since drilling wells is associated with high uncertainty, investment in well drilling is subject to risk and evidence showed that farmer run high loss due to series of unsuccessful drilling. Using the calculated probability in equation two, one can estimate farmers' loss due to unsuccessful drilling. This low probability should discourage farmers from drilling further in a depleting stock and hence investment recovery would be impossible. Farmers have reported in Rubai village in zone 1 bought drilling equipment to construct well for his land and to drill for other farmers in the village. Due to depleted aquifer, the drilling equipments were abandoned and total reported loss was estimated at $US 20000 (discussion with farmers by the author).

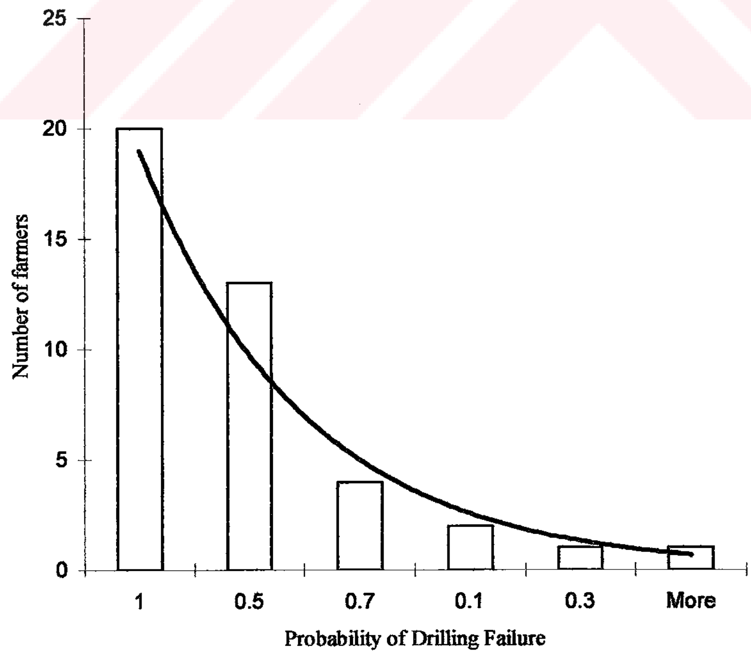

Figure 5.15 Frequency Distribution of Well Drilling Success in The Study Area

5.5.8 Dynamics of Groundwater Irrigation Investment

Investment in groundwater is not a one time investment and return on investment is assured for a longer time periods. Since depletion is a natural phenomenon, which is either incapability of replacing the resource after extraction or the time required for replacement makes such resource nonrenewable. As a consequence, the asset becomes exhausted as it is exploited. In areas where rainfall level is high groundwater may be renewable and the recharging process can replace the abstracted quantity with a given period of time. This condition is not applicable in the dry areas where the accumulation of groundwater takes long time because the rainfall level is low.

Table 5.7 Farmers Average Investment Costs in Wells and Pumping Equipments in the Villages in the Study Area.

		Village					
	Unit	Fafin West	Fafin East	Bershaya	Rubia & Bagat	Harbakieh & Hobs	Seyaleh
Zone		I	I	II	II	IV	V
Well Depth	M	150	50	63	97	51	62
Initial Water Table	M	90	28	34	75	30	38
Current Water Table	M	-150	-48	-37	-95	-42	-53
Age	Y	4	8.6	8	11	9	10
Vertical Drilling Cost	SYP	36000	19200	10500	64043	15868	52833
Testing Well Condition	SYP	4000	3000	3000	3000	3000	3000
Pipe	SYP	65000	40000	45000	50000	40500	41000
Lateral Drilling Cost	SYP		10000	36000		60000	50000
Cost of PVC Pipes	SYP	35000	8750	68500	80167	24125	37200
Lifting Equipment	SYP	150000	80000	80000	150000	85000	125000
Tank And Installation	SYP	5000	5000	5000	5000	5000	5000
Cost of Arabic Well	SYP		44000	45000		40000	43000
Total Investment Cost	SYP	295000	209950	293000	347210	228493	309033
Maintenance Cost.	SYP /Y	15000	15000	13000	12000	11556	13000
Drilling Cost	SYP SYP/m^3	240	384	167	660	311	852
Share of Pumping Equipment	%	0.51	0.38	0.27	0.43	0.37	0.40
Share of Drilling	%	0.12	0.14	0.16	0.18	0.33	0.33
Share of PVC Pipes	%	0.12	0.04	0.23	0.23	0.11	0.12

Source: Compiled by the author.

Capital investment in a depleting asset is consumed as the resource is extracted. Since, it does not manifest itself in the form of transaction during the life of the asset, it is necessary to adjust the accounting records to reflect the loss and hence arrive at the true record of the asset. Groundwater should be of no exception of other minerals such as oil, gas..etc. Further, farmers reinvest in horizontal drilling or in deepening their wells or digging additional supporting wells as shown in Table 5.7.

As subsistence farmers, most of irrigators do not consider the time component of their investment. Hence, when water is depleted before the expected life time of the well there will be considerable loss because there is no allowance for depletion and the sunk value of the capital is also high.

The classic method of evaluating investment in depleted stock is represented by the following formula (Kurtz 1984)

$$B_0 = \frac{R + L(A/F_u, n, i)}{r + (A/F_u, n, i)} \qquad (5.23)$$

B_0, R, L, A, F_u, n, r, i are the capital investment, annual income, period payment, present worth of a series, number of payments, speculative rate of return and the interest rate, respectively. The factors $(A/P_u, n, i)$ and $(A/F_u, n, i)$ are known as the capital-recovery and sinking fund factors, respectively can be expressed:

$$(A/P_u, n, i) = \frac{i}{1-(1+i)^{-n}} \qquad (5.24)$$

and

$$(A/F_u, n, i) = \frac{i}{(1+i)^n - 1} \qquad (5.25)$$

From 5.24 and 5.25 we obtain the following relationship:

$$\frac{(A/P_u,n,i)}{(A/F_u,n,i)}=(1+i)^n \tag{5.26}$$

It must be noted that farmers set high speculative rate of return. Based on Interviews and discussion with farmers regarding the expected rate of return, they estimate the speculative rate of return at 30%. The reason of high speculative rate is that a successful well, given the low fuel cost, would irrigate 2-3 hectares of cotton and wheat.

To evaluate the farmer's investment in groundwater using data presented in tables 5.7 and crop budget tables (see Appendix A) where the gross margin of crops are calculated, the above equations will be used.

The well productive life has been considered from Equation 5.18 which is the value of the intercept of the fitted line. It is also equal to the average productive life of the well in the research site villages. The official Syrian bank interest rate used was 9%. Further, the speculative rate used was 25%. Farmers expect 25% as normal return rate on investment in groundwater irrigation. Some farmers speculate 35% rate which is an extreme value. We have also used wheat and cotton which, are widely grown strategic crops in the area. The gross margin of both crops have taken from the crop budget table (Appendix A) which are calculated from the survey data in all the villages.

The calculation procedure represented in section 3 (Equations 3.19 to 3.28) and Equations 5.23 to 5.26 is summarized in table 5.8. The table demonstrates that farmer in their calculation do not take into consideration, the sunk part of groundwater investment to allow of capital recovery. Farmers in effect continue to either dig new wells or drill horizontally or deepen the existing wells and hence their investment cost increase. This computation assumes no further investment added to the existing well. The sinking fund of groundwater investment was assumed to be considered by the farmer to recover the cost after the termination of the well. Evidence, shows that many farmer entered in a chain of investment and reinvestment and without considering that investment in wells is irreversible and constitute a sunk value. Consequently, this leads to large losses and bankruptcy. Farmers face such condition, usually, abandon their land and migrate to the neighbouring cities or countries.

Given the risk involved in this investment, it is unlikely in a depleted aquifer farmer can be certain generating profit. The estimated probability of drilling success was only 0.07 and thus any investment in drilling will be subject to high risk of drilling failure or depletion in shorter time than expected. Almost in all villages in the study area it reasonable to consider groundwater is nonrenewable resource and any evaluation of investment should consider the sunk value of the investment as well as the risk involved. In order to account for capital recovery, farmers have to set 6% out of the expected rate of return. The computation also shows that the internal rate of return of investment in well to grow wheat and cotton was 25%. The estimated figure is almost equivalent to the farmer speculative rate.

Table 5.8 Groundwater Investment Calculation Procedure.

Equation Reference	Value
Capital Investment(B0) (SYP)	305688
Lifting Equipment Salvage Value(SYP) 20% of the lifting machines	22333
Annual Income(Gross Margin-Fixed Cost) ***	86400
Speculative Rate(r)	0.25
Interest Rate (i)	0.09
Life of Well (n)	10
Sinking Factor($i/(1+i)^n-1$)	0.06582
Capital Investment(B0)	278228
Annual Deposit in Fund	16843
Annual Interest Earning Fund	69557
Annual Deposit in Sinking Fund	61359
Capital Investment(B0)-Salvage	16843
Proof for r *	0.25
Internal Rate of Return (IRR)	0.25
Net Present Value (NPV)	248798
Proof for IRR **	0.00

* r= Annual Earning Fund /B_0

** IRR is the rate at which the net present value =0

*** Fixed cost is calculated from the MAAR Statistical Year Book

For computing the values (see material and methods chapter, section 3.3.3.6.3).

5.6 Economic Analysis of Crop and Groundwater Use Profitability

In water critical areas the objective of economic analysis of groundwater use in agriculture is to evaluate the costs and benefits of allocating scarce water resources to different crops and test the sensitivity of options to different policy tools. In Syria, groundwater provides 60-70% of irrigation water required for wheat in dry years and 40-50% in wet years (Soumi et al., 2000). Hence food supply rests on per unit water productivity. In this study, crop enterprise budgets were developed using data collected in farmer interviews during 1998/99 winter and 1998 summer seasons in the five villages in five different agricultural stability zones (1 though 4). These data were used to assess the profitability of different irrigated crops in the selected villages. Gross margins per hectare, which are the returns to fixed capital and management, were calculated as the difference between total revenue and total variable costs. Given water resources as the main constraint to agricultural production, farmers' water allocations were examined in the light of crop water productivity. Water productivity is defined as the value of gross margin per unit of water applied. The effect of changes in diesel fuel subsidy on the profitability of irrigated crops was analyzed.

5.6.1 Crop Budgets

Enterprise budgets were used to assess the profitability of irrigated crops in the selected villages. The cost of production for different crops in Syria has been estimated by several researchers (Naser 1994; Salkini 1992; Rahmoun 2000; Bader 2000). These estimates have shown considerable differences. Bader (2000) reported that wheat total variable cost was estimated at 30,000 SYP/ha, while Rahmoun (2000) estimated an average total variable cost of 15,000 SYP/ha. The latter estimate differs considerably from other studies and MAAR statistical yearbook estimates for 1999, which was 31,000 SYP/ha. In this study the estimated variable costs in the selected villages across the four zones were similar to the estimates reported by SMAAR (1999) and Bader (2000).

Enterprise budgets for different crops grown in the study area are summarized in crop budgets tables in Appendix A. Cost of production for different crops varies between villages and farmers within each village because of different input levels and purchase source. Transportation costs also differ according to destination and availability.

5.6.2 Land Preparation

Land preparation, seed, irrigation, and harvesting constituted the main inputs. Land preparation includes tillage, leveling, and planting. Cost of land preparation includes hiring tractors and machinery. The cost of land preparation for wheat was higher for villages in zones 3 and because farmers have to maintain a design where irrigation water was distributed through small blocks. Accordingly, the cost of land preparation for wheat in Rabia'ah and Baggat (zone 3) was estimated at 4,650 SYP/ha, which was higher than land preparation cost in other villages.

The difference in seed rate used by farmers is based on farmers' experience. Farmers are not aware of the standards or extension guidance on optimal seed rate level for different crops. As a result, seed rate used by farmers interviewed varied significantly in all selected villages. For example, wheat seed rate level applied by farmers at zone 1 was estimated at 270 kg/ha while farmers at Barshaya applied 360 kg/ha in zone 3. The overall mean seed rate for wheat was 326 kg/ha. Average wheat seed price was estimated at 15.5 SYP/kg. The difference in seed prices between villages and within villages reflects the timing of purchase from the market. Prices were usually higher during planting season. The average cost of wheat seed was 18% of the total variable costs.

Farmers reported overall mean seed rate for cotton at 83 kg/ha and ranged from 60-100 kg/ha. Prices differentials were very high and ranged from 17-47 SYP/kg. The differences in seed rates and prices indicate that farmers do not necessarily buy from official sources since cotton is not permitted in zone 3 and 4. Accordingly, farmers either buy low quality seeds, where prices are lower than the average market prices and apply high rate, or buy high quality seed and apply low rate. Farmers expect lower germination rate by using lower quality seed from the local market. However, farmers reported to have applied high seed rate which were bought at high prices. The price of seed demonstrated high variability where a farmer in Harbakieh village paid 43 SYP/kg while other farmers for Rbia'ah and Baggat paid 17.5 SYP/kg. However, cottonseed cost constituted only 5% of the total variable costs in all villages.

Faba bean was mainly grown in villages in (zone 1 and 2) and only in small plots in zone 3. Seed rate and prices did not show high variability between villages and was reflected by low coefficient of variation for prices and seed rate (23% and 19%) respectively.

Vegetables were cultivated only in zones 1 and 2. Beans seed rate and seed cost showed high variability where the seed rate ranged from 40-100 kg/ha for farmers in Barshaya. Some farmers bought imported high quality seed while others purchased local seeds. Local seed prices are lower than imported seeds. Similarly, the average cost of cucumber seed differed within villages. The average price was 3500 SYP/kg and the seed rate was 3.5 kg/ha. The variability was also high for Barshaya village and indicated by high standard error of 1 kg/ha. This was also attributed to the source of purchase and the quality of seeds. The cost of seed constituted high proportion of total variable costs of vegetables. It comprised 27% of the total variable costs and was the largest single variable cost.

5.6.3 Fertilizers

Wheat and cotton fertilizer rates and prices were relatively homogenous for farmers in most of the villages. Farmers who registered in the government plan bought fertilizers at official prices (8.3 SYP/kg). Market prices did not differ from official prices. However, farmers who participated in the government production plan can purchase fertilizers at low interest credit. The cost of fertilizers constituted only 5% of total variable costs of cotton in all villages.

Farmers reported to have used high rate per hectare fertilizers on vegetable, 350, and 545 kg/ha of N for cucumber in Fafin and Barshaya, respectively. Within villages differences reflected farmers experience and lack of extension guidance. Fertilizers cost comprised approximately 5% of the total variable cost.

5.6.4 Pesticides and Herbicides

The cost of herbicides used for crops was relatively low. While the rate and frequency of pesticides, use for vegetables was very high. Hence the cost of pesticides was relatively high and constituted 18% and 12% of cucumber total variable cost for farmers in Fafin and Barshaya villages respectively. The cost of pesticides used for beans in Barshaya was 14, 250 SYP/ha. The cost of herbicides used for wheat ranged from 1250 SYP/ha to 2000 SYP/ha. Similarly, the cost of herbicides used for cotton was relatively low compared with vegetables. It ranged from 500 SYP/ha to 4000 SYP/ha.

5.6.5 Irrigation

Wells and irrigation constitute an important investment for the farmers in the study area who rely groundwater for irrigation. This investment includes drilling of artisans wells, purchase of pumps, deepening of wells, horizontal drilling to increase potential water yields and pipes used to transfer water from the pump to the fields. Farmers may also construct Arabic wells adjacent to the artesian for the same purpose. The investment in wells ranged from SYP 210,000 in Fafin east (Zone 1) to SYP 347,000 in Raba'a and Baggat (Zone 3) and the overall average well investment was estimated at around SYP 280,000 with an additional maintenance cost of 13,300 per year.

Water lifting equipments such as the pipes and pumping engine account for most of this investment which are estimated at 60% of the total investment in irrigation, while drilling the well accounts for 24% and pipes about 15%. When farmers face decreasing well yields and depleting groundwater, they dig new wells as a replacement of dried wells, deepen existing wells, and dig horizontally to increase the number of bore holes connected to the well in an attempt to increase water flow and recover previous investment.

Irrigation cost was the highest single variable cost of irrigated crops in the study villages; the major component of this was diesel fuel. Irrigation cost was calculated based on the number of irrigations and the cost per irrigation. Farmers reported the number of hours required to irrigate one hectare and the required fuel to operate pump engine for one hour. The cost of irrigation is estimated as the product of the number of irrigations, the number of pumping hours and the cost of fuel and labour for one irrigation. All irrigation labor was carried out by farmers themselves and opportunity cost of labor is added to the irrigation.

Water cost is a function of water table depth, well water yield and volume abstracted (Arunakumaren, 2000). In the study area villages, well depths and water yield vary considerably between villages and between neighboring wells within a village because groundwater bearing formations are mostly limestone and much of the water flow takes place in fractures. The location of the well has considerable effect on its water flow and wells that are in close proximity may have different discharges. Irrigation costs, therefore, varied between villages and between farmers within a village (see section 5.5 for details).

Farmers operating wells with scarce water conditions have higher irrigation costs than those with abundant water. For example, per irrigation cost for cotton in Hobs and Harbakieh villages in zone 4 was 4,000 SYP/ha compared with 2,600 SYP/ha in Sayaleh in the same zone. This was due to severe groundwater depletion and hence higher number of pumping hours needed to irrigate one hectare. However, in most cases irrigation cost increased from high to lower rainfall zone villages.

Cotton is a high water consuming crop and farmers in all selected villages applied high number of irrigations ranged from 10-14 irrigations. The irrigation cost of cotton is correlated with rainfall level zone and water availability from zones 1 through 4. The irrigation cost per hectare of cotton was the highest in villages in zone 4 (Hobs, Harbakieh and Sayaleh) with average around 43,000 SYP/ha. Farmers in

Sayaleh village in zone 4 applied 16 irrigations in order to sustain the required level of moisture. Irrigation cost comprised 50-60% of crop total variable cost. Similarly, cotton irrigation cost in Harbakieh for all farmers was high due to low water yield. The second highest irrigation cost of cotton was about 42,000 SYP/ha reported by farmers in Fafin village in zone 1 where the eastern side faced severe water depletion. Irrigation cost of cotton was lower in the villages in zones 2 and 3 with average of 37,000 SYP/ha.

Wheat is the main irrigated winter crop; hence, farmers supplemented rainfall with irrigation in all zones. In zones 3 and 4 water allocated to wheat may reach full irrigation level during dry seasons. Like cotton, the irrigation cost of wheat increased from villages in higher to those in lower rainfall zones. Average irrigation cost per hectare of wheat ranged from about SYP 9,000 in Fafin in zone 1 and SYP 15,000 in Hobs and Harbakieh in zone 4. Farmers in the villages in zone 4 applied higher number of (on average 5 irrigations) irrigations than those in the villages in zones 1 and 2; reflecting the contribution of winter rainfall to crop water use. This was also reflected in the irrigation cost which ranged between 34% and 38% of the total variable costs in selected villages in zones 1, 2 and 3, and 51% and 45% for farmers in the villages in zone 4.

The irrigation costs of vegetables, mainly potatoes, cucumbers, beans, tomatoes, onions and garlic which ranged from SYP 8,400 to SYP 22,500 per hectare, were lower than that of cotton in all villages and similar to that of wheat in most cases. Vegetable irrigation cost share was estimated to range from 15% to 18%, which were much lower compared to wheat (34-54%) and cotton (50%-60%).

On the whole, the more water scarce zones (3 and 4) had the highest irrigation cost per hectare. But there was a considerable variability between farmers within villages even in short distances reflecting the characteristics of the aquifer. For example, the eastern part of Fafin village in Zone 1 had faced severe water depletion and irrigation cost was higher than villages in zones 2 and 3.

Research elsewhere has shown that farmers with high-cost water tend to be profit maximizers and apply efficient irrigation methods (Hoyt, 1984). Modern irrigation methods can yield productivity gains through more efficient water use, reduce costs of irrigation and increase profitability. Although, farmers in villages in the study area face water shortages, they have largely used traditional surface irrigation method because they perceive that it is suitable for their soil conditions and can achieve maximum yields. The initial investment cost required for modern irrigation methods and the uncertain water availability due to depleting groundwater may have led farmers to maintain their traditional practices. However, few innovative farmers have used sprinkler irrigation method for wheat and cotton and drip irrigation for cucumbers. Two farmers, one on half a hectare of watermelon and the other on 0.25 hectare of cucumber in different season, applied drip irrigation. The required irrigation water for watermelon, 2200 m^3/ha, was about one-third of that required under surface irrigation, about 6500 m^3/ha. The investment in the drip system used in the watermelon was 50,000 SYP, most of which the farmer was able to recover in the first year, in addition to substantial labor saving.

In this study we found that, in spite that these villages have experienced a continues drop in water tables, drying of wells and reduced irrigated areas, farmers who had sufficient water consistently over-irrigated their winter as well as their summer crops. Applied water exceeded for up to 50% of the crop water requirement. The same farmers, however, were not able to apply the crop water requirement during critical crop stages in April for wheat and July for cotton. Farmers in zone 1, 2 and 3 over irrigated wheat unless their wells exhausted. Excessive irrigation was attributed to farmer's irrigation practices including irrigation methods, frequency of irrigation and low energy cost. For example, the excess water used for wheat was 1,700 and 2,900 m^3 with additional cost of 3,500 SYP/ha and 5,000 SYP/ha for Fafin zone 1 and Barshaya Zone 2, which constituted 40% and 50% of irrigation cost in both villages respectively. Similarly, excess water applied to cotton comprised 29% ,20%,19% of crop requirement that increased irrigation cost by 12,000, 7350 and 7500 SYP/ha and constituted 25% of average irrigation cost.

5.6.6 Prices

Prices used in the analysis were government procurement prices (wheat and cotton) and market prices for other crops. Wheat and cotton prices are normally announced prior to the harvesting season. Government agencies purchase the wheat and cotton production from farmers registered in the government production plan and prices are determined according to grain and fiber quality.

Government price support for wheat and cotton were estimated, using the year 2000 international prices (FAO, 2000), at 45% and 10% of the market prices, respectively. These price supports are about US$60 per ton for wheat and US$51 per ton for cotton. Similarly, the price support for barley, of which the government purchases about 75% of the production, was estimated at 9% of the market price. Faba beans are sold at the market and prices fluctuate from season to season. Vegetable prices are also subject to seasonal fluctuations; hence, vegetable production is riskier than other crops. In order to reduce the effects of price variability, farmers grow cucumber in July and harvest in September and expect more favorable prices than that received during summer. Farmers who enter loan contracts with market commissioners are either obliged to sell the produce to these commissioners at lower prices than market prices or pay higher interest which, according to farmers, is as high as 30% per year. The official cost of diesel fuel is fixed at 6.1 SYP/liter. The diesel fuel subsidy is estimated at 47% of the international market price. Fuel subsidies shift the firms' cost curve to the right; hence reducing the marginal cost of pumping water and, as a result, increasing the consumption of groundwater and accelerating the depletion of aquifers. Farmers do not consider cost of fuel as a major constraint to irrigation. This leads to inefficient allocation of water resources.

Fertilizers are indirectly subsidized through credit facilities. Farmers participating in government production plan receive loans at 5% per year interest rate loans compared with 9% official interest rate or up to 30% in the case of private money lenders.

5.6.7 Profitability of Groundwater Irrigated Crops

Due to deteriorating groundwater and successive drought years, farmers assess their groundwater situation based on previous seasons and current year's rainfall before deciding how much land and what crops to irrigate. Accordingly, the cropping pattern reflects the water condition of the village, crop profitability as well as farmers' own preferences (Table 5.9). Wheat and potatoes were the most important crops in Fafin (zone 1). Barshaya village, in zone II, had the most diverse cropping pattern, with wheat taking the first place, followed by faba beans, beans and cucumber, in that order. The other villages in the drier zones (3 and 4) have less opportunities to diversify crops and have mainly irrigated wheat, but also cotton and barley. Vegetables were mostly grown only in small scale. Beans, potatoes, cucumber, and garlic were the only vegetables cultivated in significant areas mainly in the villages in zones 1 and 2. Farmers who have limited well capacities, in zone 1 and 2, shift to vegetable crops with shorter growing period as a substitute to cotton and sell in neighboring towns. It was observed that farmers in Barshaya (zone 2) abandoned cotton and grew vegetables. These farmers rely heavily on vegetables as cash crops and as a substitute to cotton and other summer crops. In other villages, in zone 3 and 4, vegetables were cultivated in a very limited scale and mainly for home consumption.

The gross margins per hectare of nine crops, including cotton, summer vegetables: cucumber, onions, potatoes and tomatoes; winter field crops: wheat and faba beans; and winter vegetables: garlic, were compared (Table 5.9). The three summer vegetables namely, potatoes, cucumber, and beans gave the highest gross margins per hectare, in that order. The second highest gross margins were generated by cotton, garlic and tomatoes in that order. The least profitable crops were onions, faba beans and wheat in that sequence.

Cotton generated higher income than wheat in all villages. However, cotton gross margins declined with decreasing groundwater conditions. These were estimated at around 42,000, 36,000, 30,000 and 17,000 SYP/ha for villages in zones 1 through 4 in that order. Farmers who operated wells with relatively abundant water grew cotton in all villages, while those who grew cotton under water-scarce conditions incurred losses. For example, in the year 1998/99 farmers abandoned crops due to insufficient water and dried wells in villages in zone 4. Farmers who cultivated cotton with unreliable water situation either abandoned the crop completely or received low gross margins. For example, the gross margin of cotton was negative or at break even in Hobs and Harbakieh villages in zone 4. For example, one farmer in Harbakieh village, in zone 4, failed to provide sufficient water to his cotton crop during July 2000 and incurred a net loss of 50,000 SYP/ha.

With the exception of Fafin village in zone 1, wheat gross margins were higher in the higher rainfall zones due to lower irrigation costs and higher yields. Wheat gross margin in Barshaya village, in zone 2, was estimated about 17,000 SYP/ha and was higher than that in the villages in zones 3 and 4, which received an average of about 10,000 SYP/ha, and 3,000 SYP/ha respectively. In this study we found that irrigated wheat will be feasible in zone 1 and 2 only if the yield is above four tons per hectare. For example, in 1999 wheat yield in Fafin was estimated at 3.4 tons/ha due to low rainfall and depleted groundwater. Currently, winter crops are either abandoned or irrigation is discontinued during critical growth stages in dry years. In the villages in zone 4, particularly Hobs and Harbakieh, farmers who were not able to provide sufficient irrigation water to their wheat crop discontinued irrigation due to exhausted wells in the 1998/99 season; hence incurring net losses. But because of the characteristics of the aquifer one farmer also had sufficient water and was able to produce 4.5 t/ha with a gross margin of 18,000 SYP/ha. But in most cases wheat gross margins were lower than all other crops.

Faba beans generated higher gross margins, 14,500 SYP/ha, in Barshaya (zone 2) than in Fafin (zone 1), about 13,000 SYP/ha, due to higher irrigation cost in the later. However, Faba beans generated higher gross margin than wheat in zone 1 because of the relatively lower wheat yields reported.

Potatoes, beans, and cucumber generated the highest gross margins, ranging from 42,000 SYP to 93,000 SYP in the villages in zones 1 and 2. Potatoes gross margins were 2 fold the gross margins of cotton and over seven and half times that of wheat.

Although cotton showed high gross margins, compared to other crops and was ranked in the 4th place among the nine crops analyzed, it consumed the largest volume of water across all farmers and villages compared with other crops. Water use ranged from 10.4 to 16.8 thousand cubic meters per hectare across villages. On the average, cotton generated higher gross margin per hectare than garlic and onions, but the amount of water that it consumed was about 3 times that of garlic and 3.5 times that of onions. Similarly, while the cotton gross margin was more 2 folds than that of wheat and faba beans, the volume of water diverted to cotton was more than two times that of wheat and nearly 5 times that of faba beans. Other crops with higher gross margins than cotton, such as potatoes, cucumber, and beans also consumed less water about 30-50% of the volume of irrigation water required by cotton.

The different volume of water applied to each crop resulted different ranking of the nine crops by water productivity in terms of gross margins per cubic meter than by gross margins per hectare (Table 5.11). Potatoes, cucumber, and beans ranked the highest in water productivity as well as in gross margin per hectare in that order. Onions, because of its lower water consumption, came in the 4th place in water productivity ranking compared to the 7th place in gross margin per hectare. Similarly, faba beans, ranked higher in the 6th place compared to the 8th place, because of its relatively low water use. The highest water consuming crops, cotton and tomatoes ranked lower in water productivity in the 8th and 7th places, respectively compared to the 4th and 6th places in the gross margin per hectare, while wheat remained the last crop in both rankings.

This analysis shows that although cotton and wheat gave the lowest returns to water, farmers in areas where groundwater is depleting still consider these crops as desired options. This can be explained by the more predictable returns of these crops, once irrigation is successful, than vegetables, which is the result of government price support and farmers perception of securing consumption of wheat by own production. This is changing because, the government has banned cotton cultivation in zones 3 and 4 and in some villages, farmers are replacing cotton with vegetables. However, vegetable production due to seasonal price fluctuations remains a risky option for using scarce groundwater in spite of its high returns to water.

The effect of fuel cost on the profitability of irrigated crops as mentioned earlier, irrigation cost forms a substantial portion of the total variable costs. It ranges from 52-60% for cotton, 34-51% for wheat, 35% for faba beans, and 20% for vegetables across villages in the five stability zones. Fuel cost is the main component of irrigation cost. Diesel fuel is subsidized up to 80%. Hence changes in irrigation cost, as a result of changes in fuel cost, will have varying effects on the profitability of different crops and, subsequently, on crop water allocation. In order to determine the effects of fuel costs on the profitability of irrigated crops, we used four scenarios: 25%, 50%, 75% and 100% higher fuel cost than present. These scenarios were used because fuel is highly subsidized and they reflect possible reduction or elimination of these subsidies. Other variable costs and government procurement prices were held constant and surface irrigation method is assumed in the analysis.

The effects of higher fuel costs on the profitability of different crops in the selected villages are shown in Table (5.10). The decline of the gross margins per hectare was the highest in the high water consuming crops such as cotton, wheat, faba beans, and onions. The decline was also higher in the villages in zones 3 and 4. For instance, a 25% higher fuel cost scenario, cotton gross margins per hectare decreased by 26%, 28%, 38% and 94% in the villages in zone I to 4 in that order. Similarly, wheat gross margins decreased by 22%, 14%, 34%, and 118%, in the villages in zones 1 through 4 in the same order. The gross margins per hectare of Faba beans decreased by 39% in Fafin and 17% in Barshaya under the 25% higher fuel cost scenario. The profitability of cucumbers and beans dropped by only 2-5% in Fafin and Barshaya.

The analysis shows that cotton will not be profitable in Hobs and Harbakieh villages in zone 4 at 25% higher fuel cost and in Sayaleh at 75% higher fuel cost. Wheat would not be profitable in Hobs and Harbakieh at 75% higher fuel cost and in Sayaleh at 50% higher fuel cost. Similarly, wheat will not be profitable in Rabia' and Baggat villages in zone 3 at 100% fuel cost increase and may only breakeven at 75% fuel cost increase. This shows that the removal of fuel subsidies will render wheat and cotton unprofitable in these water scarce villages. With higher energy costs, farmers in these villages would have to find more economical alternatives than these traditional crops.

The irrigated crops in Fafin and Barshaya villages are ranked by their gross margins per hectare at the four fuel cost scenarios (Table 5.11). The ranking of crops has changed in both villages as a result of higher fuel costs. The effect on cotton was the most significant. It shifted from the 3rd and 4th places in profitability at the base scenario to the 7th and 8th places at the 100% fuel cost increase scenario. The four most profitable crops were potatoes, cucumber, beans, and garlic in the two villages, but not in the same order. Cotton and wheat became the least economic options in the two villages.

The results indicate that high-value crops are the most economical use of water resources in these villages with depleted aquifers. Higher fuel costs will make them even more attractive as cotton and wheat will be less profitable. Currently, farmers grow small plots on vegetables to minimize the risk of price volatility during summer seasons. Farmers may still grow wheat under rainfed conditions or use water conserving irrigation technologies to reduce irrigation costs. Farmers may also invest in modern irrigation techniques such as drip and sprinklers that will allow them to better allocate their limited water resource. However these technologies will have little effect, if any, on the ground water use over the long-term as farmers would be able to expand irrigated areas with the water saved by modern irrigation methods.

5.6.8 Resource Scarcity, Policy and Farmer Response

Groundwater use is a classic case of institutional failure where in most cases it is an open access resource. All landowners have the exclusive right to drill and pump groundwater within the confines of their lands. Further, government energy subsidy and price support of main crops resulted in relatively high profitability for high-water-consuming crops, such as cotton and wheat in groundwater depleted areas. In this study we found that, in spite that these areas have experienced a drop in water tables, drying up of wells, and reduced irrigated area, farmers who had sufficient water consistently over-irrigated their winter as well as their summer crops. Applied water exceeded the crop water requirement for up to 50%. However, the same farmers were not able to apply the crop water requirement during critical crop growth stages in April for wheat and July for cotton. On the whole the gross margins of wheat and cotton decreased with decreasing rainfall and worsening groundwater situation due to high irrigation costs. Farmers base their crop water allocation on total gross returns rather than on per unit water productivity. For example, cotton, which has the lowest water productivity, was cultivated in zones 3 and 4 where it is banned, because it generated relatively high gross margin per hectare. Irrigated wheat was cultivated in all villages, although it had the lowest gross margins per hectare and the lowest returns to water, partly because farmers tend to ensure household food security by own production of this stable crop. In spite of the water scarcity, only few farmers have used modern irrigation methods. Vegetables had the highest gross margins per hectare as well as the highest productivity per unit of water.

The high fuel share of the irrigation cost, indicate that a reduction or removal of the diesel fuel subsidy will have a big impact on the profitability of irrigated crops and on farmers' behavior on water use. This could reduce the rate of drilling wells in the more water scarce areas where well investment and irrigation costs are relatively high. This also makes water more valuable and could shift production to crops with higher water productivity. Water productivity can also be improved by educating farmers on modern irrigation methods and by providing them access to credit that allow them to invest in these technologies. Farmers would also benefit from extension on better husbandry of horticulture crops. The models developed are of learning and understand nature. It assists the resource user and planners to observe the general behaviour of the resource use overtime and the likely consequences of resource allocation decision on a virtual world. It also shows that generating income in early periods does not represent an optimal decision. Using the present value of future use indicates the social cost of using water at the present.

Table 5.9 Water Use, Cost, Yield, Gross Margin and Area Allocated for Different Crops Across Different Stability Zones.

				Water Use	Crop Area Allocated		Irrigation Cost		Yield	Gross Margin		Rank	
Crop	Village	Zone	% of Area	1000 m^3	ha	%	SYP	%	tons	SYP	SYP/ m^3	Gm SYP/ha	GM SYP/m
Cotton	Fafin	1	2	16.8	7.7	20	42000	52	4.3	42251	2.51		
	Bershaya	2	1	14.3	9.5	18	37800	56	3.6	35596	2.49		
	Rubia & Bagat	3	33	14.4	23	49	37000	53	3.4	29256	2.03		
	Hobs & Hurbakia	4	6	10.4	3.7	16	44000	60	2.5	NG*	NG		
	Seyaleh	4	25	8.7	3.5	56	41600	60	3.0	17318	1.99		
												4	8
Wheat	Fafin	1	32	3.8	22	56	9000	34	3.4	10845	2.85		
	Bershaya	2	50	5.4	29	56	10000	38	4.0	17212	3.19		
	Rubia & Bagat	3	59	5.1	24	51	12200	35	4.3	10388	2.04		
	Hobs & Hurbakia	4	38	8.3	15.2	32	15000	51	3.0	1550	0.19		
	Seyaleh	4	60	5.1	8	70	13750	45	3.3	5435	1.07		
												9	9
Faba bean	Fafin	1	32	3.6	6.5	17	16215	41	2.5	12771	3.55		
	Bershaya	2	21	3.6	8.5	16	10200	31	2.3	14504	4.03		
												8	6
Cucumber	Fafin	1	5	6.4	2.9	7	12000	19	20.0	55365	8.65		
	Bershaya	2	9	6.4	1.2	2	8400	12	23.2	70307	10.99		
												2	2
Beans	Bershaya	2	1	6.4	3.4	7	10925	17	12.5	59374	9.28		
	Fafin	1	14	6.6	9.5	18	10800	19	10.0	41775	6.33		
												3	3
Tomato	Fafin	1	2	12.0	8.5	16	10000	22	15.0	28680	2.39		
	Bershaya	2	0.1	7.6	29	56	11250	22	15.0	23195	3.05		
												6	7
Potato	Fafin	1	21	3.8	23	49	15000	15	35.0	92860	24.44		
	Bershaya	2	0.2	3.2	24	51	21000	22	25.0	43850	13.70		
							18000					1	1
Onions	Fafin	1	3	5.3	3.7	8	16000	18	25.0	34361	6.48		
	Bershaya	2	0.2	2.0	15.2	32	22500	21	25.0	16250	8.13		
							19250					7	4
Garlic	Fafin	1	2	4.9	3.5	30	9600	14	10.0	29261	5.97		
	Bershaya	2	3	4.9	8	70	12000	13	12.0	26800	5.47	5	5

Table 5.10 Crops Gross Margin Changes Under Different Fuel Prices Scenarios.

Crop	Village	Zone	Gross Margin per Area Unit (ha) under Different Scenarios: Current Fuel Cost	25% Fuel Cost Increase	50% Fuel Cost Increase	75% Fuel Cost Increase	100% Fuel Cost Increase
Cotton	Fafin	1	42251	33501	24751	16001	7251
	Bershaya	2	35596	27896	20196	12496	4796
	Rubia & Bagat	3	29256	21256	13256	5256	NG
	Hobs & Hurbakia	4	NG	NG	NG	NG	NG
	Seyaleh	4	17318	8918	518	NG	NG
Wheat	Fafin	1	10845	8895	6945	4995	3045
	Bershaya	2	17212	15112	13012	10912	8812
	Rubia & Bagat	3	10388	7738	5088	2438	NG
	Hobs & Hurbakia	4	1550	NG	NG	NG	NG
	Seyaleh	4	5435	2497	NG	NG	NG
Faba bean	Fafin	1	12771	9187	5603	2019	NG
	Bershaya	2	14504	12354	10204	8054	5904
Cucumber	Fafin	1	55365	53165	50965	48765	46565
	Bershaya	2	70307	68907	67507	66107	64707
Beans	Bershaya	2	59374	57505	55636	53768	51899
	Fafin	1	41775	39750	37725	35700	33675
Tomato	Fafin	1	28680	26743	24805	22868	20930
	Bershaya	2	23195	21226	19258	17289	15320
Potato	Fafin	1	92860	90110	87360	84610	81860
	Bershaya	2	43850	39300	34750	30200	25650
Onions	Fafin	1	34361	31161	27961	24761	21561
	Bershaya	2	16250	11625	7000	2375	NG
Garlic	Fafin	1	29261	27461	25661	23861	22061
	Bershaya	2	26800	24400	22000	19600	17200

Table 5.11 Crops per Cubic Gross Margin Changes under Different Fuel Cost Scenarios.

Crop	Village	Zone	Gross Margin per Area Unit (ha) under Different Scenarios				
			Current Fuel Ccost	25% Fuel Cost Increase	50% Fuel Cost Increase	75% Fuel Cost Increase	100% Fuel Cost Increase
Cotton	Fafin	1	2.5	2.0	1.5	1.0	0.4
	Bershaya	2	2.5	2.0	1.4	0.9	0.3
	Rubia & Bagat	3	2.0	1.5	0.9	0.4	NG
	Hobs & Hurbakia	4	NG	NG	NG	NG	NG
	Seyaleh	4	2.0	1.0	0.1	NG	NG
Wheat	Fafin	1	2.9	2.3	1.8	1.3	0.8
	Bershaya	2	3.2	2.8	2.4	2.0	1.6
	Rubia & Bagat	3	2.0	1.5	1.0	0.5	NG
	Hobs & Hurbakia	4	0.2	NG	NG	NG	NG
	Seyaleh	4	1.1	0.5	NG	NG	NG
Faba bean	Fafin	1	3.5	2.6	1.6	0.6	NG
Faba bean	Bershaya	2	4.0	3.4	2.8	2.2	1.6
Cucumber	Fafin	1	8.7	8.3	8.0	7.6	7.3
Cucumber	Bershaya	2	11.0	10.8	10.5	10.3	10.1
Beans	Bershaya	2	9.3	9.0	8.7	8.4	8.1
Beans	Fafin	1	6.3	6.0	5.7	5.4	5.1
Tomato	Fafin	1	2.4	2.2	2.1	1.9	1.7
Tomato	Bershaya	2	3.1	2.8	2.5	2.3	2.0
Potato	Fafin	1	24.4	23.7	23.0	22.3	21.5
Potato	Bershaya	2	13.7	12.3	10.9	9.4	8.0
Onions	Fafin	1	6.5	5.9	5.3	4.7	4.1
Onions	Bershaya	2	8.1	5.8	3.5	1.2	NG
Garlic	Fafin	1	6.0	5.6	5.2	4.9	4.5
Garlic	Bershaya	2	5.5	5.0	4.5	4.0	3.5

5.7 Groundwater Use Simulation Models: System Dynamic Approach

Models are center to understanding the world around us because they enable us to make a simple representation of and manipulate a real phenomenon (Ruth and Hannon, 1997). Modeling in economics has started more that 200 years ago. Models usually deal with part of the economy and present assumption on the processes that affect that part. Models can be predictive or aimed to better understand a dynamic process. Predictive models are constructed to predict a value of an important variable at some point of time in the future. These models are some times called forecasting models. System dynamics models are constructed to help us understand why some patterns of changes happen (Ford, 1999). These models are designed for general understanding of systems not point prediction.

5.7.1 System Dynamics Technique

Systems consist of definable elements as a mathematical set consists of certain, distinguishable elements. Functional interrelation ship exists between these elements. A system is more than a mere accumulation of elements; there has to be also a certain structure of relations among these elements. Systems are characterized by having boundaries with surrounding environment, which are more or less permeable. This boundary might be material or immaterial. System borders ensure and may determine the identity of the system. The relations between a system and its environment take place in terms of input and output. Further, systems often have a dynamic behavior over time. This behavior is often related or connected to the function of the system whether it is biological or production system. On a closer perspective, individual system elements might be considered as whole sub-systems or a system might be a single element of a larger system.

Agricultural system consists of components which are connected by some form of interaction and interdependence and which operate within a prescribed boundary to achieve a specified agricultural objective on behalf of the beneficiaries of the system. Irrigation, management, farm production and animal production are subsystem of higher level called agriculture system. Similarly, this system can be on the farmer level or village or region level. As system can be express formally as

$S = f(T,R)$

where S, T, R denote, respectively, *a* system, *a* set of elements , distinguished within S, and a relation or, possibly, a set of relations defined on T (Klir, 1991). It follows that groundwater use in agriculture is a subsystem of general system consist of interacting elements.

The System Dynamics approach was founded by Jay W. Forrester at Michigan Institute of Technology (MIT) at about 1960. He developed a powerful method for describing interrelated systems using causal loop diagrams, stock-and- flow diagrams and the simulation language DYNAMO for the numerical simulation of dynamic systems. The main issue of stock-and-flow diagrams and of the system dynamics, simulation style is a clear distinction between stock and flow variables or levels and rates in the original terminology of Forrester (Forrester, 1973 ; 1989). Stocks are time-point related and flows are time-interval related system variables. As opposed to unidirectional causality among problem variables, feedback causality is emphasized. For example, while identifying the factors lead to cereal output growth, it is possible to identify the level of water and land availability as variables affecting cereal production. The unidirectional causal representation of the problem, which dominates traditional policy agendas.

On the other hand, with a feedback conceptualization of the same problem, cereal production expansion yields more cereal farming, which in turn stimulate growth rate as a result of increased land and water available to grow crops which called positive feedback loop. But cereal production also put limits to its own growth by the land and water requirement, decreasing availability of land and water, which in turn inhibits cereal production grown as negative feedback loop. Figure 5.16 represents the cereal production expansion and the feedback process that may result.

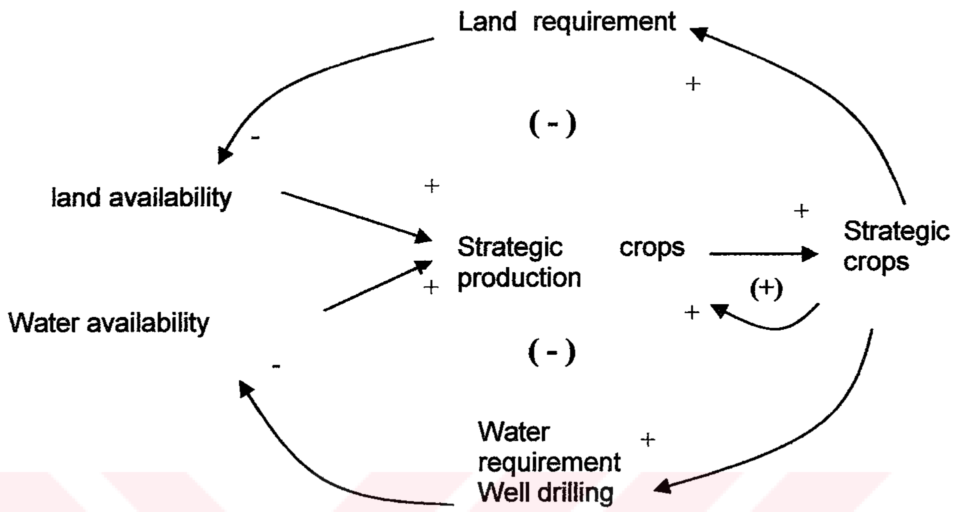

Figure 5.16 Causal Loop Diagram Representing Strategic Crop Production Growth Process.

The advantage of system dynamics simulation models are that theses models are explicit about assumptions and how they interrelate (Forrester, 1989). Constructing a computer model requires a clarification of ideas. Implicit assumption can be exposed and examined. System dynamics rely on statement made about the system structure and the policies that guide decisions and not derived statistically from time-series data.

5.7.2 System Dynamics Computer Model: Software Approach

The purpose of modeling the dynamics of natural resource use in economic system is to develop quantitative and integrated models that effectively deal with inherent uncertainty in these very complex systems (Ruth and Hannon, 1997). System dynamic models have been developed based on farm data and programmed using system dynamics *Stella* software (HPS, 2000), which provide a convenient interface for user unacquainted with dynamic systems simulation. The main purposes of the models were three is to synthesize knowledge about farmers' decisions about the use of scarce groundwater for irrigating crops from wells; to make this knowledge available to change agents such as community leaders, extension agents, researchers, and policy makers in a directly usable form; and to provide an simulated environment that allows important impacts of alternative rules and agricultural policies on sustainable groundwater use to be explored interactively.

Variables in a systemic feedback model are identified as stock, flow and converter variables. Stocks, drawn as rectangles, represent accumulating variables such as groundwater use structure. Flows, drawn as valves and arrows, represent rates or changes such as field crop production expansion or stagnation in the value of stock variables. Converters, drawn as circles, represent all intermediate variables such as land or water requirement. Stock equations are of the general form:

$$S_{(t+dt)}=S(t)+dt^{*}(\Sigma flows)$$

While flow and converter equations are specified by the modeler as functions of stocks, other flows and converters.

flows=f(stocks, flows, converters) and

converters=g(stocks, flows, converters)

Stock variables in a systemic feedback model are the state variables of the corresponding mathematical model. The behavior of these variables during the simulation constitutes the performance patterns of the system. For example, the behavior of the aquifer in groundwater model is the basic performance measure for the simple groundwater model.

The following models have been developed:

Base Irrigation Model (BIM).

Well Interference Model(WIM)

Integrated Policy Model(GPM)

5.7.3 Models Structure

Groundwater models structure includes: Underlining variables, stock and flows, converters and connectors which are represented by graphical map of the system dynamics model; the map is connected to underlining set of equations that indicate the relationships of the model variables and; the model map and equations are connected to a high level interface that is used to change the decision variable(s) at each run of the scenarios.

5.7.4 Models Description

5.7.4.1 The Base Irrigation

This model enables the user to decide on the area allocation for winter and summer crops. Barley and wheat are selected as main winter crops and cotton and vegetables as the main summer crops. The model allows the user to run different scenarios. The main theme of the base irrigation model is to create a simulated learning environment to demonstrate the likely effect of different area allocation decision on the state of the aquifer and farmer income. The model is based on the assumption that wheat, barley, cotton and vegetable prices are assumed to remain constant during the period of simulation. Further, input unit costs are assumed to be fixed during the run period. Deeper wells are assumed to have more water yield compared with shallower wells. However, since wells in the selected villages are shallow wells the maximum depth is between 100-120 m.

Aquifer and water use is modeled using the following equation:

$$AQUIFER_{(t)} = AQUIFER_{(t-dt)} + (\text{inflow - water extraction}) * dt \qquad (5.27)$$

Where

$AQUIFER_{(t)}$ = Aquifer condition at time t which is the state variable at

t = Current point in time during the simulation time.

$AQUIFER_{(t-dt)}$ = Aquifer condition at t-dt at the initial time of simulation

dt = delta t which is the step of time throughout the duration of the model.

inflow = Rainfall recharge

water extraction = Water discharge from the wells.

The above equation has an equivalent Stella model map structure which consists of stock, flow and converter variables and connectors (Figure 5.17).

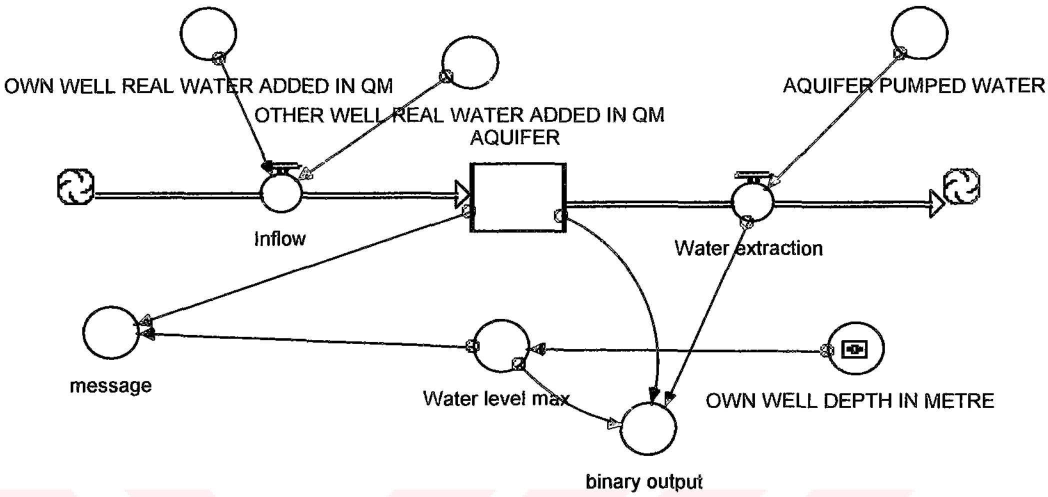

Figure 5.17 Sample of Visual Structure of the Underlining Equation of the Model.

5.7.4.2 The Well Interference Model

This model adds additional dimension to the base irrigation model that is well interference. The models allow changes in the depth of own and neighboring wells and it allows changing the distance between the wells. This model explains the effect of uncoordinated use of groundwater on the aquifer condition and future use. The outcome of the uncoordinated use is reflected also in the level of total gross margin present value of the crop mix throughout the irrigation and rainfed periods.

5.7.4.3 Global Policy Model

The model integrates the two other models with changes in prices and cost of irrigation. Hence farmer decision and policy instruments are modeled. The model shows the impact of changes of policy on the future use of water resource and that may be reflected in farmers allocation switches.

5.7.5 Scenarios Description

Farmer allocation decision model is based on area allocated to irrigated and rainfed crops. The following crop area allocation decision scenarios have been simulated. The scenario assembles many situation existed in the past and still practiced in the selected villages.

5.7.5.1 Scenario 1

Area allocation in the scenario includes 30% wheat, 20% barley, cotton 50% and 0% vegetables. This scenario represents the period where groundwater was abundant associated with government policy incentives toward the strategic crops. At the period farmers responded to policy signals in terms of prices support and input subsidies. Discussion with farmers in the selected villages shows cotton was important cash crops. Hence area allocated to cotton represented 50% of the available land (Table 5.12)

The initial volume of water existed in the aquifer was assumed to be 2 million cubic meter. Estimation of the volume of water is out of the scope of the study. However, the initial value will not distort the model representation of the likely condition of the aquifer. This initial stock value of water in the aquifer will only proportionally affect the number of periods irrigation will last.

Government procurement prices was used in the simulation and assumed to be constant through out the run period. Fuel prices used were based on the government official prices as mentioned in section 4.10. Irrigation labour cost was estimated on the basis of the survey.

5.7.5.2 Scenario 2

Area allocation in the scenario comprises 45% wheat, 20% barley, 25% cotton and 10% vegetables. Scenario 2 represents a deviation from the Scenario 1 (Table 5.12) in that farmers increase wheat area and decrease cotton. Farmer, under this scenario introduces vegetable such as cucumber and beans as summer irrigated crops. However, it was observed that few farmers allocated other irrigated summer crops when cotton is grown. Only farmer with high well water yield can adopt such allocation. This allocation exists only in zone 1- A.

Table 5.12 Impact of Different Crop Area Allocation Scenarios and on the Present Value of Returns to Water Use in Shallow Aquifers under 20% Recharge.

	Different Scenarios for Simulating Ground Water Use					
Initial Allocation	Scenario					
Crop	1	2	3	4	5	6
Wheat (% area)	30	45	55	60	60	70
Barley (% area)	20	20	20	30	30	30
Cotton (% area)	50	25	25	10	0	0
Vegetable (% area)	0	10	0	0	10	0
Total Area (ha)	20	20	20	20	20	20
Total Water Use (thousand m^3 /year)	177	123	125	84	61	63
Years Irrigation Lasted*	7	11	11	16	22	22
Number of year of % rain-fed(barley)	33	29	29	24	18	18
%5 Discount Rate						
PV of first 20 years (million SYP)	3.7	4.7	3.6	3.0	4.6	2.5
PV of second 20 years (m. SYP)	0.3	0.3	0.3	0.3	0.5	0.5
Total PV for 40 years (million SYP)	3.9	5.0	3.9	3.3	5.1	3.0
PV (SYP /m^3)	3.2	3.7	2.9	2.5	3.8	2.2
10% Discount Rate						
PV of first 20 years (million SYP)	3.0	3.6	2.8	2.2	3.1	1.7
PV of second 20 years (thous. SYP)	76.9	76.9	76.9	76.9	156.4	113.9
Total PV for 40 years (million SYP)	3.0	3.7	2.8	2.2	3.30	1.85
PV (SYP / m^3)	2.5	2.7	2.1	1.7	2.5	1.3
20% Discount Rate						
PV of first 20 years (million SYP)	2.1	2.3	1.8	1.3	1.8	1.0
PV of second 20 years (thous. SYP)	7.7	7.7	7.7	7.7	20	20
Total PV for 40 years (million SYP)	2.1	2.3	1.8	1.3	1.8	1.0
PV (SYP / m^3)	1.76	1.95	1.50	1.08	1.51	0.84
* Number of year of rainfed(barley)	33	29	29	24	18	18

5.7.5.3 Scenario 3

Area allocation in the scenario comprises 55% wheat, 20% barley, 25% cotton, and 0% vegetables. Scenario 3 demonstrates a situation where farmers in mainly in zone 1 and zone 2 where they can secure a good winter season and cotton in allocated in summer season. This is different from scenario 2 in that wheat is expanded and vegetable is not allocated. The purpose of this scenario is to demonstrate whether wheat area expansion compensates for vegetable and what is the likely effect on the aquifer.

5.7.5.4 Scenario 4

Area allocation in the scenario comprises 60% wheat, 20% barley, 10% cotton and 0% vegetables. This scenario represents a shift in cropping pattern allocation decision to more water-scarce based allocation decisions. Evidence shows that farmers in all zones have shifted to such cropping allocation not to reduce future effect of water depletion, but rather it was a result of water depletion and lack of wells capacity t meet larger water requirement. Farmers in zone 1-B are likely to face water scarcity as a result of allocation decision similar to that of scenario 1 and 2. However, under this allocation farmers unlikely allocate cotton unless they make sure that their well yield capacity meet cotton requirement in winter.

5.7.5.5 Scenario 5

Area allocation in the scenario comprises 60% wheat, 20% barley, 0% cotton, and 10% vegetables. Groundwater depletion in zone 1 has led a situation where farmers drop cotton from their allocation decision as water scarcity adjustment. They introduce vegetable as a replacement to cotton. This allocation decision may compensate for income generated through cotton allocation, however vegetable price volatility make such decision prone a high risk. However, in the selected village in zone 1 and 2, most of the farmers have adopted such cropping mix.

5.7.5.6 Scenario 6

Area allocation in the scenario comprises 70% wheat, 30% barley, 0% cotton, and 10% vegetables. Farmers' allocation decision can be a function of several factors including rainfall level in the current winter and well water flow in the previous summer flow. Hence, farmers eliminate crop from their allocation plan based on their previous summer season and winter season water availability. Because cotton crop failure cost is high farmers do not grown cotton unless they high certainty of well water capacity to provide sufficient irrigation. Farmers may abandon cotton crop or discontinue irrigating wheat. This condition entails high loss. Hence, scenario represents high water scarcity.

5.7.6 Analysis of Short Run Farmers Groundwater Use Behavior

Farmer total present value of crop allocation gross margin is a function of aquifer water level, abstraction cost, yield level and discount rate. Aquifer water level is also a function of water level abstraction, rainfall level and crop water requirement. Scenario 1 simulates the aquifer trend under myopic allocation where farmer try to extract larger volume of water to obtain high gross margin by allocating large area of cotton. Under such situation farmer is assumed to operate in independent cell. Such allocation leads to rapid aquifer depletion and high gross margin (Figure 5.19). The recharge is assumed at 20%. When allocating large cotton area, irrigation last for seven years only. However, the total gross margin present value was high during the first period (Table 5.12).

Farmers adopting such scenarios can be seen to adopt a rational profit maximizing behavior. However, since aquifer tend to dry up within a short period of time, farmer initiated such strategy and when well dries up, continue to reinvest in drilling wells on the expectation of well drilling success. Hence such farmers will conduct a chain of investment and reinvestment in a depleting stock. The return on investment will be negative due to water depletion and investment recovery will not be feasible. Farmers adopting this strategy tend to experience a bankruptcy due to loan defaulting drawn from merchants with high interest rates.

The second scenario shows that expanding wheat area and reducing cotton and introducing vegetable farming increase the gross margin present value and also lower water use (Table 5.12) .Water used for such strategy was 30%

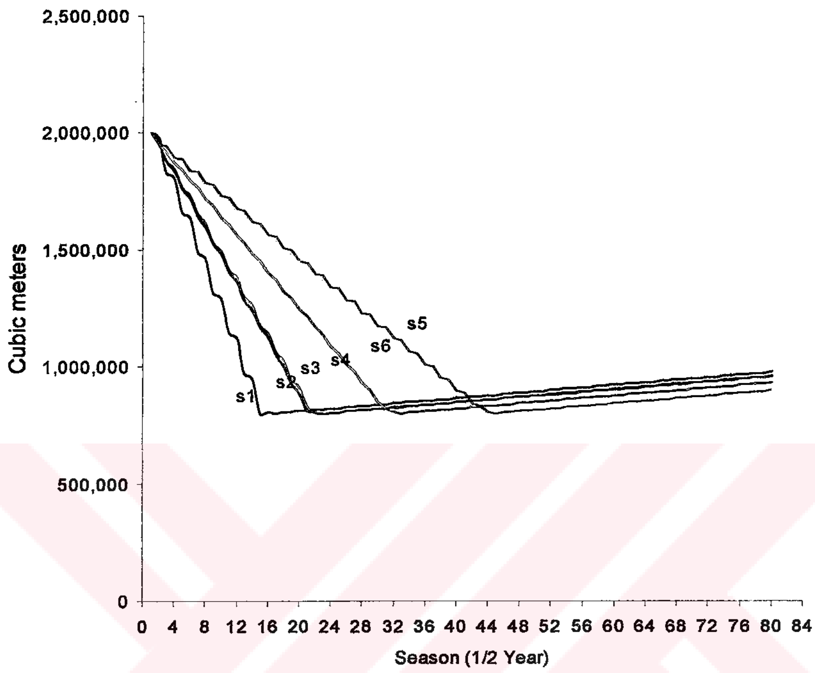

Figure 5.18 The Effect of Different Crop Choices on the Shallow Aquifer in the Study Area Represented by 6 Scenarios (S1-S6).

lower than the previous strategy represented by scenario 1 where the total annual water use was 177,000 m^3 compared with 123,000 m^3. The number of irrigation periods was 11 years which was also longer by four years. Per cubic meter present value was also higher than scenario 1. This scenario demonstrates that vegetable cropping contributes to high total gross margin present value. However, vegetable prices may be subject to fluctuations during summer season where farmer tend to rank high preferences to cotton farming as it is associated with stable prices. Under these two strategies, farming system would be transformed to rainfed cropping during the first twenty years.

Scenario 3 strategy leads to a reduction in the gross margin present value from 4.7 million SYP to 3.6 million SYP for the first period compared with second scenario. Further, under this scenario, expanding cotton and removing vegetable plan will only lead to reduction in gross margin and increase in water use. This represents an increase in water use from 123,000 m^3 in the scenario compared with 125,000 m^3 required by irrigated crops under this scenario strategy. This strategy also shows low per cubic meter present value (Table 5.12).

When scarcity has become evident, farmers adopted first strategy have abandoned their land, while other farmers whose wells still running, adopted a conservative strategy represented by scenario 4 (Table 5.12) Reduction in cotton allocation leads to more irrigation years. By reducing cotton allocation to 10% of the cultivated land, the number of irrigation years increased to 16 years. The annual total water requirement decreased from 125,000 m^3 to 84,000 cubic meters (Table 5.12). Water use requirement variation is highly correlated with cotton area allocation. Reducing cotton area by 10% leads to decrease in water requirement by 30% and increase in the number of irrigation periods by 30%. Further, reducing cotton area and expanding wheat leads to 16% reduction in total present value.

Eliminating cotton from the cropping plan and introducing vegetable as a substitute, represented by scenario 5, demonstrates the following: 1) increases the number of irrigation years by 37%.; 2) decrease in cropping plan water requirement by 27%.; 3) increase in gross margin total present value by 54% compared with previous scenario. This strategy generates high per cubic meter present value of 3.8 SYP/ m^3 (Table 5.12).

This strategy explains that diverting water to high added value activities will result in high gross margin and relatively more sustainable water use. In a situation where farmers are uncertain of well water yield capacity to provide sufficient water to summer crops, summer farming is dropped. Scenario 5 represents this situation in zone 1and zone 2. In other zone, wheat is grown on a limited scale. Under this scenario, gross margin present value is decreased by 42% and water use increased 2,000 cubic meters (Table 5.12).

5.7.7 Dynamic Efficiency and User Scarcity Rent

Static efficiency[3] explains a situation where resources are allocated efficiently within a single period of time. While dynamic efficiency is defined as the resource are allocated efficiently over multiple time periods. Using the resource generates profit to the user but also involve an opportunity cost called marginal use cost (Tietenberg, 1984). Which is defined as the largest opportunity forgone rent that unit could be expected to earn if its sold or used at other future time. In comparing current versus expected future rents, the owner *discounts* the future rents at some discount rate r, and only sells now if $R_0 >= R_t/(1+r)^t$ for all future time periods where R is the profit earned. Resource user are indifferent between selling in different time periods if their expected rents are rising at the rate of discount through time: $R_0 = R_1/(1+r) = R_2/(1+r)^2 = ... = R_T/(1+r)^T$ (Tietenberg, 1984).

In order to evaluate the resource use over time, it essential to simulate different discount rates and assess the impact on the allocation of the resource. In the previous discussion, 5% percent discount rate was used. We have simulated the above six scenarios on 10% and 20% percent discount rate. Users who use their groundwater allocations early increase future pumping costs for users who conserve more and use their groundwater allocations more slowly. Over time, this externality reduces the market value of groundwater deeds, and may actually discourage conservation. Further, at high discount rate (Table 5.13) at 10% for example demonstrates shifts in the result of the scenarios discussed earlier. For the case of Scenario 4, per cubic gross margin present value become lower than scenario 1 while it was higher under 5% discount rate. Per cubic meter gross margin dropped from 3.8 SYP/m^3 to 2.5 for scenario 1 while switched from 3.2 SYP/ m^3. Similarly, the total gross margin for the two periods was also higher under 5% discount rate for scenario

[3] Dynamic efficiency is defined as an allocation of resources across *n* time periods is a dynamically efficient if it maximizes the present value of net benefits that could be received from all possible ways of allocating those resources over n periods (Tietenberg 1984).

1 as shown in (Table 5.13). Hence, under free access resource situation farmers tends to exploit the resource and compete for higher yield than per resource unit productivity. Under perfect competition, producer may postpone the use of the resource until it becomes more efficient to use the resource. Government can also use taxation on resource use to rectify the exploitation of depleting resources.

5.7.8 Fuel Cost Effect on Irrigated Crops Area Allocation.

Table 5.13 demonstrates the changes in output of the above scenarios when fuel cost changes. As fuel is highly subsidized, the scenarios have been run under 75% fuel cost increase. By increasing fuel cost the gross margin total present value for scenaro1 decreased from 3.2 million SYP to 1.4 million SYP due to higher area allocated to cotton. While it dropped from 3.8 to 2.4 million SYPL for scenario 5 where cotton is not included in the plan. This demonstrates that subsidized fuel leads to inefficient use of groundwater because lower prices of fuel signal the user to bring the use of the resources to an efficient level since marginal cost of the resource use still lower than prices (Table 5.13).

Table 5.13 Impact of Crop Area Allocation Scenarios on the Present Value (PV) of Returns to Water in Shallow Aquifers in the Study Area (75% Price Increase)

	Different Scenarios for Simulating Ground Water Use					
Initial Allocation	Scenario					
Crop	1	2	3	4	5	6
Wheat (% area)	30	45	55	60	60	70
Barley (% area)	20	20	20	30	30	30
Cotton (% area)	50	25	25	10	0	0
Vegetable (% area)	0	10	0	0	10	0
Total Area (ha)	20	20	20	20	20	20
Total Water Use (thousand m^3/year)	177	123	125	84	61	63
Years Irrigation Lasted*	7	11	11	12	22	22
Number of year of % rainfed(barley)	33	29	29	28	18	18
%5 Discount Rate						
PV of first 20 years (million SYP)	1.7	3.1	1.5	1.3	2.8	1.1
PV of second 20 years (million SYP)	0.3	0.3	0.3	0.3	0.3	0.3
Total PV for 40 years (million SYP)	2.0	3.4	1.8	1.6	3.1	1.4

5.7.9 Well interference

Given the open access characteristics of groundwater use, water abstraction competition has considerable effect on the sustainability of the aquifer and farmer income. Well interference model introduces the effect of neighboring wells, distance between wells and horizontal drilling on the aquifer and the present value of the future use of groundwater stock.

The model establishes the joint abstraction of the neighboring wells and calculates the total abstraction of the two wells. Uncoordinated use of the resource results in rapid depletion of the aquifer and change in the farming system to rainfed. The model estimates water abstraction by both wells based on the same allocation scenarios. Figure 5.19 shows that the aquifer depletion occurs in much shorter time than the previous scenarios. Under well interference model, all allocation scenarios showed lower total gross margin present value for first period and lower per cubic gross margin present value (Table 5.14).

The present value per cubic meter give spurious indicator on the water use since the number of years of irrigation is less than under no well interference and hence it shows higher gross margin per cubic meter. This model presents the problem of uncoordinated use of common access natural resources use.

Well interference model demonstrates a situation where coordinated action is required. User can adjust their allocation decision through time scheduling or common water polling and distribution. These uncoordinated uses always lead to rapid depletion.and consequently affect income of the farmers subject to this condition Table 5.14.

The site visits and discussion with farmers provided evidence for well interference based on distance and location. Well interference may affect not only the adjacent well but can cause a conflict between farmers. Farmers in two villages reports cases were conflicts between farmers occurred

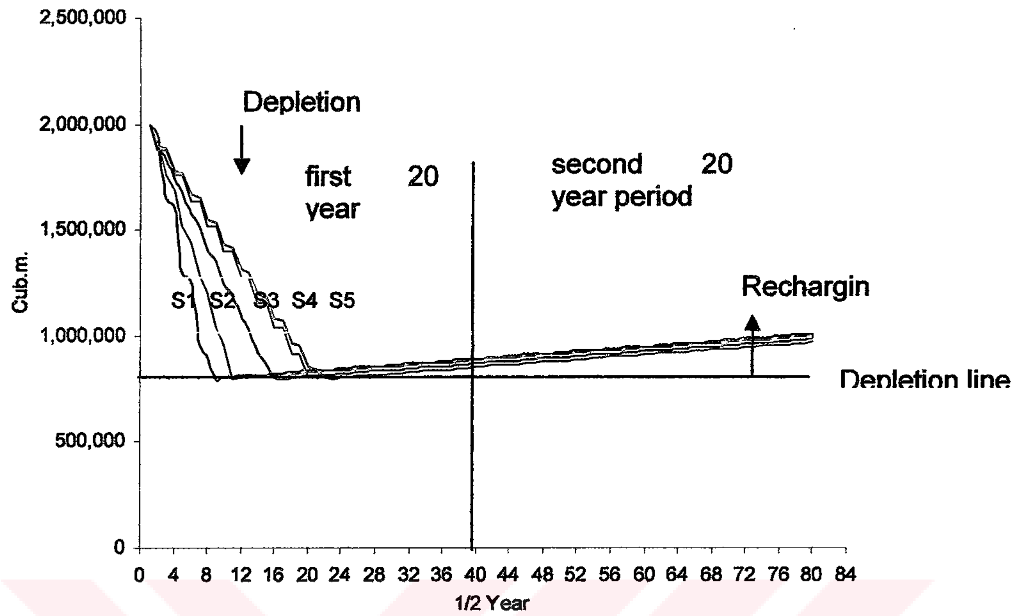

Figure 5.19 The Effect of Well Interference on Aquifer under Different Irrigated Crop Area Allocation Scenarios (S1-S6).

Table 5.14 Different Crop Area Allocation Scenarios on the Present Value (PV) of Returns to Water in Shallow Aquifers in the Study Area When Wells' Interference Exists.

	Different Scenarios for Simulating Ground Water Use					
Initial Allocation	Scenario					
Crop	1	2	3	4	5	6
Wheat (% area)	30	45	55	60	60	70
Barley (% area)	20	20	20	30	30	30
Cotton (% area)	50	25	25	10	0	0
Vegetable (% area)	0	10	0	0	10	0
Total Area (ha)	20	20	20	20	20	20
Total Water Use (thousand cub. M./year)	177	123	125	84	61	63
Years Irrigation Lasted*	5	6	6	8	11	10
%5 Discount Rate						
PV of first 20 years (million SYP)	2.9	3.2	2.5	2.1	3.3	1.9
PV of second 20 years million SYP)	0.3	0.3	0.3	0.3	0.3	0.3
Total PV for 40 years (million SYP)	3.2	3.4	2.8	2.4	3.6	2.1
PV (SYP /m^3)	2.7	2.9	2.3	2.0	3.0	1.8

In summary, the models used are of learning and understand nature. It assists the resource user and planners to observe the general behavior of the resource use overtime and the likely consequences of resource allocation decision on a virtual world. It also shows that generating income in early periods does not represent an optimal decision. Using the present value of future use indicates the social cost of using water at the present. Government can use interest rate a policy instrument to send signal to the resource user in order to influence efficient use of the resources.

6. CONCLUSION AND RECOMMENDATIONS

This concluding chapter reflects the finding of this research and the relationship between the interacting factors that determine groundwater allocation, return on groundwater investment and demand and supply for water. Groundwater aquifer depletion and related economic implication was discussed in the first chapter. It follows by the approach and method s of analysis. Since, there have been few studies of the economics and institutional aspect of groundwater use and economic importance of groundwater for the economy of Syria. This study has shed a light and critical discussion on the previous research on water use and the applicability of the recommendation of the result of the technical and socioeconomic studies.

In this study logistic model was fitted to the total irrigated data for the period 1961-2000, it was found that the rapid growth occurred during the last 15 years. The study has found that policy issues have to consider the capacity of the natural resource base when adopting an option. The model can be a powerful prediction tools to associate a natural resource with policy decision. The model shows that the natural saturation of the growth of groundwater based irrigation has occurred with a short period of time due to the limited capacity of the basins in Syria to accommodate additional new irrigated area. Equally, the model also validates the hypothesis that growth in irrigation has been associated with drilled wells and expansion in groundwater irrigation. The aggregate data used to model the well drilling and groundwater irrigation shows that the saturation and consequent decline are not linked to a given basin but they have country wide implications. The study also clearly identified that price support, fuel subsidy and common access which have largely contributed to the depletion of groundwater.

Contrary to the conventional proposition that groundwater use has curbed migration and stabilizes farmer income, in this study, it was found that groundwater intensive use has led to the transformation of a sustainable barley-livestock system to non-sustainable full-irrigation system based on a depleting natural resource. The consequence of such transformation is apparent where migration has taken place in most of the villages in zone 2, 3 and 4. Further, reintroducing barley-livestock in these areas will be questionable. The rise in farmer income was only on the short run and followed by substantial decrease in the medium run.

The result of demand for water analysis shows that although fuel prices are not high, demand for water is price elastic particularly for high water consuming crops. However, for low water consuming crops demand for water was inelastic. Further, farmer water allocation decision is linked with product price. The analysis shows that the supply of water in the case of cotton is associated with high cotton price. However, farmers were rational and the quantity allocated to most crops ranges between 5000-1000 m^3/hectare. This implies that fuel and product price can play a major role in the efficiency of groundwater use.

The study also concluded that farmer investment in groundwater has not been based on rational decision and associated with high risk. The cumulative density function shows that drilling success was only 0.07. However, farmer conducted chain of investment and reinvestment disregard to the low probability of drilling success. Further, farmer return on investment does not account the sunk portion of groundwater investment which has implication in terms of failure to pay credits and bankruptcy. It was also found that the absence of other investment option has led farmers to invest in a depleted stock. The study has introduced an groundwater investment model to evaluate the return on groundwater investment. Groundwater should be treated, in water critical dry areas, as non-renewable natural resource similar to other non-renewable minerals because the low level of recharge which usually associated with low rainfall level particularly in dry areas.

In this study it was found that, in areas which have experienced a drop in water tables, drying up of wells, and reduced irrigated area, farmers who still have sufficient water consistently over-irrigated their winter as well as summer crops. Applied water exceeded the crop water requirement, in some certain cases, for up to 50%. However, the same farmers were not able to apply the crop water requirement during critical crop growth stages in April for wheat and July for cotton. On the whole, the gross margins of wheat and cotton decreased with decreasing rainfall and worsening groundwater situation due to high irrigation costs.

Farmers base their crop water allocation on total gross returns rather than on per unit water productivity. For example, cotton, which has the lowest water productivity, was cultivated in zones 2 and 3 where it is banned, because it generated relatively high gross margin per hectare. Irrigated wheat was cultivated in all villages, although it had the lowest gross margins per hectare and the lowest returns to water, partly because farmers tend to ensure household food security by own production of this stable crop. In spite of the water scarcity, only few farmers have used modern irrigation methods. Vegetables had the highest gross margins per hectare as well as the highest productivity per unit of water.

Since fuel constitute the major component of the irrigation cost, it indicates that a reduction or removal of the diesel fuel subsidy will have a considerable impact on the profitability of irrigated crops and on farmers' water use behavior. This could reduce the rate of drilling wells in the more water scarce areas where well investment and irrigation costs are relatively high. It would likely make water more valuable and could shift production to crops with higher per unite of water productivity. Water productivity can also be improved by educating farmers on modern irrigation methods and by providing them access to credit that allow them to invest in these technologies. Farmers would also benefit from extension on better husbandry of horticulture crops.

System dynamics model based on interactive software can assist planner, researcher and even farmers the likely outcome of their different strategies and options through a simulated environment.

The models used are of learning and understand nature. It assists the resource user and planners to observe the general behaviour of the resource use overtime and the likely consequences of resource allocation decision on a virtual world. It also shows that generating income in early periods does not represent an optimal decision.

Using the present value of future returns and water use indicates the social cost of using water is higher private cost.

The result of this study shows that it is not viable to grow cotton under groundwater irrigation. Such practice has a devastating long term effect on individual farmer level, community and national level. In addition to aquifer depletion, it results in collapse of traditional viable farming system (barley and livestock) which may not be easily restored. The study also suggests that in water scarce areas, demand and supply management only can not remedy the deteriorating aquifer condition without considering viable investment alternatives available to farmers. Government and private sector can provide viable alternatives other than cotton farming. These alternatives may be high value added products such as diary products, investment in livestock, olive trees, women employment schemes within villages.

Extension and training on the use modern irrigation technologies is required prior to the use of such technologies. Credit schemes might be counter productive. In the sense that farmers may divert these credit to other off-farm activities.

Fuel subsidy may be eliminated because it operates against the intended objectives. Irrigation is characterized by being highly inefficient. Farmers operate on quantity rather than on productivity basis. Due to low cost of energy, farmers tend to over-irrigate. Over irrigation has a dual effect. It increases the private and social cost of energy resource and water resource. The subsidy can be channeled toward high efficient water resource use methods or support viable investment options.

Future research is suggested to model basin-wide demand for water associated with wider water abstraction monitoring scheme. The need of comprehensive investment model integrates bioeconomic variables with groundwater investment variables to suggest the best option. Studies on alternative options in water scarce areas is required as necessary condition for an integrated approach to the sustainability of groundwater use.

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CURRICULUM VITAE

Following is a short CV on my qualification and work experience.

I was born in Missan/Iraq 1956 and graduated from Al-Mustansria University- Economics and Administration Faculty (1978). I pursued my higher studies and earned a Postgraduate Diploma in Economics of Energy and Development from University of Surrey-England (1984-5) and a Master Degree in International Studies and my major and thesis was in International Economics, from the University of Salford-England (1986-1987).

I worked for America Mideast Educational and Training Services Inc. (Amideast) -Damascus for 4 years (1988-2002) as a computer technical support and accounting officer. I also worked as consultant an economist for two companies prior to this position for three years.

I joined the International Center for Research in the Dry Areas (ICARDA) as scientific analyst programmer since December 1992. I worked as statistical programmer/ analyst and application developer.

I have taken up a new position in ICARDA as computer application specialist (Oracle Financials) as of February 2002.

I am married and have two children. My mother tongue is Arabic language and I am fluent in spoken and written English.

APPENDICES

Appendix A - Crop budget tables:

A-1 Rainfed Barley Crop Budget for 1999 Winter Season for Villages in Different Zones

ZONE			I			II			III			IV
Yield (kg/ha)			2000			1300			1000			1000
Price/kg			11			9.5			11			10
Input	Qty	Cost	Total Cost	Qty	Cost	Total Cost	Qty	Cost	Total Cost	Qty	Cost	Total Cost
Seed Rate (Kg/ha)	150	16	2385	300	13	3900	150	17	2550	200	15	3000
Fertilizer N (Kg/ha)	150	8	1400	150	8.3	1245	100	8.3	830	50	8.3	415
Fertilizer P (Kg/ha)	150	8	1140	150	8.3	1245	0	0	0	100	8.3	830
Manure (Kg/ha)	0	0	0	0	0	950	0	0	500	0	0	0
Pesticide (Litter/ha)	0	0	0	0	0	0	0	0		0	0	0
Herbicide (Litter/ha)	3	500	1500	0	0	0	0	0	0	0	0	0
Irrigation (SYP/Irrigation)	0	0	0	0	0	0	0	0	0	0	0	0
Land Preparation +Sowing Cost (SYP)			2000			2250		500	4650		1500	2570
Weeding and Other Costs (SYP)			500			200		0	200		0	200
Harvesting Cost (SYP)			1500			850		0	2685		0	2250
Post Harvesting Cost (SYP)			2000			1000		0	3080		0	1200
Total Variable Costs			12425			11640			14495			10465
Yield (Kg/ha)			2300			1350			1000			1000
Price (SYP/Kg)			11			9.5			11			10.5
Total Revenue			25300			12825			10500			10500
Gross Margin			12875			1185			-3995			35

A-2 Cotton Crop Budget for 1999 Summer Season for Villages in Different Zones.

ZONE			I			II			III			IV			IV
Yield (kg/ha)			4250			3550			3400			2500			3000
Price/kg			29			29			29			29			29
Input	Qty	Cost	Total Cost	Qty	Cost	Total Cost	Qty	Cost	Total Cost	Qty	Cost	Total Cost	Qty	cost	Total Cost
Seed Rate (Kg/ha)	90	43	3855	72.5	34	2465	100	17.5	1750	100	47.5	4750	60	33	1980
Fertilizer N (Kg/ha)	100	8.3	1030	172.5	8.35	1440	275	9.35	2571	350	8.3	2905	265	8.5	2253
Fertilizer P (Kg/ha)	400	8.3	3260	197.5	8.35	1649	283.33	9.3	2635	225	8.3	1867.5	200	8.5	1700
Manure (Kg/ha)	0	0	0	0	1500	950	0	250	500	0	2500	2500	0	1000	1000
Pesticide (litter/ha)	0	0	0	0	0	0	1	750	750	0	0	0	0	0	0
Herbicide (litter/ha)	4	1000	4000	1	950	950	2.5	545	1363	0.5	400	200	1.5	900	1350
Irrigation (SYP/Irrigation)	14	3000	35000	14	2700	30800	10	3700	32000	11	4000	38500	16	2600	33600
Irrigation Labour (SYP/day)	35	200	7000	35	200	7000	25	200	5000	27.5	200	5500	40	200	8000
Land Preparation+Sowing cost (SYP)			5500			3900			4800			3850			3500
Weeding and Other Costs			5000			3775			4125			3500			3100
Harvesting Cost (SYP)			12000			10575			11150			9125			8150
Post Harvesting Cost (SYP)			4354			3850			2700			1250			5050
Total Variable Costs			80999			67355			69344			73948			69683
Yield (Kg/ha)			4250			3550			3400			2500			3000
Price (SYP /Kg)			29			29			29			29			29
Total Revenue			123250			102950			98600			72500			87000
Gross Margin			42251			35596			29256			-1448			17318
Water Related Contribution*			77251			66396			61256			37053			50918
Water Cost/Variable Cost			0.52			0.56			0.53			0.60			0.60

A-3 Cucumber Crop Budget for 1999 Summer Season for Villages in Different Zones

ZONE			I			II
Village			Fafin			Barshaya
Crop			Cucumber			Cucumber
Yield (kg/ha)			20000			23200
Price/kg			6			6
Input	Qty	Cost	Total Cost	Qty	Cost	Total Cost
Seed Rate(Kg/ha)	4.5	4000	18000	3.5	3750	13125
Fertilizer N (Kg/ha)	100	8.3	830	580	8.3	4814
Fertilizer P (Kg/ha)	350	8.3	2905	380	8.3	3154
Manure (Kg/ha)			2650	0		2300
Pesticide (litter/ha)	15	500	7500	18	500	9000
Herbicide (litter/ha)	0	0	0	0	0	0
Irrigation (SYP/Irrigation)	16	750	8800	14	600	5600
Irrigation Labour(SYP/day)	16	200	3200	14	200	2800
Land Preparation+Sowing Cost (SYP)			2500			2650
Weeding and Other Costs			4750			6000
Harvesting Cost (SYP)			10000			11250
Post Harvesting Cost (SYP)			3500			7000
Total Variable Costs (SYP)			64635			67693
Yield (kg/ha)			20000			23000
Price (SYP/kg)			6			6
Total Revenue (SYP)			120000			138000
Gross Margin			55365			70307
Water Related Contribution*			64165			75907
Water Cost/Variable Cost			0.19			0.12

A-4 Supplementary-Irrigated Faba bean Crop Budget for Winter 1999 Season for Villages in Different Zones

ZONE			I			II
Yield (kg/ha)			2500			2250
Price/kg			21			21
Input	Qty	Cost	Total Cost	Qty	Cost	Total Cost
Seed rate(Kg/ha)	145	29	4205	200	33	6600
Fertilizer N (Kg/ha)	215	8.3	1785	160	8.3	1328
Fertilizer P (Kg/ha)	220	8.3	1825	122	6.5	793
Manure (Kg/ha)			1650	0	1375	1375
Pesticide (litter/ha)	1	1250	1250	1	550	550
Herbicide (litter/ha)	1	1000	1000	0.5	700	350
Irrigation (SYP/Irrigation)	5	3450	14335	4	2550	8600
Irrigation Labour(SYP/day)	9	200	1880	8	200	1600
Land Preparation+Sowing Cost (SYP)			2300			2550
Weeding and Other Costs			3500			2800
Harvesting Cost (SYP)			4000			3700
Post Harvesting Cost (SYP)			2000			2500
Total Variable Costs			39730			32746
Yield (Kg/ha)			2500			2250
Price (SYP/Kg)			21			21
Total Revenue (SYP)			52500			47250
Gross Margin			12771			14504
Water Related Contribution			27106			23104
Water Cost/Variable Cost			0.41			0.32

A-5 Supplementary-Irrigated Wheat Crop Budget for 1999 Season for Villages in Different Zones.

ZONE			I			II			III			IV			IV
Area (ha)			3			4			2			2.04			2
Yield (kg/ha)			3350			3950			4250			3000			3300
Price/kg			11			11			10.5			10.5			11
Input	Qty	Cost (SYP)	Total Cost	Qty	Cost	Total Cost	Qty	Cost	Total Cost	Qty	Cost	Total Cost	Qty	cost	Total Cost
Seed Rate(Kg/ha)	270	16.5	4440	325	14	4550	360	16.5	5940	340	13	4420	300	17.5	5250
Fertilizer N (Kg/ha)	220	8	1960	165	7	1155	182	8.5	1547	250	8.5	2125	175	8.5	1488
Fertilizer P (Kg/ha)	250	8	1940	130	7	910	235	8.5	1998	140	8	1120	165	8.5	1403
Manure (Kg/ha)	0	0	0	0	950	950	0	500	500	0	600	0	0	0	0
Pesticide (litter/ha)	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Herbicide (litter/ha)	2	1000	2000	1.5	1500	2250	1.5	1100	1650	0.5	1250	625	1.25	825	1050
Irrigation (SYP/irrigation)	3	3000	7800	4	2500	8400	4	3050	10600	5	3000	13000	5	2750	11750
Irrigation Labour (SYP/day)	6	200	1200	8	200	1600	8	200	1600	10	200	2000	10	200	2000
Land Preparation+Sowing Cost (SYP)			2000			2250			4650			2570		3500	3500
Weeding and Other Costs			500			200			200			200		325	325
Harvesting Cost (SYP)			2500			2250			2685			2000		2100	2100
Post Harvesting Cost (SYP)			2000			2000			3080			1200		2250	2000
Total Variable Costs (SYP)			26340			26515			34450			29260			30865
Yield (Kg/ha)			3350			3950			4250			3000			3300
Price (SYP/Kg)			11			11			11			10.27			11
Total Revenue (SYP)			37185			43727			44838			30810			36300
Gross Margin (SYP)			10845			17212			10388			1550			5435
Water Related Contribution*			18645			25612			20988			14550			17185
Water Cost/Variable Cost			0.30			0.32			0.31			0.44			0.38

APPENDIX - B Crop Budget Sheet Survey

- Village : ____________________
- Sub-district : ____________________
- District : ____________________
- Rainfall zone : ____________________
- Farmer's name : ____________________
- Enumerator's name : ____________________
- Date of interview : ____________________
- Season : ____________________

Socioeconomics ,Land Allocation And Irrigation Investment:

1- General:

1.1 Resident at the village :________ . if no , Is land rented:_________ or owned:________

1.2 Number of the family members:________

1.3 Work in agriculture

1.3.1 Full-time_________

1.3.2 Part-time_________

1.3.3 Other jobs:___________

2. Source of income:

2.1 Off-farm income (%) :__________, Please specify

2.2 Farm income (%) :__________

2.3 Crop production: (%): __________

2.4 Livestock (%) ____________

2.5 Fruit trees(%):___________

2.6 Others , Please specify:___________________

2.6.1 -

2.6.2 -

2.6.3 -

2.6.4 -

3. Land Characteristics And Ownership:

3.1 Soil characteristics: Which of these types of land you have?
3.1.1 Sandy
3.1.2 Heavy
3.1.3 Medium
3.1.4 Do you consider your land Good [ ] Fair [ ] Bad [ ]

4. Ownership:

4.1 Is your land rented :____________ if yes what is the rent (SYP/ha):___________ or any other contract, please specify:

4.2 Is it freehold:____________

4.3 Is it shared :____________ if yes how many members of the family :___________

4.4 Cropping Patterns Allocation Decision: Is It Based On: (Year 1998/1999)
<u>Winter Cropping:</u>

How do you allocate the area to winter crops ? is base on:

4.4.1 State Cropping policy plan ?:_______%

4.4.2 Market expectation ? :____________%

4.4.3 Water availability (constraint) ?:_________%

4.4.4 Non of the above and no alternative (Please specify):___________________________

Government Plan for Winter 1998/1999

Crop	Area (ha)

<u>Summerr Cropping (1998):</u>

How do you allocate the area to winter crops ? is base on:

4.4.5 State cropping policy plan ?:_______%

4.4.6 Market expectation ? :____________%

4.4.7 Water availability (constraint) ?:_________%

Government Plan for Summer 1998

Crop	Area (ha)

4.4.8 What is the total landholding (ha)? ________

4.4.9 Total area of crop production (ha):________

4.4.10 Area allocated to rainfed crops(ha):_______

4.4.11 Area allocated to full-irrigation(ha):______

4.4.12 Area allocated to supplementary irrigation(ha):__________

4.4.13 Area allocated to trees (ha):_____________

4.4.14 Area allocated to vegetable (ha): _____________

5. **Livestock production:** Do you have any livestock:_________ if yes? How many ?

5.1 Sheep (No.) :__________

5.2 Goat (No.):__________

5.3 Cows: (No):___________

6. <u>Land allocation by season:</u>

Land allocation over time :
Please specify the land allocation to irrigated crops since 1980:

Year	Crop	Area (ha)	Water condition
1990			
1991			
1992			
1993			

1994			
1995			
1996			
1997			
1998			

1999			

6.1 Land allocation for Winter Season Crops 1998/1999

6.1.1 Land Allocation to Rainfed crops and Inputs:

Land allocation:

Crops	Area (ha)	Date of plantation	Date of harvest	Yield (kg/ha)	Price SYP/kg	Seed Rate (kg/ha)	Highest Yield (kg/ha)	Lowest Yield (kg/ha)

6.1.2 Inputs : Winter (Rainfed) (1998/1999)

Crops	Fertilizers						Pesticides Herbicides				Irrigation[1]		Seed	Machinery				Labour		Othrs (SYP)
	N		P		Manure		Pesticides		Herbicides					Pre-harvst Plowing, weeding ,		Harvst Tran-loading		Family (SYP)	Hired (SYP)	
	Qty	SYP/ kg	Qty	SYP/ kg	Qty	SYP/ kg	Qty	SYP/lit	Qty	SYP/lit	No.	SYP	SYP/ kg	SYP/ Ha	SYP/ Ha	SYP/ Ha	SYP/ ha			

B) Supplementary Irrigated Crops.

- **Winter (1998/1999) Land Allocation**

Crops	Area (ha)	Date of plantation	Date of harvest	Yield (kg/ha)	Price SYP/kg	Seed Rate (kg/ha)	Highest Yield (kg/ha)	Lowest Yield (kg/ha)

CROP INPUT: WINTER (1998/1999)

Crops	Fertilizers						Pesticides /Herbicides				Irrigation		Seed	Machinery				Labour		Othrs* (SYP)
	N		p		Manure		Pesticides		Herbicides		SYP/Irrig.			Pre-plantin	Pre-Hrvst	Harvst	Loadin Trans	Family (SYP/ha	Hired (SYP/ha	
	Qty	SYP/ kg	Qty	SYP/ kg	Qty	SYP/ kg	Qty	SYP/ lit	Qty	SYP/ lit	No.	SYP	SYP/ kg	SYP/ Ha	SYP/ Ha	SYP/ Ha	SYP/ ha			

C) **Full-Irrigation Crops:**

- **Winter (1998/1999) Land Allocation:**

Crops	Area (ha)	Date of plantation	Date of harvest	Yield (kg/ha)	Price SYP/kg	Seed Rate (kg/ha)	Highest Yield (kg/ha)	Lowest Yield (kg/ha)

Crop Inputs : Full Irrigation Winter (1998/1999)

Crops	Fertilizers						Pesticides /Herbicides				Irrigation		Seed	Machinery				Labour		Othrs* (SYP)
	N		p		Manure		Pesticides		Herbicides		SYP/Irrig.			Pre-plantin	Pre-Hrvst	Harvst	Loadin Trans	Family (SYP/ha	Hired (SYP/ha	
	Qty	SYP/ kg	Qty	SYP/ kg	Qty	SYP/ kg	Qty	SYP/ lit	Qty	SYP/ lit	No.	SYP	SYP/ kg	SYP/ Ha	SYP/ Ha	SYP/ Ha	SYP/ ha			

Summer Crops

- **(1998) Land Allocation:**

Crops	Area (ha)	Date of plantation	Date of harvest	Yield (kg/ha)	Price SYP/kg	Seed Rate (kg/ha)	Highest Yield (kg/ha)	Lowest Yield (kg/ha)

Crop Input Summer (1998):

Crops	Fertilizers						Pesticides /Herbicides				Irrigation		Seed	Machinery				Labour		Othrs* (SYP)
	N		p		Manure		Pesticides		Herbicides		SYP/Irrig.			Pre-plantin	Pre-Hrvst	Harvst	Loadin Trans	Family (SYP/ha	Hired (SYP/ha	
	Qty	SYP/ kg	Qty	SYP/ kg	Qty	SYP/ kg	Qty	SYP/ lit	Qty	SYP/ lit	No.	SYP	SYP/ kg	SYP/ Ha	SYP/ Ha	SYP/ Ha	SYP/ ha			

7. Irrigation Investment:

Village Water Resource Description:

7.1 Groundwater Use History:

7.1.1 When did you successfully dig the first well for irrigation (date or number of years) ?________ years.

7.1.2 What was the average depth of wells in the village at the beginning of ground water use?___________ meters.

7.1.3 What was the wells average diameter (inch):________

7.1.4 What was the distance of the closest wells?______________ m

7.1.5 When the groundwater began to become scarce (date or years ?____________ m

7.1.6 What were the major winter crops prior to water scarcity ?1. ____________ 2. ___________ 3. _______________ 4. _______________ 5.

____

7.1.7 What was the major summer crop prior to water scarcity ? 1. _____________ 2. __________________ 3. ______________ 4. ___________ 5.

____

7.1.8 What was the highest area used under groundwater irrigation?_______________ ha

7.1.9 What was the irrigation method prior to water scarcity? 1. ________________ 2.________________ 3.________________

7.1.10 What are in your opinion the main factors have led to the current situation of the groundwater availability?

1. ____

2. ____

3. ____

4. ____

5. ____

7.1.11 Do you think there has been a drop in the your farm income ? ____________ if yes, Can you estimate the yearly percentage drop in your Income that can be attributed to the scarcity of groundwater?____________ %.

Other Reason for the decline in income:

1- ______________________________

2- ______________________________

____

Can you please state your income for the last five years:

Year	Income SYP	Irrigation Cost SYP
1993		
1994		
1995		
1996		
1997		
1998		

7.1.12 Do you think groundwater investment prior to the scarcity was much less than the present time by what percentage?_____________ %.

7.1.13 How much do you invest in irrigation out of total farm investment?:___________

7.1.14 Given the current groundwater condition, are you still willing to invest in drilling wells (yes/no):___________ if yes what is the expected yearly Income from the well:__________

7.1.15 What is the expected annual return from a well of 3" (12 hours /day water lifting) :______________ SYP.

7.1.16 What is the expected annual return from a well of 4" (12 hours/day water lifting):__________SYP

7.1.17 Can you estimate how much your annual return from your 3" well :_________SYP , and 4" well:_______SYP.

7.1.18 Can you estimate the yearly drop in water table (m) ?________________

7.2 Current Condition Of The Groundwater Resource:

7.2.1 How many wells in the village?(m):______________

7.2.2 What is the average depth (m) ?___________

7.2.3 What is the average well head (m)?__________

7.2.4 What is the average diameter (inch):_________

7.2.5 What is the current average distance between wells (m)?_________

7.2.6 What is the percentage of the total area being irrigated by groundwater ?___________ %

7.2.7 What are the months when the water table declines ?________________ _____________ ________________ _______________

7.2.8 What is the total average cost of drilling artizian a well (SYP):_____________

7.2.9 What is the total average cost of drilling Arabi Well (SYP):____________

7.2.10 How many abandoned wells (no):____________

7.2.11 How many shared wells if any (no):___________

7.2.12 How do you decide the location of the well :_________

1- Random :_________.

2- Expectation of water availability:_________

3- Expert's opinion:___________

4- Driller's opinion:__________

5- Consultation with others:_________

6- Others please specify:_____________

7.2.13 Do you have to register your wells ? Yes/No if Yes how many wells are registered No__________

7.2.14 When you drilled your last well how much the percentage that you might fail ?_________%

7.2.15 Do you think well investment is too risky (YES/NO)?__________

8. Wells Description And Groundwater Investment:

8.1 Well Description And Fixed Cost: (Abandoned And In Use):

Well # and Type	Initial depth M	Diameter Mm	Initial Well head M	Current Well head	Age	Drilling cost SYP/M^3		Transport of water cost(PVC)		Type of Motor Mech. 1 Elect. 2		Water daily Discharge (hours)		Yearly Decline of well head (m)	Hectares Irrigated		Type of Water Salty, Sulfuric, Drinkable
						V	H	M	SYP/M	Mech.	Elect	Wint.	Sum.	Yearly	Wint	Sum	

8.2 **Finance** : What is the source of financing well drilling:

8.2.1 Government loan:__________ % of the total cost of the well.

8.2.2 If government loan what is the terms of paying pack the loan:

8.2.3 Loan from merchant :_________ % of the total cost.

8.2.4 Own budget ___________% of the total cost

8.2.5 Others: ____________ % of the total cost

8.2.6 If loans from merchants how you payback the loan :

1- Cash with interest how much interest :________%

2- Share in your yield (percentage) :__________%

3- Compulsory sale of crops (yes/No) ___________

4- Others please specify:____________

9. Water Management Systems:

9.1 System Description And Utilization

Crop	Irrigation system Drip, Sprinkler, Surface Well#	Irrig. Period/ Month	No off irrigation per month (no) Month								Hours per irrigation (no) Hours								Discharge (m^3)/ hour.
			1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	

9.2 Irrigation Cost :

9.2.1 Fixed cost

Well	Installation/Drilling SYP	Registration Fees(SYP)	Depreciation (SYP)	Bump (SYP)	Pipes (SYP)	Others (SYP)

9.2.2 Operational Cost

Well no:	Labour		Fuel				Operation Period		Maintain Cost (SYP)	Total Oper Cost
	Wage SYP/Hr		Diesel/oil SYP/Litter		Elect		Month and Days			SYP
	Hrs	SYP/ Hour	Oil	Fuel	Watt	SYP	Month	Day/ Month	SYP	SYP

9.2.3 Please specify the cost of fuel per hour at each irrigation:

Irrigation no	Litter/hour

9.3: Water Application :

9.3.1 Water application according to : on what basis to you decide to apply water to crops:

1- Calendar schedule :__________

2- Sensing devices:___________

3- Experience :--_________

4- Extension advice:____________

9.3.2 **Did you discontinue irrigation and an effect occurred on crops yield** ? No:_________

Yes :_________

If yes : Please list the crops:

Crops	No of required irrigation	Drop in yield (%)

9.3.3 Annual Groundwater Use Budget :

Calculated : Number of irrigation per month * Number hours per irrigation * Amount (m^3) of water applied /hour)

Irrigation Season

Crop	Jan		Feb		March		April		May		June		July		August		Sept.		October		Nov.		Dec.	
	N irr	N Hrs	N Irr	N Hrs	N Irr	N Hrs	N Irr	N Hrs	N Irr	N Hrs	N Irr	N Hrs	N Irr	N Hr	N Irr	N Hr	N Irr	N Hrs	N Irr	N Hrs	N Irr	N Hrs	N Irr	N Hr

9.3.4 Irrigation Techniques:

9.3.4.1 How do you decide on the irrigation technique:

1- Type of the crop:____________________

2- Cost of irrigation used:____________________

3- Suitability to crop:____________________

4- Saving water:____________________

5- Other reasons:____________________

9.3.4.2 What is the allocation of land to different irrigation technique:

Crop	Surface Irrigation Area (ha)	Sprinkler Irrigation Area(ha.)	Drip Irrigation Area(ha.)

9.3.4.3 Do you think you can save water by using different irrigation method (yes/no):____ if yes

If yes by how much:_______

9.3.4.4 In your opinion what is the most efficient irrigation system:_______________

9.3.4.5 What are the reasons that prevent you from using it please specify:

1. _________________________
2. _________________________
3. _________________________
4. _________________________

Institutions And Resource Profile:

10. Village Resource Profile Characteristics:

10.1. **Physical Attributes:**

10.1.1 What is the total geographical area of the villager (ha):________________

10.1.2 What is the area of cultivatable land(ha):______________

10.1.3 What is the irrigated area using groundwater (ha):____________

10.1.4 Average Annual rainfall:(mm)___________

10.1.5 What is the number of Abandoned wells (No):______________

10.1.6 What is the number of productive wells (No):_____________

10.1.7 What is the average depth of wells in the village(meter) :____________

10.1.8 What is the average well head (water table depth) (meter) :____________

10.1.9 What is the average diameter of the wells (mm):____________

10.1.10 What is the source of drinking water:

1- Wells: how many wells for drinking water in the village:____________

2- Bought : How much is the cost of barrel (SYP/barrel):__________

3- Government provide by tanks (cost of transport SYP/Barrel):___________

4- Water system:___________

10.2 Population

10.2.1 Total population (No):____________

10.2.2 Total number of house holds (No):____________

10.2.3 Literacy %:______________

10.2.4 Social structure (Homogenous or heterogeneous):_____________

10.2.5 Existing organizations (No.):___________________

11. Water Resource Access:

11.1 Are there any existing rule for groundwater access:

1. -

2. -

3. -

4. -

11.2 Do you consult the neighbouring farmer before you dig a wells (Yes/No):___________

11.3 If the other farmer show objection will continue drilling how do you act? , Ignore him__________ convince him_________ ,Other means ________

Please specify:

11.4 Do you think the groundwater table is a property which is shared by every farmer:(Yes/No)__________

11.5 Have any agreement been set up in the village on the number of hours of water lifting: (yes)__________ if yes?

11.6 What type of agreement : sharing the water,______ , Limiting the number of hours:_________ , diameter limit________

11.7 Do you think such arrangements are useful for the future of water availability:__________

11.8 Do you think when water abstracted by others are excluding you (yes/no):____________ if yes ?

11.9 What is type of arrangement of sharing should be put into action:_________________________________

11.10 -Does your neighbor have wells (yes)? _____

11.11 - If yes, how many? _____

11.12 How far from your own? _____ m

11.13 Is there any interaction between your wells and his? ____

11.14 Does the water table in your wells and his decline because of the interaction? ____

11.15 Do you have any problem with your neighbor concerning digging wells? _____

11.16 Do you think ground water decline is a threatening phenomenon and why? ________________________________

11.16.1 In the long run, if the groundwater declined more and more because of the interaction between close wells, what would you suggest as a

solution? Deepening wells – Cooperation - Managing the natural resources and how - Go back to rainfed crops - Others.

11.16.2 If the answer is deepening wells, then why farmers don't think of alternative solution?:____________________________

11.16.3 What are the constraints which impede the cooperation in the community?:___________________________________

11.16.4 How far are you willing to cooperate in spite of all the constraints?:______________________________

11.16.5 What is the role of the extension units concerning this issue of cooperation?:______________________________

11.16.6 Do you thing farmers' organization can assist in creating irrigation arrangement that might help:__________

11.16.7 Do you think farmers are willing to setup such arrangement and adhere to their rules (Yesy/No)________ if No

11.16.8 Why not ?____________________

12. Water Market Condition:

12.1 Are there any sale or purchase of water is taking place (yes/No) ?________ If Yes

12.2 Are these transaction for drinking water or crop irrigation:__________

12.3 Do sell water :____________ if Yes , How do you set the prices ? According to :1- Fuel Cost ____ Or transportation cost:_____

12.4 What is the price of a barrel :__________SYP/Barrel

12.5 Do you Buy water :___________ is it for drinking or for irrigation:______________

12.6 How much is the cost of a barrel :___________SYP/barrel.

12.7 What other type of water market transaction is taking place:_________________

12.8 Renting a land close to yours to dig a well:(Yes/No), If yes what is the hectar cost:___________SYP/ha

12.9 Renting a well ? How the cost is arranged .Please specify the cost?_________________

Appendix C

C-1 System Dynamics Equations List

```
Alpha = IF(x=0) THEN(0) ELSE(((ARCTAN(h/ABS(x)))*(180/PI)))
b = If TOTAL_DISTANCE_IN_METRE=0 then 0 else ((TOTAL_DISTANCE_IN_METRE-ABS(x)))
betta = if TOTAL_DISTANCE_IN_METRE=0 then 0 else (ARCTAN(h/b)*(180/PI))
Depth1= (ABS(x)*h)
Depth2 = (b*h)
G_1 =  If OWN_RADIUS_IN_METRE>RADIUS_OF_NEIGHBOUR_IN_METRE+TOTAL_DISTANCE_IN_METRE then
((RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE*PI)/2) else if
RADIUS_OF_NEIGHBOUR_IN_METRE>OWN_RADIUS_IN_METRE+TOTAL_DISTANCE_IN_METRE then
((OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE*PI)/2) else ((H1+H2)/2)
h = If x<0 then 0 else if TOTAL_DISTANCE_IN_METRE<(x) then 0 else if x=0 then 0 else
(SQRT((OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE)-ABS(x)*ABS(x)))
H1 = (T1-Depth1)
H2 = (T2-Depth2)
Tot1 = (2*Alpha*OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE*PI)/360
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Tot2 = ((2*betta*RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE*PI)/360)
x = If (OWN_RADIUS_IN_METRE>TOTAL_DISTANCE_IN_METRE+RADIUS_OF_NEIGHBOUR_IN_METRE) then 0 else If
(TOTAL_DISTANCE_IN_METRE>RADIUS_OF_NEIGHBOUR_IN_METRE+OWN_RADIUS_IN_METRE) then 0 else If
(TOTAL_DISTANCE_IN_METRE=0) then 0 else If (RADIUS_OF_NEIGHBOUR_IN_METRE=0) then 0 else If
(OWN_RADIUS_IN_METRE=0) then 0 ELSE (((((OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE)-
(RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE)+(TOTAL_DISTANCE_IN_METRE*TOTAL_DISTANC
E_IN_METRE))/(2*TOTAL_DISTANCE_IN_METRE))))
Alpha_2 = If x1=0 then 0 else  ((ARCTAN(h1/ABS(x1)))*(180/PI))
b2 = if x1=0 then 0 else ((ABS(x1)-TOTAL_DISTANCE_IN_METRE))
Betta_2 = If b2 =0 then 0 else  ((ARCTAN(h1/b2))*(180/PI))
Depth4 = (b2*h1)
Depth_3 = (h1*ABS(x1))
Gesamt_2 =  ((H3+H4)/2)
h1 = if ((RADIUS_OF_NEIGHBOUR_IN_METRE>OWN_RADIUS_IN_METRE) AND(
RADIUS_OF_NEIGHBOUR_IN_METRE>OWN_RADIUS_IN_METRE+TOTAL_DISTANCE_IN_METRE)) then 0 else if
TOTAL_DISTANCE_IN_METRE>(x1) then 0 else if RADIUS_OF_NEIGHBOUR_IN_METRE>OWN_RADIUS_IN_METRE then
(SQRT((RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE)-(ABS(x1)*ABS(x1))))  else
(SQRT((OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE)-(ABS(x1)*ABS(x1))))
H3 = (Tot3-Depth3)
H4 = Depth4+Tot4
Tot3 = If RADIUS_OF_NEIGHBOUR_IN_METRE>OWN_RADIUS_IN_METRE then
(2*Alpha_2*RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE*PI)/(360) else
(2*Alpha_2*OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE*PI)/(360)
Tot4 = If Betta_2=0 then 0 else If RADIUS_OF_NEIGHBOUR_IN_METRE>OWN_RADIUS_IN_METRE then  ((2*(180-
Betta_2)*OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE*PI)/360) else ((2*(180-
Betta_2)*RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE*PI)/360)

x1 = If OWN_RADIUS_IN_METRE>TOTAL_DISTANCE_IN_METRE+RADIUS_OF_NEIGHBOUR_IN_METRE then 0 else If
TOTAL_DISTANCE_IN_METRE>OWN_RADIUS_IN_METRE+RADIUS_OF_NEIGHBOUR_IN_METRE then 0 else If
TOTAL_DISTANCE_IN_METRE=0 then 0 else If RADIUS_OF_NEIGHBOUR_IN_METRE=0 then 0 else If OWN_RADIUS_IN_METRE=0
then 0 else if RADIUS_OF_NEIGHBOUR_IN_METRE>OWN_RADIUS_IN_METRE then
```

(((RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE)-
(OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE)+(TOTAL_DISTANCE_IN_METRE*TOTAL_DISTANCE_IN_METRE))/(2*TOT
AL_DISTANCE_IN_METRE)) else (((OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE)-
(RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE)+(TOTAL_DISTANCE_IN_METRE*TOTAL_DISTANC
E_IN_METRE))/(2*TOTAL_DISTANCE_IN_METRE))
TOTAL_WATER_ADDED_TO_AQUIFER =
OTHER_WELL_REAL_WATER_ADDED_IN_QM+OWN_WELL_REAL_WATER_ADDED_IN_QM
WATER_TAKEN_FROM_AQUIFER_IN_qm =
((OWN_WELL_REAL_WATER_ADDED_IN_QM+OTHER_WELL_REAL_WATER_ADDED_IN_QM)-AQUIFER_PUMPED_WATER)*(-1)
UNUSED_CROPLAND_IN_ha = ((CROP_AREA_HA-Irrigated_area_winter)*MOD(Time,2))+(LAND_NOT_USED*(((MOD(TIME,2))-1)*(-1)))
BARLEY_AREA_IN_HA = BARLEY_RF/100*CROP_AREA_HA*MOD(Time,2)
BARLEY_ENERGY_COSTS_IN_SL = BARLEY_AREA_IN_HA*BARLEY_ENERGY_COSTS_IN_SL_PER_HA
BARLEY_ENERGY_COSTS_IN_SL_PER_HA =
ENERGY_PRIZE_IN_SL_PER_QM*BARLEY_ENERGY_RATE_IN_QM_PER_HA*OWN_WELL_DEPTH_IN_METRE
BARLEY_ENERGY_RATE_IN_QM_PER_HA = 0*MOD(Time,2)
BARLEY_FERTILIZER_N_COSTS_IN_SL = BARLEY_AREA_IN_HA*BARLEY_FERTILIZER_N_COSTS_IN_SL_PER_HA
BARLEY_FERTILIZER_N_COSTS_IN_SL_PER_HA =
BARLEY_FERTILIZER_N_IN_KG_PER_HA*BARLEY_FERTILIZER_N_PRIZE_IN_SL_PER_KG
BARLEY_FERTILIZER_N_IN_KG_PER_HA = 100*MOD(Time,2)
BARLEY_FERTILIZER_N_PRIZE_IN_SL_PER_KG = 8.3*BARLEY_PRICE_SWITCH
BARLEY_FERTILIZER_P_COSTS_IN_SL = BARLEY_AREA_IN_HA*BARLEY_FERTILIZER_P_COSTS_IN_SL_PER_HA
BARLEY_FERTILIZER_P_COSTS_IN_SL_PER_HA =
BARLEY_FERTILIZER_P_IN_KG_PER_HA*BARLEY_FERTILIZER_P_PRICE_IN_SL_PER_KG
BARLEY_FERTILIZER_P_IN_KG_PER_HA = 100*MOD(Time,2)
BARLEY_FERTILIZER_P_PRICE_IN_SL_PER_KG = 8.3*BARLEY_PRICE_SWITCH
BARLEY_GROSS_MARGIN_IN_SL = BARLEY_SALES_IN_SL-BARLEY_VARIABLE_COSTS_IN_SL
BARLEY_HERBIZIDES_COSTS_IN_SL = BARLEY_AREA_IN_HA*BARLEY_HERBIZIDES_COSTS_IN_SL_PER_HA
BARLEY_HERBIZIDES_COSTS_IN_SL_PER_HA =
BARLEY_HERBIZIDES_IN_L_PER_HA*BARLEY_HERBIZIDES_PRICE_IN_SL_PER_L
BARLEY_HERBIZIDES_IN_L_PER_HA = 0*MOD(Time,2)
BARLEY_HERBIZIDES_PRICE_IN_SL_PER_L = 0*BARLEY_PRICE_SWITCH

```
BARLEY_PESTICIDES_COSTS_IN_SL_PER_HA = BARLEY_PESTIZIDES_IN_L_PER_HA*BARLEY_PESTIZIDES_PRICE_IN_SL_PER_L
BARLEY_PESTIZIDES_COSTS_IN_SL = BARLEY_AREA_IN_HA*BARLEY_PESTICIDES_COSTS_IN_SL_PER_HA
BARLEY_PESTIZIDES_IN_L_PER_HA = 0*MOD(Time,2)
BARLEY_PESTIZIDES_PRICE_IN_SL_PER_L = 0*BARLEY_PRICE_SWITCH
BARLEY_PRICE_SWITCH =  1*MOD(Time,2)
BARLEY_SALES_IN_SL = BARLEY_AREA_IN_HA*BARLEY_SALES_IN_SL_PER_HA
BARLEY_SALES_IN_SL_PER_HA = BARLEY_SELLING_PRICE_IN_SL_PER_KG*BARLEY_YIELD_IN_KG_PER_HA
BARLEY_SEED_COSTS_IN_SL = BARLEY_AREA_IN_HA*BARLEY_SEED_COSTS_IN_SL_PER_HA
BARLEY_SEED_COSTS_IN_SL_PER_HA = BARLEY_SEED_PRICE_IN_SL_PER_KG*BARLEY_SEED_RATE_IN_KG_PER_HA
BARLEY_SEED_PRICE_IN_SL_PER_KG = 9*BARLEY_PRICE_SWITCH
BARLEY_SEED_RATE_IN_KG_PER_HA = 200*MOD(Time,2)
BARLEY_SELLING_PRICE_IN_SL_PER_KG = 6.5*PROPORTIONAL_CHANGE_IN_PRICE_LEVEL*MOD(Time,2)
BARLEY_VARIABLE_COSTS_IN_SL = BARLEY_AREA_IN_HA*BARLEY_VARIABLE_COSTS_IN_SL_PER_HA
BARLEY_VARIABLE_COSTS_IN_SL_PER_HA =
(BARLEY_SEED_COSTS_IN_SL_PER_HA+BARLEY_FERTILIZER_N_COSTS_IN_SL_PER_HA+BARLEY_FERTILIZER_P_COSTS_IN_S
L_PER_HA+BARLEY_HERBIZIDES_COSTS_IN_SL_PER_HA+BARLEY_PESTICIDES_COSTS_IN_SL_PER_HA+BARLEY_ENERGY_CO
STS_IN_SL_PER_HA)
BARLEY_YIELD_IN_KG_PER_HA = 1000*MOD(Time,2)
ENERGY_PRICE_IN_SL_PER_QM = PROPORTIONAL_CHANGE_IN_PUMP_COSTS*0.05*MOD(Time,2)
PROPORTIONAL_CHANGE_IN_PRICE_LEVEL = 1
DISTANCE_TO_NEXT_WELL_IN_METRE = 0
TOTAL_DISTANCE_IN_METRE = DISTANCE_TO_NEXT_WELL_IN_METRE-HORIZONTAL_SHAFT_IN_METRE
COTTON_AREA_IN_HA = COTTON_FI/100*AREA_SUMMER*(((MOD(TIME,2))-1)*(-1))
COTTON_ENERGY_COSTS_IN_SL = COTTON_AREA_IN_HA*COTTON_ENERGY_COSTS_IN_SL_PER_HA
COTTON_ENERGY_COSTS_IN_SL_PER_HA =
ENERGY_PRICE_IN_SL_PER_QM_AND_M*COTTON_ENERGY_RATE_IN_QM_PER_HA*OWN_WELL_DEPTH_IN_METRE
COTTON_ENERGY_RATE_IN_QM_PER_HA = 15000*(((MOD(TIME,2))-1)*(-1))
COTTON_FERTILIZER_N_COSTS_IN_SL = COTTON_AREA_IN_HA*COTTON_FERTILIZER_N_COSTS_IN_SL_PER_HA
COTTON_FERTILIZER_N_COSTS_IN_SL_PER_HA =
COTTON_FERTILIZER_N_IN_KG_PER_HA*COTTON_FERTILIZER_N_PRICE_IN_SL_PER_KG
COTTON_FERTILIZER_N_IN_KG_PER_HA = 300*(((MOD(TIME,2))-1)*(-1))
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COTTON_FERTILIZER_N_PRICE_IN_SL_PER_KG = 8.3*Price_Switch_cotton
COTTON_FERTILIZER_P_COSTS_IN_SL = COTTON_AREA_IN_HA*COTTON_FERTILIZER_P_COSTS_IN_SL_PER_HA
COTTON_FERTILIZER_P_COSTS_IN_SL_PER_HA =
COTTON_FERTILIZER_P_IN_KG_PER_HA*COTTON_FERTIZER_P_PRICE_IN_SL_PER_HA
COTTON_FERTILIZER_P_IN_KG_PER_HA = 250*(((MOD(TIME,2))-1)*(-1))
COTTON_FERTIZER_P_PRICE_IN_SL_PER_HA = 8.3*Price_Switch_cotton
COTTON_GROSS_MARGIN_IN_SL = COTTON_SALES_IN_SL-COTTON_VARIABLE_COSTS_IN_SL
COTTON_HERBIZIDES_COSTS_IN_SL = COTTON_AREA_IN_HA*COTTON_HERBIZIDES_COSTS_IN_SL_PER_HA
COTTON_HERBIZIDES_COSTS_IN_SL_PER_HA =
COTTON_HERBIZIDES_IN_KG_PER_HA*COTTON_HERBIZIDES_PRICE_IN_SL_PER_L
COTTON_HERBIZIDES_IN_KG_PER_HA = 2*(((MOD(TIME,2))-1)*(-1))
COTTON_HERBIZIDES_PRICE_IN_SL_PER_L = 550*Price_Switch_cotton
COTTON_PESTIZIDES_COSTS_IN_SL = COTTON_AREA_IN_HA*COTTON_PESTIZIDES_COSTS_IN_SL_PER_HA
COTTON_PESTIZIDES_COSTS_IN_SL_PER_HA = COTTON_PESTIZIDES_L_PER_HA*COTTON_PESTIZIDES_PRICE_IN_SL_PER_L
COTTON_PESTIZIDES_L_PER_HA = 0*(((MOD(TIME,2))-1)*(-1))
COTTON_PESTIZIDES_PRICE_IN_SL_PER_L = 0*Price_Switch_cotton
COTTON_SALES_IN_SL = COTTON_AREA_IN_HA*COTTON_SALES_IN_SL_PER_HA
COTTON_SALES_IN_SL_PER_HA = COTTON_SELLING_PRICE_SL_PER_KG*COTTON_YIELD_IN_KG_PER_HA*binary_output
COTTON_SEED_COSTS_IN_SL = COTTON_AREA_IN_HA*COTTON_SEED_COSTS_IN_SL_PER_HA
COTTON_SEED_COSTS_IN_SL_PER_HA = COTTON_SEED_PRICE_IN_SL_PER_KG*COTTON_SEED_RATE_IN_KG_PER_HA
COTTON_SEED_PRICE_IN_SL_PER_KG = 30*Price_Switch_cotton
COTTON_SEED_RATE_IN_KG_PER_HA = 100*(((MOD(TIME,2))-1)*(-1))
COTTON_SELLING_PRICE_SL_PER_KG = 28*PROPORTIONAL_CHANGE_IN_PRICE_LEVEL*(((MOD(TIME,2))-1)*(-1))
COTTON_VARIABLE_COSTS_IN_SL = COTTON_AREA_IN_HA*COTTON_VARIABLE_COSTS_IN_SL_PER_HA
COTTON_VARIABLE_COSTS_IN_SL_PER_HA =
(COTTON_SEED_COSTS_IN_SL_PER_HA+COTTON_FERTILIZER_N_COSTS_IN_SL_PER_HA+COTTON_FERTILIZER_P_COSTS_IN_S
L_PER_HA+COTTON_HERBIZIDES_COSTS_IN_SL_PER_HA+COTTON_PESTIZIDES_COSTS_IN_SL_PER_HA+COTTON_ENERGY_CO
STS_IN_SL_PER_HA)
COTTON_YIELD_IN_KG_PER_HA = 3500*(((MOD(TIME,2))-1)*(-1))
ENERGY_PRICE_IN_SL_PER_QM_AND_M = PROPORTIONAL_CHANGE_IN_PUMP_COSTS*0.05*(((MOD(TIME,2))-1)*(-1))
Price_Switch_cotton = 1*(((MOD(TIME,2))-1)*(-1))
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CUCMBER_PESTIZIDES_PRICE_IN_SL_PER_L = 500*CUCUMBER_PRICE_SWITCH
CUCUMBER_AREA_IN_HA = CUCUMBER_SI/100*AREA_SUMMER*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_ENERGY_COSTS_IN_SL = CUCUMBER_AREA_IN_HA*CUCUMBER_ENERGY_COSTS_IN_SL_PER_HA
CUCUMBER_ENERGY_COSTS_IN_SL_PER_HA =
ENERGY_PRICE_IN_SL_PER_QM_AND_M*CUCUMBER_ENERGY_RATE_IN_QM_PER_HA*OWN_WELL_DEPTH_IN_METRE
CUCUMBER_ENERGY_RATE_IN_QM_PER_HA = 3500*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_FERTILIIZER_N_IN_KG_PER_HA = 500*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_FERTILIZER_N_COSTS_IN_SL = CUCUMBER_AREA_IN_HA*CUCUMBER_FERTILIZER_N_COSTS_IN_SL_PER_HA
CUCUMBER_FERTILIZER_N_COSTS_IN_SL_PER_HA =
CUCUMBER_FERTILIIZER_N_IN_KG_PER_HA*CUCUMBER_FERTILIZER_N_PRICE_IN_SL_PER_KG
CUCUMBER_FERTILIZER_N_PRICE_IN_SL_PER_KG = 8.3*CUCUMBER_PRICE_SWITCH
CUCUMBER_FERTILIZER_P_COSTS_IN_SL = CUCUMBER_AREA_IN_HA*CUCUMBER_FERTILIZER_P_COSTS_IN_SL_PER_HA
CUCUMBER_FERTILIZER_P_COSTS_IN_SL_PER_HA =
CUCUMBER_FERTILIZER_P_IN_KG_PER_HA*CUCUMBER_FERTILIZER_P_PRICE_IN_SL_PER_KG
CUCUMBER_FERTILIZER_P_IN_KG_PER_HA = 350*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_FERTILIZER_P_PRICE_IN_SL_PER_KG = 8.3*CUCUMBER_PRICE_SWITCH
CUCUMBER_GROSS_MARGIN_IN_SL = CUCUMBER_SALES_IN_SL-CUCUMBER_VARIABLE_COSTS_IN_SL
CUCUMBER_HERBIZIDES_COSTS_IN_SL = CUCUMBER_AREA_IN_HA*CUCUMBER_HERBIZIDES_COSTS_IN_SL_PER_HA
CUCUMBER_HERBIZIDES_COSTS_IN_SL_PER_HA =
CUCUMBER_HERBIZIDES_IN_L_PER_HA*CUCUMBER_HERBIZIDES_PRICE_IN_SL_PER_L
CUCUMBER_HERBIZIDES_IN_L_PER_HA = 0*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_HERBIZIDES_PRICE_IN_SL_PER_L = 0*CUCUMBER_PRICE_SWITCH
CUCUMBER_PESTIZIDES_COSTS_IN_SL = CUCUMBER_AREA_IN_HA*CUCUMBER_PESTIZIDES_COSTS_IN_SL_PER_HA
CUCUMBER_PESTIZIDES_COSTS_IN_SL_PER_HA =
CUCUMBER_PESTIZIDES_IN_L_PER_HA*CUCMBER_PESTIZIDES_PRICE_IN_SL_PER_L
CUCUMBER_PESTIZIDES_IN_L_PER_HA = 20*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_PRICE_SWITCH = 1*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_SALES_IN_SL = CUCUMBER_AREA_IN_HA*CUCUMBER_SALES_IN_SL_PER_HA
CUCUMBER_SALES_IN_SL_PER_HA =
CUCUMBER_SELLING_PRICE_IN_SL_PER_KG*CUCUMBER_YIELD_IN_KG_PER_HA*binary_output
CUCUMBER_SEED_COSTS_IN_SL = CUCUMBER_AREA_IN_HA*CUCUMBER_SEED_COSTS_IN_SL_PER_HA
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CUCUMBER_SEED_COSTS_IN_SL_PER_HA =
CUCUMBER_SEED_PRICE_IN_SL_PER_KG*CUCUMBER_SEED_RATE_IN_KG_PER_HA
CUCUMBER_SEED_PRICE_IN_SL_PER_KG = 4000*CUCUMBER_PRICE_SWITCH
CUCUMBER_SEED_RATE_IN_KG_PER_HA = 3*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_SELLING_PRICE_IN_SL_PER_KG = 6*PROPORTIONAL_CHANGE_IN_PRICE_LEVEL*(((MOD(TIME,2))-1)*(-1))
CUCUMBER_VARIABLE_COSTS_IN_SL = CUCUMBER_AREA_IN_HA*CUCUMBER_VARIABLE_COSTS_IN_SL_PER_HA
CUCUMBER_VARIABLE_COSTS_IN_SL_PER_HA =
(CUCUMBER_SEED_COSTS_IN_SL_PER_HA+CUCUMBER_FERTILIZER_N_COSTS_IN_SL_PER_HA+CUCUMBER_FERTILIZER_P_C
OSTS_IN_SL_PER_HA+CUCUMBER_HERBIZIDES_COSTS_IN_SL_PER_HA+CUCUMBER_PESTIZIDES_COSTS_IN_SL_PER_HA+CUC
UMBER_ENERGY_COSTS_IN_SL_PER_HA)
CUCUMBER_YIELD_IN_KG_PER_HA = 20000*(((MOD(TIME,2))-1)*(-1))
ENERGY_PRICE_IN_SL_PER_QM_AND_M = PROPORTIONAL_CHANGE_IN_PUMP_COSTS*0.05*(((MOD(TIME,2))-1)*(-1))
TOTAL_GROSS_MARGIN_IN_SL =
BARLEY_GROSS_MARGIN_IN_SL+COTTON_GROSS_MARGIN_IN_SL+CUCUMBER_GROSS_MARGIN_IN_SL+WHEAT_GROSS_MA
RGIN_IN_SL
not_useful_water = (Area*Rainfall_together)*0.5
OWN_WELL_NET_LOSE_IN_% = IF(OWN_WELL_POTENTIAL_WATER_ADDED_IM_QM=0)then 0
else (not_useful_water*100)/OWN_WELL_POTENTIAL_WATER_ADDED_IM_QM
OWN_WELL_REAL_WATER_ADDED_IN_QM = OWN_WELL_POTENTIAL_WATER_ADDED_IM_QM-not_useful_water
AQUIFER(t) = AQUIFER(t - dt) + (Inflow - Water_extraction) * dt
INIT AQUIFER = 2000000
Inflow = OWN_WELL_REAL_WATER_ADDED_IN_QM +OTHER_WELL_REAL_WATER_ADDED_IN_QM
Water_extraction = if AQUIFER-AQUIFER_PUMPED_WATER<Water_level_max then AQUIFER-Water_level_max else
AQUIFER_PUMPED_WATER*(((MOD(TIME,2))-1)*(-1))+AQUIFER_PUMPED_WATER*MOD(TIME,2)
binary_output = If Water_extraction=AQUIFER-Water_level_max then 0 else 1
message = if AQUIFER<Water_level_max+0.1 then 10 else 1
Water_level_max = if OWN_WELL_DEPTH_IN_METRE>100 then 2000000-(100*2000000*0.01) else 2000000-
(2000000*0.01*OWN_WELL_DEPTH_IN_METRE)
Area_neighbour = RADIUS_OF_NEIGHBOUR_IN_METRE*RADIUS_OF_NEIGHBOUR_IN_METRE*PI
OTHER_WELL_NET_LOSE_IN_% = IF(OTHER_WELL_POTENTIAL_WATER_ADDED_IN_QM=0)then 0
else (not_useful_water*100)/OTHER_WELL_POTENTIAL_WATER_ADDED_IN_QM
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```
OTHER_WELL_POTENTIAL_WATER_ADDED_IN_QM = (Area_neighbour*Rainfall_together)*0.5
OTHER_WELL_REAL_WATER_ADDED_IN_QM = OTHER_WELL_POTENTIAL_WATER_ADDED_IN_QM-not_useful_water
RADIUS_OF_NEIGHBOUR_IN_METRE = WELL_DEPTH_OF_NEIGHBOUR_IN_METRE*TAN(PI*70/180)
WELL_DEPTH_OF_NEIGHBOUR_IN_METRE = 0
Area = OWN_RADIUS_IN_METRE*OWN_RADIUS_IN_METRE*PI
OWN_RADIUS_IN_METRE = OWN_WELL_DEPTH_IN_METRE*TAN(PI*70/180)
OWN_WELL_DEPTH_IN_METRE = 0
OWN_WELL_POTENTIAL_WATER_ADDED_IM_QM = (total_Area*Rainfall_together)*0.5
total_Area = Area+own_Area_Region
Rainfall_together = Rainfall_distribution*SW_rain_switch
SW_rain_switch = MOD(Time,2)
Rainfall_distribution = GRAPH(random(300,350))
(300, 0.3), (305, 0.31), (310, 0.32), (315, 0.33), (320, 0.34), (325, 0.35), (330, 0.34), (335, 0.33), (340, 0.32), (345, 0.31), (350, 0.3)
More_Rainf = If Rainfall_Area=0 then 0 else ((Rainfall_Area *100)/ Rainfall_Area)-100
Rainfall_all_Area = (Rainfall_together*Area)*0.5
Depth = Depth1+Depth2
CROP_AREA_SUMMER_IN_ha = (((MOD(TIME,2))-1)*(-1))*AREA_SUMMER
CROP_AREA_WINTER_IN_ha = MOD(Time,2)*CROP_AREA_HA
OTHER_WATER_REQUIREMENT_IN_QM = IF WELL_DEPTH_OF_NEIGHBOUR_IN_METRE=0 then 0 else
Water_requirement_summer+Water_requirement_winter
OWN_WATER_REQUIREMENT_IN_QM = Water_requirement_summer+Water_requirement_winter
TOTAL_WATER_REQUIREMENT_IN_QM = OTHER_WATER_REQUIREMENT_IN_QM+OWN_WATER_REQUIREMENT_IN_QM
AREA_SUMMER = CROP_AREA_HA-Irrigated_area_winter
COTTON_FI = 0
CUCUMBER_SI = 0
LAND_NOT_USED = AREA_SUMMER-(AREA_SUMMER*(COTTON_FI/100)+AREA_SUMMER*(CUCUMBER_SI/100))
TOTAL_OF_COTTON_IN_ha = ((COTTON_FI/100)*AREA_SUMMER)*(((MOD(TIME,2))-1)*(-1))
TOTAL_OF_CUCUMBER_IN_ha = ((CUCUMBER_SI/100)*AREA_SUMMER)*(((MOD(TIME,2))-1)*(-1))
Water_requirement_summer =
(AREA_SUMMER*(COTTON_FI/100)*15000+AREA_SUMMER*(CUCUMBER_SI/100)*3500)*(((MOD(TIME,2))-1)*(-1))
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VARIABLE_COSTS_IN_SL =
BARLEY_VARIABLE_COSTS_IN_SL+COTTON_VARIABLE_COSTS_IN_SL+CUCUMBER_VARIABLE_COSTS_IN_SL+WHEAT_VARI
ABLE_COSTS_IN_SL
TOTAL_SALES_IN_SL = BARLEY_SALES_IN_SL+COTTON_SALES_IN_SL+CUCUMBER_SALES_IN_SL+WHEAT_SALES_IN_SL
own_Area_Region = 2*OWN_RADIUS_IN_METRE*HORIZONTAL_SHAFT_IN_METRE
HORIZONTAL_SHAFT_IN_METRE = 0
Rainfall_ own_Area_Region  = (Area*Rainfall_together)*0.5+( own_Area_Region *Rainfall_together)*0.5
AQUIFER_PUMPED_WATER = IF WELL_DEPTH_OF_NEIGHBOUR_IN_METRE>0 then 2*pumped_water else pumped_water
pumped_water = If MOD(TIME,2) then Water_requirement_winter else  Water_requirement_summer
ENERGY_PRICE__IN_SL_PER_QM_AND_M = PROPORTIONAL_CHANGE_IN_PUMP_COSTS*0.05*MOD(Time,2)
PROPORTIONAL_CHANGE_IN_PUMP_COSTS = 1
WHEAT_AREA_IN_HA = WHEAT_SI/100*CROP_AREA_HA*MOD(Time,2)
WHEAT_ENERGY_COSTS_IN_SL = WHEAT_AREA_IN_HA*WHEAT_ENERGY_COSTS_IN_SL_PER_HA
WHEAT_ENERGY_COSTS_IN_SL_PER_HA =
ENERGY_PRICE__IN_SL_PER_QM_AND_M*WHEAT_ENERGY_RATE_IN_QM_PER_HA*OWN_WELL_DEPTH_IN_METRE
WHEAT_ENERGY_RATE_IN_QM_PER_HA = 4500*MOD(Time,2)
WHEAT_FERTILIZER_N_COSTS_IN_SL = WHEAT_AREA_IN_HA*WHEAT_FERTLIZER_N_COSTS_IN_SL_PER_HA
WHEAT_FERTILIZER_N_IN_KG_PER_HA = 200*MOD(Time,2)
WHEAT_FERTILIZER_N_PRICE_IN_SL_PER_KG = 8.3*WHEAT_PRICE_SWITCH
WHEAT_FERTILIZER_P_COSTS_IN_SL = WHEAT_AREA_IN_HA*WHEAT_FERTILIZER_P_COSTS_IN_SL_PER_HA
WHEAT_FERTILIZER_P_COSTS_IN_SL_PER_HA =
WHEAT_FERTILIZER_P_IN_KG_PER_HA*WHEAT_FERTILIZER_P_PRICE_IN_SL_PER_KG
WHEAT_FERTILIZER_P_IN_KG_PER_HA = 200*MOD(Time,2)
WHEAT_FERTILIZER_P_PRICE_IN_SL_PER_KG = 8.3*WHEAT_PRICE_SWITCH
WHEAT_FERTLIZER_N_COSTS_IN_SL_PER_HA =
WHEAT_FERTILIZER_N_IN_KG_PER_HA*WHEAT_FERTILIZER_N_PRICE_IN_SL_PER_KG
WHEAT_GROSS_MARGIN_IN_SL = WHEAT_SALES_IN_SL-WHEAT_VARIABLE_COSTS_IN_SL
WHEAT_HERBIZIDES_COSTS_IN_SL = WHEAT_AREA_IN_HA*WHEAT_HERBIZIDES_COSTS_IN_SL_PER_HA
WHEAT_HERBIZIDES_COSTS_IN_SL_PER_HA =
WHEAT_HERBIZIDES_IN_KG_PER_HA*WHEAT_HERBIZIDES_PRICE_IN_SL_PER_L
WHEAT_HERBIZIDES_IN_KG_PER_HA = 1*MOD(Time,2)
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WHEAT_HERBIZIDES_PRICE_IN_SL_PER_L = 1000*WHEAT_PRICE_SWITCH
WHEAT_PESTIZIDES_COSTS_IN_SL = WHEAT_AREA_IN_HA*WHEAT_PESTIZIDES_COSTS_IN_SL_PER_HA
WHEAT_PESTIZIDES_COSTS_IN_SL_PER_HA = WHEAT_PESTIZIDES_IN_KG_PER_HA*WHEAT_PESTIZIDES_PRICE_IN_SL_PER_L
WHEAT_PESTIZIDES_IN_KG_PER_HA = 0*MOD(Time,2)
WHEAT_PESTIZIDES_PRICE_IN_SL_PER_L = 0*WHEAT_PRICE_SWITCH
WHEAT_PRICE_SWITCH = 1*MOD(Time,2)
WHEAT_SALES_IN_SL = WHEAT_AREA_IN_HA*WHEAT_SALES_IN_SL_PER_HA
WHEAT_SALES_IN_SL_PER_HA = WHEAT_SELLING_PRICE_IN_SL_PER_KG*WHEAT_YIELD_IN_KG_PER_HA*binary_output
WHEAT_SEED_COSTS_IN_SL = WHEAT_AREA_IN_HA*WHEAT_SEED_COSTS_IN_SL_PER_HA
WHEAT_SEED_COSTS_IN_SL_PER_HA = WHEAT_SEED_PRICE_IN_SL_PER_KG*WHEAT_SEED_RATE_IN_KG_PER_HA
WHEAT_SEED_PRICE_IN_SL_PER_KG = 15*WHEAT_PRICE_SWITCH
WHEAT_SEED_RATE_IN_KG_PER_HA = 325*MOD(Time,2)
WHEAT_SELLING_PRICE_IN_SL_PER_KG = 11*PROPORTIONAL_CHANGE_IN_PRICE_LEVEL*MOD(Time,2)
WHEAT_VARIABLE_COSTS_IN_SL = WHEAT_AREA_IN_HA*WHEAT_VARIABLE_COSTS_IN_SL_PER_HA
WHEAT_VARIABLE_COSTS_IN_SL_PER_HA =
(WHEAT_SEED_COSTS_IN_SL_PER_HA+WHEAT_FERTLIZER_N_COSTS_IN_SL_PER_HA+WHEAT_FERTILIZER_P_COSTS_IN_SL_P
ER_HA+WHEAT_HERBIZIDES_COSTS_IN_SL_PER_HA+WHEAT_PESTIZIDES_COSTS_IN_SL_PER_HA+WHEAT_ENERGY_COSTS_I
N_SL_PER_HA)
WHEAT_YIELD_IN_KG_PER_HA = 3500*MOD(Time,2)
BARLEY_RF = 0
CROP_AREA_HA = 0
Irrigated_area_winter = CROP_AREA_HA*Irrigation_share_winter
Irrigation_share_winter = WHEAT_SI/100+BARLEY_RF/100
TOTAL_OF_BARLEY_IN_ha = ((BARLEY_RF/100)*CROP_AREA_HA)*MOD(Time,2)
TOTAL_OF_WHEAT_IN_ha = ((WHEAT_SI/100)*CROP_AREA_HA)*MOD(Time,2)
Water_requirement_winter = ((WHEAT_SI/100)*CROP_AREA_HA*4500)*MOD(Time,2)
WHEAT_SI = 0
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Appendix D

D-1 Villages Location Map