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USING GEOMEMBRANES TO IMPROVE THE STORAGE EFFICIENCY OF RUNOFF CATCHMENT PONDS IN THE COMMUNITY OF EL RINCON, IN QUERETARO, MEXICO: A BENEFIT-COST ANALYSIS

presented by

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ABSTRACT

USING GEOMEMBRANES TO IMPROVE THE STORAGE EFFICIENCY OF RUNOFF CATCHMENT PONDS IN THE COMMUNITY OF EL RINCÓN, IN QUERÉTARO, MEXICO: A BENEFIT-COST ANALYSIS

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This study presents a benefit-cost analysis of using geomembrane liners to improve the water storage efficiency of four runoff catchment ponds for one case study in Querétaro, Mexico. The lining technique is intended to help increase irrigation capacity (agricultural production) by eliminating the infiltration loss of stored pond water. The study uses rainfall, evaporation, and animal consumption data to calculate rainfall runoff (potential catchment) and each source of stored water loss from the four ponds. After determining that rainfall runoff is sufficient to fill the ponds on an annual basis, the study calculates project-generated water savings by comparing rates of runoff accumulation and evaporation loss for the critical dry season carry-over. The value of this water is calculated by predicting its yield-enhancing effect on two crops: irrigated ("punta de riego") corn and cempasuchil. A net present value and benefit-cost ratio is calculated for each of the four ponds to determine the project's cost-effectiveness.

This study concludes that for the ponds and crops studied, the installation of geoemembranes is not a cost-effective means of increasing agricultural production. However, Geomembranes should not be fully discounted as a potential water management tool for the site without further study as to their cost-effectiveness and overall feasibility.

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LIST OF ABBREVIATIONS

AMST American Materials Standards and Testing
AUQ – Autonomous University of Querétaro
Cu. - Cubic
FAO – Food and Agriculture Organization (of the United Nations)
GC – Granja Carnation (weather station)
GIS - Geographic Information Systems
HEC - Hydrologic Engineering Center
INEGI - Instituto Nacional de Estadística Geografía y Informática (National Institute of Statistics, Geography, and Information)
INIFAP - Instituto Nacional de Investigaciones Forestales Agricolas y Pecuarias (National Institute of Agri-Forestry and Fishery Investigations)
IRR – Internal Rate of Return
LDPE - Low Density Polyethelene
LP – Las Palmillas
M. - Meters
MI – NRCS – Natural Resource Conservation Service of Michigan
Mo. – Month(s)
MSU – Michigan State University
NPV- Net Present Value
NRCS – Natural Resource Conservation Service (formerly SCS)
NWC – National Water Commission of Mexico
PE - Polyethylene
PR – Punta de Riego
PVC – Polyvinyl Chloride
RRA – Rapid Rural Appraisal
SCS – Soil Conservation Service (now NRCS)
SAGAR - (Secretaría de Agricultura, Ganadería y Desarrollo Rural (Secretary of Agriculture, Animal Husbandry, and Rural Development)
SEMARNAP - Secretaria de Medio Ambiente, Recursos Naturales, y Pesca (Secretary of the Environment, Natural Resources, and Fisheries)
SMT - San Miguel Tilaxcalte
USDA – United States Department of Agriculture

Symbols
Δ - Change (in)
π - Pie (approx. 3.14)

Chapter 1: Introduction

1.1 The Problems of Food Demand and Water

To meet the projected food demand for a world population expected to reach 8.4 billion by 2025 (World Bank, 1992), global agricultural productivity will have to nearly double (McCalla, 1994). To feed an additional 80 million people per year, and satisfy demand for diversified diets created by rising incomes, will require annual increases in grain production of 26 million tons – or 71,000 tons per day (Brown, 1998). As 90% of future population growth will occur in developing nations, such countries will have to increase agricultural productivity between 1.8 and 2% annually to keep pace with demand (McCalla, 1994). For these countries, achieving and maintaining such productivity levels will be extremely difficult for several reasons:

1.) Most nations have little or no remaining fertile land that can be added to the production base (Brown, 1998). In many countries, population pressure and urban sprawl are pushing production onto marginal lands that are unsuitable for cultivation and prone to environmental degradation. World-wide, the quantity of grain land per person has declined from .23 ha/person in 1950 to .12 ha/person in 1997, and will further decline to .08 ha/person by 2030 (Brown, 1998). As the quantity of production land per person continues to decrease, agricultural intensification will be the only option for producing enough food.

2.) Yield growth responses to the Green Revolution formula of improved grain varieties, fertilizer, and irrigation appear to be diminishing (Brown, 1998). Between 1950 and 1990, agricultural productivity grew an average rate of 2.1% per year; between

1990 and 1995, the rate of growth dropped to 1% per year (Brown, 1998). While five years does not constitute a trend, grain varieties may be reaching the outward limits of efficiency in photosynthetic energy conversion (Brown, 1998). If yields continue along the same course, the Green Revolution strategy will prove insufficient for meeting the next generation of food demand. It is unclear if biotechnology will be effective and affordable to farmers in developing nations.

3.) Water scarcity is increasing world-wide, a factor that Brown (1998) deems the most "underrated" problem confronting us in the coming millennium. Since 1950, global water use has tripled, 70% of it used for agricultural production, and water tables are dropping on every continent (Brown, 1998).[1] Brown (1998) warns that while water and food scarcity are often treated as distinct problems, they are not. A future marked by scarcity in water will be a future of scarcity in food.

If arid and semi-arid countries (regions) continue to pump water from their aquifers unsustainably for irrigation purposes, they will eventually be forced to remove irrigated regions from their production base and offset production losses with increased grain imports (Brown, 1998).[2] Countries such as China, Egypt, India, Iran, Mexico, Pakistan, and Saudi Arabia are among the most prominent of nations likely to gamble on this tradeoff (Brown, 1998).[3]

However, as Paarlberg (1994) notes, reliance on world markets for grain imports has historically not worked well for developing nations. He warns that even while food prices decreased over the past 30 years, 700 million people in the developing world

[1] Water tables are falling in the following regions: southern and southwestern U.S., southern Europe, North Africa, southern Africa, the Middle East, Central Asia, the Indian subcontinent, and central and northern China (Brown, 1998).
[2] Importing 1 ton of grain is the equivalent of importing 1,000 tons of water (Brown, 1998).

remain hungry because of distances to markets and low income. If the fore-mentioned nations "go-for-broke" with their irrigation water supplies and begin to compete with each other in the world grain markets, poorer nations will soon be priced out of the market.

The beginning of this process may already be taking place. Between 1950 and 1993, the world prices of wheat, corn, and rice fell in real terms by 67%, 83%, and 88% respectively (Brown, 1998). Since 1993, the trend has reversed. Between 1993 and 1996, the price of wheat rose 39%, rice 30%, and corn 58% (Brown, 1998). If arid and semi-arid countries deplete their aquifers and forgo food self-sufficiency in favor of imports, millions may be left malnourished or starving.

In short, the world is on the verge of unprecedented demand for food at a time when its tools and natural systems are questionably inadequate to the task. The food problem will be especially acute in arid and semi-arid environments, regions comprising one-third of the earth's surface (Branson, et al. 1981) and exhibiting signs of increasing water scarcity and soil degradation (Siegert, 1993). Intensifying cultivation in these fragile environments jeopardizes future production capacity through the ruination of watersheds, soil nutrients, and range lands (Paarlberg & Breth, 1994). Meeting the growing demand for food will depend on increasing productivity while improving soil and water conservation strategies (Goodrich and Simanton, 1995). If arid and semi-arid nations are to maintain some level of food security through self-sufficiency in production, they must reduce aquifer use to sustainable levels and invest in water conservation systems.

China and India are number one and three grain producers in the world (Brown, 1998).

1.2 Farm-Scale Water Harvesting/Storage Systems

To increase production in the context of decreasing water resources, small farmers in semi-arid environments need better systems for harvesting and storing water more

efficiently (Sanchez Cohen, et al.1995). Because rainfall in semi-arid regions is both erratic and minimal, rain-fed agriculture carries a high risk of yield failure (Sanchez Cohen, et al. 1995), and limits productivity. To maximize productivity in arid and semi-arid regions while alleviating dependency on irrigation wells, farmers need better water harvest and storage systems.

Water harvesting is defined as the "collection of runoff for its productive use", and includes the collection of rainwater (rooftop and runoff) and floodwater (Siegert, 1993). Though ancient in practice (Frasier, 1993), water harvesting is receiving increased attention as a method for augmenting agricultural water supply (Siegert, 1993). Water may be harvested using various kinds (shapes) of microcatchments, bunds, ridges, or dams (Siegert, 1993), depending on local conditions and resources. Harvested water can be stored as "soil storage" or in "deep ponding", which is long-term storage using any variety of basins including dams, reservoirs, and man-made tanks (Siegert, 1993).

The key to the effective carryover of water is the creation of impermeable storage structures. Soil-based retention barriers are ineffective in the absence of impermeable soils such as clay. Coarse, sandy, and porous soils make poor water retention barriers. In areas where water-retaining soils are absent, farmers need an affordable, yet effective alternative for making storage basins impermeable. One technique that merits investigation as a tool for constructing such storage is the installation of geomembranes in earthen water ponds.

Geomembranes are low permeability synthetic liners made from various plastic polymers and fibers, and are used for the control of fluids in "man-made project structure[s] or system[s]" (GeoSource, 1998). Geomembranes have a variety of environmental applications, including the lining of landfills and wastewater treatment ponds. Little scholarship has focused on the use of liners as a tool for improving the water management capacity of small farmers in semi-arid regions of developing countries. As water scarcity increases the challenge of meeting food demand for poor farmers around the world, scholarly studies are needed to help find effective, accessible, and affordable alternatives for increasing the capacity of small farmers to manage and use water efficiently.

To contribute case study information to the body of knowledge available to farmers, project planners, and scholars concerning potential tools for increasing water storage capacity, this research examines the economics of using plastic liners in water storage ponds in the Central-Mexican state of Querétaro. This case study uses data from existing ponds and agricultural production practices in the community of El Rincón, Querétaro to calculate the financial costs and benefits of lining water ponds with geomembranes to create water-tight storage basins.

1.3 Water Storage in Querétaro, Mexico

The community of El Rincón provides a useful context for the study of pond improvement for several reasons. First, the Central Mexico region exemplifies the difficulty of increasing small-farmer water management capacity (Pineda López, 1996), despite massive public sector investment in farm-scale systems for water harvest and storage. During the mid-1980's, the Mexican National Water Commission constructed thousands of ponds to capture and store rain runoff for agricultural use (García, 1998). Many of those ponds, however, are largely ineffective because of structural deficiency (use of coarse soils in pond construction) and/or poor positioning relative to drainage courses (Pineda López, 1996). Water scarcity remains one of the primary constraints to agricultural production in the region (García, 1998), and most farmers do not have adequate or reliable year-round supplies of water (Pineda López, 1996).

Secondly, the region is useful contextually because it illustrates the relationships between agricultural practice and land degradation. As with other semi-arid regions, poverty-induced agricultural practices (mono-cropping, overgrazing, over-reliance on chemical fertilizers and pesticides) have resulted in natural resource and environmental degradation (Pineda López, 1996). In as much as harvesting and storing water effectively is important to improving agricultural productivity, it has the potential to help alleviate pressure to intensify production unsustainably.

Finally, the El Rincón case is compelling because it exemplifies the potential for collaboration that exists between community, national, and international institutions for investigating and solving community problems. Teams of scholars from the Autonomous University of Querétaro (AUQ) have partnered with community members to investigate, discuss, and pose solutions to agricultural, natural resource, environmental, and socioeconomic problems (Pineda López, 1996). This partnership has included collaboration with Michigan State University, and the Natural Resource Conservation Service of Michigan (MI-NRCS). Such multi-level and multi-disciplinary collaboration between institutions lends new power to the solving of natural resource and agricultural production challenges.

It is through such collaboration that problems associated with water pond effectiveness in El Rincón came to the attention of visiting professionals from MSU and the MI-NRCS. During a recent visit to the community (1998), a team of professionals from MI-NRCS responded to farmer complaints about water infiltration loss by proposing the installation of geomembranes in pond basins (Burgdorf and Pérez, 1998). The presence of coarse soils, and in some cases, rocky substrate in pond floors, facilitates water seepage into the sub-surface (Pineda López, 1996). Under ideal circumstances, ponds are designed to provide water carry over from the rainy season (June-September) to allow for a one-time irrigation (or soaking) of the fields in April or May (about one month prior to planting) in the following crop cycle (García, 1998). In ponds where infiltration rates are high, the combination of evaporation and infiltration dries the pond out by the month of November or December, making no water available for irrigation. Consequently, agricultural productivity remains low.

While the installation of geomembranes in storage ponds would likely allow farmers to produce more food and fiber, no data exist as to likely increments in water supply or agricultural production, nor as to the costs of liner installation and maintenance. Such data need to be collected and analyzed to determine the financial feasibility of lining ponds with geomembranes to boost agricultural productivity. The goal of this study is to collect such information to determine the advisability of such an investment.

1.4 Statement of the Research Problem

To increase agricultural production, small farmers in semi-arid Central Mexico need efficient systems for capturing and storing rainfall for crop and animal production. To address this need, the Mexican NWC constructed thousands of water storage ponds in

Central Mexico during the mid-1980's. Many of those ponds are ineffective, however, and do not provide water to farmers because of water loss through coarse and sandy soil-based pond basins. Lining inefficient ponds with geomembranes may reduce or eliminate water loss due to infiltration. Because no data is available regarding the financial costs and benefits of using geomembranes in small scale, semi-arid farming scenarios, this analysis uses a case study approach to calculate such costs and benefits.

1.5 Research Objective

The objective of this research is to determine the cost-effectiveness of lining farm ponds with geomembranes through the completion of a financial benefit-cost analysis.

1.6 Research Design

This study includes the following areas of analysis:

1.) Calculation of Rainfall Runoff and Pond Catchment

2.) Calculation of Stored Water Loss

3.) Calculation of Crop Production Yields and Budgets

4.) Calculation of Project Investment and Operating Costs

5.) Benefit-Cost Analysis

The study uses local pond and agricultural production data to calculate the financial benefits and costs of lining four selected study ponds with geomembranes. A projected water surplus is calculated by calculating rainfall runoff and catchment, as well as stored water loss – including evaporation, animal consumption, and estimates of infiltration. An economic value for the project-generated water surplus is calculated by estimating its production increasing effect for corn and cempasuchil[4]. Project investment costs are

[4] Cempasuchil (or Tagetes erecta Linnaeus Compositae) is a traditional ornamental flower used as a food coloring and additive to poultry feed (INEGI, 1997a).

calculated using estimates of site preparation time, local wage and contractor rates, and liner installation price quotations. Costs and benefits are calculated using a 15-year farm-level budget for each pond that includes a yearly and incremental (or cumulative) net benefit.

A project net benefit is calculated by subtracting the production (operating) costs and project investment costs from the market value of the crop (gross returns). A net present value for the project is calculated by discounting the future value of the benefit stream over the project life-cycle (15 years in this case). Future benefits are discounted by the opportunity cost of capital or the interest rate used for borrowing capital.

If, for the conditions of the case study, the project is shown to be cost-effective, this study will conclude that the technique merits further investigation as a potential water management tool for small farmers in El Rincón and the larger surrounding region. More importantly, the summary data will be shared with the community members and leaders of El Rincón, so that they can make informed decisions about the potential investment.

1.7 Study Significance

The study is designed to determine the financial feasibility of the liner technique for farmers in the El Rincón case, but also contribute case study data about liner feasibility to a larger body of information about farm-scale water storage systems as a means for increasing agricultural production in semi-arid regions. To the degree that the conditions of this study site may resemble those of other semi-arid agricultural regions, the findings of this study have potential application to other communities in Central Mexico and abroad. If the liner technique is found to be cost-effective for the production conditions of the case, geomembranes may become an important tool for helping small farmers in semi-arid regions conserve water and increase food production. The results of the study can help farmers and development professionals make informed decisions about investment in this water management option.

1.8 Study Organization

This study is organized in five chapters. Chapter One presents the problem background and analysis, framing the research problem and objectives in the larger context of farm-scale water management in semi-arid agriculture. Chapter Two presents a problem-focused review of the literature pertinent to the financial feasibility of geomembranes in the Central Mexico Region. Chapter Three provides a description of the study site, including insight into the agricultural production and natural systems. Chapter Four outlines the study methods and calculations. Study results are presented in Chapter Five, and Chapter Six provides a summary of the study, conclusions, and recommendations for further investigation. Appendices A, B, C, and D present additional information on geomembranes, the study site, cempasuchil, and local rainfall analysis, respectively.

Chapter 2: Literature Review

2.1 Introduction

This research problem involves the potential infusion of a capital-intensive technology into a resource and capital constrained, low input agricultural system that is dependent upon highly variable rainfall. The implication for such an investment is the potential risk of the agricultural production system not keeping pace with the debt service in the case of one or a series of crop failures. Thus, the major consideration is not only whether liners would augment the efficiency of water storage ponds, but whether the benefits of such an investment outweigh the costs, and to what degree.

In an effort to create more insight into issues related to the cost-effectiveness of liners in the El Rincón case, a problem-focused literature review was conducted addressing the following questions:

- What are geomembranes and how are they made and used?
- Have farmers in other low-input agricultural systems had experience with geomembranes as pond liners? Under what circumstances?
- What were the outcomes of those experiences?
- Did the farmers receive financial assistance or pay for the liners themselves?
- Were the projects cost-effective? Under what circumstances?
- What problems were incurred? How were they dealt with?
- What parallels can be made between those adoption cases and the case of El Rincón?

Because this study also relies on hydrological and benefit-cost analysis, those areas were also included in the literature review.

Unfortunately, upon examination of literature bases in the areas of agriculture, development, engineering, and natural resource conservation, it became apparent that very few studies chronicle the use of geomembrane liners in water storage ponds in developing agriculture, and no studies were found addressing the economics of such an investment. In short, what is known about geomembranes in agriculture appears to be primarily in the domain of technical design and performance. The economics of geomembrane use in scenarios such as that of El Rincón appear to be relatively unstudied. It is not clear why this is the case.

2.2 Literature Search

The literature search conducted for this study includes the following topic areas, titles, and years of publication (in the case of journals, generally the most recent 10 years of the stated title were reviewed):

Agriculture:

Agricultural Water Management: An International Journal (1988-99)

AMA – Agricultural Mechanization in Asia, Africa, and Latin America (1989-98)

American Journal of Agricultural Economics (1990-98)

Irrigation Science (1987-1994)

Journal of Irrigation and Drainage Engineering (1989-98)

Journal of Production Agriculture (1989-99)

Benefit-Cost Analysis:

Economic Analysis of Agriculture Projects, Gittinger (1996)

The Principles of Practical Cost-Benefit Analysis, Sugden & Williams (1978)

Miscellaneous Class Notes from AEC 865, Agricultural Benefit-Cost Analysis, Crawford & Oehmke (1998)

Development:

Grassroots Development (1990-97)

Miscellaneous publications by: The World Bank ("Technical Papers"), FAO, UNDP, USAID

Engineering:

Geosynthetics Engineering (miscellaneous years)

Geosynthetics International (miscellaneous years)

Miscellaneous publications by: The Bureau of Reclamation and Army Corps of Engineers

Hydrology

Agricultural Compendium For Rural Development in the Tropics and Subtropics, Elsevier (1989)

Applied Modeling in Catchment Hydrology, Singh (1981)

Computer-Assisted Floodplain Hydrology & Hydraulics, Hoggan (1989)

Contemporary Hydrology, Wilby (ed.) 1997

Design Hydrology and Sedimentology for Small Catchments, Haan, Barfield, and Hayes (1994)

Global Hydrology: Processes, Resources, and Environmental Management, Jones (1997)

Hydrology and Floodplain Analysis, Bedient & Huber (1988)

Land Surface Evaporation, Management & Parameterization, Schmugge & Andre (eds.) (1991)

Management of Water Use in Agriculture, Tanji & Yaron (eds.) (1994)

Rain and Stormwater Harvesting in Rural Areas, UNEP (1983)

Rainfall Runoff Relationship, Singh (ed.) (1981)

Runoff, Infiltration and Subsurface Flow of Water in Arid and Semi-Arid Regions, Issar & Resnick (eds.) (1996)

Semiarid Soil and Water Conservation, Finkel (1986)

Water Resources Management in the Face of Climatic/Hydrologic Uncertainties (1996)

Water Saving Techniques for Plant Growth, Verplancke, Strooper, and De Boodt (1992)

Watershed Hydrology, Black (1990)

Miscellaneous Internet Resources

Natural Resources:

Ambio (1989-99)

Journal of Soil and Water Conservation (1987-98)

Resources (1993-99)

As part of the search, the following data bases were referenced in an Electronic Resources Library at Michigan State University: *CAB, Agricola, Soil and Water*. These data bases produced several potentially relevant articles, copies of which could not be procured, including:

Plastics and Control of Water and Storage of Liquids in Agriculture, Comite des Plastiques en Agriculture, Paris, France. 1992 (French)

Proceedings of the International Study Day about Waterproofing Water Basins, Societa Solvay, Milan, Italy, 1983 (Italian)

Proceedings of the 12th International Congress of Plastics in Agriculture, CEPLA, Granada, 1992.

Third World Conference on Geosynthetics Use in Rural Engineering, Galan-Lopez

2.3 Introduction to Geomembrane Technology

For purposes of identification and description, a brief introduction to geomembranes is presented here. Additional information – including geomembrane properties pertinent to project design and liner selection are presented in Appendix A. For more information regarding geomembranes, their properties, and project design considerations, see: Robert M. Koerner's, *Designing with Geosynthetics* 3rd ed. (1998). As director of the Geosynthetics Research Institute at Drexel University, and author of numerous articles and texts on geosynthetics, Koerner is one of this nation's pre-eminent scholars on geosynthetics and geosynthetic design. More recent publications of Koerner and the Institute may be found through the Institute's internet address: www.drexel.edu/gri/backgrnd.html . Unless otherwise cited, this overview of geomembrane technology (section 2.3 and Appendix A) summarizes information taken from Koerner's treatment of geomembranes in his 1998 text *Designing with Geosynthetics* 3rd ed (pages 1-45, 362-510).

Geomembranes are one group of a family of geosynthetic products that combine synthetic materials with geoenvironmental design for application in areas such as geotechnical and environmental engineering, heavy construction, building construction, and hydrogeology (Koerner, 1998). Geosynthetics include plastic polymers, and other materials such as rubber and fiberglass, and thus tend to be non-degradable, durable, versatile, light-weight, transportable, low maintenance, and often less expensive than alternatives (Koerner, 1998). Koerner identifies five principal geosynthetic functions: soil separation, soil reinforcement, soil filtration, water drainage, and moisture containment. Based on those functions and material design, Koerner breaks the family of geosynthetics into six categories based on design and function:

1.) Geotextiles – similar to cloth textiles in form; woven, knited, or matted with synthetic (plastic) fibers; may be used for any of five geosynthetic functions

2.) Geogrids - panels of grid-shaped plastic rods; used primarily for soil separation and reinforcement

3.) Geonets - nets made of plastic or "polymeric ribs"; used exclusively for drainage applications

4.) Geocomposites - combinations of geo-textiles, grids, nets, or membranes; or one of those products in combination with other materials such as deformed plastic sheets, steel cables, or steel anchors; may be designed and used for any of the five major geosynthetic functions.

5.) Geomembranes - "impervious thin sheets of rubber or plastic material used primarily for linings and covers of liquid (or solid) storage facilities"

6.) Geo-Others - a vast array of newer geosynthetic innovations not easily categorized because of their diversity; include "threaded soil masses, polymeric anchors, and encapsulated soil cells"; used for any of the five geosynthetic functions.

This study focuses exclusively on geomembranes and borrows a slightly more detailed definition provided by GeoSource (www.geosource.com) (1998):

Geomembranes are very low permeability synthetic membrane liners or barriers used with any geotechnical engineering related material so as to control fluid migration in a man-made project structure or system. Most geomembranes are made from extruded or co-extruded polymers such as HDPE, PP, CPE, PVC, EPDM, etc. [High Density Polyethylene, Polypropylene, Chlorinated Polyethylene, Polyvinyl Chloride, and

Ethylene Propylene Diene Monomer] that are extruded in large sheets which are welded or glued together in the field. Some extruded geomembranes are reinforced with high tenacity fibers to increase their tensile strength, while others are embossed, roughened, or co-extruded with geotextiles to increase their frictional resistance to sliding.

Per Koerner (1998), the first geomembranes were made from butyl rubber and Hypalon during World War II and were used as pond liners for potable water. Today, geomembranes have many uses, all of which involve the blockage or entrapment of liquids, vapors, or even solids. Several identified by Koerner (1998) include:

- Storage of potable water and reservoir water
- Storage of waste and radioactive waste liquids
- Lining of water conveyance canals
- Lining/capping of solid-waste landfills
- Containment of odors and/or vapors
- Control of expansive or frost-susceptible soils
- Blockage of water infiltration into sensitive areas

According to Koerner (1998), one of the potential growth areas for liner use is in the lining of irrigation canals. Koerner states, "when properly designed, constructed, and maintained, geomembrane materials should have a positive impact on the canal lining industry". No mention is made of the current status of liner use in irrigation or runoff catchment ponds either in industrialized or developing nation agriculture.

2.4 Geomembrane Materials

All geomembranes are made of one of three types of plastic polymer: amorphous thermoplastic, semicrystalline thermoplastic, or thermoset (Koerner, 1998). Amorphous thermoplastic polymers exhibit plasticity when heated, and thus can be repeatedly heated and molded without changes in "inherent" properties. Semicrystalline thermoplastic polymers are aligned in crystallite shapes, the number of which affect how the polymer behaves. Increased crystallinity increases hardness, heat resistance, tensile strength, and chemical resistance. Conversely, it reduces permeability, elongation potential, flexibility, impact strength, and crack resistance. Thermoset polymers are polymers that once made, are set, and cannot be re-heated without burning and degradation of the polymer.

Koerner (1998) categorizes specific liner types as follows – all of which he indicates constitute "candidate materials" for the "conveyance of domestic or agricultural water".

Thermoplastic Polymers
Polyvinyl chloride (PVC)
Polyethylene (VLDPE, LDPE, LLDPE, MDPE, HDPE) – very low, low, linear low, medium, and high density
Chlorinated polyethylene (CPE)
Elasticized polyolefin (CPE)
Ethylene interpolymer alloy (EIA)
Polyamide (PA)

Thermoset Polymers
Isoprene-isobutylene (IIR), or butyl
Epichlorohydrin rubber
Ethylene propylene diene monomer (EPDM)
Polychloroprene (neoprene)
Ethylene propylene terpolymer (EPT)
Ethylene vinyl acetate (EVA)

Combinations
PVC-nitrile rubber
PE-EPDM
PVC – ethyl vinyl acetate
Cross-linked CPE
Chlorosulfonated polyethylene (CSPE), also called Hypalon

Koerner indicates that the majority of geomembranes in use today are of the thermoplastic variety.

2.5 Geomembrane Construction

Geomembrane sheets are manufactured in one of three ways (Koerner, 1998). The most basic involves the melting of raw materials and extrusion of a single ply membrane ranging in thickness from 5 to 200 mils (0.13 to 5.10 mm). A second method involves the lamination of two or more plies together with or without a fabric scrim reinforcement sandwiched between the membrane layers. A newer method called spread coating, involves pouring molten polymer evenly across a geo-textile base. Because the latter two methods use reinforcing material, these membranes exhibit higher tensile strength and resistance to tears, impact, and puncture. Reinforced liners also tend to be more expensive.

2.6 Geomembrane Installation (See Appendix A)

2.7 Geomembrane Lifetimes

To-date there is not a good quantifiable method for measuring how long geomembranes will last – especially in relation to the potential synergistic effects of membrane degrading forces such as ultra-violet light, radiation, chemicals, extreme heat or cold, fungi and animals. Koerner (1998), offers that if properly protected (i.e. covered with soil), the lifetimes of liners for agricultural water storage are "often approximately" twenty years.

2.8 Other Sources of General Information

More information about geomembranes may be found in the fore-mentioned Koerner text, as well as: Koerner, *Durability and Aging of Geosynthetics*, 1989; and Rollin and Rigo, *Geomembranes Identification and Performance Testing*, 1991. As well, the AMST (American Materials Standards and Testing) publishes descriptions of membrane testing and classification. See: *The Annual Book of ASTM Standards* or the *ASTM Geotechnical Testing Journal.*

According to Koerner (1998), The Bureau of Reclamation, Army Corps of Engineers, and U.S. Department of Agriculture were influential in the early development and use of geomembranes and have published extensively regarding their experiences with the material. The Bureau of Reclamation and USDA have focused on geomembrane use in irrigation canals and reservoirs. The Army Corps of Engineers' use of geomembranes has historically focused on the areas of dams, reservoirs, canals, and road construction. Because many of these projects are of a massive scale, involve heavily industrialized construction or agriculture, and have been subsidized by government funds, they tend to offer little insight into the research question at hand. For project descriptions, see: *Use of Geomembranes in Bureau of Reclamation Canals, Reservoirs, and Dam Rehabilitation,* Morrison, 1995; or *Bureau of Reclamation Research*, The Bureau of Reclamation, 1992. The Bureau of Reclamation homepage can be found at: www.usbr.gov/main/ . USDA publications can be found through the USDA homepage: www.usda.gov.

GeoSource(www.geosource.com) provides on-line advertising and resource information for a number of geomembrane manufacturers, distributors, and engineering firms. The PVC Geomembrane Institute provides research and education for PVC liner use. The Institute may be contacted on-line at: pgi-tp@uiuc.edu. Another on-line source for geomembrane publications is the Geosynthetics Bookstore at: GuideMe.com Geosynthetics Bookstore. Other potential sources of information for geomembranes include the following journals: *Environmental Engineering Science, Geosynthetics*

International, Geotechnical Engineering, Geotextiles & Geomembranes, Journal of Applied Polymer Science, Journal of Geotechnical and Geoenvironmental Engineering, Journal of Hydrologic Engineering, Journal of Polymer Science, Journal of Reinforced Plastics and Composites, Journal of Polymer Science, Modern Plastics, Plastics Engineering, Plastics Technology, Polymer, Polymer Engineering and Science, Polymer – Plastics Technology and Engineering, Water Environment Research, Water, Environment, and Technology

2.9 Summary of Like Cases

In contrast to the great number of studies available regarding the technology and engineering of geomembranes, no studies were found addressing the economics of geomembranes in the context of developing country agriculture. While the World Bank and FAO have published extensively on irrigation and water harvesting, virtually no treatment is given to geomembranes as water conservation tools.

One potential explanation for this absence of treatment is the relative infancy of geomemrbane use in geo-technical engineering. Koerner (1998), indicates that sales projections for geomembrane sales are "extremely strong due to their only becoming recently known to many civil engineers". Thus, if geomembranes are just catching on in industrialized nations, a lag in adoption would be expected for use in developing countries. The absence of trials and publications for geomembranes in developing country agriculture may simply reflect the relative newness of the technology. The few references found in the literature relevant to this study are highlighted here:

Blanco et. al. (1998) provide an historical account of geomembrane use (PVC mostly) in Spanish agriculture, including project initiatives in the Canary Islands and

Iberian Peninsula. While Blanco et. al., describe geomembrane types and project design considerations, they fail to address economic or other feasibility considerations related to pond liners. No mention is made of intended water use, project beneficiaries or financing, benefit-cost streams, or other feasibility considerations. Other works by Blanco are available in: Ingeniería Civil (Civil Engineering) (1993) [Spanish]; Proceedings of the Ibero-American Congress of Construction Pathology and Quality Control, 1995 [Spanish]; and Spanish Dam Works, 1996 [Spanish].

Lakshmana Rao et. al. (1990) provide a brief case study of using an LDPE membrane (Low Density Polyethelene) to rehabilitate a masonry fish pond for an inland fishery in Karnataka, India. Though their analysis is more concerned with seepage loss rates than economics, they do mention that the installation of LDPE is about 40% cheaper than constructing a stone masonry pond of equal size. Otherwise, no insight is given into project economics, intended beneficiaries, or liner integration into the agricultural production and natural systems.

Monticelli (1979) makes general reference to the use of geomembranes in irrigation water storage in *L' Irrigazione*. This dated article, however, makes no reference to economics or specific project initiatives.

Kraatz (1977), in his FAO publication on canal lining, provides an overview of design considerations for using geomembranes as canal liners. He indicates that PVC , PE, and butyl rubber have been the most commonly used materials. He indicates that as of 1977, PE was the most economical of membrane materials for "buried flexible canal lining". Kraatz (1977) does provide some specific examples of canal lining projects, but again, coverage is from a design perspective. No references are made to pond lining.

Kumar (1993) describes the use of polyethylene to line rain catchment ponds for irrigation use in Garhwal Himalaya. The author indicates that cost analysis was done for the lining project, and states that the liner proved to be "economically viable" for "low economic status" farmers. No details were provided as to the type of agricultural production under which this proved to be true. Neither was information provided about project financing, ownership, nor the distribution of benefits.

Gonzalez-Ruiz (1992) does provide some insight into the historical and potential use of geomembranes for agricultural water management in Mexico with a description of geomembranes used for irrigation canal rehabilitation. Gonzalez-Ruiz (1992) states that only since the early 1990's has Mexico begun to use liners as a viable alternative to lining canals with masonry, cement, or compacted clay – materials which can be expensive to transport and install, and are susceptible to seismic activity. He suggests that plastic liners provide an effective alternative that can be installed quickly and at lower costs. He further indicates that PVC is an appropriate material for use in Mexico because of:

- its flexibility and manageability
- its availability in large sheets – reducing time and labor needed for installation seaming
- its potential for conformity to changes in underlying base material
- its wide-spread and successful global use in canal rehabilitation

The article makes only brief reference to irrigation ponds when the author suggests that by reducing or eliminating sedimentation and the need for pond reconstruction, pond lining projects may pay for themselves in a very short time. No indication is given as to the agricultural production conditions under which this might be true. Nor is information provided regarding specific projects, project costs or financing, amortization schedules, or the distribution of benefits.

2.10 Conclusions about the Geomembrane Literature Base Pertinent to this Study

The absence of information provided by similar studies makes it difficult to anticipate all of the factors that may affect the cost-effectiveness of installing liners in El Rincón ponds. Though determining factors are ultimately site-specific, the findings of other case studies would be useful for creating a greater depth of understanding of if and how such a technology adoption can be made. Studies such as this one will hopefully better inform both scholars and practitioners addressing the conservation and more efficient use of agricultural water.

2.11 Introduction to Rainfall Runoff Modeling

Because quantifying rainfall runoff is central to the accounting of costs and benefits for this study, it is useful to review briefly some of the basic theories and methods available for computing runoff. The number of approaches available relates to the complexity and number of variables inherent to rainfall-runoff processes – variables that make calculation and modeling especially difficult (Hoggan, 1989). Per Jones (1997), runoff is part of a hydrological balance that can be expressed as:

Runoff = Precipitation – Evaporation +/- Δ Storage

(evaporation and storage change are often referred to as loss functions (Hoggan, 1989))

Precipitation minus abstractions or total loss is called rainfall excess, or effective rainfall, and is equal in volume to storm water runoff, or the amount of flow occurring during and immediately after a precipitation event (Hoggan, 1989).

Rainfall events tend to vary in intensity over time and space within a watershed (Hoggan, 1989). This temporal and spatial variability greatly affects runoff, but is often not represented in available data (Hoggan, 1989). Evaporation involves moisture being taken back into the atmosphere from soil, water, and vegetation surfaces, and is often treated in conjunction with transpiration loss (plant uptake), and thus referred to as evapotranspiration (Hoggan, 1989, and Jones, 1997). Evapotranspiration is affected by such variables as land use, vegetation, and atmospheric conditions (Jones, 1997). Storage change is infiltration into soil and rocks (Jones, 1997), the rate of which is affected by variables such as land use, soil properties (permeability), soil moisture content, vegetative cover, and rainfall intensity and duration (Hoggan, 1989).

Runoff may be calculated for single rainfall events or for extended time periods depending on the purpose of quantification (Hoggan, 1989). It may also be calculated in total volumes, peak volumes, or as hydrographs (distribution of flow over time) (Hoggan, 1989, and Olivera, 1999). Hydrograph methods are useful for the design of runoff handling infrastructure such as drains, sewers, canals, reservoirs, etc. that must handle peak volumes of storm flow. There exist a number of approaches for creating hydrographs, however, as this research is interested only in the total quantity of flow, and not its distribution over time, such methods are not addressed here. In short, runoff estimation involves quantifying rainfall, loss, and often the distribution of flow over time, and for each of these calculations, there exist a number of methods.

2.12 Rainfall

Rainfall is "fundamental" to any rainfall-runoff model, but its accurate temporal and spatial representation across a basin is often hindered by a sparseness of data

(Hoggan, 1989). It is common to calculate an average of precipitation data collected from various points within a basin. Three basic approaches include a simple arithmetic mean, the Thiessen Polygon Method, and the Isohyetal Method (Hoggan, 1989).

Calculation of a simple mean is the most basic of approaches, however, because of the potential for spatial and temporal variability in rainfall, such an average may misrepresent actual rainfall distribution across a watershed (Hoggan, 1989). Hoggan (1989) states that calculating a simple arithmetic mean from gauge data is "satisfactory" if gauges are "uniformly distributed and topography is flat".

The Thiesen Polygon Method can be used where rainfall data is taken from points unevenly distributed across a basin (Hoggan, 1989). The method uses bi-sectors to divide a basin into polygons corresponding to data collection points, the size of which determine the weight of each data point's contribution to a basin-wide average (Hoggan, 1989).

The Isohyetal Method assumes that because of topographical features, a particular gauge does not necessarily best represent the rainfall of the area closest to it (Hoggan, 1989). The technique uses contour lines to connect data points of equal rainfall amounts. An average for each area of constant rainfall (isohyet) is calculated, weighted by the size of its corresponding area, and then combined with others to create an overall average (Hoggan, 1989).

The temporal dimension of rainfall events can be accounted for by using recording precipitation gauges which measure rainfall amounts according to time, the results of which can be represented in a mass curve (Hoggan, 1989). Often however, rainfall is available only from non-recording or standard gauges providing a 24-hour total

(Haan, et. al., 1994). Such is the case with data available for the El Rincón region. However, because this analysis is more interested in total volumes of runoff and not its distribution over time, the absence of timed data is not problematic.

2.13 Loss Functions

Haan, et. al. (1994) provide a slightly more detailed compilation of loss functions, sometimes called abstractions, including: interception, evaporation, bank storage, surface storage and detention, and infiltration. Interception is rainfall captured on vegetation surfaces before it hits the ground – a very small portion of loss for individual storm events (Haan, et. al., 1994). Per Haan, et. al., (1994). evapotranspiration is "generally a minor factor and not included in storm water computations" (it is more important to calculation of runoff over longer time periods). Bank storage is actually only a delay in runoff that occurs when water saturates and is held temporarily in stream banks until stream water levels subside (Haan, et. al., 1994). Surface storage and detention is the amount of water that fills ground surfaces and depressions before overland flow (runoff) can begin. Per Haan, et. al. (1994), this source of loss is extremely difficult to measure. Haan et. al. (1994) state that infiltration is the major source of precipitation loss, and as such, infiltration loss approaches to estimating runoff (called Hortonian approaches) tend to be the most common of methods for calculating runoff (Haan et. al., 1994).

Infiltration loss approaches include the Richards Equation, Horton's Equation, Holtan's Equation, and the Green-Ampt Equation (Haan et. al., 1994). Because these methods involve empirical measurement of infiltration rates and soil hydraulic conductivity, and such data is not available in the El Rincón region, these methods are not viable approaches for estimating runoff for this study. As such, they are mentioned only briefly here.

The Richards Equation calculates infiltration loss as a function of change in infiltration rate measured under conditions of given soil moisture content and constant precipitation (Haan, et. al., 1994). Similarly, Hortan's Equation calculates infiltration loss by calculating the rate of decrease in infiltration through comparisons of initial and final infiltration rates (empirically measured) (Haan, et. al., 1994). Holtan's Equation calculates infiltration by basing the rate of loss on the unfulfilled capacity of soil to hold water – information provided for many soil types by the USDA (Haan, et. al., 1994). The Green-Ampt Equation calculates infiltration rates base on hydraulic conductivity, depth of soil that absorbs moisture, and the depth of surface ponding. (Haan, et. al., 1994).

2.14 SCS Curve Number Method

One of the simplest and most widely used methods for calculating precipitation loss is the U.S. Soil Conservation Service (SCS) (Now the Natural Resource Conservation Service) Curve Number Method (Hoggan, 1989). The method was developed primarily as a way of studying the effects of early soil conservation practices in the U.S. (Hoggan, 1989). It uses curve numbers developed through empirical study of small watersheds to represent runoff-affecting variables such as land use, land cover, soil type, hydrologic condition, and "antecedent runoff conditions" (Hoggan, 1989). The method has proven popular because of its simplicity – requiring only precipitation data and selection of a curve number based on land conditions. According to V.P. Singh (1982), the method is generally reliable. Because of its simple data requirement, it is the method chosen for this study, and is described in more depth in the methods section (chapter 4) of this study.

2.15 Computer Models

Computers have increased the sophistication, ease, and data management capabilities of rainfall-runoff modeling (Olivera, 1999). Computer models provide several method options for representing precipitation, loss, and flow so that input of precipitation and basin data yield runoff hydrographs of a specified variety. Two pioneering agencies in the development of hydrological and hydraulic modeling software are the Hydrologic Engineering Center (HEC) at the U.S. Army Corps of Engineers, and the Soil Conservation Service (Olivera, 1999). The Hydrolgic Engineering Center has developed an extensive array of hydrology and hydraulic modeling software with a variety of functions and applications (Hoggan, 1989). Its principal rainfall-runoff modeling software package is HEC-1 (now available in a Windows version – HEC HMS), which calculates "discharge hydrographs" for historical or hypothetical single storm events using basin input parameters such as basin boundaries, precipitation data, and runoff routing information (Hoggan, 1989, and Olivera 1999). The program includes options for calculating runoff in overland flow plains or in channels (Olivera, 1999). More information about the software can be found on the HEC web page at: www.wrc-hec.usace.army.mil/

The U.S. Soil Conservation Service SCS TR-20 (and more basic cousin TR-55) models rainfall-runoff for single events using "design storms" as rainfall input (Olivera, 1999). Runoff hydrographs are computed using the SCS curve number method based on land use conditions and soil type (Olivera, 1999). TR-20 has been widely used by SCS engineers to conduct urban and rural watershed planning, predict flood risks, and design reservoirs and channels (Olivera, 1999). More information about this program can be found at the NRCS web site at: www.nrcs.usda.gov/

Geographic Information Systems (GIS) are gaining importance in the area of hydrological modeling, especially in providing more sophisticated spatial analysis in runoff (Olivera, 1999). Whereas programs such as HEC-1 and TR-20 average or "lump" rainfall for an entire basin, GIS allows for more spatial definition in rainfall input (Olivera, 1999). Grid systems are especially useful for modeling runoff flow in basins where flow direction is greatly influenced by topographical features (Olivera, 1999). Two such programs are ESRI Arc/Info – GRID and the U.S. Army Corps of Engineers' GRASS program (Olivera, 1999). More information about these programs can be found at the HEC web site (www.wrc-hec.usace.army.mil/) or the ESRI web site (www.esri.com/).

2.16 Conclusions Regarding Runoff Calculation Modeling

Because very little data is available for the El Rincón site, and because this study seeks only to determine if runoff is generally sufficient to fill the study ponds, the study requires a simplistic approach to estimating runoff. The majority of approaches including infiltration methods and computer models require more data than is available here. As such, the SCS Curve Number Method was chosen to calculate runoff based on the data available for precipitation and land use in this site.

2.17 Introduction to Benefit-Cost Analysis

Benefit-cost analysis is a tool used in economic analysis that involves an organized and systematic accounting of financial/economic gains and losses to allow for comparison between alternative projects or "ways of using resources" (Sudgen & Williams, 1978). Grounded in social welfare economics, the technique assumes that private and public entities such as farm families, businesses, or societies have a basic interest in increasing their own welfare – often expressed in financial terms such as an increase in net economic benefit or income (Gittinger, 1997). It also assumes that through efficient allocation of society's scarce resources, certain projects can improve the well-being of particular groups without hurting others (a Pareto Improvement), or in such a way that the benefits accrued to beneficiaries outweigh the costs borne by other segments (a Potential Pareto Improvement) (Gittinger, 1997).

Benefit-cost analysis involves quantification and summation of costs (aspects of the project that hinder the project objective) and benefits (aspects that advance the objective) (Gittinger, 1997). In financial terms, benefits and costs can be described as inflows and outflow respectively. Once summed and discounted (stated in present values), benefits and costs can be presented as a ratio (benefit-cost ratio) or in terms of a net present value (net income minus net expenditures) (Gittinger, 1997). Projects with a benefit-to-cost ratio greater than one or with a net present value that is positive are said to be cost-effective. A third descriptor, the internal rate of return, is the maximum rate of interest that a project could repay and still break even (i.e. the discount rate that produces an NPV of zero). Generally, projects are chosen that have an IRR equal or higher than the opportunity cost of capital.

The benefit-cost approaches used in this study are taken from the Michigan State University graduate course: "Agricultural Benefit-Cost Analysis" (AEC 865) taught by Eric Crawford and Jim Oehmke, 1998.

Chapter 3: Site Description

3.1 Introduction

The following description of the study area, unless otherwise cited, is summarized from the AUQ team's report entitled "Rural Participation Diagnostic of the El Rincón (Aguacate) Watershed" (1996). The site description is also augmented by information gathered during two site visits by this author and from other publications as well. Additional site information is available in Appendix B.

3.2 History of the Diagnostic Report

The rural participation diagnostic is the product of a collaborative relationship between the Autonomous University of Querétaro and the El Rincón community. The participatory diagnostic represents the AUQ's primary contribution to a joint project between The Secretaria de Medio Ambiente, Recursos Naturales, y Pesca (SEMARNAP) and the Food and Agriculture Organization of the United Nations (FAO) entitled "Development of the El Aguacate Watershed, Ejido El Rincón". As is stated in its introduction, the diagnostic was designed to create a preliminary image of the watershed community, including its interest in resource conservation, perceptions related to the SEMARNAP-FAO project, and levels of community commitment to project activities[1].

3.3 Study Site

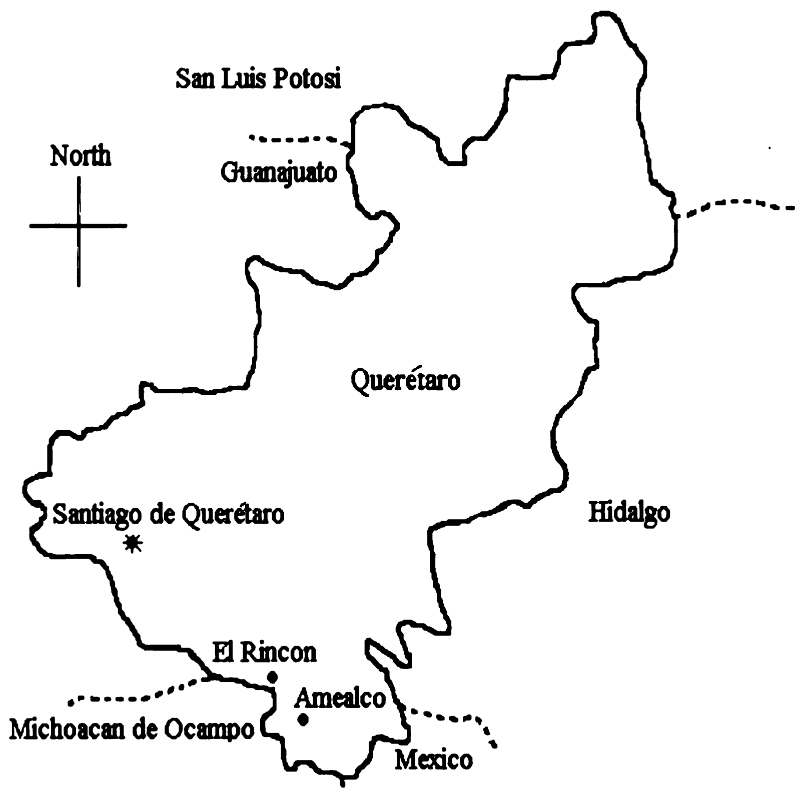
El Rincón is one of thousands of ejidos created as part of the post-revolution land reform which broke up large haciendas and endowed the land to its peasant occupants

[1] Conducted in September, 1996, the RRA included interviews of 45 households using questions about community lifestyles, production and leisure activities, and problems related to those activities. Included were group discussions about community problems and potential solutions (Pineda Lopez, 1996).

(INEGI, 1998 a). As with all ejidos, El Rincón includes three types of land use categories: human settlement areas (villages), common use zones (e.g. pasture and forest), and parceled lands (farmers' fields) (INEGI, 1998 a).

El Rincón includes an area of 9 sq. km. occupied by 1,242 inhabitants (García, 1998), and is located in the southern most municipality (Amealco de Bonfil) of the central-Mexican state of Querétaro (See Figure 1). More specifically, the ejido is located 10 km. northwest of the city of Amealco, 40 km. southeast of the state capital Santiago de Querétaro, and 140 km. northwest of Mexico City (INEGI, 1986).

Figure 1 Map of Querétaro



3.4 Physical Geography

Both the ejido and larger region can be characterized as a contrasting geography of mountains, hills, and valleys created by the intersection of several mountain chains including, "Pinal de Zamorano", "Pinal de Amoles", "El Doctor", and "Sierra Madre Oriental" (INEGI, 1997 b). Elevations in the site range from 2,850 m. on the western side to 2,400 m. in the eastern valley. The INEGI soil map classifies the El Rincón topography as low hills and mountains with grades ranging between 8 and 20% (INEGI, 1982). El Rincón is part of the soil geologic region described as New-Volcanic with acidic ignaceous bedrock (50-100 cm. deep), giving rise to yellow and brown Luvisol soils (INEGI, 1997 b) of medium texture (INEGI, 1982) and some clay content.

Pineda – Lopez, (1998) describes the upper elevations of the ejido as forest comprised primarily of pine and oak. The middle elevations of the ejido are dedicated primarily to parceled fields. The lowest regions of the ejido consist mostly of pasture land (Pineda-Lopez, 1998).

3.5 Climate

El Rincón's climate is listed as "temperate sub-humid" with stable temperatures of between 12 and 18 degrees Celcius (54-64 degrees Farenheit) (INEGI, 1997 b). The warmest temperatures occur between April and June. Precipitation is low, with a municipality average of 659.5 mm/year (INEGI, 1997 a). The highest year of precipitation listed for the municipality for the period 1945-86 is 1,252.8 mm/year, and the lowest is 447 mm/year (INEGI, 1997 a). July is the wettest month (160 mm ave.) and February is the driest (10 mm.) (INEGI, 1997 b). Droughts are most intense (or common) between November and June, frosts between November and March, rains between June and September, winds between February and April, and hail between June and November (Pineda-Lopez, 1996).

3.6 Economic Activities

According to the AUQ publication (1996), El Rincón community members are vocal about what they perceive as a lack of local economic/employment opportunities, and have cited the need for creating alternative sources of employment. Local leadership has expressed concern over high levels of economically-forced emigration (as much as one third of the entire community population), and its negative impact on community development initiatives that are participatory in nature.

Agriculture is the principal economic activity of the region (Pineda-Lopez, 1996), but is often supplemented by other sources of off-farm income generated by the farmers themselves, their children, or both (Purdy, 1999)[2]. According to the AUQ report, men generally work as farmers, day laborers, construction workers, or students. Women work as homemakers, domestic servants, store clerks, or students. Women and children also help with farm work, mostly as caretakers of grazing animals.

Local rural wage rates are described as "low" (i.e. $40 Pesos or $4 U.S./day for farm labor at the time of the 1999 site visit) and consequently, the purchase of food consumes nearly 100% of locally earned income. As such, it is common for young and middle aged men (between the ages of 15 and 45) of the ejido to go to the U.S. in search of employment.

[2] Many of the interviewed farmers have worked and have children working in the U.S.

3.7 Agriculture

Local agriculture consists of both crop and livestock production. The 45 households interviewed for the RRA reported land holdings totaling 170 hectares (a mean of 3.78 ha./family). Approximately 60% of this land is dedicated to rain-fed crop production; the remaining 40% is cultivated under a process called "punta de riego" (cover irrigation). In both cases, the crop cycle reflects the precipitation cycle. Planting is done in April or May when the rains begin, and harvest takes place in the dry season (November or December).

Corn is the principal crop of the watershed area, indeed of the entire municipality, however, two-thirds of the respondents are said to plant corn in association with other crops such as kidney beans, pumpkins, peas, and broad beans[3]. Agricultural mechanization is described by the report as "incipient" with 7 ejido members using tractors, 13 using backpack sprayers, and 22 using teams of horses, mules, or oxen. Most agricultural inputs are purchased in Amelco, and crops (if sold) are taken there as well.

Nineteen of the 45 respondents reported that they consider the soil to be "fertile", seventeen reported that they felt it was not. One explanation offered for this difference is the location of fields, as soil depths tend to vary between .15 and 1 meter.

Farmers indicate that crop yields are "low and variable" with two major risks threatening plant growth: pests and drought. Lack of water is considered not only a problem related to agricultural production, but to the completion of all daily activities. The community has emphasized the importance of better capturing water during the rainy season for use during the dry season. It has solicited funds for the construction of a dam

[3] Amealco (the "corn municipality") provides about 30-40% of all corn grown in Querétaro (Garcia, 1999).

(with no success to-date), but has also discussed the possibility of building more runoff catchment ponds with greater care to ensure that they are well-built and effective at retaining water.

The most common pests are: "Gallina Ciega" (Blind Worm) 40% and "Gusano Soldado" (Soldier Worm) 31%. The use of herbicides is reportedly more frequent than insecticides, both are applied at excessively high rates, and neither are said to be used in conjunction with appropriate safety measures. The most common herbicides are Herbamina, Gesaprin, and Esteron, used by 58%, 29%, and 38% of RRA respondents respectively. The most commonly used insecticides are Furadan and Basudin, used by 18 and 20% of the respondents respectively.

Residents report corn yields ranging from zero to 3 tons per hectare (generally considered the maximum attainable yield). The average 1994-95 corn yield for the entire municipality was 2.8 tons/hectare (INEGI, 1997 a). The following yield data obtained from the office of the Secretaría de Agricultura, Ganadería, y Desarrollo Nacional (Secretary of Agriculture, Livestock Production, and Rural Development) in the city of Amealco shows how El Rincón yields compare to those of the larger municipality for the year 1998.

• Corn:

El Rincón:

Rain-fed: 598.35 tot. ha. planted	1 ton/ha (obtained yield) 598.35 tons tot. prod.
Punta de Riego: 170.25 tot. ha. planted	1.8 tons/ha (obtained yield) 306 tons tot. prod.

Entire Municipality:

Rain-fed: 10,579.09 tot. ha planted	1.6 ton/ha (estimated yield) 16,926.54 tot. prod.

Punta de Riego: 5,824 tot. ha planted 4 tons/ha (estimated yield) 23,296.4 tons tot. prod.

• Cempasuchil:

El Rincón: no data avail. – none planted.

Entire Municipality:
1,200 tot. ha. planted; 15 ton/ha. (ave. yield); 37 ton/ha (max. yield); 12 ton/ha. (min. yield)

3.8 Agricultural Extension

Eduardo Garcia Cordoba, an independent agricultural engineer contracted by the SEMARNAP-FAO project, has worked in the community for three years and is its primary resource for agricultural extension education. He seems to have established quite good raport with many, if not most of the local farmers and families (Purdy, 1999). The diagnostic report indicates that while the majority of respondents complain that agricultural extension is insufficient, they do indicate that they consider Eduardo to be an important resource and have requested that his presence in the community be maintained.

According to Eduardo, the three biggest limitations to local crop production are: 1.) insufficient water, 2.) acidic soils, and 3.) pests (Purdy, 1999). He also states that the upper layer of soil is thin with very little organic matter. Eduardo has worked with several farmers to treat acidic soils with calcium carbonate, and indicates that in some cases, yields have as much as doubled with this treatment. (Purdy, 1999).

3.9 Corn

The production of corn (Zea mays) dwarfs the production of all other crops. For example, in 1994-95, 47,838 tons of corn were harvested in the Amealco municipality (INEGI, 1997 a). The next most commonly produced crop was wheat with a harvest of 898 tons (INEGI, 1997 a). Eduardo (1999) estimates that approximately 90% of the household economy is based on corn production. Corn is consumed by families (1-2 tons per year per family) in the form of tortillas (Purdy, 1998).

Despite the availability and promotion of numerous high yielding corn hybrids, the farmers included in this study rely on indigenous varieties known as "criollo". These varieties are locally adapted and require less water to reach maturation. Corn yields for rain fed corn are typically in the 1-2 tons per hectare range depending on the levels of precipitation and pests.

Production activities for corn generally follow the following calendar, which is applicable to other crops as well.

Plowing/Disking ("Barbecho") – January
Raking ("Rastreo") – March – April
Ridging ("Surcado") – April – May
Planting (Siembra) – April – May
Weeding ("Escarda") – May - June
Fertilizer 1 – April – May
Fertilizer 2 – June – July
Irrigation 1 (optional) – April – May
Irrigation 2 (optional) – June – July
Irrigation 3 (optional) – July
Herbicide/Pesticide Application – May
Harvest – November – December
Collection of Stalks – November – January

Corn is usually sold in the city of Amealco at one of any number of grain dealers or agricultural product stores. During the 1999 site visit, shelled corn was being purchased for $1.40 Pesos per kilogram ($1,400 Pesos or $140 U.S. per ton).

3.10 Punta de Riego (Irrigation Cover)

Punta de riego is essentially rain-fed crop production with the addition of a one-time irrigation applied to fallow fields in March or April (approximately one month prior to the planting of criollo varieties). The local practice involves siphoning water from catchment ponds using plastic hoses, and distributing the water over fields during a 12-24 hour period. Soaking the ground in this manner gives the crop a head start by providing sub-soil moisture for early plant germination, emergence, and growth, (Garcia, 1999).

Punta de riego is practiced only by those farmers whose ponds effectively capture the rains of one season (June/July) and carry it over to the following planting cycle (April). Thus, for the practice to offer any real advantage, there must be adequate rainfall, effective runoff capture, and minimal storage loss. No cases were reported of farmers using well or spring water for irrigation (Purdy, 1999).

Though the technique gives the crop a head start, harvest yields are still dependent on levels of seasonal rainfall and other production factors such as pests. Eduardo (1999) indicates that in good years, the punta de riego technique can double yields. In years of low rainfall, the technique may offer no real advantage.

3.11 Environmental & Natural Resource Problems

The diagnostic report identifies a number of natural resource and environmental problems including: over-grazing, excessive use of agri-chemicals, water erosion, deforestation, over-hunting, and improper disposal of garbage. The report states that while community members recognize these problems, they tend to look externally for solutions rather than generating and promoting them from within.

According to the report, overgrazing of pasture (especially by horses) is endemic, and both a major limitation to livestock production and a leading cause of soil erosion. Because pasture resources are generally open-access, all farmers may use them to graze their animals. This, in combination with limitations in crop production, results in severe overgrazing with no incentive for farmers to conserve the resource. During the author's

1999 visit, the community was in the process of dividing (fencing) common pasture areas into private holdings in an effort to create incentive for more sustainable management (Purdy, 1999). It remains to be seen if this will result in better pasture management.

Water erosion is considered a critical problem, especially in relation to the formation of gullies in the upper and middle areas of the micro-watershed. It is also the major cause of top soil loss. Some efforts have been made to reduce erosion by constructing filter barriers of rock or branches to slow water travel through erosion gullies. The report states, however, that while the community expresses interest in programs designed to repair or prevent erosion, it does not readily take initiative to prevent erosion.

3.12 Water Storage Ponds

The ponds in El Rincón are embankment ponds, which are defined in an NRCS Agricultural Handbook Publication entitled "Ponds – Planning, Design, Construction" (1997) as ponds created by "building an embankment or dam across a stream or watercourse where the stream valley is depressed enough to permit storing 5 feet or more of water". According to local farmers, the ponds were built in the early to mid 1980's by bulldozing earthen embankments across natural drainage courses (Purdy, 1999). There are a total of 18 such ponds in El Rincón, of which only 10 retain water effectively.

The eight non-functioning ponds tend to have beds consisting of fractured rock or soil that is excessively permeable (i.e. low in clay content). Such factors were reportedly not considered by project engineers during site selection (Purdy, 1999). The farmers indicate that some ponds lose water through infiltration in the pond floor itself, and others lose water through the plane of contact between the base of the embankment and the existing grade (Purdy, 1999). One pond owner stated that he has seen water emerging from the ground approximately 100 meters down-grade from the pond, what he believes to be seepage loss from the pond (Purdy, 1999).

With the exception of one pond which has a large section removed from its earth embankment, the four farmers selected for the study indicate that their ponds do fill with water[4] (Purdy, 1999). One farmer indicated that his pond can fill in one night, but can also drop 40 cm. in one day due to what he believes is primarily infiltration (Purdy, 1999). The farmers recognize that evaporation also causes water loss, but feel it may account for only 10% of total loss. The other 90%, they believe is caused by infiltration (Purdy, 1999). Because the ponds do not effectively conserve water, they are essentially used only to water livestock.

3.13 Conclusions

In sum, the people of El Rincón experience economic hardship as both a function and cause of natural resource depletion. Because water scarcity is a major limitation to agricultural production, the site is representative of the larger region, and thus, a good site for studies on water conservation techniques such as this one.

[4] The berm was opened to allow water flow to the farmer's fields.

Chapter 4: Study Methods

4.1 Overview

This study measures the cost effectiveness of using geomembranes in runoff ponds to create a water surplus for use in agricultural production. To determine the project-generated water surplus, the study uses a 21-year aggregated rainfall data history with the SCS Runoff Curve Number Equation to calculate monthly excess for the 21-year data history. The values of excess were then multiplied by the size of the pond catchment areas (in square meters) to determine the total surface runoff within each pond catchment area. This historical look at runoff provides insight into the quantity of runoff available for capture and a starting point for calculation of stored water loss.

While a lack of infiltration data prevents exact calculation of stored water loss, the study does use evaporation and animal consumption data to create a framework for modeling plausible infiltration rates. The project-generated water surplus will be assumed to equal the quantity of runoff water lost to infiltration from a full pond (or some portion thereof).

The project-generated water surplus is valued by calculating the market value of increased crop yields for one traditional crop (corn) and one alternative crop (cempasuhcil) over a 15-year project cycle. A net present value for each pond was calculated by subtracting the sum of discounted costs from discounted benefits using a discount rate of 10% (the opportunity cost of capital). The results of the benefit-cost calculations are presented in Chapter 5.

4.2 Data Collection

In addition to research conducted at Michigan State University, two week-long trips were made to the Querétaro region to gather the following types of data: meteorological, site background, agricultural production, environmental-natural resource, and agricultural input/crop prices. Between the two trips, approximately 5 visits were made to the El Rincón study site, as well as numerous visits to the AUQ, various governmental agencies, local markets, and agricultural supply stores.

Topographical, land use, and soil maps, as well as aerial photos and annual statistical information were purchased from INEGI (the Instituto Nacional de Estadística Geografía y Informática) in the city of Querétaro[1]. All meteorological data (including daily & monthly precipitation and evaporation totals) used in this study was procured from one weather station in the city of Querétaro[2]. Crop yield data for El Rincón and the Amealco Municipality was obtained from the office of SAGAR (Secretaría de Agricultura, Ganadería y Desarrollo Rural) in the municipal city of Amealco. Information on regional crop and animal production was provided by INIFAP (the Instituto Nacional de Investigaciones Forestales Agricolas y Pecuarias). Several visits were made to the AUQ library where literature was obtained on local agricultural production, the Mexican ejido system, natural resource and environmental issues, and food security. Interviews were conducted with Eduardo García (local extensionist), Raúl Pineda López (AUQ biologist and author of the rural participation diagnostic), Miguel Angel Domingez (hydrologist at the AUQ), various farmers and community leaders in El Rincón, agricultural supply store owners, and various officials from the fore-mentioned

[1] INEGI is a good starting point for any subsequent research endeavors of this type in Mexico.
[2] Copies of data from the stations used in this study were available at the Querétaro Station

agencies.

4.3 Site Selection

Though the inclusion of multiple study sites in this research would allow for an insightful inter-site comparison, it was decided to use one site because of limitations of time and financial resources. The El Rincón site was selected after visiting several rural communities around the city of Querétaro in August, 1998 (including La Barreta along Highway 49 north of Querétaro, and the community of Huimílpan south of Querétaro). The study site is actually one of several communities peripheral to the Amealco municipal city that is referred to as El Rincón. The particular community described here is known locally as "El Rincón – El Aguacate" – referring to the name of the watershed in which it is located.

El Rincón was selected over other potential study sites based in-part upon the recommendation of Dr. Raúl Pineda López of the Biological Resources Department at the AUQ. His recommendation encompasses the following considerations:

- The existing rapport between AUQ faculty (especially Dr. Raúl Pineda) and community members
- The existence of a published study of the community conducted by students and scholars from the AUQ
- The facilitative and supportive influence of Eduardo García who has special rapport with the community and extensive knowledge of local agricultural and natural resource issues
- The community's organizational strength, and interest and history in community development.

In addition to Dr. Pineda's suggestions, other considerations included:

- The fertility of El Rincón soils relative to other sites visited in the region, increasing the potential for a cost-effective return on investment.
- The region's importance in corn production for the state of Querétaro.
- Existing awareness and interest in the liner technique based in-part upon the previous visit of the MSU/NRCS team to the area.
- Relatively easy access to the site by road

The first visit to El Rincón made in August of 1998 was facilitated by Eduardo García, so that during subsequent visits, the author was recognized by the community and free to move independently about the micro-watershed area. In all instances, community members were extremely friendly, gracious, and helpful in providing information.

4.4 Pond Selection & Measurement

Approximately 15 ponds were visited in August of 1998, of which four were selected to serve as the basis for calculations and analysis. The ponds were not selected randomly, but rather as a function of owner interest and willingness to provide information and host pond visits. Through the help of Eduardo García, the author was able to attend a regular meeting of the ejido (8/98), explain the nature of the study, and make contact with farmers who expressed interest in having their ponds studied[3].

Though it was carefully explained to the farmers that the purpose of the study was to gather data and provide analysis (and did not constitute an initiative to have the ponds lined) it is nonetheless presumed that the farmers were motivated to collaborate in-part by

[3] To maintain their privacy, the names of the farmers are not stated in this study.

the hope that such a study might lead to a project proposal and external financing. It was further explained that the results of the study would be made available to interested community members in both a thesis format (English) and condensed report format (Spanish), and that any further action with regard to lining the ponds would have to be initiated by the community itself.

The four ponds selected to serve as models for analysis vary in size, shape, area of runoff catchment, and quantity of adjacent crop land (i.e. the total quantity of land owned by the pond owner that is down-grade from the pond, and could potentially be irrigated using a siphon and gravity flow). However, all ponds chosen for study are reported by the owners to exhibit high (but unknown) rates of infiltration loss. Table 1 (facing page) provides a basic summary of the pond characteristics.

The approximate plan shapes of the ponds were determined by locating the ponds on an aerial photo purchased from the INEGI office in the city of Querétaro[4]. Based on the determination of shape (circle, ellipse, parabola, etc.) the appropriate area/volume formulas (taken from Appendix A of an NRCS publication entitled "Ponds – Planning, Design, and Construction") were used to calculate the ponds' surface area and volume. Pond dimensions were measured by pacing their length and width (or radius where appropriate), where the author's pace is equal to approximately one meter. The volume of each pond was calculated by multiplying the product of its surface area and maximum depth (or the highest point of the earth embankment) by one-half. The one-half

[4] All four ponds are visible on "ORTOFOTO" No. F14C76, scale 1:5,000

Table 1 **Study Pond Characteristics**

No.	Shape	Dimen. (m.)	Depth (m.)	Surf. Area (sq.m.)	Vol. (cu. M.)	Prod. Land (ha.)	Catch. Area (sq. m.)
1	Half-Circle	43 m. radius	1.8	2,903	2,612	1	78,125
2	Elipse	40 x 63	2	1,979	1,979	1.5	46,875
3	1 Rectangle + 2 - Triangles	75 x 75 75x70 & 70x25	2	9,125	9,125	4.5	343,750
4	Parbola	58 x 58	1.8	2,254	2,028.50	6	78,125

multiplier was used to reflect the change in pond depth from back (up-grade) to front (down-grade) which is triangular shaped in a profile view. See figure 2 (facing page). The area and volume calculations for ponds 1-4 were made as follows:

Pond 1:

Surface Area (one-half circle) = $.5 (\pi r^2)$ or $.5(3.14 \times (43^2))$ = 2,902.93 sq. meters

Volume = .5(surface area x depth) = .5(2,902.93 x 1.8) = 2,612 cu. meters

Pond 2:

Surface Area (full ellipse) = $(\pi/4)(W)(L)$ = (3.14/4)(40)(63) = 1,979 sq. meters

Volume = .5(surface area x depth) = .5(1,979)(2) = 1,979 cubic meters

Pond 3:

Surface Area (the area of 1 rectangle + 2 triangles) = [(WxL) + .5(WxL) + .5(WxL)] = (75)(75) + .5(70)(75) + .5(70)(25) = 9,125 sq. meters

Volume = .5(surface area x depth) = .5(9,125)(2) = 9,125 cubic meters

Pond 4:

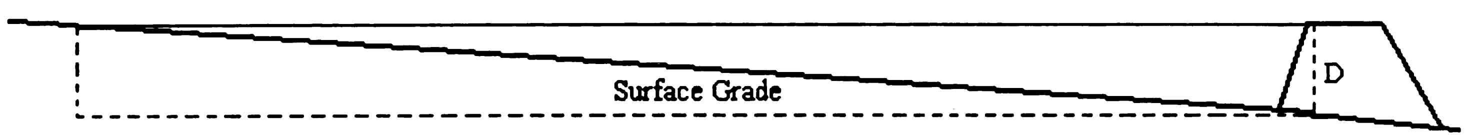
Surface Area (parabola) = .67(L)(W) = .67(58)(58) = 2,253.88 sq. meters

Volume = .5(2,253.88)(1.8) = 2,028.5 cu. meters

It is important to note that to some degree, the ponds defy exact measurement and size calculation because of irregularities in pond surfaces and boundaries, and the occasional presence of erosion gullies. The shape classifications listed in Table 1 were selected as the "best-fit" representation of the pond shapes as determined using aerial photography. In some cases, pond boundaries are not clearly defined, and none of the ponds match their shape classification perfectly. As well, because the pond dimensions

Figure 2. Cross Section View of Ponds

Volume = 1/2 (Surface Area x D)



were paced and not measured with a tape, their measure is not exact. Nonetheless, the figures listed in Table 1 are good approximations and should be sufficient for the completion of a sound benefit-cost analysis.

Also, this study includes the re-shaping of ponds (making them deeper and tighter in diameter to reduce evaporation loss) as part of the cost of preparing sites for liner installation. For purposes of study however, it will be assumed here that any re-shaping will result in no net change in pond volume (from their current state), and the said pond dimensions are thus used for all hydrological calculations.

4.5 Rainfall Analysis

This study generates in-part from farmer-made assertions that annual rainfall and runoff are sufficient for the filling of ponds on an annual basis. To test this assertion, the study uses local rainfall data to create an historical picture of rainfall and rainfall excess.

In the absence of an historically complete rainfall record (data tends to be spotty and inconsistent), a 21-year span of data was created by aggregating rainfall data from four different meteorological stations located in the region. To do so, data was taken from the following stations listed in the order of preference by which their data was used:

Station	Distance from Site	Avail. Data
Granja Carnation Lat: 20 deg., 13' 23"/ Alt: 2,650 m. Long: 100 deg., 09' 10"	7 km.	1978-1989
Amealco I Lat: 20 deg., 11' 05"/ Alt: 2,648 m. Long: 100 deg., 08' 44"	11 km.	1988-1991
San Miguel Tilaxcalte Lat: 20 deg., 08' 32"/ Alt: 2,420 m. Long: 100 deg., 04' 00	20 km.	1975-1989

Station	Distance from Site	Avail. Data
Las Palmillas Lat: 20 deg., 19' 32"/ Alt. 2,148 m. Long.: 99 deg., 56' 13"	25 km.	1971-1991

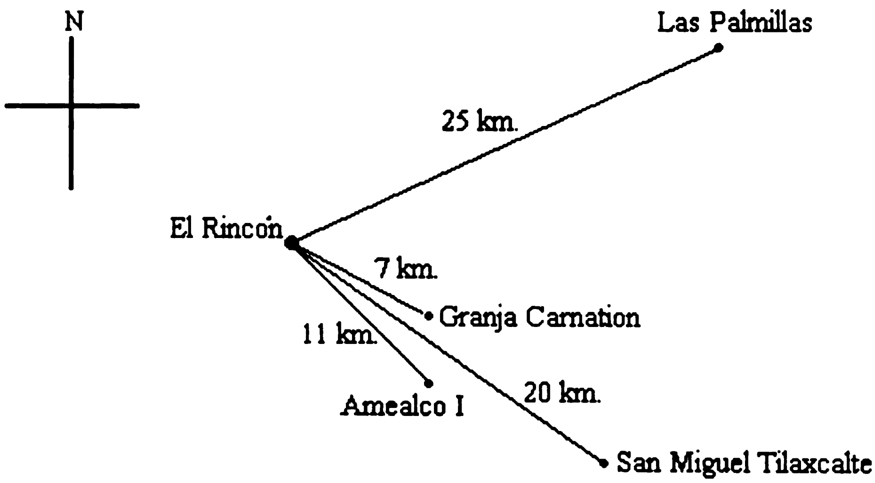
Figure 3 (facing page) shows the location of the four weather stations relative to the study site. Tables 76-79 (Appendix D) show the rainfall data available from each of the four contributing stations:

As the station closest to El Rincón (7 km.), Granja Carnation data was selected to represent the rainfall of the study site (i.e. For this study, it was assumed that the rainfall of El Rincón and Granja Carnation were the same). Because no data exists for the study site itself, there is no way to test this assumption without further data collection.

The rainfall data above reveal quantitative differences between stations (see monthly averages), which if applied to an aggregated total, would potentially misrepresent the monthly and annual rainfall patterns of El Rincón. Thus, before rainfall data was taken from the Amealco I, San Miguel Tilaxcalte, and Las Palmillas stations and applied to the aggregate, it was first adjusted by a correction factor so as to better represent the rainfall patterns of the study site. Station and month-specific correction factors were created by comparing the monthly rainfall averages of each of the stations to those of the Granja Carnation station, where: Adjustment Factor = Mo. Average of Granja Carnation /Mo. Ave. of Comparison Station

The correction factors were subsequently multiplied by the corresponding rainfall data and then added to the Granja Carnation base to create the 21-year data history. In the cases where data were missing for individual months, it was taken from the next

Figure 3. Map of Weather Stations



closest station. Tables 80-82 (Appendix D) indicate the correction factors used for each weather station and month. Table 2 (facing page) presents the 21-year aggregated rainfall data with the contributions of each meteorological station color-coded to indicate their origin. Graphical representation of monthly averages and annual totals for the aggregated data are presented in Table 83 and Figures 5 & 6 in Appendix D.

4.6 Calculation of Runoff

The quantity of runoff generated within the catchment area of each pond was calculated for every month of the 21-year rainfall data cycle by multiplying rainfall excess in meters (difference between total precipitation and soil infiltration) by the area of each catchment zone (in square meters). It is important to note that this value (runoff) represents the total quantity of water available for capture, not actual quantities of capture. For certain months, more runoff will be generated than can be held by the ponds, in which case, the ponds will overflow and the excess runoff will drain away down-slope.

4.7 Catchment Area

The boundaries of the catchment area corresponding to each of the four ponds were determined by examining contour lines on an INEGI topographical map (1:50,000 scale), and studying drainage patterns on a rectified aerial photo (INEGI, 1999). As well, video footage of the catchment zones taken during site visits was used in certain instances to help determine the direction of drainage slopes. Final decisions concerning the boundaries of catchment areas were made under the direction of Dr. Scott Witter at Michigan State University, who has extensive experience in the hydrological interpretation of aerial photos. Once determined, the boundaries of each catchment area

Table 2. Aggregated Rainfall Data (mm./mo.) 1971-1991

LP SMT
Am. I

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
LP 91	0.0	8.2	0.0	0.0	22.5	187.2	398.4	30.1	287.7	74.6	NA	NA	1,008.8
Am. 90	20.8	23.3	16.7	38.6	94.0	2.6	364.6	325.7	316.9	0.0	24.9	NA	1,228.1
GC89/Am. I/LP	**0.0**	6.0	**0.0**	0.0	***58.8***	96.0	**116.9**	**196.2**	**126.1**	**170.9**	**0.0**	**15.6**	786.5
GC88/Am. I/LP	0.0	***0.0***	25.0	5.0	8.0	124.5	**149.9**	**0.0**	**10.5**	0.0	24.0	0.0	346.9
GC87/LP	0.0	1.8	0.0	22.0	***0.0***	58.8	233.0	107.2	103.2	***0.0***	***0.0***	0.0	526.0
GC86	0.0	0.0	0.0	36.0	29.3	324.3	233.2	181.2	92.6	66.8	9.9	0.0	973.3
GC85	0.0	0.0	0.0	14.6	155.4	285.6	287.2	183.7	168.9	56.3	18.9	0.0	1,170.6
GC84/LP	17.0	11.5	0.0	0.0	28.0	134.8	***373.4***	194.4	176.9	63.6	***1.8***	0.0	1,001.4
GC83	53.4	7.6	10.0	0.0	71.2	51.4	369.0	179.4	273.0	32.4	12.5	0.0	1,059.9
GC82	0.0	16.3	4.4	32.6	129.6	56.0	150.6	130.4	62.9	87.5	0.0	20.1	690.4
GC81	74.5	27.5	14.0	62.3	42.7	206.2	121.8	161.3	50.9	72.5	0.0	5.0	838.7
GC80	111.0	4.5	0.0	76.5	90.8	125.1	78.5	266.6	160.2	62.7	1.2	0.0	977.1
GC79 & SMT	3.0	43.5	**1.4**	**15.6**	291.0	**75.5**	**112.7**	182.7	230.0	7.5	0.0	55.7	1,018.5
GC78 & SMT	**22.2**	**23.6**	**8.0**	**23.3**	**106.8**	**115.7**	**139.5**	152.8	193.0	120.2	**7.6**	5.0	917.7
SMT 77	14.1	11.8	9.9	NA	55.9	182.9	129.7	206.1	156.4	32.2	4.1	19.7	822.6
SMT 76	7.5	0.7	7.6	28.5	87.3	47.1	333.0	246.1	220.4	144.4	17.1	11.7	1,151.5
LP 75	110.3	11.5	0.0	0.0	182.6	217.4	280.6	217.6	45.4	3.3	0.9	0.0	1,069.5
LP 74	0.0	0.0	28.6	17.8	50.8	119.0	186.9	83.7	225.2	21.9	9.7	18.2	761.7
LP 73	0.0	0.0	0.0	32.7	125.8	234.9	288.9	178.9	152.8	35.6	0.0	0.0	1,049.5
LP 72	19.8	0.0	0.0	16.1	39.4	54.0	172.0	39.5	134.3	23.6	17.5	0.0	516.3
LP 71	0.0	0.0	9.1	3.0	57.7	322.9	104.2	181.6	269.6	98.6	0.0	19.7	1,066.3
AVE.	21.6	9.4	6.4	21.2	82.3	143.9	220.2	164.1	164.6	55.9	7.5	9.0	906.1

were outlined on the aerial photo. To calculate the surface area of the catchment zones, the photo's scale was used to measure and superimpose a grid pattern of squares (representing 125 x 125 meters) over the four delineated areas on the photo.

The area of each zone was calculated by totaling the number of squares (15,625 m^2 each) within its boundaries (partial squares were added with other partial squares to be counted as one). The size of each is listed below:

Pond	Catchment Area (sq. m.)
1	78,125
2	46,875
3	343,750
4	78,125

These figures represent the size of the areas within which rainfall excess is diverted to each of the four study ponds.

4.8 Calculation of Excess

The rainfall excess corresponding to the 21-year aggregated rainfall data was calculated by applying a curve number and daily precipitation totals to the SCS Runoff Curve Number Equation. As stated in the literature review, the SCS method was selected for its simplicity and minimal requirement for data (curve number and precipitation totals). Using the SCS equation, the quantity Q of excess for individual rainfall "events" was calculated where:

$$Q = [(P - .2S)^2] / [P + .8S] \qquad \text{and } S = 1000/CN - 10 \qquad \text{and:}$$

Q = Runoff in inches

P = Rainfall in inches

S = Potential maximum retention after rainfall begins

CN = The curve number selected based on soil type and land use (Hoggan, 1989)

4.9 Curve Number Selection

A curve number is used in the SCS equation to represent the "land use, cover, soil classification, hydrological conditions, and antecedent runoff conditions" of a study site (Hoggan, 1989). A curve number may be selected from one of several SCS-provided charts that correspond with different kinds of land use. This study uses a curve number of 80 to calculate monthly excess for all four of the ponds and all 21 years of rainfall data. This number was selected from the "Cultivated Agricultural Lands" chart and reflects the following land use and soil type designations within that particular chart.

Land Use Chart: "Cultivated Agricultural Lands:"

Cover Type: "Row Crops"

Cover Description: Combination of "Straight Row" and "Contoured"

Hydrologic Soil Group: Group B (moderate infiltration rate)

Hydrologic Condition: "Poor" (with factors that tend to "impair infiltration")

(NRCS, 1997)

The "Cultivated Agricultural Lands" chart was selected (as opposed to "Urban Areas", "Other Agricultural Lands", or "Arid/Semi-Arid Rangelands")(NRCS, 1997) because the catchment areas in question are dedicated almost exclusively to corn production (with the exception of some narrow grass and bare strips between corn plots) (Purdy, 1998). The "Row Crops" cover type was selected for the same reason (as opposed to "small grains", "meadow", or "legumes") (NRCS, 1997).

The SCS chart provides four "Hydrologic Soil Groups": (Hoggan, 1989)

Group A: low runoff potential; high infiltration rates; deep, well – to excessively drained sands or gravels; high rates of water transmission .3 in./hr.

Group B: moderate infiltration rates; moderately-deep to deep, moderately well-drained to well- drained soils with moderately- fine to moderately-coarse textures; moderate rate of water transmission: .15-.3 in/hr.

Group C: low infiltration rates; soils with a layer that impedes downward movement of soils; moderately-fine to fine texture; low rate of water transmission .05-.15 in./hr.

Group D: high runoff potential; very low infiltration rates; clay soils, soils with a permanent high water table, or soils with a clay pan layer at or near the surface; very low rate of water transmission 0-.05 in./hr.

Based on a description of the El Rincón soils provided by an INEGI Soils Map, the Group B Hydrological Condition was selected to represent the study site[5]. According to the INEGI map (1974), El Rincón soils are "medium" textured Luvicos of the Phaeozem Family. The topography is characterized as low hills and mountains, with slopes ranging between 8 and 20 degrees, and "deep" bedrock between 50 and 100 cm in depth. Because the hard pan layer is deep (allowing more percolation), the soils "medium textured", and the slope gradual, it was decided that the type B class would best represent El Rincón.

The SCS chart (1997) provides two options for a soil's hydrological condition "good" and "poor". According to the chart, the "poor" condition pertains to soils that have "factors [that] impair infiltration and tend to increase runoff". Conversely, soils in "good" hydrologic condition have "factors [that] encourage average and better-than

[5] Map may be referenced as "Carta Edafologica"; La Estancia F-14-C-76; Scale: 1:50,000.

average infiltration and tend to decrease runoff" (NRCS, 1997). Those factors include the following – the increase of which causes higher infiltration and decreased runoff (NRCS, 1997).

a.) "density and canopy of vegetative areas"

b.) "amount of year-round cover"

c.) "amount of grass or close-seeded legumes in rotations"

d.) "percentage of residue cover on the land surface (good $\geq$ 20%)"

"degree of surface roughness"

(NRCS, 1997)

The "poor" hydrologic condition was selected to represent El Rincón soils for several reasons:

1.) The catchment areas in question are canopied with low-density vegetation during only 5 months of the year (i.e. mid to latter part of the corn growth cycle; June – October) (Purdy, 1998).

2.) The catchment areas do not include grass or legumes in substantial quantity (estimated $\leq$ 5% of catchment area) (Purdy, 1998).

3.) The soils of El Rincón are low in organic matter (Garcia, 1998 and Pineda Lopez, 1996) because farmers remove corn stalks during or soon after harvest to feed to livestock. ($\leq$ 20% coverage)

4.) The existence of erosion gullies in bare areas would tend to indicate a "poor" condition.

Within the "row crops" category, one of several "treatment" options may be selected, including "straight row", "contoured", "terraced", "bare soil", "crop residue", or combinations thereof (NRCS, 1997). Because the fields comprising the catchment zones of each pond tend to include both contoured fields (curve number = 81) and straight row fields (curve number = 79) with little crop residue (Purdy, 1998), the average (or "weighted curve number") (80) of the two treatment options was selected for this study. Because of similarity in land use and soil conditions between the four ponds, and for the sake of simplicity, this number was used to calculate excess for all four of the ponds[6]. Substituting the curve number 80 in the equation:

$Q = (P - .2S)^2 / P + .8S$ where $S = (1000/CN) - 10$ $= (1000/80) - 10 = 2.5$

Yields: $Q = (P - .2(2.5))^2 / P + .8(2.5)$

Substitution of the remaining variable P yields the quantity Q of excess.

4.10 Substitution of Precipitation Totals

As Hoggan (1989) notes, spatial and temporal parameters are important for modeling rainfall-runoff relationships, however, a "sparseness" of data can often make exact definition difficult. Because the rainfall data available in the study region are presented as daily totals only, some assumptions had to be made about the time and space dimensions of the rainfall. Lacking information about the number and duration of individual rainfall events within a 24-hour period, it was decided to use daily totals to represent individual rainfall events. Similarly, daily precipitation totals for contiguous days of rainfall were totaled and treated as one event. For instance, 2 inches of rainfall falling each day for three contiguous days would be entered into the equation as one rainfall event of 6 inches.

[6] More in-depth soil studies might result in selection of different curve numbers for each pond.

Because the SCS formula is designed to receive and provide data in inches (NRCS, 1997), data from the various weather stations were converted from millimeters to inches prior to substitution in the equation. Daily rainfall totals were taken from the appropriate contributing stations (described earlier), adjusted by the station and month-specific adjustment factor (where appropriate), converted to inches, and entered into the SCS equation. These conversions and calculations were performed in a simple program created in Microsoft Excel (Microsoft Inc., 1997) to calculate excess from precipitation.

4.11 Conversion of Excess to Runoff

Table 84 (Appendix D) shows rainfall excess (in meters) for each month of the 21-year rainfall data. These values were treated as a constant for calculating total runoff within each pond catchment area. To convert excess to runoff, the excess values were multiplied by the area of catchment corresponding to each of the four ponds (Belcher, 1999). The product of these two is the quantity of runoff available for capture each month (not necessarily the actual amount captured).

Tables 3-5 (facing pages) present rainfall runoff (in cubic meters) available for catchment. Note: Because Ponds 1 & 4 have the same sized catchment area, one table is used to represent runoff values for both ponds.

4.12 Comparison of Runoff to Pond Capacity

While ignoring briefly the forces of pond water loss (evaporation, infiltration, and consumption), is enough runoff generated each year to fill the study ponds? If so, what percentage of the time and based on how many months of runoff? Are there any singular months of runoff sufficient to fill the ponds?

Table 3 **Rainfall Runoff Available for Catchment (cubic meters) - Ponds 1 & 4**

Catchment Area = 78,125 sq. meters

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*	Total
1971-72	699	13,730	2,363	3,964	9,070	2,911	0	55	55	0	0	71	32,919
1972-73	129	1,135	4,697	111	2,191	3	260	0	0	0	0	362	8,888
1973-74	1,816	10,117	14,407	4,487	5,102	385	0	0	0	0	361	135	36,809
1974-75	549	638	3,478	774	9,531	91	397	32	4,628	2	0	0	20,120
1975-76	3,555	5,430	6,288	6,629	575	365	211	0	37	219	471	694	24,474
1976-77	1,239	971	13,114	12,807	9,001	2,454	295	135	238	188	10	271	40,720
1977-78	798	8,144	2,163	5,266	3,483	407	586	107	264	302	695	181	22,398
1978-79	1,493	2,319	3,264	7,540	10,428	5,286	35	83	137	787	192	468	32,030
1979-80	17,720	792	2,230	9,679	11,304	36	0	1,428	4,516	322	0	2,091	50,119
1980-81	895	1,691	717	9,124	5,430	737	199	0	1,713	245	294	565	21,609
1981-82	621	10,370	1,611	3,989	200	1,092	0	83	0	229	325	82	18,602
1982-83	3,848	556	4,611	1,117	1,355	3,165	0	60	198	35	9	0	14,952
1983-84	1,808	294	18,311	6,854	11,335	149	0	0	47	183	0	0	38,981
1984-85	86	810	19,711	5,827	6,066	787	178	0	0	0	0	79	33,544
1985-86	3,291	6,524	8,677	6,286	3,472	1,389	180	0	0	0	0	228	30,047
1986-87	228	13,440	5,965	3,358	1,630	1,902	10	0	0	176	0	104	26,815
1987-88	0	733	7,163	1,885	1,648	0	0	0	0	0	156	83	11,669
1988-89	29	2,699	1,254	5,217	597	0	134	0	0	62	0	0	9,992
1989-90	519	2,598	1,117	0	2,423	8,825	0	10	29	325	420	128	16,397
1990-91	924	149	23,307	13,535	15,877	0	155	105	0	213	0	0	54,265
1991-92	419	5,191	17,158	35	12,457	555	132	105	565	157	140	264	37,176
Ave.	1,936	4,206	7,696	5,166	5,865	1,454	132	105	592	164	146	277	27,739

Table 4 **Rainfall Runoff Available for Catchment (cubic meters) - Pond 2**

Catchment Area = 46,875 sq. meters

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*	Total
1971-72	419	8,238	1,418	2,378	5,442	1,747	0	33	33	0	0	43	19,751
1972-73	78	681	2,818	67	1,315	2	156	0	0	0	0	217	5,333
1973-74	1,090	6,070	8,644	2,692	3,061	231	0	0	0	0	217	81	22,086
1974-75	329	383	2,087	465	5,719	54	238	19	2,777	1	0	0	12,072
1975-76	2,133	3,258	3,773	3,977	345	219	127	0	22	132	283	416	14,684
1976-77	743	582	7,868	7,684	5,400	1,472	177	81	143	113	6	162	24,432
1977-78	479	4,886	1,298	3,160	2,090	244	352	64	159	181	417	109	13,439
1978-79	896	1,391	1,958	4,524	6,257	3,172	21	50	82	472	115	281	19,218
1979-80	10,632	475	1,338	5,808	6,783	22	0	857	2,709	193	0	1,255	30,071
1980-81	537	1,015	430	5,475	3,258	442	119	0	1,028	147	177	339	12,965
1981-82	373	6,222	967	2,393	120	655	0	50	0	137	195	49	11,161
1982-83	2,309	334	2,767	670	813	1,899	0	36	119	21	6	0	8,971
1983-84	1,085	177	10,986	4,112	6,801	89	0	0	28	110	0	0	23,388
1984-85	52	486	11,827	3,496	3,640	472	107	0	0	0	0	48	20,126
1985-86	1,974	3,914	5,206	3,772	2,083	833	108	0	0	0	0	137	18,028
1986-87	137	8,064	3,579	2,015	978	1,141	6	0	0	106	0	63	16,089
1987-88	0	440	4,298	1,131	989	0	0	0	0	0	94	50	7,001
1988-89	18	1,619	752	3,130	358	0	80	0	0	37	0	0	5,995
1989-90	312	1,559	670	0	1,454	5,295	0	6	18	195	252	77	9,838
1990-91	554	89	13,984	8,121	9,526	0	93	63	0	128	0	0	32,559
1991-92	251	3,115	10,295	21	7,474	333	79	63	339	94	84	158	22,306
Ave.	1,162	2,524	4,617	3,100	3,519	873	79	63	355	98	88	166	16,644

Table 5 **Rainfall Runoff Available for Catchment (cubic meters) - Pond 3**

Catchment Area = 343,750 sq. meters

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*	Total
1971-72	3,076	60,412	10,398	17,441	39,908	12,808	0	241	243	0	0	315	144,841
1972-73	569	4,993	20,665	488	9,641	13	1,144	0	0	0	0	1,592	39,105
1973-74	7,990	44,516	63,390	19,744	22,447	1,693	0	0	0	0	1,588	592	161,961
1974-75	2,414	2,807	15,305	3,408	41,938	399	1,746	141	20,364	8	0	0	88,530
1975-76	15,641	23,891	27,666	29,168	2,531	1,606	930	0	162	966	2,072	3,053	107,686
1976-77	5,450	4,270	57,700	56,351	39,603	10,797	1,297	595	1,045	826	45	1,190	179,170
1977-78	3,512	35,833	9,517	23,170	15,325	1,792	2,580	472	1,163	1,330	3,060	798	98,549
1978-79	6,569	10,202	14,360	33,175	45,882	23,258	153	365	601	3,464	845	2,059	140,932
1979-80	77,966	3,486	9,811	42,590	49,740	159	0	6,284	19,869	1,418	0	9,202	220,524
1980-81	3,936	7,441	3,154	40,147	23,891	3,244	874	0	7,536	1,076	1,295	2,485	95,079
1981-82	2,734	45,628	7,088	17,550	879	4,804	0	365	0	1,008	1,430	362	81,848
1982-83	16,930	2,446	20,288	4,915	5,962	13,925	0	262	869	153	41	0	65,789
1983-84	7,955	1,295	80,567	30,158	49,875	655	0	0	207	803	0	0	171,515
1984-85	378	3,562	86,730	25,638	26,691	3,462	783	0	0	0	0	349	147,594
1985-86	14,479	28,705	38,181	27,660	15,276	6,111	792	0	0	0	0	1,005	132,208
1986-87	1,003	59,137	26,247	14,775	7,172	8,371	44	0	0	776	0	459	117,984
1987-88	0	3,226	31,518	8,296	7,250	0	0	0	0	0	688	365	51,343
1988-89	129	11,875	5,518	22,957	2,626	0	589	0	0	271	0	0	43,964
1989-90	2,285	11,433	4,917	0	10,663	38,830	0	44	129	1,432	1,850	565	72,147
1990-91	4,066	656	102,552	59,553	69,857	0	682	462	0	938	0	0	238,765
1991-92	1,844	22,840	75,495	155	54,809	2,440	581	462	**2,485**	**689**	**615**	**1,161**	163,576
Ave.	8,520	18,507	33,860	22,730	25,808	6,398	581	462	2,604	722	644	1,217	122,053

To answer these questions the calculated values for monthly and annual runoff were compared to the holding capacity of each pond. For the sake of simplicity, the monthly comparison uses monthly totals for years of high, low, and average runoff instead of trying to graph monthly totals for all 21 years. This comparison helps illustrate the maximum possible range of monthly runoff values and the number of months necessary for the ponds to fill. The annual comparison compares yearly totals for all 21 years to holding capacity. A third comparison was done to test the runoff calculations for sensitivity to error. If the methods used to calculate runoff for this study resulted in over-statement of runoff quantities, how much can the calculations be off before the study ponds would not fill? For this comparison, runoff values were halved and compared to the ponds' holding capacities. The results of these comparisons are presented in Appendix D. Note: For purposes of continuing, the calculations do reveal that for all 21 years of available data, total annual runoff was sufficient to fill the ponds. As well, during the 21-year data span, there occurred years where runoff from singular months was sufficient to fill the ponds.

4.13 Calculation of Stored Water Loss

Having established that the ponds can and do fill, the study looks at how much water is currently lost from the ponds once captured. Stored water is lost from the ponds in the following ways:

- Evaporation (from surface)
- Infiltration (through pond floor and berm)
- Animal Consumption (when water available & animals allowed access)
- Irrigation (not currently practiced in the case of the four selected ponds because

of water deficiency)

Because the farmers indicate that the ponds are always dry by the months of November or December, this study will assume that total annual loss is greater than total runoff catchment (not necessarily greater than total annual runoff generation within the catchment area) 100% of the time. To determine the water benefit to be generated by lining the ponds, this study quantifies each source of loss.

4.14 Calculation of Stored Water Loss Due to Evaporation

Similar to rainfall data, evaporation data is not widely available and tends to be discontinuous in its record (i.e. recorded for some years, but not others). To create a data record corresponding to the 21-year rainfall record, evaporation pan data was aggregated from the Granja Carnation and San Miguel Tilaxcalte weather stations. Tables 97 & 98 (Appendix D) show the data available from the two stations.

Again, because of its proximity to the study site (7 km.), the Granja Carnation data was selected to represent the evaporation conditions of El Rincón. To adjust for differences in evaporation rates between the two stations, a comparison was made of the monthly averages of each station to calculate month-specific adjustment factors, where the adjustment factor = Granja Carnation data / San Miguel Tilaxcalte data. Table 99 (Appendix D) shows the calculation of these factors. The factors were subsequently used to adjust the San Miguel Tilaxcalte data. Once adjusted, the San Miguel Tilaxcalte data was added to the Granja Carnation data, creating a data history for the years 1976-1988. The monthly averages of this aggregated data were then used to represent missing data for the years (1971-1975 and 1989-1991). Table 100 (Appendix D) shows the aggregated data.

To represent the evaporation loss occurring in a larger body of water such as a pond or lake, evaporation pan data from a U.S. Class A Pan is normally adjusted by a coefficient of .7 (Sharp, 1984). This coefficient reflects differences in evaporation rates between a large body of water such as a lake and a small metal pan – which tends to heat up faster, increasing the water temperature and evaporation rate). The .7 coefficient is used in this study as well, however, because the volume of water contained in each pond changes as a function of seasonal runoff, two adjustments were made to the data (Belcher, 1999).

The month-to-month changes in stored water volume affect not only the surface area of water exposed to evaporation forces, but also the rate of evaporation as a function of temperature differences (Belcher, 1998). For the months when the ponds are estimated (based on farmer reports) to be full (June – August), the .7 coefficient is used. During the months when the ponds contain less water, a higher coefficient should be used to reflect higher water temperatures (i.e. higher evaporation rates). Thus, it is assumed that the more empty the pond, the more evaporation loss will resemble that of a metal pan (approaching a coefficient of 1.0). Dr. Harold Belcher (1999), an agricultural engineer at Michigan State University, suggested using a coefficient of .85 for those months when the ponds are near empty. To account for the gradual change between maximum and minimum pond capacity (Oct.- Jan. and May- July), the difference between .7 and .85 was divided incrementally among the intervening months. Table 6 below shows the coefficient used for each month.

Table 6 Evaporation Pan Coefficients

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Pan Coefficient	0.85	0.85	0.85	0.85	0.775	0.7375	0.7	0.7	0.7	0.7375	0.775	0.8125

To account for monthly changes in the surface area of water exposed to evaporation forces, percentage estimates of the maximum pond surface area were assigned to each month. For the months when the ponds are estimated to be full (June - August), the pan coefficient and data are applied to 100% of each pond's maximum surface area. For the months when the ponds are estimated to be empty or near empty, the pan coefficient and data are applied to only 10% of the total surface area. Again, the difference between the two percentage extremes was distributed incrementally among the intervening months to reflect gradual increases and decreases in water volume (from the rainy season to the dry season). Table 7 (below) shows the month-specific coefficients used to adjust pond surface area:

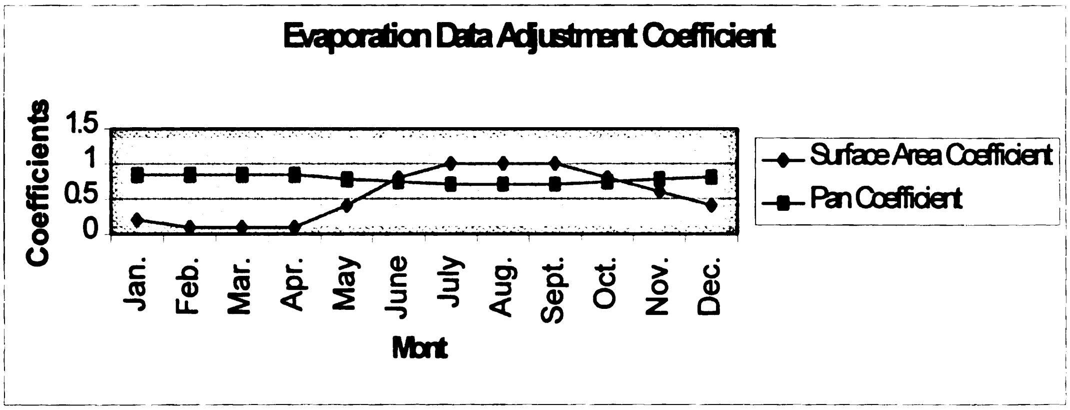
Table 7 Evaporation Surface Area Coefficients

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Area Coefficient	0.2	0.1	0.1	0.1	0.4	0.8	1	1	1	0.8	0.6	0.4

Thus, as pond volume increases, the area exposed to evaporation increases, but the rate of evaporation decreases. This inverse relationship is illustrated in Figure 4 (facing page).

All adjustment factors and coefficients were subsequently applied to the 21-year evaporation pan data, and then multiplied by the total surface area of each pond to calculate evaporation loss in cubic meters. The 21-year monthly totals for evaporation loss are presented in Tables 8-11 (pages 70-73). Note: These tables are set up to correspond to the tables of runoff totals). These values represent the amounts of stored water lost each month from evaporation, which can in turn, be subtracted from values of total runoff for corresponding months).

Figure 4. Evaporation Data Adjustment Coefficients



4.15 Calculation of Animal Consumption

Because the farmers own relatively few livestock that consume water from the ponds during only those months when water is available, consumption loss is quite low relative to evaporation and infiltration. Lacking data about the numbers of livestock owned by each farmer for the period 1971-1991, it was decided to calculate consumption based on the number of animals owned currently and use consumption as a constant for all 21 years.

Monthly and annual consumption totals were calculated using daily water requirements for the kinds and number of livestock accessing the ponds and estimated number of days of access. By doing so, this study assumes that during those months when water is available, the animals meet 100% of their daily water requirement from the ponds. This is likely not the case as the animals are often free to roam and may have access to other water sources. As well, the data used for daily consumption rates pertains to livestock in the U.S. Those of El Rincón tend to be smaller and less well nourished –

Table 8 **Evaporation Loss from Pond Surface in Cubic Meters - Pond 1**

Surface Area = 2,903 sq. meters

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*	Total
1970-71	184	254	275	270	252	216	140	96	54	33	41	40	1,855
1971-72	184	254	275	270	252	216	140	96	54	33	41	40	1,855
1972-73	184	254	275	270	252	216	140	96	54	33	41	40	1,855
1973-74	184	254	275	270	252	216	140	96	54	33	41	40	1,855
1974-75	184	254	275	270	252	216	140	96	54	33	41	40	1,855
1975-76	184	254	275	270	252	216	140	96	54	33	41	40	1,855
1976-77	184	254	268	275	302	209	133	89	63	36	57	51	1,921
1977-78	220	318	283	288	277	237	144	92	60	32	58	45	2,054
1978-79	282	253	262	334	257	242	128	146	70	36	51	46	2,106
1979-80	270	315	326	253	260	287	166	88	61	35	54	38	2,152
1980-81	196	310	342	290	328	189	119	89	39	23	33	54	2,012
1981-82	185	315	328	300	261	197	152	114	70	36	45	55	2,058
1982-83	166	351	336	315	284	222	160	115	52	43	46	45	2,135
1983-84	203	335	264	274	233	187	125	66	48	32	38	29	1,834
1984-85	156	244	275	249	203	219	140	104	56	26	31	34	1,737
1985-86	140	161	216	258	265	292	176	95	54	29	39	28	1,753
1986-87	135	202	279	303	242	218	154	125	51	33	22	16	1,779
1987-88	184	136	115	99	111	216	140	63	26	33	17	40	1,179
1988-89	73	111	275	270	252	98	85	60	54	33	41	40	1,390
1989-90	184	254	275	270	252	216	140	96	54	33	41	40	1,855
1990-91	184	254	275	270	252	216	140	96	54	33	41	40	1,855
1991-92	184	254	275	270	252	216	140	96	54	33	41	40	1,855
Ave.	184	254	275	270	252	216	140	96	54	33	41	40	1,855

Table 9 **Evaporation Loss from Pond Surface In Cubic Meters - Pond 2**

Surface Area = 1,979 sq. meters

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*	Total
1970-71	126	173	187	184	172	147	96	65	37	22	28	27	1,264
1971-72	126	173	187	184	172	147	96	65	37	22	28	27	1,264
1972-73	126	173	187	184	172	147	96	65	37	22	28	27	1,264
1973-74	126	173	187	184	172	147	96	65	37	22	28	27	1,264
1974-75	126	173	187	184	172	147	96	65	37	22	28	27	1,264
1975-76	126	173	187	184	172	147	96	65	37	22	28	27	1,264
1976-77	126	173	183	187	206	143	90	60	43	25	39	35	1,310
1977-78	150	217	193	196	189	162	98	63	41	22	40	31	1,400
1978-79	192	173	179	227	175	165	87	99	47	25	35	32	1,436
1979-80	184	215	222	172	177	195	113	60	42	24	37	26	1,467
1980-81	134	212	233	197	224	129	81	61	27	16	23	37	1,372
1981-82	126	215	224	204	178	134	104	78	48	24	31	37	1,403
1982-83	113	239	229	215	194	152	109	78	35	29	31	30	1,456
1983-84	139	228	180	187	159	127	85	45	33	22	26	20	1,250
1984-85	106	166	187	170	138	149	96	71	38	18	21	23	1,184
1985-86	95	110	147	176	180	199	120	64	37	20	27	19	1,195
1986-87	92	137	190	207	165	148	105	86	34	22	15	11	1,213
1987-88	126	92	78	68	75	147	96	43	17	22	11	27	804
1988-89	50	75	187	184	172	67	58	41	37	22	28	27	948
1989-90	126	173	187	184	172	147	96	65	37	22	28	27	1,264
1990-91	126	173	187	184	172	147	96	65	37	22	28	27	1,264
1991-92	126	173	187	184	172	147	96	65	37	22	28	27	1,264
Ave.	126	173	187	184	172	147	96	65	37	22	28	27	1,264

Table 10 **Evaporation Loss from Pond Surface in Cubic Meters - Pond 3**

Surface Area = 9,125 sq. meters

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*	Total
1970-71	579	799	863	848	792	680	440	301	171	103	129	126	5,830
1971-72	579	799	863	848	792	680	440	301	171	103	129	126	5,830
1972-73	579	799	863	848	792	680	440	301	171	103	129	126	5,830
1973-74	579	799	863	848	792	680	440	301	171	103	129	126	5,830
1974-75	579	799	863	848	792	680	440	301	171	103	129	126	5,830
1975-76	579	799	863	848	792	680	440	301	171	103	129	126	5,830
1976-77	579	799	844	863	949	657	417	279	198	113	180	162	6,039
1977-78	690	999	891	904	870	745	452	290	190	101	183	142	6,457
1978-79	886	796	823	1,049	809	762	401	458	219	113	160	146	6,621
1979-80	847	990	1,024	794	818	901	522	277	192	109	171	120	6,764
1980-81	616	976	1,076	910	1,031	594	373	279	123	72	104	171	6,325
1981-82	581	990	1,032	943	821	619	478	358	221	112	142	172	6,470
1982-83	522	1,103	1,056	990	892	699	504	361	163	135	145	141	6,711
1983-84	639	1,052	830	860	732	586	393	207	152	100	120	92	5,766
1984-85	490	767	863	784	638	688	440	328	175	82	97	107	5,459
1985-86	440	507	679	811	832	918	553	297	170	91	123	87	5,509
1986-87	423	633	876	954	759	684	485	394	159	103	70	50	5,591
1987-88	579	426	361	311	348	680	440	199	80	103	52	126	3,706
1988-89	230	347	863	848	792	308	267	188	171	103	129	126	4,370
1989-90	579	799	863	848	792	680	440	301	171	103	129	126	5,830
1990-91	579	799	863	848	792	680	440	301	171	103	129	126	5,830
1991-92	579	799	863	848	792	680	440	301	171	103	129	126	5,830
Ave.	579	799	863	848	792	680	440	301	170	103	129	126	5,830

Table 11 **Evaporation Loss from Pond Surface in Cubic Meters - Pond 4**

Surface Area = 2,254 sq. meters

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*	Total
1970-71	143	197	213	209	196	168	109	74	42	25	32	31	1,440
1971-72	143	197	213	209	196	168	109	74	42	25	32	31	1,440
1972-73	143	197	213	209	196	168	109	74	42	25	32	31	1,440
1973-74	143	197	213	209	196	168	109	74	42	25	32	31	1,440
1974-75	143	197	213	209	196	168	109	74	42	25	32	31	1,440
1975-76	143	197	213	209	196	168	109	74	42	25	32	31	1,440
1976-77	143	197	208	213	234	162	103	69	49	28	44	40	1,492
1977-78	171	247	220	223	215	184	112	72	47	25	45	35	1,595
1978-79	219	197	203	259	200	188	99	113	54	28	39	36	1,636
1979-80	209	244	253	196	202	222	129	68	47	27	42	30	1,671
1980-81	152	241	266	225	255	147	92	69	30	18	26	42	1,562
1981-82	144	244	255	233	203	153	118	89	55	28	35	43	1,598
1982-83	129	272	261	245	220	173	124	89	40	33	36	35	1,658
1983-84	158	260	205	212	181	145	97	51	38	25	30	23	1,424
1984-85	121	190	213	194	157	170	109	81	43	20	24	26	1,349
1985-86	109	125	168	200	205	227	137	73	42	23	30	21	1,361
1986-87	105	156	216	236	188	169	120	97	39	25	17	12	1,381
1987-88	143	105	89	77	86	168	109	49	20	25	13	31	915
1988-89	57	86	213	209	196	76	66	46	42	25	32	31	1,080
1989-90	143	197	213	209	196	168	109	74	42	25	32	31	1,440
1990-91	143	197	213	209	196	168	109	74	42	25	32	31	1,440
1991-92	143	197	213	209	196	168	109	74	42	25	32	31	1,440
Ave.	143	197	213	209	196	168	109	74	42	25	32	31	1,440

therefore likely to consume less water per day. This potential overstatement of consumption loss is likely balanced by the possibility of animals from neighboring farmers consuming water from the study ponds. Without more accurate data, the stated technique represents a best guess scenario of consumption patterns. Animal consumption loss in cubic meters is presented for each pond in Tables 12-15 (facing page).

4.16 Calculation of Stored Water Loss Due to Infiltration

In the absence of empirical data for soil infiltration rates, this study estimates infiltration loss as a multiple of evaporation using calculated quantities of runoff, evaporation, and livestock consumption, in conjunction with anecdotal evidence about year-end pond water levels as parameters for a calculation model. Because the farmers indicate that their ponds consistently go dry between the months of November and January every year, it can be assumed that total annual loss (evaporation plus infiltration plus consumption) is greater than total annual runoff capture for any given year (i.e. storage carryover between years is zero). Thus, the combined quantities of evaporation, infiltration, and consumption must be greater than the quantity of runoff capture for the May – November period. (Again, it is important to distinguish between total runoff and total capture as more runoff may occur than that which is actually captured.) The assumption made here is that an infiltration rate that produces an empty pond (zero water balance) would approximate actual infiltration rates were such empirical data available.

For each month, monthly totals for evaporation and livestock consumption were subtracted from either total monthly runoff or maximum pond capacity - in cases where monthly runoff exceeds capacity. An estimated value for infiltration was also subtracted from runoff. The difference between capture and loss was treated as a carry-

Table 12 **Animal Consumption Loss in Cu. M. - Pond 1**

Animal	Gal./Day	No.	Gal./Mo.	No. Mo.	Gal./Yr.	Cu. Mtrs.
Bovine	15	15	6,750	12	81,000	307
Equine	15	4	1,800	12	21,600	82
Ovine	2	10	600	12	7,200	27
				Total	109,800	416

Table 13 **Animal Consumption Loss in Cu. M. - Pond 2**

Animal	Gal./Day	No.	Gal./Mo.	No. Mo.	Gal./Yr.	Cu. Mtrs.
Bovine	15	7	3,150	12	37,800	143
Equine	15	1	450	12	5,400	20
				Total	43,200	164

Table 14 **Animal Consumption Loss in Cu. M. - Pond 3**

Animal	Gal./Day	No.	Gal./Mo.	No. Mo.	Gal./Yr.	Cu. Mtrs.
Bovine	15	4	1,800	12	21,600	82
Ovine	2	5	300	12	3,600	14
Equine	15	2	900	12	10,800	41
				Total	36,000	136

Table 15 **Animal Consumption Loss in Cu. M. - Pond 4**

Animal	Gal./Day	No.	Gal./Mo.	No. Mo.	Gal./Yr.	Cu. Mtrs.
Bovine	15	7	3,150	12	37,800	143
Equine	15	4	1,800	12	21,600	82
				Total	59,400	225

over value and added to the runoff quantity of the subsequent month. These calculations for loss and carryover were performed for each month using different infiltration rates to find a zero water balance by the months of November to December. To find the maximum possible range of infiltration loss without performing these laborious calculations 84 times (4 ponds x 21 years of rainfall runoff data) infiltration rates were modeled for three different kinds of years: the year of highest total runoff, the year of lowest total runoff, and the year of average runoff for the 21 years. Tables 16-27 (facing pages) show the zero-producing infiltration multiples calculated for each pond for the three types of runoff years.

4.17 Comparison of Stored Water Loss

Having calculated totals for all three sources of stored water loss, a comparison was made to illustrate how water is lost from the ponds. Again, instead of comparing values for all 21 years, a comparison was made for high, low, and average runoff years for all four ponds. The results of these comparisons are presented in Appendix D.

4.18 Re-Calculation of Evaporation Under Project Conditions

In a lined pond scenario, evaporation from pond surfaces will be different than from unlined ponds since more water will retained in lined ponds – and thus a greater surface area will be exposed to the evaporation forces of sun and wind. However, because there is more water in the ponds, its temperature will also be cooler as the sun's energy is distributed over a greater mass. Thus, to create a more accurate picture of a water surplus created by lining ponds, it is necessary to adjust the coefficients for evaporation. Note: This study also proposes re-shaping the ponds in preparation for lining, making them deeper with less exposed surface area, with no net change in volume.

Table 16 **Zero Water Balance - Producing Infiltration Rate - Pond 1- Average Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 1	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612
Tot. Runoff	1,936	4,206	7,696	5,166	5,865	1,454	132	105	592	164	146	277
Less Evaporation	1,752	3,952	7,421	4,896	5,614	1,238	-8	9	538	131	105	236
Less Consumption	1,718	3,917	7,386	4,862	5,579	1,203	-43	-26	503	97	71	202
Less Infiltration	61	1,630	4,916	2,434	3,312	-744	-1,304	-888	15	-198	-298	-159
Mo.-end Water Qty.	61	1,691	2,612	2,612	2,612	1,868	564	0	0	0	0	0
Infiltration Multiple	9	9	9	9	9	9	9	9	9	9	9	9

Table 17 **Zero Water Balance - Producing Infiltration Rate - Pond 1- Highest Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 1	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612
Tot. Runoff	924	149	23,307	13,535	15,877	0	155	105	0	213	0	0
Less Evaporation	740	-105	23,033	13,265	15,625	-216	15	9	-54	180	-41	-40
Less Consumption	705	-140	22,998	13,230	15,590	-251	-20	-26	-89	146	-76	-75
Less Infiltration	-399	-1,665	21,351	11,612	14,079	-1,549	-861	-601	-415	-51	-321	-315
Mo.-end Water Qty.	0	0	2,612	2,612	2,612	1,063	202	0	0	0	0	0
Infiltration Multiple	6	6	6	6	6	6	6	6	6	6	6	6

Table 18 **Zero Water Balance - Producing Infiltration Rate - Pond 1- Lowest Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 1	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612
Tot. Runoff	129	1,135	4,697	111	2,191	3	260	0	0	0	0	362
Less Evaporation	-55	881	4,422	-159	1,939	-213	120	-96	-54	-33	-41	322
Less Consumption	-89	846	4,387	-193	1,905	-248	85	-130	-89	-67	-76	287
Less Infiltration	-1,194	-679	2,740	-1,812	393	-1,546	-755	-705	-415	-264	-321	47
Mo.-end Water Qty.	0	0	2,612	800	1,194	0	0	0	0	0	0	0
Infiltration Multiple	6	6	6	6	6	6	6	6	6	6	6	6

Table 19 **Zero Water Balance - Producing Infiltration Rate - Pond 2- Average Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 2	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979
Tot. Runoff	1,162	2,524	4,617	3,100	3,519	873	79	63	355	98	88	166
Less Evaporation	1,036	2,350	4,430	2,916	3,348	725	-16	-2	318	76	60	139
Less Consumption	1,023	2,337	4,417	2,902	3,334	711	-30	-16	304	62	46	125
Less Infiltration	-107	778	2,732	1,247	1,789	-616	-890	-604	-28	-139	-205	-121
Mo.-end Water Qty.	0	778	1,979	1,979	1,979	1,363	473	0	0	0	0	0
Infiltration Multiple	9	9	9	9	9	9	9	9	9	9	9	9

Table 20 **Zero Water Balance - Producing Infiltration Rate - Pond 2- Highest Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 2	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979
Tot. Runoff	554	89	13,984	8,121	9,526	0	93	63	0	128	0	0
Less Evaporation	429	-84	13,797	7,937	9,354	-147	-3	-2	-37	106	-28	-27
Less Consumption	415	-97	13,784	7,923	9,341	-161	-16	-16	-51	92	-42	-41
Less Infiltration	-589	-1,483	12,286	6,452	7,967	-1,341	-780	-539	-347	-87	-265	-259
Mo.-end Water Qty.	0	0	1,979	1,979	1,979	638	0	0	0	0	0	0
Infiltration Multiple	8	8	8	8	8	8	8	8	8	8	8	8

Table 21 **Zero Water Balance - Producing Infiltration Rate - Pond 2- Lowest Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 2	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979
Tot. Runoff	78	681	2,818	67	1,315	2	156	0	0	0	0	217
Less Evaporation	-48	508	2,631	-117	1,143	-146	61	-65	-37	-22	-28	190
Less Consumption	-62	494	2,617	-131	1,129	-159	47	-79	-51	-36	-42	176
Less Infiltration	-689	-372	1,681	-1,050	271	-897	-431	-406	-236	-148	-181	40
Mo.-end Water Qty.	0	0	1,681	631	902	5	0	0	0	0	0	0
Infiltration Multiple	5	5	5	5	5	5	5	5	5	5	5	5

Table 22 Zero Water Balance - Producing Infiltration Rate - Pond 3- Average Runoff Year

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 3	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125
Tot. Runoff	8,520	18,507	33,860	22,730	25,808	6,398	581	462	2,604	722	644	1,217
Less Evaporation	7,942	17,708	32,997	21,882	25,016	5,718	140	160	2,433	619	515	1,091
Less Consumption	7,930	17,697	32,986	21,871	25,005	5,707	129	149	2,422	607	504	1,079
Less Infiltration	1,564	8,909	23,493	12,545	16,296	-1,773	-4,716	-3,164	547	-526	-913	-309
Mon.-end Water Qty.	1,564	9,125	9,125	9,125	9,125	7,352	2,635	0	547	21	0	0
Infiltration Multiple	11	11	11	11	11	11	11	11	11	11	11	11

Table 23 Zero Water Balance - Producing Infiltration Rate - Pond 3- Highest Runoff Year

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 3	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125
Tot. Runoff	4,066	656	102,552	59,553	69,857	0	682	462	0	938	0	0
Less Evaporation	3,487	-143	101,689	58,706	69,066	-680	241	160	-171	835	-129	-126
Less Consumption	3,476	-154	101,677	58,694	69,054	-692	230	149	-182	823	-140	-138
Less Infiltration	-2,890	-8,942	92,185	49,368	60,345	-8,172	-4,616	-3,165	-2,059	-311	-1,556	-1,523
Mo.-end Water Qty.	0	0	9,125	9,125	9,125	953	0	0	0	0	0	0
Infiltration Multiple	11	11	11	11	11	11	11	11	11	11	11	11

Table 24 Zero Water Balance - Producing Infiltration Rate - Pond 3- Lowest Runoff Year

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 3	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125
Tot. Runoff	569	4,993	20,665	488	9,641	13	1,144	0	0	0	0	1,592
Less Evaporation	-9	4,194	19,802	-360	8,849	-667	704	-301	-171	-103	-129	1,466
Less Consumption	-21	4,182	19,791	-371	8,838	-679	692	-313	-182	-115	-140	1,454
Less Infiltration	-3,493	-611	14,613	-5,458	4,088	-4,759	-1,951	-2,120	-1,206	-733	-912	698
Mo.-end Water Qty.	0	0	9,125	3,667	7,755	2,996	1,045	0	0	0	0	0
Infiltration Multiple	6	6	6	6	6	6	6	6	6	6	6	6

Table 25 **Zero Water Balance - Producing Infiltration Rate - Pond 4- Average Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 4	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029
Tot. Runoff	1,936	4,206	7,696	5,166	5,865	1,454	132	105	592	164	146	277
Less Evaporation	1,793	4,009	7,482	4,957	5,670	1,286	23	30	550	139	115	245
Less Consumption	1,775	3,990	7,464	4,938	5,651	1,267	4	12	531	120	96	227
Less Infiltration	345	2,017	5,332	2,844	3,696	-412	-1,084	-732	110	-135	-222	-85
Mo.-end Water Qty.	345	2,029	2,029	2,029	2,029	1,616	533	0	0	0	0	0
Infiltration Multiple	10	10	10	10	10	10	10	10	10	10	10	10

Table 26 **Zero Water Balance - Producing Infiltration Rate - Pond 4- Highest Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 4	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029
Tot. Runoff	924	149	23,307	13,535	15,877	0	155	105	0	213	0	0
Less Evaporation	781	-48	23,094	13,325	15,681	-168	46	31	-42	188	-32	-31
Less Consumption	762	-67	23,075	13,307	15,662	-187	27	12	-61	169	-51	-50
Less Infiltration	-95	-1,251	21,796	12,050	14,489	-1,195	-625	-435	-314	16	-241	-236
Mo.-end Water Qty.	0	0	2,029	2,029	2,029	834	209	0	0	16	0	0
Infiltration Multiple	6	6	6	6	6	6	6	6	6	6	6	6

Table 27 **Zero Water Balance - Producing Infiltration Rate - Pond 4- Lowest Runoff Year**

	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
Capacity - Pond 4	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029	2,029
Tot. Runoff	129	1,135	4,697	111	2,191	3	260	0	0	0	0	362
Less Evaporation	-14	937	4,483	-98	1,996	-165	151	-74	-42	-25	-32	331
Less Consumption	-32	919	4,465	-117	1,977	-184	133	-93	-61	-44	-51	312
Less Infiltration	-890	-265	3,186	-1,374	804	-1,192	-520	-540	-314	-197	-241	125
Mo.-end Water Qty.	0	0	2,029	655	1,458	267	0	0	0	0	0	0
Infiltration Multiple	6	6	6	6	6	6	6	6	6	6	6	6

However, since final dimensions are unknown, this study relies on the current dimensions to re-calculate evaporation. This should affect study results only by slightly overstating evaporation loss and thus slightly understating the potential water surplus created by liners.

The same calculation models used to model infiltration loss (see Tables 16-27), show that for most months, runoff generated within the pond catchment areas is greater than evaporation alone (i.e. by eliminating infiltration and consumption, ponds will stay full because more water is supplied to ponds in runoff each month than is lost due to evaporation). Thus, for purposes of calculation, it is assumed here that under project conditions, evaporation will take place from ponds that are full, or close to full. As such, pan evaporation data was re-adjusted by the .7 pan evaporation coefficient to calculate evaporation loss for project conditions (i.e. the recommended coefficient for larger bodies of water). Also, because under project conditions, the ponds will stay closer to full, the adjusted evaporation data was multiplied by 100% of the pond surface area (versus the changing percentage of total surface area used in previous calculations). Because pan evaporation data was not available for all 21 years corresponding to rainfall data, the monthly averages of the available data were used in these calculations. These annual evaporation totals (see Tables 28-30 facing page) were then used as yearly constants for the calculation of a project-generated water surplus (i.e. the same quantities of total annual evaporation were used every year in the calculation of water surplus).

4.19 Calculation of Project-Generated Water Surplus

Having quantified runoff and all sources of loss, it is now possible to quantify a hydrological benefit provided by eliminating one or more sources of loss – infiltration in

Table 28 Re- Calculation of Ave. Evaporation for Lined Pond - Ponds 1 & 4

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yrly. Tot.
	0	0	0	0	0	0	0	0	0	0	0	0	1
Pond 1	223	270	337	331	416	302	275	270	252	257	211	206	3,348
Pond 4	173	209	262	257	323	234	213	209	196	199	164	160	2,600

Oct.-Apr. Total - Pond 1 = 1,835 cu. M.
Oct.-Apr. Total - Pond 4 = 1,424 cu. M.

Table 29 Re- Calculation of Ave. Evaporation for Lined Pond - Pond 2

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yrly. Tot.
0	0	0	0	0	0	0	0	0	0	0	0	1
152	184	230	225	283	206	187	184	172	175	144	141	2,283

Oct.-Apr. Total = 1,250 cu. M.

Table 30 Re-Calculation of Ave. Evaporation for Lined Pond - Pond 3

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yrly. Tot.
0	0	0	0	0	0	0	0	0	0	0	0	1
702	848	1,061	1,039	1,307	948	863	848	792	807	663	649	10,525

Oct.-Apr. Total = 5,768 cu. M.

this case. Thus, the project-generated surplus (or quantity of water available for agricultural use in May) will equal some quantity of runoff catchment from the previous year minus some quantity of evaporation. The results of the monthly runoff analysis (see Appendix D) indicate that for an average year, September is the last month during which runoff of a singular month is sufficient to fill the ponds. Similarly, the models used to calculate infiltration (Tables 16-27) show that Total Runoff – Total Loss is almost always greater than holding capacity for the month of September. Therefore, it is assumed here that under project conditions, ponds will be full at the end of every September, and any water surplus will equal the full pond value minus the difference between total runoff and total evaporation for the months of October – April. Note: Animal consumption is not factored as loss in the lined pond scenario since lining ponds necessitates fencing out livestock who can damage the liners. In years where October – April runoff is greater than evaporation, the project surplus will equal pond capacity (since additional runoff cannot be held by an already full pond). For years where October – April runoff is less than evaporation, the project surplus will equal pond capacity minus the net quantity (positive) of evaporation.

A value for year-end water surplus was calculated for each pond and all 21 years. For the sake of simplicity, it was decided to make the average of the 21-year surpluses represent the average with-project water surplus. In other words, using 21 different surplus values to calculate changes in crop production would be more work than possible for this particular study. The 21-year average of these yearly totals was used as a best predictor of project-generated benefits, as well as for the calculation of agricultural production under project conditions. Tables 31-34 (facing pages) show the calculation of the project-generated water surpluses.

4.20 Calculation of Production Land Base as a Function of Project-Generated Water Surplus

Economic values for the project-generated water surpluses were calculated by estimating their production enhancing effects on two crops: corn and cempasuchil. The interviewed farmers as well as Eduardo Garcia have indicated that when practiced, punta de riego typically produces corn yields of 3-4 tons per hectare, and per his recommendation a value of 3.6 tons/ha. was used for this study. While no data is available as to how much water is applied (required) per hectare to produce such corn yields, the farmers have indicated that a punta de riego water application typically lasts 12-24 hours per hectare. This study assumes that such an application might constitute the equivalent of a 3 inch rainfall, which is 81,462 gallons (or 762 cu. m.) of water applied per hectare (NRCS, 1997). Thus, it is assumed here that to produce 3.6 tons of corn per hectare requires a one-time application of 762 cubic meters of water per hectare. Thus, to calculate the quantity of corn-producing land that could be irrigated with project-generated water, the surplus amount for each pond (21-year average) was divided by 762.

Calculating the water requirement for cempasuchil production is slightly more complex. Production of the crop involves the creation of a small seed germination plot and the eventual transfer of seedlings to larger growing plots. According to INEGI, (1997), the total process of preparing germination plots and harvesting seedlings requires a total of 12 irrigations – though not particularly heavy ones. To calculate the total water requirement for germination plots, this study uses the recommended plot size of 25 x 25

Table 31 Calculation of With-Project Water Surplus
Pond 1

Year	Capac.	Oct.-Apr. Runoff	Oct.-Apr. Evap.	Difference	Surplus
1971-72	2,612	3,093	1,835	1,258	2,612
1972-73	2,612	625	1,835	-1,210	1,402
1973-74	2,612	880	1,835	-955	1,657
1974-75	2,612	5,150	1,835	3,315	2,612
1975-76	2,612	1,998	1,835	163	2,612
1976-77	2,612	3,590	1,835	1,755	2,612
1977-78	2,612	2,544	1,835	709	2,612
1978-79	2,612	6,987	1,835	5,152	2,612
1979-80	2,612	8,394	1,835	6,559	2,612
1980-81	2,612	3,752	1,835	1,917	2,612
1981-82	2,612	1,811	1,835	-24	2,588
1982-83	2,612	3,466	1,835	1,631	2,612
1983-84	2,612	379	1,835	-1,456	1,156
1984-85	2,612	1,044	1,835	-791	1,821
1985-86	2,612	1,797	1,835	-38	2,574
1986-87	2,612	2,193	1,835	358	2,612
1987-88	2,612	239	1,835	-1,596	1,016
1988-89	2,612	195	1,835	-1,640	972
1989-90	2,612	9,739	1,835	7,904	2,612
1990-91	2,612	473	1,835	-1,362	1,250
1991-92	2,612	1,917	1,835	82	2,612
				AVE.	2,180

Table 32 Calculation of With-Project Water Surplus
Pond 2

Year	Capac.	Oct.-Apr. Runoff	Oct.-Apr. Evap.	Difference	Surplus
1971-72	1,979	1,856	1,251	605	1,979
1972-73	1,979	375	1,251	-876	1,103
1973-74	1,979	528	1,251	-723	1,256
1974-75	1,979	3,090	1,251	1,839	1,979
1975-76	1,979	1,199	1,251	-52	1,927
1976-77	1,979	2,154	1,251	903	1,979
1977-78	1,979	1,526	1,251	275	1,979
1978-79	1,979	4,192	1,251	2,941	1,979
1979-80	1,979	5,036	1,251	3,785	1,979
1980-81	1,979	2,251	1,251	1,000	1,979
1981-82	1,979	1,087	1,251	-164	1,815
1982-83	1,979	2,080	1,251	829	1,979
1983-84	1,979	227	1,251	-1,024	955
1984-85	1,979	627	1,251	-624	1,355
1985-86	1,979	1,078	1,251	-173	1,806
1986-87	1,979	1,316	1,251	65	1,979
1987-88	1,979	144	1,251	-1,107	872
1988-89	1,979	117	1,251	-1,134	845
1989-90	1,979	5,843	1,251	4,592	1,979
1990-91	1,979	284	1,251	-967	1,012
1991-92	1,979	1,150	1,251	-101	1,878
				AVE.	1,648

Table 33 Calculation of With-Project Water Surplus
Pond 3

		Oct.-Apr.	Oct.-Apr.		
Year	Capac.	Runoff	Evap.	Difference	Surplus
1971-72	9,125	13,607	5,768	7,839	9,125
1972-73	9,125	2,748	5,768	-3,020	6,105
1973-74	9,125	3,872	5,768	-1,896	7,229
1974-75	9,125	22,659	5,768	16,890	9,125
1975-76	9,125	8,789	5,768	3,021	9,125
1976-77	9,125	15,796	5,768	10,028	9,125
1977-78	9,125	11,194	5,768	5,425	9,125
1978-79	9,125	30,744	5,768	24,975	9,125
1979-80	9,125	36,932	5,768	31,164	9,125
1980-81	9,125	16,510	5,768	10,742	9,125
1981-82	9,125	7,969	5,768	2,201	9,125
1982-83	9,125	15,250	5,768	9,482	9,125
1983-84	9,125	1,665	5,768	-4,103	5,022
1984-85	9,125	4,595	5,768	-1,174	7,951
1985-86	9,125	7,908	5,768	2,140	9,125
1986-87	9,125	9,650	5,768	3,882	9,125
1987-88	9,125	1,053	5,768	-4,715	4,410
1988-89	9,125	860	5,768	-4,908	4,217
1989-90	9,125	42,850	5,768	37,082	9,125
1990-91	9,125	2,081	5,768	-3,687	5,438
1991-92	9,125	8,433	5,768	2,665	9,125
				AVE.	8,006

Table 34 Calculation of With-Project Water Surplus
Pond 4

		Oct.-Apr.	Oct.-Apr.		
Year	Capac.	Runoff	Evap.	Difference	Surplus
1971-72	2,029	3,093	1,425	1,668	2,029
1972-73	2,029	625	1,425	-800	1,228
1973-74	2,029	880	1,425	-545	1,484
1974-75	2,029	5,150	1,425	3,725	2,029
1975-76	2,029	1,998	1,425	573	2,029
1976-77	2,029	3,590	1,425	2,165	2,029
1977-78	2,029	2,544	1,425	1,119	2,029
1978-79	2,029	6,987	1,425	5,562	2,029
1979-80	2,029	8,394	1,425	6,969	2,029
1980-81	2,029	3,752	1,425	2,327	2,029
1981-82	2,029	1,811	1,425	386	2,029
1982-83	2,029	3,466	1,425	2,041	2,029
1983-84	2,029	379	1,425	-1,046	982
1984-85	2,029	1,044	1,425	-381	1,648
1985-86	2,029	1,797	1,425	372	2,029
1986-87	2,029	2,193	1,425	768	2,029
1987-88	2,029	239	1,425	-1,186	843
1988-89	2,029	195	1,425	-1,230	799
1989-90	2,029	9,739	1,425	8,314	2,029
1990-91	2,029	473	1,425	-952	1,076
1991-92	2,029	1,917	1,425	492	2,029
				AVE.	1,736

meters INEGI, (1997), and assumes that each irrigation might constitute the equivalent of 1.5 inches of rainfall. Thus, one-half of a three inch rainfall (762 cu. m./hectare) for a 625 sq. meter area would be 22.86 cu. m. per irrigation – or 274 cu. m. of water needed for the establishment of cempasuchil seedlings.

Generally, five cempasuchil crops (cuttings) can be harvested from each plot per season with one irrigation after each cutting. Thus, this study calculates the water requirement for five growing plot irrigations. Unlike the punta de riego process which involves one heavier irrigation (assumed equal to 3 inches), cempasuchil requires more irrigations spaced evenly over the growing period. For that reason, it is assumed here that each irrigation needn't be as heavy as 3 inches per hectare. Instead a figure of 1.5 inches per application is used to calculate the water requirement for the growing plots. Thus, the water requirement per application would be one-half of the 762 cu. m., or 381 cu. m. Five applications would require 1,905 cu. m. Thus, producing a annual cempasuchil crop consisting of five cuttings would require 2,179 cu. m. of water per ha. per year. To calculate the amount of land that could be dedicated to cempasuchil production based on available water, the project-generated water surplus for each pond was divided by 2,179.

In several cases, the amount of land actually available for production (owned by the pond owner) near each pond is less than what could be irrigated based on the amount of available water. In these cases, crop production calculations were based on the maximum amount of available land. Table 35 (facing page) presents the calculation of the production land bases for each crop and each pond based on project-generated water surpluses.

Table 35 **Calculation of Production Land Base as a Function of Surplus Water**

Pond	Runoff Area sq. m.	Surf. Area sq. m.	Pond Vol. cu. m.	H20 Surplus cu. m.	Irrig. Land Corn - Ha.	Irrig. Land Cemp. - Ha.	Land Avail. Ha.	Prod. Base Corn - Ha.	Prod. Base Cemp. - Ha.
1	78,125	2,903	2,612	2,180	2.86	1.00	1.00	1.00	1.00
2	46,875	1,979	1,979	1,648	2.16	0.76	1.50	1.50	0.76
3	343,750	9,125	9,125	8,006	10.51	3.67	4.50	4.50	3.67
4	78,125	2,254	2,029	1,736	2.28	0.80	6.00	2.28	0.80

Irrig. = Irrigable based on available water

corn 1 - 3 in. irrigation = 762 cu. M. water
cempasuchil 2179 cu. m. water

4.21 Calculation of Production Values (i.e. Project Income)

The following yield rates were selected as best predictors of crop yields under project conditions, and were used to calculate market values for crop surpluses.

Rain-fed Corn = 2 tons per hectare (per local farmers and Eduardo Garcia, 2000)

Punta de Riego Corn = 3.6 tons per hectare (per local farmers and Eduardo Garcia, 2000)

Cempasuchil = 16 tons per hectare (Eduardo Garcia, 2000).

Market values for crops were calculated based on market price information obtained during the March 1999 visit to Querétaro where:

Corn = $1,400 Pesos/ton

Cempasuchil = $1,300 Pesos/ton

Tables 36-39 (facing page) show the calculation of market values for corn and cempasuchil crops corresponding to each pond. These market values were then used to represent total financial inflow for each year of the 15-year project budget.

4.22 Calculation of Crop Production Costs

Because corn production costs are specific to each locale and each particular farmer's production traditions, and no such cost data were available for the El Rincón site, crop production budgets were prepared for rain-fed and punta de riego corn based on information solicited during farmer interviews. Farmers provided estimates of time and labor for each procedure, as well as the type and quantity of other inputs that were used to calculate total production costs.

Because no local tradition exists for cempasuchil production, and general production cost data were available for this study, such data were used in lieu of site-

Table 36 **Calculation of Crop Surplus Values - Pond 1**

Crop	Prod. Base Ha.	Yield. Tons/Ha.	Mrkt. Price Pesos	Prod. Value Pesos
Rain-Fed Corn	1.0	2.0	$1,400	$2,800
P. de Riego Corn	1.0	3.6	$1,400	$5,040
Cempasuchil	1.0	16.0	$1,300	$20,800

Table 37 **Calculation of Crop Surplus Values - Pond 2**

Crop	Prod. Base Ha.	Yield. Tons/Ha.	Mrkt. Price Pesos	Prod. Value Pesos
Rain-Fed Corn	1.5	2.0	$1,400	$4,200
P. de Riego Corn	1.5	3.6	$1,400	$7,560
Cempasuchil	0.8	16.0	$1,300	$15,808

Table 38 **Calculation of Crop Surplus Values - Pond 3**

Crop	Prod. Base Ha.	Yield. Tons/Ha.	Mrkt. Price Pesos	Prod. Value Pesos
Rain-Fed Corn	4.5	2.0	$1,400	$12,600
P. de Riego Corn	4.5	3.6	$1,400	$22,680
Cempasuchil	3.7	16.0	$1,300	$76,336

Table 39 **Calculation of Crop Surplus Values - Pond 4**

Crop	Prod. Base Ha.	Yield. Tons/Ha.	Mrkt. Price Pesos	Prod. Value Pesos
Rain-Fed Corn	2.3	2.0	$1,400	$6,384
P. de Riego Corn	2.3	3.6	$1,400	$11,491
Cempasuchil	0.8	16.0	$1,300	$16,640

specific production budgets. Using these cost data assumes that they offer the best prediction of actual costs for cempasuchil production in El Rincón. A list of the recommended cultivation procedures for cempasuchil is provided in Appendix C.

Budgets for rain-fed corn were prepared for each pond and then adjusted to account for any additional procedures necessary for the production of punta de riego corn. Such adjustments were made under the advisement of the local extensionist Eduardo Garcia (1999). All labor was valued at $40 Pesos per day (the reported rural daily wage rate). Values for inputs such as fertilizers, pesticides, and herbicides were calculated using price information procured from local agricultural supply stores in the city of Amealco (where most inputs are purchased).

Values for farm equipment were calculated based on the following locally procured price data and depreciation schedules:

Item	Cost	Depreciation Schedule
Plow/Planter	$2,000	10 years
Rake	$900	10 years
Backpack Sprayer	$503	5 years
Horse	$10,000	20 years

Note: The plow/planter implement is used for plowing, ridging, planting, and weeding. The rake is used for both raking and leveling.

The value of equipment portioned to the project land base was calculated by dividing the cost of the equipment by its estimated life span in years as well as the number of hectares under production for each farmer (i.e. total land over which implement is used annually). This quantity was then multiplied by the production base in hectares for rain-fed and punta de riego corn (see Table 35). Tables 40-47 (facing pages) show the calculation of equipment depreciation for each of the four ponds. Equipment

Table 40 Equipment Depreciation - Rain-Fed Corn - Pond 1

	Cost	Lifetime	Land Base		Prod. Base	Cost/Use
Item	Pesos	Yrs.	Ha.	No. Uses	Ha.	Pesos
*Plow/Planter	$2,000	10	5	4	1	$10
Rake	$900	10	5	2	1	$9
*Sprayer	$503	5	5	2	1	$10

* Plow used for 2 weedings only *Sprayer used for insect. & herb. Appl.

Table 41 Equipment Depreciation - Rain-Fed Corn - Pond 2

	Cost	Lifetime	Land Base		Prod. Base	Cost/Use
Item	Pesos	Yrs.	Ha.	No. Uses	Ha.	Pesos
*Plow/Planter	$2,000	10	3	5	1.5	$20
Rake	$900	10	3	2	1.5	$23
*Sprayer	$503	5	3	2	1.5	$25

* Plow used for soil prep. & 2 weedir *Sprayer used for insect. & herb. Appl.

Table 42 Equipment Depreciation - Rain-Fed Corn - Pond 3

	Cost	Lifetime	Land Base		Prod. Base	Cost/Use
Item	Pesos	Yrs.	Ha.	No. Uses	Ha.	Pesos
*Plow/Planter	$2,000	10	4.5	4	4.5	$50
Rake	$900	10	4.5	2	4.5	$45
*Sprayer	$503	5	4.5	2	4.5	$50

* Plow used for 2 weedings only *Sprayer used for insect. & herb. Appl.

Table 43 Equipment Depreciation - Rain-Fed Corn - Pond 4

	Cost	Lifetime	Land Base		Prod. Base	Cost/Use
Item	Pesos	Yrs.	Ha.	No. Uses	Ha.	Pesos
*Plow/Planter	$2,000	10	7	4	2.28	$16
Rake	$900	10	7	2	2.28	$15
*Sprayer	$503	5	7	2	2.28	$16

* Plow used for 2 weedings only *Sprayer used for insect. & herb. Appl.

Table 44 Equipment Depreciation - Punta de Riego Corn - Pond 1

Item	Cost Pesos	Lifetime Yrs.	Land Base Ha.	No. Uses	Prod. Base Ha.	Cost/Use Pesos
*Plow/Planter	$2,000	10	5	4	1	$10
Rake	$900	10	5	2	1	$9
*Sprayer	$503	5	5	2	1	$10

* Plow used for 2 weedings only *Sprayer used for insect. & herb. Appl.

Table 45 Equipment Depreciation - Punta de Riego Corn - Pond 2

Item	Cost Pesos	Lifetime Yrs.	Land Base Ha.	No. Uses	Prod. Base Ha.	Cost/Use Pesos
*Plow/Planter	$2,000	10	3	5	1.5	$20
Rake	$900	10	3	2	1.5	$23
*Sprayer	$503	5	3	2	1.5	$25

* Plow used for soil prep. & 2 weedir *Sprayer used for insect. & herb. Appl.

Table 46 Equipment Depreciation - Punta de Riego Corn - Pond 3

Item	Cost Pesos	Lifetime Yrs.	Land Base Ha.	No. Uses	Prod. Base Ha.	Cost/Use Pesos
*Plow/Planter	$2,000	10	4.5	4	4.5	$50
Rake	$900	10	4.5	2	4.5	$45
*Sprayer	$503	5	4.5	2	4.5	$50

* Plow used for 2 weedings only *Sprayer used for insect. & herb. Appl.

Table 47 Equipment Depreciation - Punta de Riego Corn - Pond 4

Item	Cost Pesos	Lifetime Yrs.	Land Base Ha.	No. Uses	Prod. Base Ha.	Cost/Use Pesos
*Plow/Planter	$2,000	10	7	4	2.28	$16
Rake	$900	10	7	2	2.28	$15
*Sprayer	$503	5	7	2	2.28	$16

* Plow used for 2 weedings only *Sprayer used for insect. & herb. Appl.

values were then included in the calculation of production costs for both rain fed and punta de riego corn. See Tables 48-55 (facing pages). Note: The budgets reflect some variance in task-specific costs due to differences in reported time/labor requirements for same tasks.

The calculation of cempasuchil production costs for each pond were made using data taken from the INEGI (1997) publication. According to INEGI (1997), annual production costs for cempasuchil range between $9,900 and $10,500 Pesos per ha. Thus, this study uses the average of that range, or a per hectare cost of $10,200 P. This rate per hectare figure yields the following totals for production costs.

Pond	Prod. Base (ha.)	Cempasuchil Prod. Cost (P)
1	1	$10,200
2	.76	$7,752
3	3.67	$37,434
4	.80	$8,160

The production costs calculated for this study were subsequently used as constants for every year of a 15-year project budget (the duration being a function of liner life span – see Appendix A). By treating production costs as constants, it is assumed that once changed to reflect the use of surplus water, production techniques will not change significantly over a 15-year project cycle.

4.23 Calculation of Geomembrane Installation Costs

Total installation costs reflect three major components:

- Site Preparation (one-time, local labor)
- Liner Installation (one-time, professional contractor)
- Liner Maintenance (on-going, local labor)

Table 48 **Production Budget for Rain-Fed Corn - Pond 1**

Processo	Obreros	Sueldo/Dia	Dias/Ha.	No. Ha.	C. Obrero	Invers.	Maq.	Costo Tot.	Costo/Ha.
Process	Wrkrs.	Wage/Day	Days/Ha.	No. Ha.	Lab. Cost	Inputs	Equip.	Tot. Cost	Cost/Ha.
Barbecho (Disking)	1	$350	1	1	$350			$350	$350
Rastreo (Raking)	1	$40	0.5	1	$20		$9	$29	$29
Nivelacion (Leveling)	1	$40	1	1	$40		$9	$49	$49
Surcado (Ridging)	1	$40	1	1	$40		$10	$50	$50
Riego (Irrigation)	0	$40	0	1	$0			$0	$0
Siembra (Planting)	2	$40	2	1	$160	$40	$10	$210	$210
Fertilizante (Fertilizer)	1	$40	1	1	$40	$795		$835	$835
Herbecida (Herbicide)	1	$40	1	1	$40	$160	$10	$210	$210
Escarda 1 (Weeding 1)	2	$40	2	1	$160		$10	$170	$170
Escarda 2 (Weeding 2)	2	$40	2	1	$160		$10	$170	$170
Insecticida (Insecticide)	1	$40	1	1	$40	$450	$10	$500	$500
Cosecha (Harvesting)	15	$40	1	1	$600			$600	$600
Almacen. (Storage)	0	$40	0	1	$0	$20		$20	$20
Transporte (Transport)	0	$40	0	1	$0		$20	$20	$20
Yunta (Mule)	0	$40	0	1	$0		$15	$15	$15
				Totals	$1,650	$1,465	$113	$3,228	$3,228
				Tot. /Ha.	$1,650	$1,465	$113		

Total Cost Per Ha. Excluding Labor **$1,578**

Table 49 **Production Budget for Rain-Fed Corn - Pond 2**

Processo	Obreros	Sueldo/Dia	Dias/Ha.	No. Ha.	C. Obrero	Invers.	Maq.	Costo Tot.	Costo/Ha.
Process	Wrkrs.	Wage/Day	Days/Ha.	No. Ha.	Lab. Cost	Inputs	Equip.	Tot. Cost	Cost/Ha.
Barbecho (Disking)	1	$40	3	1.5	$180		$20	$200	$133
Rastreo (Raking)	1	$40	1	1.5	$60		$23	$83	$55
Nivelacion (Leveling)	1	$40	1	1.5	$60		$23	$83	$55
Surcado (Ridging)	1	$40	1	1.5	$60		$20	$80	$53
Riego (Irrigation)	0	$40	0	1.5	$0	$0		$0	$0
Siembra (Planting)	2	$40	2	1.5	$240	$40	$20	$300	$200
Fertilizante (Fertilizer)	1	$40	1	1.5	$60	$1,193		$1,253	$835
Herbecida (Herbicide)	1	$40	1	1.5	$60	$240	$25	$325	$217
Escarda 1 (Weeding 1)	2	$40	2	1.5	$240		$20	$260	$173
Escarda 2 (Weeding 2)	2	$40	2	1.5	$240		$20	$260	$173
Insecticida (Insecticide)	1	$40	1	1.5	$60	$65	$25	$150	$100
Cosecha (Harvesting)	15	$40	1	1.5	$900			$900	$600
Almacen. (Storage)	0	$40	0	1.5	$0	$30		$30	$20
Transporte (Transport)		$40	0	1.5	$0		$20	$20	$13
Yunta (Mule)		$40	0	1.5	$0		$27	$27	$18
				Totals	$2,160	$1,568	$243	$3,971	$2,647
				Tot./Ha.	$1,440	$1,045	$162		

Total Cost Per Ha. Excluding Lab‹ **$1,207**

Table 50 **Production Budget for Rain-Fed Corn - Pond 3**

Processo	Obreros	Sueldo/Dia	Dias/Ha.	No. Ha.	C. Obrero	Invers.	Maq.	Costo Tot.	Costo/Ha.
Process	Wrkrs.	Wage/Day	Days/Ha.	No. Ha.	Lab. Cost	Inputs	Equip.	Tot. Cost	Cost/Ha.
Barbecho (Disking)	1	$350	1	4.5	$1,575			$1,575	$350
Rastreo (Raking)	1	$40	1	4.5	$180		$45	$225	$50
Nivelacion (Leveling)	1	$40	1	4.5	$180		$45	$225	$50
Surcado (Ridging)	1	$40	1	4.5	$180		$50	$230	$51
Riego (Irrigation)	0	$40	0	4.5	$0			$0	$0
Siembra (Planting)	2	$40	2	4.5	$720	$40	$50	$810	$180
Fertilizante (Fertilizer)	1	$40	1	4.5	$180	$3,577		$3,757	$835
Herbecida (Herbicide)	1	$40	1	4.5	$180	$720	$50	$950	$211
Escarda 1 (Weeding 1)	2	$40	2	4.5	$720		$50	$770	$171
Escarda 2 (Weeding 2)	2	$40	2	4.5	$720		$50	$770	$171
Insecticida (Insecticide)	1	$40	1	4.5	$180	$2,025	$50	$2,255	$501
Cosecha (Harvesting)	15	$40	1	4.5	$2,700			$2,700	$600
Almacen. (Storage)	0	$40	0	4.5	$0	$90		$90	$20
Transporte (Transport)		$40	0	4.5	$0		$20	$20	$4
Yunta (Mule)		$40	0	4.5	$0		$63	$63	$14
				Totals	$7,515	$6,452	$474	$14,441	$3,209
				Tot./Ha.	$1,670	$1,434	$105		

Tot. Cost Per Ha. Excluding Labor **$1,539.02**

Table 51 **Production Budget for Rain-Fed Corn - Pond 4**

Processo	Obreros	Sueldo/Dia	Dias/Ha.	No. Ha.	C. Obrero	Invers.	Maq.	Costo Tot.	Costo/Ha.
Process	Wrkrs.	Wage/Day	Days/Ha.	No. Ha.	Lab. Cost	Inputs	Equip.	Tot. Cost	Cost/Ha.
Barbecho 1 (Disking 1)	1	$400	1	2.28	$912			$912	$400
Barbecho 2 (Disking 2)	1	$400	1	2.28	$912			$912	$400
Rastreo (Raking)	1	$40	1	2.28	$91		$15	$106	$46
Nivelacion (Leveling)	1	$40	1	2.28	$91		$15	$106	$46
Surcado (Ridging)	1	$40	1	2.28	$91		$16	$107	$47
Riego (Irrigation)	0	$40	0	2.28	$0			$0	$0
Siembra (Planting)	3	$40	2	2.28	$547	$40	$16	$603	$265
Fertilizante (Fertilizer)	1	$40	1	2.28	$91	$2,070		$2,161	$948
Herbecida (Herbicide)	1	$40	1	2.28	$91	$960	$16	$1,068	$468
Escarda 1 (Weeding 1)	3	$40	2	2.28	$547		$16	$563	$247
Escarda 2 (Weeding 2)	3	$40	2	2.28	$547		$16	$563	$247
Insecticida (Insecticide)	1	$40	1	2.28	$91	$3,408	$16	$3,516	$1,542
Cosecha (Harvesting)	15	$40	1	2.28	$1,368			$1,368	$600
Almacen. (Storage)	0	$40	0	2.28	$0	$120		$120	$53
Transporte (Transport)		$40	0	2.28	$0		$20	$20	$9
Yunta (Mule)		$40	0	2.28	$0		$38	$38	$17
				Totals	$5,381	$6,598	$185	$12,164	$5,335
				Tot./Ha.	$2,360	$2,894	$81		

Total Cost Per Ha. Excluding Labor **$2,975**

Table 52 **Production Budget for Punta de Riego Corn - Pond 1**

Processo	Obreros	Sueldo/Dia	Dias/Ha.	No. Ha.	C. Obrero	Invers.	Maq.	Costo Tot.	Costo/Ha.
Process	Wrkrs.	Wage/Day	Days/Ha.	No. Ha.	Lab. Cost	Inputs	Equip.	Tot. Cost	Cost/Ha.
Barbecho (Disking)	1	$350	1	1	$350			$350	$350
Rastreo (Raking)	1	$40	0.5	1	$20		$9	$29	$29
Nivelacion (Leveling)	1	$40	1	1	$40		$9	$49	$49
Surcado (Ridging)	1	$40	1	1	$40		$10	$50	$50
Riego (Irrigation)	2	$40	2	1	$160			$160	$160
Siembra (Planting)	2	$40	2	1	$160	$40	$10	$210	$210
Fertilizante (Fertilizer)	1	$40	1	1	$40	$795		$835	$835
Herbecida (Herbicide)	1	$40	1	1	$40	$160	$10	$210	$210
Escarda 1 (Weeding 1)	2	$40	2	1	$160		$10	$170	$170
Escarda 2 (Weeding 2)	2	$40	2	1	$160		$10	$170	$170
Insecticida (Insecticide)	1	$40	1	1	$40	$450	$10	$500	$500
Cosecha (Harvesting)	15	$40	1	1	$600			$600	$600
Almacen. (Storage)	0	$40	0	1	$0	$20		$20	$20
Transporte (Transport)	0	$40	0	1	$0		$20	$20	$20
Yunta (Mule)	0	$40	0	1	$0		$15	$15	$15
				Totals	$1,810	$1,465	$113	$3,388	$3,388
				Tot. /Ha.	$1,810	$1,465	$113		

Total Cost Per Ha. Excluding Labor **$1,578**

Table 53 **Production Budget for Punta de Riego Corn - Pond 2**

Processo	Obreros	Sueldo/Dia	Dias/Ha.	No. Ha.	C. Obrero	Invers.	Maq.	Costo Tot.	Costo/Ha.
Process	Wrkrs.	Wage/Day	Days/Ha.	No. Ha.	Lab. Cost	Inputs	Equip.	Tot. Cost	Cost/Ha.
Barbecho (Disking)	1	$40	3	1.5	$180		$20	$200	$133
Rastreo (Raking)	1	$40	1	1.5	$60		$23	$83	$55
Nivelacion (Leveling)	1	$40	1	1.5	$60		$23	$83	$55
Surcado (Ridging)	1	$40	1	1.5	$60		$20	$80	$53
Riego (Irrigation)	2	$40	2	1.5	$240	$0		$240	$160
Siembra (Planting)	2	$40	2	1.5	$240	$40	$20	$300	$200
Fertilizante (Fertilizer)	1	$40	1	1.5	$60	$1,193		$1,253	$835
Herbecida (Herbicide)	1	$40	1	1.5	$60	$240	$25	$325	$217
Escarda 1 (Weeding 1)	2	$40	2	1.5	$240		$20	$260	$173
Escarda 2 (Weeding 2)	2	$40	2	1.5	$240		$20	$260	$173
Insecticida (Insecticide)	1	$40	1	1.5	$60	$65	$25	$150	$100
Cosecha (Harvesting)	15	$40	1	1.5	$900			$900	$600
Almacen. (Storage)	0	$40	0	1.5	$0	$30		$30	$20
Transporte (Transport)		$40	0	1.5	$0		$20	$20	$13
Yunta (Mule)		$40	0	1.5	$0		$27	$27	$18
				Totals	$2,400	$1,568	$243	$4,211	$2,807
				Tot./Ha.	$1,600	$1,045	$162		

Total Cost Per Ha. Excluding Labor **$1,207**

Table 54 **Production Budget for Punta de Riego Corn - Pond 3**

Processo	Obreros	Sueldo/Dia	Dias/Ha.	No. Ha.	C. Obrero	Invers.	Maq.	Costo Tot.	Costo/Ha.
Process	Wrkrs.	Wage/Day	Days/Ha.	No. Ha.	Lab. Cost	Inputs	Equip.	Tot. Cost	Cost/Ha.
Barbecho (Disking)	1	$350	1	4.5	$1,575			$1,575	$350
Rastreo (Raking)	1	$40	1	4.5	$180		$45	$225	$50
Nivelacion (Leveling)	1	$40	1	4.5	$180		$45	$225	$50
Surcado (Ridging)	1	$40	1	4.5	$180		$50	$230	$51
Riego (Irrigation)	2	$40	2	4.5	$720		$0	$720	$160
Siembra (Planting)	2	$40	2	4.5	$720	$40	$50	$810	$180
Fertilizante (Fertilizer)	1	$40	1	4.5	$180	$3,577		$3,757	$835
Herbecida (Herbicide)	1	$40	1	4.5	$180	$720	$50	$950	$211
Escarda 1 (Weeding 1)	2	$40	2	4.5	$720		$50	$770	$171
Escarda 2 (Weeding 2)	2	$40	2	4.5	$720		$50	$770	$171
Insecticida (Insecticide)	1	$40	1	4.5	$180	$2,025	$50	$2,255	$501
Cosecha (Harvesting)	15	$40	1	4.5	$2,700			$2,700	$600
Almacen. (Storage)	0	$40	0	4.5	$0	$90		$90	$20
Transporte (Transport)		$40	0	4.5	$0		$20	$20	$4
Yunta (Mule)		$40	0	4.5	$0		$63	$63	$14
				Totals	$8,235	$6,452	$474	$15,161	$3,369
				Tot./Ha.	$1,830	$1,434	$105		

Tot. Cost Per Ha. Excluding Labor **$1,539**

Table 55 **Production Budget for Punta de Riego Corn - Pond 4**

Processo	Obreros	Sueldo/Dia	Dias/Ha.	No. Ha.	C. Obrero	Invers.	Maq.	Costo Tot.	Costo/Ha.
Process	Wrkrs.	Wage/Day	Days/Ha.	No. Ha.	Lab. Cost	Inputs	Equip.	Tot. Cost	Cost/Ha.
Barbecho 1 (Disking 1)	1	$400	1	2.28	$912			$912	$400
Barbecho 2 (Disking 2)	1	$400	1	2.28	$912			$912	$400
Rastreo (Raking)	1	$40	1	2.28	$91		$15	$106	$46
Nivelacion (Leveling)	1	$40	1	2.28	$91		$15	$106	$46
Surcado (Ridging)	1	$40	1	2.28	$91		$16	$107	$47
Riego (Irrigation)	2	$40	2	2.28	$365			$365	$160
Siembra (Planting)	3	$40	2	2.28	$547	$40	$16	$603	$265
Fertilizante (Fertilizer)	1	$40	1	2.28	$91	$2,070		$2,161	$948
Herbecida (Herbicide)	1	$40	1	2.28	$91	$960	$16	$1,068	$468
Escarda 1 (Weeding 1)	3	$40	2	2.28	$547		$16	$563	$247
Escarda 2 (Weeding 2)	3	$40	2	2.28	$547		$16	$563	$247
Insecticida (Insecticide)	1	$40	1	2.28	$91	$3,408	$16	$3,516	$1,542
Cosecha (Harvesting)	15	$40	1	2.28	$1,368			$1,368	$600
Almacen. (Storage)	0	$40	0	2.28	$0	$120		$120	$53
Transporte (Transport)		$40	0	2.28	$0		$20	$20	$9
Yunta (Mule)		$40	0	2.28	$0		$38	$38	$17
				Totals	$5,746	$6,598	$185	$12,529	$5,495
				Tot./Ha.	$2,520	$2,894	$81		

Total Cost Per Ha. Excluding Labor **$2,975**

This portion of the installation process entails all tasks necessary to take the ponds from their current state and make them ready for the placement of liner material by professional contractors. It is estimated (by this author) that proper preparation would include the following procedures, which could be performed by local laborers and grading contractors:

1.) Re-shaping of the ponds, making them deeper with less exposed surface area (assuming no net change in volume), by excavating soil from the pond floor and reducing total diameter[7].

2.) Grading and compacting pond floors and wall surfaces (to prevent shifting and settling)

3.) Smoothing and clearing all surfaces of debris potentially damaging to an installed geomembrane (rocks, sticks, roots, and other foreign objects)

4.) Cleaning and re-shaping pond intake channels and installing anti-sediment curtains (dams of piled rocks or branches) to reduce the washing of soil sediment into ponds.

It is estimated that steps one and two would require the use of a contracted bulldozer ($650 P/hr.), whereas step three would require use of a smaller row crop tractor ($300 P./hr.) in conjunction with disk, harrow, and roller implements. Cost estimates for these procedures were based on local contractor rates and rough estimates (by this author) of the time necessary to complete each task. All human labor was valued at the local rural wage rate of $40 Pesos per day. Tables 56-59 (facing page) show the calculation of

[7] Care would need to be taken to not excavate the pond floor lower than the level of the fields down-grade to be irrigated.

Table 56 Pond Preparation Costs in Pesos - Pond 1 Pond Size - 2,903 sq. m.

Procedure	Labor/Equip.	Rate/Hr.	No. Hrs.	Materials	Tot. Cost
Re-Shape Pond	Bulldozer	$650.00	8		$5,200.00
Grade & Compact	Bulldozer	$650.00	4		$2,600.00
Surface Grade	Tractor/Disk	$300.00	2		$600.00
Smooth/Roll	Tractor/Roller	$300.00	2		$600.00
Clear Debris	Human	$5.00	4		$20.00
In-Take Channels	Human	$5.00	16		$80.00
Constr. Filter Dams	Human	$5.00	24		$120.00
Fences	Human	$5.00	40	$ 500.00	$700.00
			Total		$9,920.00

Table 57 Pond Preparation Costs in Pesos - Pond 2 Pond Size - 1,979 sq. m.

Procedure	Labor/Equip.	Rate/Hr.	No. Hrs.	Materials	Tot. Cost
*Re-Shape Pond	Bulldozer	$650.00	8		$5,200.00
Grade & Compact	Bulldozer	$650.00	3		$1,950.00
Surface Grade	Tractor/Disk	$300.00	2		$600.00
Smooth/Roll	Tractor/Roller	$300.00	2		$600.00
Clear Debris	Human	$5.00	4		$20.00
In-Take Channels	Human	$5.00	16		$80.00
Constr. Filter Dams	Human	$5.00	24		$120.00
Fences	Human	$5.00	40	$ 500.00	$700.00
			Total		$9,270.00

*** includes replacement of berm section**

Table 58 Pond Preparation Costs in Pesos - Pond 3 Pond Size - 9,125 sq. m.

Procedure	Labor/Equip.	Rate/Hr.	No. Hrs.	Materials	Tot. Cost
Re-Shape Pond	Bulldozer	$650.00	16		$10,400.00
Grade & Compact	Bulldozer	$650.00	8		$5,200.00
Surface Grade	Tractor/Disk	$300.00	4		$1,200.00
Smooth/Roll	Tractor/Roller	$300.00	4		$1,200.00
Clear Debris	Human	$5.00	8		$40.00
In-Take Channels	Human	$5.00	16		$80.00
Constr. Filter Dams	Human	$5.00	24		$120.00
Fences	Human	$5.00	80	$ 1,000.00	$1,400.00
			Total		$19,640.00

Table 59 Pond Preparation Costs in Pesos - Pond 4 Pond Size - 2,254 sq. m.

Procedure	Labor/Equip.	Rate/Hr.	No. Hrs.	Materials	Tot. Cost
Re-Shape Pond	Bulldozer	$650.00	8		$5,200.00
Grade & Compact	Bulldozer	$650.00	4		$2,600.00
Surface Grade	Tractor/Disk	$300.00	2		$600.00
Smooth/Roll	Tractor/Roller	$300.00	2		$600.00
Clear Debris	Human	$5.00	4		$20.00
In-Take Channels	Human	$5.00	16		$80.00
Constr. Filter Dams	Human	$5.00	24		$120.00
Fences	Human	$5.00	40	$ 500.00	$700.00
			Total		$9,920.00

estimated site preparation costs for all four ponds. Site preparation costs were used in the project budgets as one-time expenditures.

4.24 Liner Installation Costs

Projected costs for liner installation were calculated using price quotations procured from several geomembrane contractors both in the U.S. and Mexico. The material selected for cost calculations for this study is 20 mil PVC (.5 mil thickness). This material and grade was selected based on recommendations made in the Koerner text (see Appendix A) as well as information provided by geomembrane distributors. The final price quotation selected for use in this study ($100 P. per square meter) was offered by the *Soluciones Ambientales* (Environmental Solutions) firm in Mexico City and includes the cost of material, transport to site, deployment, and seaming of material, as well as per diem allowances for installation workers. This quotation was selected because it was the only cost quotation received that offered a "final cost", whereas other quotations excluded import and in-country freight costs, or the cost of actual installation. Thus, to avoid understating potentially hidden costs, the *Soluciones Ambientales* quote was selected to represent actual costs for professionally installing liners in this site. Table 60 (below) shows the final installation cost for each pond.

Table 60 Liner Installation Costs in Pesos

Pond No.	Surface Area sq. m.	Installation Cost (Pesos)
1	2,903	$ 290,300
2	1,979	$ 197,900
3	9,125	$ 912,500
4	2,254	$ 225,400

4.25 Liner Maintenance Costs

Projected costs for annual liner maintenance were calculated using estimates of the number of days per month that farmers may have to dedicate to properly caring for liners and ponds. Such maintenance might include:

- Patching punctured or torn geomembranes
- Removing debris from pond areas and water entrance channels
- Cleaning ponds when empty
- Repairing filter dams and fences
- Replacing soil cover on side slopes

It is estimated that the fore-mentioned activities might require one half-day per month or 6 days of labor per year for general maintenance, plus one day per year for a more thorough cleaning of the pond, for a total of 7 days per year. Two days per year were added to the work requirement for pond number three because of its larger size (9,125 sq. m.) Maintenance labor costs were calculated based on the $40 Peso per day rural wage. Also included in the annual maintenance costs is one gallon of patching adhesive at a cost of $45. Total annual maintenance costs for each pond are presented in Table 61 (below). Maintenance costs were treated as annual expenditures for all 15 years of the project budget.

Table 61 Annual Liner Maintenance Costs

Pond No.	Days/Yr.	Rate	Tot. Labo	Materials	Tot. Cost
1	7	$40.00	$280.00	$22.50	$302.50
2	7	$40.00	$280.00	$22.50	$302.50
3	9	$40.00	$360.00	$22.50	$382.50
4	7	$40.00	$280.00	$22.50	$302.50

Materials = 1/2 gallon liner adhesive per year

4.26 Calculation of Project Budgets

Three kinds of production budgets were prepared for each of the four ponds: rain-fed corn, punta de riego corn, and cempasuchil. The budgets use project income (inflows) and expenditures (outflows) to calculate a "net benefit before financing", or difference between project income and expenditures (i.e. annual net income). Future income is discounted (stated in present terms) at a rate of 10% (or the estimated opportunity cost of capital). The sum of the discounted net income stream (15-year) yields the net present value (NPV) of the project – or its worth stated in today's terms. Benefit-cost ratios were calculated for each project scenario by dividing total discounted benefits by total discounted expenditures. Project budgets are presented in Tables 62 – 73 on the facing pages. Results of the benefit-cost calculations are presented in Chapter 5 (Results).

Table 62 **Pond 1 without Project - Rain-fed Corn (In $ Pesos)**

Production Base - 1 Ha. Yield - 2 tons/ha. Price - $1,400 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Rain-fed Corn	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800
Total Inflow	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800	2,800
Discounted	2,545	2,313	2,103	1,912	1,739	1,579	1,436	1,308	1,187	1,081	980	893	812	736	669
OUT FLOW															
Investment															
Pond Prep.															
Liner Install.															
Equipment															
Liner Main.															
Other															
Tot. Invest.															
Operating Exp.															
Prod. Costs	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228
Total Outflow	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228	3,228
Discounted	2,934	2,666	2,424	2,205	2,004	1,820	1,656	1,507	1,369	1,246	1,130	1,030	936	849	771
Net Ben. Before															
Financing															
Total	-428	-428	-428	-428	-428	-428	-428	-428	-428	-428	-428	-428	-428	-428	-428
Incremental	-428	-855	-1,283	-1,711	-2,139	-2,566	-2,994	-3,422	-3,849	-4,277	-4,705	-5,132	-5,560	-5,988	-6,416
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-389	-353	-321	-292	-266	-241	-219	-200	-181	-165	-150	-136	-124	-112	-102
Net Pres. Value	**-3,253**														
Ben.-Cost Ratio	**0.87**														

Table 63 **Pond 1 with Project - Punta de Riego Corn (in $ Pesos)**

Production Base - 1 Ha. Yield 3.6 tons/ha. Price - $1,400 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
P.R. Corn	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040
Total Inflow	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040	5,040
Discounted	4,581	4,163	3,785	3,442	3,130	2,843	2,586	2,354	2,137	1,945	1,764	1,608	1,462	1,326	1,205
OUT FLOW															
Investment															
Pond Prep.	13,820														
Liner Install.	290,300														
Equipment	850							850							
Liner Maint.	303	303	303	303	303	303	303	303	303	303	303	303	303	303	303
Other															
Tot. Invest.	305,273	303	303	303	303	303	303	1,153	303	303	303	303	303	303	303
Operating Exp.															
Prod. Costs	3,388	3,388	3,388	3,388	3,388	3,388	3,388	3,388	3,388	3,388	3,388	3,388	3,388	3,388	3,388
Total Outflow	308,660	3,690	3,690	3,690	3,690	3,690	3,690	4,540	3,690	3,690	3,690	3,690	3,690	3,690	3,690
Discounted	280,572	3,048	2,771	2,520	2,292	2,081	1,893	2,120	1,565	1,424	1,292	1,177	1,070	971	882
Net Ben. Before															
Financing															
Total	-303,620	1,350	1,350	1,350	1,350	1,350	1,350	500	1,350	1,350	1,350	1,350	1,350	1,350	1,350
Incremental	-303,620	-302,270	-300,921	-299,571	-298,221	-296,871	-295,521	-295,022	-293,672	-292,322	-290,972	-289,622	-288,273	-286,923	-285,573
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-275,991	1,115	1,014	922	838	761	692	233	572	521	472	431	391	355	323
Net Pres. Value	**-267,349**														
Ben.-Cost Ratio	**0.13**														

Table 64 **Pond 1 with Project - Cempasuchil (in $ Pesos)**

Production Base .95 Ha. Yield 16 tons/ha. Price $1,300 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Cempasuchil	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800
Total Inflow	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800	20,800
Discounted	18,907	17,181	15,621	14,206	12,917	11,731	10,670	9,714	8,819	8,029	7,280	6,635	6,032	5,470	4,971
OUT FLOW															
Investment															
Pond Prep.	13,820														
Liner Install.	290,300														
Equipment	850							850							
Liner Maint.	303	303	303	303	303	303	303	303	303	303	303	303	303	303	303
Other															
Tot. Invest.	305,273	303	303	303	303	303	303	1,153	303	303	303	303	303	303	303
Operating Exp.															
Prod. Costs	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200	10,200
Total Outflow	315,473	10,503	10,503	10,503	10,503	10,503	10,503	11,353	10,503	10,503	10,503	10,503	10,503	10,503	10,503
Discounted	286,765	8,675	7,887	7,173	6,522	5,923	5,388	5,302	4,453	4,054	3,676	3,350	3,046	2,762	2,510
Net Ben. Before															
Financing															
Total	-294,673	10,298	10,298	10,298	10,298	10,298	10,298	9,448	10,298	10,298	10,298	10,298	10,298	10,298	10,298
Incremental	-294,673	-284,375	-274,078	-263,780	-253,483	-243,185	-232,888	-223,440	-213,143	-202,845	-192,548	-182,250	-171,953	-161,655	-151,358
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-267,857	8,506	7,733	7,033	6,395	5,808	5,283	4,412	4,366	3,975	3,604	3,285	2,986	2,708	2,461
Net Pres. Value	**-199,302**														
Ben.-Cost Ratio	**0.44**														

Table 65 **Pond 2 without Project - Rain-fed Corn (in $ Pesos)**

Yield - 2 tons/ha. Price $1,400 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Rain-fed Corn	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200
Total Inflow	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200	4,200
Discounted	3,818	3,469	3,154	2,869	2,608	2,369	2,155	1,961	1,781	1,621	1,470	1,340	1,218	1,105	1,004
OUT FLOW															
Investment															
Pond Prep.															
Liner Install.															
Equipment															
Liner Maint.															
Other															
Tot. Invest.															
Operating Exp.															
Prod. Costs	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971
Total Outflow	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971	3,971
Discounted	3,609	3,280	2,982	2,712	2,466	2,239	2,037	1,854	1,684	1,533	1,390	1,267	1,151	1,044	949
Net Ben. Before															
Financing															
Total	229	229	229	229	229	229	229	229	229	229	229	229	229	229	229
Incremental	229	459	688	918	1,147	1,376	1,606	1,835	2,065	2,294	2,523	2,753	2,982	3,212	3,441
Disc. Fac.-10%)	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	209	189	172	157	142	129	118	107	97	89	80	73	67	60	55
Net Pres. Value	**1,745**														
Ben.-Cost Ratio	**1.06**														

Table 66 **Pond 2 with Project - Punta de Riego Corn (In $ Pesos)**

Production Base - 1.5 Ha. Yield - 3.6 tons/ha. Price - $1,400 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
P.R. Corn	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560
Total Inflow	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560	7,560
Discounted	6,872	6,245	5,678	5,163	4,695	4,264	3,878	3,531	3,205	2,918	2,646	2,412	2,192	1,988	1,807
OUT FLOW															
Investment															
Pond Prep.	11,870														
Liner Instal.	197,900														
Equipment	850							850							
Liner Maint.	303	303	303	303	303	303	303	303	303	303	303	303	303	303	303
Other															
Tot. Invest.	210,923	303	303	303	303	303	303	1,153	303	303	303	303	303	303	303
Operating Exp.															
Prod. Costs	4,211	4,211	4,211	4,211	4,211	4,211	4,211	4,211	4,211	4,211	4,211	4,211	4,211	4,211	4,211
Total Outflow	215,133	4,513	4,513	4,513	4,513	4,513	4,513	5,363	4,513	4,513	4,513	4,513	4,513	4,513	4,513
Discounted	195,556	3,728	3,389	3,082	2,803	2,545	2,315	2,505	1,914	1,742	1,580	1,440	1,309	1,187	1,079
Net Ben. Before															
Financing															
Total	-207,573	3,047	3,047	3,047	3,047	3,047	3,047	2,197	3,047	3,047	3,047	3,047	3,047	3,047	3,047
Incremental	-207,573	-204,526	-201,479	-198,432	-195,386	-192,339	-189,292	-187,095	-184,048	-181,001	-177,954	-174,907	-171,860	-168,813	-165,767
Disc. Fac.-10%)	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-188,684	2,517	2,288	2,081	1,892	1,718	1,563	1,026	1,292	1,176	1,066	972	884	801	728
Net Pres. Value	**-168,679**														
Ben.-Cost Ratio	**0.25**														

Table 67 **Pond 2 with Project - Cempasuchil (in $ Pesos)**

Production Base - .72 Ha. Yield 16 tons/ha. Price - $1,300 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Cempasuchil	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808
Total Inflow	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808	15,808
Discounted	14,369	13,057	11,872	10,797	9,817	8,916	8,110	7,382	6,703	6,102	5,533	5,043	4,584	4,158	3,778
OUT FLOW															
Investment															
Pond Prep.	11,870														
Liner Install.	197,900														
Equipment	850							850							
Liner Maint.	303	303	303	303	303	303	303	303	303	303	303	303	303	303	303
Other															
Tot. Invest.	210,923	303	303	303	303	303	303	1,153	303	303	303	303	303	303	303
Operating Exp.															
Prod. Costs	7,752	7,752	7,752	7,752	7,752	7,752	7,752	7,752	7,752	7,752	7,752	7,752	7,752	7,752	7,752
Total Outflow	218,675	8,055	8,055	8,055	8,055	8,055	8,055	8,905	8,055	8,055	8,055	8,055	8,055	8,055	8,055
Discounted	198,775	6,653	6,049	5,501	5,002	4,543	4,132	4,158	3,415	3,109	2,819	2,569	2,336	2,118	1,925
Net Ben. Before															
Financing															
Total	-202,867	7,754	7,754	7,754	7,754	7,754	7,754	6,904	7,754	7,754	7,754	7,754	7,754	7,754	7,754
Incremental	-202,867	-195,113	-187,360	-179,606	-171,853	-164,099	-156,346	-149,442	-141,689	-133,935	-126,182	-118,428	-110,675	-102,921	-95,168
Disc. Fac.-10%)	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-184,406	6,404	5,823	5,296	4,815	4,373	3,978	3,224	3,287	2,993	2,714	2,473	2,249	2,039	1,853
Net Pres. Value	**-132,885**														
Ben.-Cost Ratio	**0.47**														

Table 68 **Pond 3 without Project - Rain-fed Corn (in $ Pesos)**

Production Base - 4.5 Ha. Yield 2 tons/ha. Price $1,400 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Rain-fed Corn	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
Total Inflow	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600	12,600
Discounted	11,453	10,408	9,463	8,606	7,825	7,106	6,464	5,884	5,342	4,864	4,410	4,019	3,654	3,314	3,011
OUT FLOW															
Investment															
Pond Prep.															
Liner Install.															
Equipment															
Liner Maint.															
Other															
Tot. Invest.															
Operating Exp.															
Prod. Costs	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441
Total Outflow	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441	14,441
Discounted	13,127	11,928	10,845	9,863	8,968	8,144	7,408	6,744	6,123	5,574	5,054	4,607	4,188	3,798	3,451
Net Ben. Before															
Financing															
Total	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841	-1,841
Incremental	-1,841	-3,681	-5,522	-7,362	-9,203	-11,044	-12,884	-14,725	-16,565	-18,406	-20,247	-22,087	-23,928	-25,768	-27,609
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-1,673	-1,520	-1,382	-1,257	-1,143	-1,038	-944	-860	-780	-710	-644	-587	-534	-484	-440
Net Pres. Value	**-13,998**														
Ben.-Cost Ratio	**0.87**														

Table 69 **Pond 3 with Project - Punta de Riego Corn (in $ Pesos)**

Production Base - 4.5 Ha. Yield 3.6 tons/ha. Price - $1,400 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
P.R. Corn	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680
Total Inflow	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680	22,680
Discounted	20,616	18,734	17,033	15,490	14,084	12,792	11,635	10,592	9,616	8,754	7,938	7,235	6,577	5,965	5,421
OUT FLOW															
Investment															
Pond Prep.	25,490														
Liner Install.	912,500														
Equipment	850							850							
Liner Maint.	383	383	383	383	383	383	383	383	383	383	383	383	383	383	383
Other															
Tot. Invest.	939,223	383	383	383	383	383	383	1,233	383	383	383	383	383	383	383
Operating Exp.															
Prod. Costs	15,161	15,161	15,161	15,161	15,161	15,161	15,161	15,161	15,161	15,161	15,161	15,161	15,161	15,161	15,161
Total Outflow	954,383	15,543	15,543	15,543	15,543	15,543	15,543	16,393	15,543	15,543	15,543	15,543	15,543	15,543	15,543
Discounted	867,534	12,839	11,673	10,616	9,652	8,766	7,974	7,656	6,590	6,000	5,440	4,958	4,507	4,088	3,715
Net Ben. Before															
Financing															
Total	-931,703	7,137	7,137	7,137	7,137	7,137	7,137	6,287	7,137	7,137	7,137	7,137	7,137	7,137	7,137
Incremental	-931,703	-924,566	-917,429	-910,292	-903,156	-896,019	-888,882	-882,595	-875,458	-868,321	-861,184	-854,047	-846,910	-839,773	-832,637
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-846,918	5,895	5,360	4,875	4,432	4,025	3,661	2,936	3,026	2,755	2,498	2,277	2,070	1,877	1,706
Net Pres. Value	**-799,526**														
Ben.-Cost Ratio	**0.18**														

Table 70 **Pond 3 with Project - Cempasuchil (In $ Pesos)**

Production Base - 3.5 Ha. Yield 16 tons/ha. Price - $1,300 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Cempasuchil	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336
Total Inflow	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336
Discounted	69,389	63,054	57,328	52,137	47,405	43,054	39,160	35,649	32,366	29,466	26,718	24,351	22,137	20,076	18,244
OUT FLOW															
Investment															
Pond Prep.	25,490														
Liner Install.	912,500														
Equipment	850							850							
Liner Maint.	383	383	383	383	383	383	383	383	383	383	383	383	383	383	383
Other															
Tot. Invest.	939,223	383	383	383	383	383	383	1,233	383	383	383	383	383	383	383
Operating Exp.															
Prod. Costs	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434
Total Outflow	976,657	37,817	37,817	37,817	37,817	37,817	37,817	38,667	37,817	37,817	37,817	37,817	37,817	37,817	37,817
Discounted	887,781	31,236	28,400	25,829	23,484	21,329	19,400	18,057	16,034	14,597	13,236	12,063	10,967	9,946	9,038
Net Ben. Before															
Financing															
Total	-900,321	38,520	38,520	38,520	38,520	38,520	38,520	37,670	38,520	38,520	38,520	38,520	38,520	38,520	38,520
Incremental	-900,321	-861,801	-823,282	-784,762	-746,243	-707,723	-669,204	-631,534	-593,015	-554,495	-515,976	-477,456	-438,937	-400,417	-361,898
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-818,391	31,817	28,928	26,309	23,921	21,725	19,761	17,592	16,332	14,869	13,482	12,288	11,171	10,131	9,206
Net Pres. Value	**-560,862**														
Ben.-Cost Ratio	**0.51**														

Table 70 **Pond 3 with Project - Cempasuchil (In $ Pesos)**

Production Base - 3.5 Ha. Yield 16 tons/ha. Price - $1,300 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Cempasuchil	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336
Total Inflow	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336	76,336
Discounted	69,389	63,054	57,328	52,137	47,405	43,054	39,160	35,649	32,366	29,466	26,718	24,351	22,137	20,076	18,244
OUT FLOW															
Investment															
Pond Prep.	25,490														
Liner Install.	912,500														
Equipment	850							850							
Liner Maint.	383	383	383	383	383	383	383	383	383	383	383	383	383	383	383
Other															
Tot. Invest.	939,223	383	383	383	383	383	383	1,233	383	383	383	383	383	383	383
Operating Exp.															
Prod. Costs	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434	37,434
Total Outflow	976,657	37,817	37,817	37,817	37,817	37,817	37,817	38,667	37,817	37,817	37,817	37,817	37,817	37,817	37,817
Discounted	887,781	31,236	28,400	25,829	23,484	21,329	19,400	18,057	16,034	14,597	13,236	12,063	10,967	9,946	9,038
Net Ben. Before															
Financing															
Total	-900,321	38,520	38,520	38,520	38,520	38,520	38,520	37,670	38,520	38,520	38,520	38,520	38,520	38,520	38,520
Incremental	-900,321	-861,801	-823,282	-784,762	-746,243	-707,723	-669,204	-631,534	-593,015	-554,495	-515,976	-477,456	-438,937	-400,417	-361,898
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-818,391	31,817	28,928	26,309	23,921	21,725	19,761	17,592	16,332	14,869	13,482	12,288	11,171	10,131	9,206
Net Pres. Value	**-560,862**														
Ben.-Cost Ratio	**0.51**														

Table 71 **Pond 4 without Project - Rain-fed Corn (in $ Pesos)**

Production Base - 2.28 Ha. Yield - 2 tons/ha. Price - $1,400 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Rain-fed Corn	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384
Total Inflow	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384	6,384
Discounted	5,803	5,273	4,794	4,360	3,964	3,601	3,275	2,981	2,707	2,464	2,234	2,036	1,851	1,679	1,526
OUT FLOW															
Investment															
Pond Prep.															
Liner Install.															
Equipment															
Liner Maint.															
Other															
Tot. Invest.															
Operating Exp.															
Prod. Costs	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164
Total Outflow	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164	12,164
Discounted	11,057	10,047	9,135	8,308	7,554	6,861	6,240	5,681	5,158	4,695	4,257	3,880	3,528	3,199	2,907
Net Ben. Before															
Financing															
Total	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780	-5,780
Incremental	-5,780	-11,560	-17,340	-23,120	-28,900	-34,680	-40,460	-46,240	-52,020	-57,800	-63,580	-69,360	-75,141	-80,921	-86,701
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-5,254	-4,774	-4,341	-3,948	-3,589	-3,260	-2,965	-2,699	-2,451	-2,231	-2,023	-1,844	-1,676	-1,520	-1,381
Net Pres. Value	**-43,957**														
Ben.-Cost Ratio	**0.52**														

Table 72 **Pond 4 with Project - Punto de Riego Corn (In $ Pesos)**

Production Base - 2.28 Ha. Yield - 3.6 tons/ha. Price - $1,400 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
P.R. Corn	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491
Total Inflow	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491	11,491
Discounted	10,446	9,492	8,630	7,848	7,136	6,481	5,895	5,366	4,872	4,436	4,022	3,666	3,332	3,022	2,746
OUT FLOW															
Investment															
Pond Prep.	12,520														
Liner Install.	225,400														
Equipment	1,700							1,700							
Liner Main.	303	303	303	303	303	303	303	303	303	303	303	303	303	303	303
Other															
Tot. Invest.	239,923	303	303	303	303	303	303	2,003	303	303	303	303	303	303	303
Operating Exp.															
Prod. Costs	12,529	12,529	12,529	12,529	12,529	12,529	12,529	12,529	12,529	12,529	12,529	12,529	12,529	12,529	12,529
Total Outflow	252,451	12,831	12,831	12,831	12,831	12,831	12,831	14,531	12,831	12,831	12,831	12,831	12,831	12,831	12,831
Discounted	229,478	10,599	9,636	8,764	7,968	7,237	6,582	6,786	5,440	4,953	4,491	4,093	3,721	3,375	3,067
Net Ben. Before															
Financing															
Total	-240,960	-1,340	-1,340	-1,340	-1,340	-1,340	-1,340	-3,040	-1,340	-1,340	-1,340	-1,340	-1,340	-1,340	-1,340
Incremental	-240,960	-242,300	-243,640	-244,981	-246,321	-247,661	-249,001	-252,041	-253,381	-254,721	-256,062	-257,402	-258,742	-260,082	-261,422
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-219,033	-1,107	-1,006	-915	-832	-756	-687	-1,420	-568	-517	-469	-428	-389	-352	-320
Net Pres. Value	**-228,800**														
Ben.-Cost Ratio	**0.28**														

Table 73 **Pond 4 with Project- Cempasuchil (in $ Pesos)**

Production Base - .76 Ha. Yield 16 tons/ha. Price - $1,300 P./ton

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
INFLOW															
Value of Prod.															
Cempasuchil	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640
Total Inflow	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640	16,640
Discounted	15,126	13,745	12,497	11,365	10,333	9,385	8,536	7,771	7,055	6,423	5,824	5,308	4,826	4,376	3,977
OUT FLOW															
Investment															
Pond Prep.	12,520														
Liner Install.	225,400														
Equipment	1,700							1,700							
Liner Maint.	303	303	303	303	303	303	303	303	303	303	303	303	303	303	303
Other															
Tot. Invest.	239,923	303	303	303	303	303	303	2,003	303	303	303	303	303	303	303
Operating Exp.															
Prod. Costs	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160	8,160
Total Outflow	248,083	8,463	8,463	8,463	8,463	8,463	8,463	10,163	8,463	8,463	8,463	8,463	8,463	8,463	8,463
Discounted	225,507	6,990	6,356	5,780	5,256	4,773	4,342	4,746	3,588	3,267	2,962	2,700	2,454	2,226	2,023
Net Ben. Before															
Financing															
Total	-231,443	8,177	8,177	8,177	8,177	8,177	8,177	6,477	8,177	8,177	8,177	8,177	8,177	8,177	8,177
Incremental	-231,443	-223,266	-215,089	-206,912	-198,735	-190,558	-182,381	-175,904	-167,727	-159,550	-151,373	-143,196	-135,019	-126,842	-118,665
Disc. Fac.-10%	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value	-210,382	6,754	6,141	5,585	5,078	4,612	4,195	3,025	3,467	3,156	2,862	2,608	2,371	2,151	1,954
Net Pres. Value	**-156,422**														
Ben.-Cost Ratio	**0.45**														

Chapter 5: Results

Tables 74 and 75 below present the results of the net present value and benefit-cost ratio calculations performed for this study.

Table 74 Net Present Values for Project Scenarios in Pesos

Pond No.	Rain-Fed Corn	P. de Riego	Cempasuchil
1	-$3,253	-$267,349	-$199,302
2	$1,745	-$168,679	-$132,885
3	-$13,998	-$799,526	-$560,862
4	-$43,957	-$228,800	-$156,422

Table 75 Benefit-Cost Ratios for Project Scenarios

Pond No.	Rain-Fed Corn	P. de Riego	Cempasuchil
1	0.87	0.13	0.44
2	1.06	0.25	0.47
3	0.87	0.18	0.51
4	0.52	0.28	0.45

The results show a negative return on investment (negative NPV's and Benefit-Cost Ratios) for all project cases except the production of rain-fed corn at pond no. 2.

5.1 Without-Project Results (Rain-fed Corn)

Results of the benefit-cost calculations indicate that when the value of human labor is included as a production cost, rain-fed corn production yields a negative return on investment (with the exception of pond no. 2). Pond No. 2 earns a positive return of $1.06 P., whereas ponds 1,3, and 4 earn negative returns of $.87, $.87, and $.52 on the Peso respectively. NPV's for rain-fed corn range from - $43,957 to $ 1,745.

5.2 With-Project Results (Punta de Riego Corn and Cempasuchil)

Results of the benefit-cost calculations for corn and cempasuchil production indicate a negative return on investment for all cases. Benefit-cost ratios for punta de riego production range from .13 to .18 (or a $.13 to $.18 centavo return on each Peso invested). NPV's for punta de riego range from - $168,679 P. to - $ 799,526 P.

Results for cempasuchil production indicate slightly better returns on investment (however, still negative) ranging from $.44 to $.51 centavos on the Peso. Net present values for cempasuchil production scenarios range from - $132,885 to - $560,862.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

Based on the results of the benefit-cost calculations performed in this analysis, this study concludes that a.) for the ponds studied, and b.) for the assumptions and conditions described:

1.) Installation of the specified geoemembranes as pond liners is not a cost-effective means of increasing agricultural production for punta de riego corn or cempasuchil, and:

2.) Using liners under the given conditions would not be cost-effective even allowing for a 50% margin of error in the calculation of project-generated water surplus, yield increases, or market prices.

3.) Due to the level of disparity between project-generated production increases and investment costs, geomembranes appear initially not to be a financially appropriate (cost-effective) tool for increasing agricultural production in general, unless a much higher-yielding and market value crop or production system can be found, however:

4.) Geomembranes should not be fully discounted as a potential water management tool for the site without further exploration of alternative agricultural production systems (crops and animals) and alternative uses in industry or supply to the city of Querétaro.

The results of the NPV and Benefit-Cost Ratio calculations in the with-project cases indicate that geomembranes are not a cost-effective investment for the production of corn and cempasuchil for the four ponds studied. The risk of price or crop failure not withstanding, the project-generated increases in crop production are not sufficient to recuperate investment and production costs. Even in the case of cempasuchil, which provides the greatest increase in production value, project income is only 44-51% of what is required to break even at the end of a 15-year cycle. In other words, even if the price of cempasuchil doubled, projects relying on cempasuchil production would just break even at the 15-year mark provided that no failure occurred in crop yields or price. As well, such levels of income would be insufficient to account for liner depreciation and replacement costs. This great disparity between project income and expenditure suggests that generating production values sufficient to service debt will be extremely difficult, even in optimum conditions. Thus, based on these initial results, it appears that lining ponds with geomembranes may not be financially feasible in any production scenario. Again, more studies should be conducted before final conclusions are made.

The results of the study also indicate that when the value of human labor is included as a production cost, growing rain-fed indigenous corn varieties is in most cases, not cost-effective (the exception being pond no. 2). If the farms selected for study are representative of the site, (which is not established) it appears that a certain percentage of farmers may be producing rain-fed corn at a net loss when the value of their own labor is considered. It would seem that given the percentage of residents seeking off-farm income (both in Mexico and the U.S.), seasonal corn production is a subsidized activity. This phenomena begs for further investigation into the perceived benefits (i.e. value) of growing and storing/securing one's own corn and maintaining a connection to food production. If, from a purely financial perspective, farmers are being under-compensated for their efforts, they might be better served to invest their efforts elsewhere. This finding may help explain the high rates of economically-forced emigration from the site.

6.2 Project Recommendations

Based on the results obtained in this study, it is recommended that no investment in pond liners occur in the El Rincón case without further study unless such investment were to occur on a trial basis with the support of outside institutions, whereby any financial burden/risk to participating farmers would be eliminated, or at least minimized.

Secondly, before any final conclusions are made regarding the financial feasibility of geomembranes as water management tools in local agriculture, it is recommended that a number of further studies be conducted addressing both their cost-effectiveness and overall feasibility.

6.3 Summary (Assumptions/Limitations of the Study)

Due in no small part to severe limitations in the availability of data pertinent to the research question, as well as the number of resulting assumptions, the conclusions of this study are not 100% conclusive. First, the study is quite limited in scope in that it is makes calculations for only four ponds in only one of thousands of agricultural communities in the region. Therefore, apart from any data considerations, the results of this study may or may not be generalizeable to the larger community and region. As such, the study should be regarded as merely a beginning point for addressing pond water conservation methods and agricultural water management in regional agriculture.

Secondly, the study is limited in that it addresses two crops (punta de riego corn and cempasuchil), that are either not currently grown in the site (cempasuchil), or for which no yield or production cost data exist apart from that which is anecdotal. Thus, final conclusions regarding the use of liners in the production of corn or cempasuchil should not be made without integrating stronger data into calculations.

Thirdly, because the hydrolocial phenomena of the site are largely unstudied, it cannot be established conclusively that sufficient runoff can be effectively and consistently captured and stored to generate necessary levels of production. Because no local data is available for rainfall or sources of pond water accumulation and loss (runoff, evaporation, infiltration, animal consumption, and use), calculation of project-generated water surplus is made extremely difficult, making subsequent benefit-cost assertions necessarily inconclusive. As well, the potential for high variability in rainfall trends makes historical data less than a perfect predictor of the future.

Fourth, the modeling used to quantify the project-generated water surplus, apart from relying on limited data, is in itself quite simplistic. This simplicity, while an asset for capitalizing on limited data, necessitates using conclusions as guideposts rather than as final and comprehensive. In short, better hydrological data should be collected and analyzed before final conclusions are made about the hydrologic feasibility of the project proposal.

The assumptions and data constrictions described here necessitate that the conclusions of this study be limited to this study with the said conditions, and not be generalized to all cases. As well, the conclusions made here are best used as an initial indication as to the financial feasibility of liners, but more importantly as a means of highlighting variables most critical to the research question. While the conclusions of the study are limited, the disparity between income and expenditure evidenced in the calculations do help illuminate the challenge and critical variables inherent in finding an agricultural production scenario under which lining ponds with geomembranes would be warranted financially - or alternatively, finding a water conservation tool that is appropriate to local agricultural production systems and levels of income.

Other assumptions/limitations of this study relate to the following:

- Are the selected study ponds representative of the larger population of ponds in the site?
- Lack of like-case information in literature that can be brought to bear in El Rincón
- Poor spatial/temporal representation of rainfall data
- Simplistic model (SCS) for calculating runoff relying on estimations of soil conditions
- Estimation of pond shape used to calculate size and capacity
- Would on-going sedimentation create added costs, affect storage (and loss), or eliminate the use of ponds alltogether.
- Use of temperature/surface area coefficient to calculate evaporation loss based on an estimation of seasonal changes in pond volume
- Estimation of animal consumption
- Model for calculation of infiltration based on anecdotal evidence (when ponds go dry) and the estimation used to calculate evaporation
- Use of a 21-year average to calculate project-generated water surplus, and subsequent crop production per ha.
- Use of estimation of water requirement for punta de riego application
- Estimation of water requirement for cempasuchil production
- Corn yields calculated based on anecdotal information
- Cempasuchil yields/costs based on outside data

- Estimations concerning nature, quantity, and cost of work necessary to prepare ponds for installation of liner material
- Estimation of liner maintenance costs

6.4 Recommendations for Further Study:

Before any action or decision is made regarding geomembrane use in El Rincón, a number of other studies should be conducted. Such studies should include:

1.) More localized and in-depth studies of rainfall:

- Collect rainfall data in-site, create an historical picture of precipitation
- Compare local data to regional data
- Calculate runoff rates
- Collect evaporation pan data
- Calculate evaporation rates
- Determine the probability of drought

2.) Studies of pond water accumulation and loss

- Measure changes in pond water levels throughout seasons and between years and compare to rainfall- runoff/evaporation rates
- Determine annual probability of ponds filling with runoff rain water
- Measure pond levels before and after irrigation application to determine application rates/requirements
- Collect data on the numbers of animals consuming from ponds and months/frequency of consumption

3.) Corn production studies

- Collect annual yield data (rain-fed and punta de riego)

- Compare hybrid varieties with indigenous varieties for like conditions
- Compare corn yields to rainfall for both punta de riego and rain-fed corn
- Determine the probability of corn crop failure
- Collect corn market price data and determine monthly/annual fluctuations and probability of failure
- Explore alternative markets for corn

4.) Studies of alternative crops, integrated production systems, and their markets

- Conduct trials of cempasuchil production (or other crops) and/or collect data for similar sites
- Look at the feasibility of creating integrated systems of crop and animal production
- Study the feasibility of fruit/vegetable production
- Determine barriers to change in agricultural production

5.) Studies of geomembranes

- Explore alternative grades, materials, sources of purchase, and price
- Explore alternatives to geomembranes as liners
- Study geomembrane durability/life-span in-site

6.) Study institutional context or levels of support (including development agencies potentially willing to fund trial)

- Access to equipment, financing, training, information
- Subsidies

7.) Debt Service

- Determine credit interest rates

- Determine levels of financial risk
- Determine the immediacy/distribution of benefits through time
- Determine re-investment costs for liners

8.) Studies of potential effects on the environmental and natural resource systems

- Changes in regional hydrology
- Re-charge of acquifers
- Erosion
- Salinization of crop land

9.) Studies of social/cultural/political variables

- Levels of farmer interest and concern, and prioritization of goals
- Levels of cooperation in cases of joint investment

10.) Study alternative sources/uses of water

- Wells and dams
- Agricultural vs. industrial use
- Market for sale of water to industry or municipalities?
- Compensation to farmers for non-use of water in order to help re-charge Querétaro city aquifers?
- Removal of ponds altogether

11.) Explore other options for off-farm income (or land uses – e.g. recreation)

6.5 Final Thoughts

While it appears initially that geomembranes may not represent a cost-effective means of increasing the availability of water for agricultural production in El Rincón, the results of this study should be used as a point of entry for more in-depth studies that address the financial and overall feasibility of geomembranes. Subsequent studies should attempt to gather and incorporate data that is more accurate so as to develop a better picture of local hydrology and agricultural production, allowing potential tools to be measured against a more concrete backdrop of conditions and variables. This study does provide a starting point for helping local farmers make decisions regarding options for water management on their own farms and helps contribute to a larger discussion of the problem of increasing water availability for agricultural production in zones similar to that of Querétaro.

The study provides initial insight into the financial feasibility of the liner technique for farmers in the El Rincón case, but also contributes case study data about liner feasibility to a larger body of information about farm-scale water storage systems as a means for increasing agricultural production in semi-arid regions. The results of this and subsequent studies can help farmers and development professionals make informed decisions about investment in this water management option.

Appendix A: Geomembrane Information Continued

The following information expands on that presented in Chapter 2 and is abstracted from Koerner *Designing with Geosynthetics*, 3^{rd}. ed., 1998.

1.) Considerations for Liner Selection: Geomembrane Properties

Depending on their material composition and construction, geomembranes exhibit a broad range of performance properties. It is these properties along with performance testing and standards that inform project design. Koerner (1998) organizes geomembrane properties as follows:

- Physical Properties
    - Thickness
    - Density
    - Mass per Unit Area (weight)
    - Water Vapor Transmission
    - Solvent Vapor Transmission
- Mechanical Properties
    - Tensile Behavior
    - Seam Behavior
    - Tear Resistance
    - Impact Resistance
    - Puncture Resistance
    - Geomembrane Friction
    - Geomembrane Anchorage
    - Stress Cracking
- Chemical Properties
    - Swelling Resistance
    - Chemical Resistance
    - Ozone Resistance
    - UV Light Resistance
- Biological Properties
    - Resistance to Animals
    - Resistance to Fungi
    - Resistance to Bacteria
- Thermal Properties
    - Warm Temperature Behavior
    - Cold Temperature Behavior
    - Coefficient of Thermal Expansion

- Identification Properties
  - Thermogravimetric Analysis (TGA)
  - Differential Scanning Calorimetry (DSC)
  - Thermomechanical Analysis (TMA)
  - Dynamic Mechanical Analysis (DMA)
  - Melt Index
  - Molecular Weight Determination

Seven of these properties seem especially pertinent to selection of a liner material for El Rincón and are expanded upon here.

2.) Thickness

Any membrane installed in El Rincón is likely to undergo a number of environmental stressors. Because the strength of liners relates in-part to their thickness, which in-turn affects project costs, this aspect is important to a benefit-cost analysis. To help protect against damage that might be caused during transport, handling, and installation (when liners are most susceptible to damage), Koerner (1998) recommends using a liner of 20 mils (.5 mm) regardless of project goals. For irrigation canal lining in Mexico, Gonzalez- Ruiz also recommends a liner thickness of 20 mils, which he indicates has been shown to last up to 30 years in trials. Based on these recommendations, a 20 mil. Grade liner was selected for computing the cost portions of this study (see 4.26 Liner Installation Costs).

3.) Water vapor transmission

Though liners are not 100% impermeable and some sweating of contained liquids through the membrane material does occur, the rates are low enough in the context of this hypothetical project goal that this is not a major consideration for liner selection. Liners are assigned a vapor transmission number depending on thickness (typical values of impermeability range from 10^{-10} to 10^{-13} ft./minute) (Koerner, 1998). For example, 20 mil PVC allows the permeation of 2.9 grams per square meter per day (Koerner, 1998). The loss per day from a 50x50 m. pond would be 1.9 gallons per day, or about 2.6 cubic meters per year. For this study, such a quantity will be considered negligible. In short, any liner of the 20 mil suggested thickness should provide a more than adequate moisture barrier for this project.

4.) Tensile behavior

Tensile behavior is an important consideration for large (deep) reservoir projects where the weight of the installed liner on basin side slopes exerts a tremendous downward pull against its own composition. Because the side slopes of the ponds in El Rincón are shallow (1-2 meters), tensile strength should not be an important factor here.

5.) Seam Behavior

Seam behavior per se (i.e. the performance of membrane seams under certain kinds of stressors) is likely not as important a consideration as the kind of geomembrane and seam selected for the project. Any of the seaming techniques is likely to offer a seal sufficient to the goal of drastically reducing seepage loss from the catchment ponds. There is, however, reason to believe that if farmers in El Rincón are to be able to successfully maintain and repair liner systems over an extended period of time, they must have easy access to the tools and resources necessary to patch and/or re-seam the membrane material. Seaming techniques involving expensive or locally unavailable equipment or materials (i.e. thermal methods) may preclude this ability.

6.) Resistance to Tears, Impact, and Puncture

Because of the project conditions at El Rincón, liner resistance to damage is an especially important consideration. Geomembranes may be torn by equipment or wind uplift. The impact of falling objects can pierce membranes, causing leaks and further tearing. Geomembranes may also be easily punctured by rocks, sticks, or other debris lying on the soil sub-grade (Koerner, 1998).

The tear resistance of thin non-reinforced membranes is quite low – from 4 to 30 pounds (Koerner, 1998). Tear resistance values for geomembranes reinforced with fabric scrims are somewhat better – 20-100 pounds. Typical values for puncture resistance are 10-100 pounds for thin nonreinforced membranes, and 50 – 500 pounds for reinforced membranes. Generally, the thicker the membrane is, the more resistant it is to tearing, puncture, and impact. Reinforced membranes exhibit higher resistance to damage than nonreinforced, and underlaying geomembranes with a geotextile greatly increases its resistance to all of these. If carefully handled during installation, a non-reinforced geomembrane covered with adequate soil should perform adequately for the application at hand. Again, following the installation guidelines can substantially reduce the risk of liner damage.

7.) Ultra-violet resistance

Long-term exposure to ultra-violet light is known to cause degradation of exposed polymeric materials (Koerner, 1998). Because liners installed in Central Mexico will face high levels of sun exposure, this is an important consideration to membrane selection. Different base materials perform very differently in response to UV ray exposure – a range of resistance that Koerner terms “enormous”. For example, non-reinforced PVC is more sensitive to ozone and ultra-violet light exposure, and thus must be covered with soil to prevent embrittlement and cracking. Conversely, CPE and CSPE show more resistance to ultraviolet degradation. Koerner (1998) indicates that the best protection against ultra-violet degradation is covering liners with at least 12 inches of soil – a recommendation integrated in the selection of liner for this analysis.

8.) Resistance to animals

Buried membranes are susceptible to animals burrowing through them, however, the degree to which they are susceptible is not well known (Koerner, 1998). There are no well established test procedures and the theoretical maxim holds that the thicker, harder, and stronger membranes are, the less susceptible they are to this type of damage (Koerner, 1998).

The likely greater potential for animal damage in El Rincón would be that caused by horses or cattle walking on exposed liners in the pond area. Such damages can be eliminated both by covering the material with soil and constructing a fence around the perimeter of the ponds to keep animals out of the pond area. Both measures are included in project costing.

9.) Liner Installation

Generally, membranes are manufactured by one firm and installed by another. Proper installation is key to creating an effective liner system. While the specifics of proper installation are project-specific, a few generalities apply.

Liners are susceptible to damage during transport, handling, and deployment. Great care should be taken during these stages to ensure that the liner is not damaged. Secondly, the surface area to be lined should be graded, compacted, smoothed, and cleared of all debris that may exert stress or puncture the liner once placed. Koerner (1998), recommends installing a geotextile underlayment beneath the geomembrane to help absorb the stress of intruding debris or shifts in the sub-grade.

One of the major quality control aspects of liner installation is the seaming or joining of membrane sheets. Because geomembranes are manufactured and transported to project sites in sheets or rolls, they must be seamed together to form a single continuous liner that fits the size and contour of the pond basin. Thus, the integrity of any liner systems is only as good as the seams that hold its pieces together. Faulty seams will usually result in water seepage through the liner system.

There are two types of seams – those made in the factory, and those made in the field. Because factory seams are made in controlled environments, their quality is more consistent. Because field seams are made under less controllable environmental conditions, they represent the greater risk for seam failure. The quality of field seams may be compromised by irregular preparation surfaces, dirt, temperature changes, air pockets, or moisture.

Field seaming may be done with solvents, adhesives, hot air, hot knives or wedges, and tapes. Solvents, used primarily with thermoplastic liners, actually dissolve the membrane edges which are then joined together under pressure and allowed to re-harden as a bonded surface. Contact adhesives can be used with most any of the membrane types and cause the membranes to stick together without breakdown of the polymer. Thermal methods such as hot air or hot knives/wedges can be used on thermoplastic and semi-crystalline geomembranes. Heat is used to melt the membrane edges into a semi-liquid state so they may be joined together under pressure and allowed to cool and re-harden into a contact seam. Extrusion welding, used only with polyethylene materials, involves using a ribbon of molten polymer between the surfaces (which are also slightly melted by an electrode). Tapes and mechanical seams can be used where 100% water-tight seals are not required. Single sided tape can be used over the top of overlapping edges, or two sided tape can be used between the edges. Certain kinds of clamps and sewing techniques can also be used.

Because the kind of membrane material selected has implications for the seaming techniques used for installation and repair (i.e. equipment and costs), this is an important consideration for a project environment like El Rincón where farmers have limited financial resources and access to special equipment.

Once deployed and seamed, a geomembrane should be secured in place by anchoring (burying) its edges in an anchor trench excavated around the perimeter of the basin. Koerner (1998), also recommends that the membrane material be covered with soil to protect it from ultra-violet rays and other damage-causing agents. Another general consideration for liner installation in a rural context such as El Rincón, is the construction of a fence around the pond perimeter to keep out livestock that might otherwise tread on, and damage the membrane material.

Appendix B: Site Description Continued

The following information expands on that presented in Chapter 3 and is taken from the AUQ Report described in Chapter 1.

1.) Local Economics

Of 45 households interviewed by the AUQ team, there were 58 cases (27%) reported of men who had worked or were currently working in the U.S. Men were said to make their first trip between the ages of 15 and 18, and to work almost exclusively as agricultural laborers, but in some cases as construction workers or store clerks as well. The most common destinations are the states of California, Montana, Oregon, Washington, and Georgia, and in some cases, families do not know where members have gone. The duration of any one stay in the U.S. ranges between 4 months and 3 years. At the time of the RRA, one family reported that 5 of its 15 members were working in the U.S. There were also 5 reported cases of men who had legal documentation to live in the U.S. for at least part of the year. According to the report, these men live in El Rincón during the agricultural growing season (6-8 months), and spend the rest of the year working in the U.S.

The report indicates that those who work in the U.S. are generally able to earn higher wages ($3.50 - $10/hr. in 1996) which are sufficient for the purchase of extra items such as land and farm equipment, and new or improved homes[1].

[1] Many vehicles in the community have U.S. license plates.

2.) Economic Alternatives

Alternative sources of income within the community are seemingly few. The majority of women make cross point napkins, carpets, and embroidery. According to the report, however, these hand crafts are generally not viewed as opportunities for extra income. Reportedly, few families sell these items for a minimal price and there is no immediate market for their sale.

As one economic alternative, community members have expressed interest in the development of a tourism or picnic area in the community to provide jobs and recreational opportunities. The report states that El Rincón is already a popular site for weekend day trippers. During the author's March 1999 visit to El Rincón, work was being completed on a small garment assembly factory within the ejido, which according to several residents, will employ 20-30 individuals from the community. To-date, the more common alternative seems to be short or long-term migration to the U.S. in search of employment (Purdy, 1999).

3.) Food

The AUQ team found that families in the ejido eat two to three meals per day, consisting mostly of corn tortillas and beans. Meat consumption is low. The report concludes that ejido members generally take advantage of locally available fruits and vegetables, but that nutritional education would benefit the community's overall nutrition status – the report cites excessive consumption of soft drinks and junk food such as cookies and chips.

Levels of fruit and vegetable consumption depend on season and climate. The community is reportedly well suited for the production of apples, pears, figs, and peaches, as well as vegetables such as greens, beets, pumpkins, string beans, and mushrooms. To a small degree, people supplement their diets with foods taken from the forest including prickly pears ("nopales"), greens, and edible mushrooms.

Whatever food consumed that is not grown or collected locally, is usually purchased in the city of Amealco where there is some variety and prices are lower than those offered in local stores. A few families, however, do buy food in the smaller local stores within the ejido, where they sacrifice price and selection for the sake of convenience.

The overall picture of food security is not made clear by the report. No mention is made of cases of chronic hunger or malnutrition, though it is indicated that a free breakfast is offered at school to those children who are on need-based scholarships.

4.) Health

Very little information is presented in terms of community health and health resources. According to the report, only 30% of local families (interviewed) participate in local vaccination and parasite treatment campaigns. Eight families reported that they seek treatment/vaccinations one time per year, and 7 families reportedly seek such treatment twice per year. This wide-spread failure to seek preventative medical treatment is considered by the AUQ team to have a negative impact on community health, especially with regard to children. The report also indicates a need for more recreation activities for youth, the lack of which is associated with the clandestine sale of alcohol to minors in the community.

5.) Education

Of the 45 households interviewed, the highest level of education reported is the completion of secondary school. The community has facilities for kindergarten (CONAFE), primary, and televised secondary school (lessons are televised to eliminate the need for students to travel to other communities to receive a secondary education). Twenty-nine adults reported having no formal education and the inability to read or write. The report does not indicate if community members perceive any relationship between education levels/resources and employment opportunities.

6.) Community Leadership, Perceptions, and Participation

Community leadership consists of a municipal delegate and an ejido commissioner who may also represent ejido matters at the municipal level. Community members may serve on committees – regardless if they are actual ejido members or private land holders. One such committee deals exclusively with the procurement and management of potable water service. As one project, this committee facilitated the building of a new spring deposit and contributed labor and materials to its construction. Local leadership has expressed concern over a lack of local employment opportunities, high rates of emigration, low agricultural production due to drought and pests, and a lack of governmental support in community development. Leaders feel that better community organization is needed and identify the following initiatives as key to fostering cohesion and participation.

- The purchase of a Catepillar D8 tractor
- Soil conservation measures
- Reforestation measures

• The prevention of erosion gullies

The report indicates that community members exhibit an increasing lack of faith in development programs due to past failures and decreasing production. Consequently, people tend to include themselves, but not participate in projects until such time that resource become available or the project appears to be successful. The AUQ team cites a need for more careful project planning where short- and medium-term benefits are demonstrated through pilot projects. Also cited is the need for better communication of project goals to the entire community.

One project cited as successful in generating participation is Eduardo Garcia's involvement in creating farmer interest in treating soils with calcium carbonate through proven results in pilot trials. By working with a few farmers and producing demonstrably favorable results, Eduardo has developed increased interest in the technique.

7.) Forest Resources

The major problems identified with regard to forest resources are:

• Deforestation
• Over- Hunting
• Forest pests
• Excessive use of agri-chemicals
• Improper garbage disposal

The families of the ejido rely on the open-access forested areas primarily as sources of firewood for cooking and heating their homes. While the AUQ study was unable to determine the exact quantity of firewood consumed by families, it does indicate that most families cook with a combination of butane gas and firewood (families prefer certain foods cooked with wood).

Between 1984 and 1994, the community experimented with assigning quotas for tree cutting, where each family was assigned a determined number of trees, which could be cut for personal consumption. Between 1993 and 94, families were granted permission to sell their allotted wood. During other years, it was designated for personal use only. Since 1994 (2 years previous to the release of the AUQ report), there has been no use of the forest. Community members express a desire for renewed access to the forest and would like to learn how to select trees that may be pruned or cut for firewood.

Locals residents also hunt armadillo, rabbits, coyote, birds, and fish on a year-round basis. According to the report, these animals present a very limited resource for alternative food because of their diminishing numbers, reportedly the product of over-hunting and overuse of chemicals in agricultural production. The hunting of predatory animals, such as coyote has been increasing as the reduction of their natural food sources has forced them to prey on domesticated fowl and rabbits around people's homes.

The report states that the community recognizes the need for soil and forestry conservation, but perceives itself as lacking the decision making and technical expertise needed to design and implement conservation measures. As well, there exists a tendency to view the government as ultimately responsible for providing solutions to the problem.

8.) Agricultural Alternatives

During the workshop portion of the rural diagnostic, community members expressed interest in the following agricultural alternatives: the raising of rabbits, the introduction of deer into the woods with permission to hunt them, the raising of dairy cows, the raising of fish in ponds, the cultivation of mushrooms, family gardens, and the creation of agro-micro-enterprises such as bottling jams and marmalades made from a local fruit called tejocote. To-date, none of these have been tried.

During site visit interviews conducted as part of this study, several farmers expressed interest in growing cempasuchil if the ponds could be improved to provide sufficient water.

9.) Local Hydrology

Querétaro is divided into two hydrologic drainage regions. The larger known as "El Panuco" drains into the Gulf of Mexico, and the smaller "Lerma-Chapala-Santiago" drains into the Pacific (INEGI, 1997d). The majority of the Amealco Municipality, including El Rincón, is situated in the El Panuco region, and thus all surface runoff from the site drains toward the Gulf of Mexico (INEGI, 1997a).

El Rincón is part of the "El Aguacate" micro-watershed, located within the "Drenaje Caracol" (Snail Drain) Sub-Watershed of the greater watershed known as "Rio Moctezuma" (INEGI, 1997a). The ponds selected for study are adjacent to the "Los Tules" and "El Aguacate" streams which drain into the "Paso de Vigas River"; that river flows into the "River Las Zunigas", and eventually into the "Constitution 1917 Dam" (INEGI, 1996).

Appendix C: Introduction to Cempasuchil and its Production

According to INEGI (1997), cempasuchil, known locally as "flor de los muertos", (flower of the dead) is a traditional plant of pre-Colombian origin grown and used by the Aztecs in religious ceremonies to honor the spirits of the deceased. The cempasuchil flower is still used as an ornament in the celebration of Dia de Los Muertos, however, the majority of modern-day cempasuchil production goes toward the manufacture of food coloring and as an ingredient in poultry feeds (INEGI, 1997). The flower extract can be used to enhance the yellow color of poultry carcasses and egg yolks. The plant is grown either in the spring-summer or fall-winter seasons, and can produce as many as five crops or cuttings (of the flower) per season, and as many as 16 metric tons per hectare (Garcia, 2000). Soils rich in clay produce the best crops with larger and more abundant flowers, while light and sandy soils make the management of soil moisture and fertility more difficult. Buyers in the Querétaro region include "Alcosa", "Bioquimex" and "Piveg". The current market price is $1,300 Pesos per metric ton (wet).

According to INEGI (1997), cempasuchil production offers the following advantages in comparison to other crops:

- Better return on investment compared to crops of similar production cost
- More secure market and price
- Rapid recuperation of investment (1st cutting 3 months post-transplant)
- Doesn't deplete the soil as rapidly as other crops – allowing for 2 or 3 crops per season, depending on the zone
- Plant can be tilled back into soil for reincorporation of organic material

• Cempasuchil roots release a substance that helps keep soil free of certain parasites

According to INEGI (1997), the production of cempasuchil includes the following tasks:

Establishment of Seedlings:

• Selection of nursery plot (25m x 25m) and soil preparation (should be pulverized - devoid of all soil clumps)

• Disinfectant of soil (use 1 kg. *Dazomet* with 6 kg. *Basamid* per hectare) and incorporate into soil

• Three irrigations

• Soil cultivation (wait 7 days to plant)

• Fertilizer application (18-46-00) or 00-46-00) and incorporate

• Planting (.75 kg. seed/ha.)

• Covering of seeds with uniform layer of animal manure mixed with sand and soil

• Light irrigation every 3 days

• Transplant to field plot after 20-25 days (at 12-15 cm height)

Field Plot Preparation:

• Plowing/disking of soil to 30 cm. depth

• Two rakings to eliminate all clumps

• Cultivation of soil into ridges

• Fertilizer application (P-K-N)

- Transplant of seedlings (keeping roots moist during transplant)
- Planting of seedlings on ridges @ 30 cm. spacing
- First irrigation 4 days post-transplant with consecutive irrigations every 15-20 days
- Cultivation of weeds at 20, 40, and 60 days post-transplant
- Fertilizer application at 40 days post-transplant
- Hand weeding if necessary
- First harvest (cutting) when 80-90% of plot is in flowered state (usually 90-100 days post- transplant)
- Irrigate after each cutting
- Cut every 12-15 days for 5 total cuttings

Appendix D: Rainfall Analysis

1.) Rainfall Data from Contributing Stations

Tables 76–79 (pages 164-166) show the rainfall data taken from each of the four weather stations (Granja Carnation, Amealco I, SMT, and Las Palmillas) contributing to the 21-year aggregated rainfall data. Tables 80-82 (pages 167-168) show the adjustment factors used to adjust the data from the Amealco I, SMT, and Las Palmillas stations to create the 21-year aggregated total (presented in Chapter 4).

Table 83 and Figure 5 (page 169) present the monthly averages of the aggregated rainfall data where it is evident that May-September is the critical period for rainfall capture, July consistently being the month of highest rainfall totals. The variability in annual rainfall totals is evident in a between-year comparison for the aggregated data (see Figure 6 page 170).

The yearly average for the 21-year aggregated data is 906.2 mm. – a figure that contrasts somewhat with an average listed for Querétaro of 549.3 mm. for the period 1921-1995 (INEGI – Cuad. Est. Munic. 1998). Thus, it appears that the rainfall of the study site is somewhat greater than that of the state as a whole.

Values for calculated rainfall excess are presented in Table 84 (page 171)

2.) Comparison of Monthly Runoff Totals to Pond Capacity

Tables 85-88 and Figures 7-10 (pages 172-175) show monthly runoff totals within the four pond catchment zones for each of three kinds of runoff years: high, low, and average. Not surprisingly, runoff directly reflects seasonal rainfall so that, just as July is consistently the highest month of rainfall, so too is it the highest month of runoff, August

Table 76 **Rainfall Data - Granja Garnatio 1978-1989 Lat: 20 deg. 13' 23" Long: 100 deg. 09' 10" Alt: 2,650 m.**

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
1989	NA	6.0	NA	0.0	NA	96.0	NA	NA	NA	NA	NA	NA	NA
1988	0.0	NA	25.0	5.0	8.0	124.5	NA	NA	NA	0.0	24.0	0.0	NA
1987	0.0	1.8	0.0	22.0	NA	58.8	233.0	107.2	103.2	NA	NA	0.0	NA
1986	0.0	0.0	0.0	36.0	29.3	324.3	233.2	181.2	92.6	66.8	9.9	0.0	973.3
1985	0.0	0.0	0.0	14.6	155.4	285.6	287.2	183.7	168.9	56.3	18.9	0.0	1,170.6
1984	17.0	11.5	0.0	0.0	28.0	134.8	NA	194.4	176.9	63.6	NA	0.0	NA
1983	53.4	7.6	10.0	0.0	71.2	51.4	369.0	179.4	273.0	32.4	12.5	0.0	1,059.9
1982	0.0	16.3	4.4	32.6	129.6	56.0	150.6	130.4	62.9	87.5	0.0	20.1	690.4
1981	74.5	27.5	14.0	62.3	42.7	206.2	121.8	161.3	50.9	72.5	0.0	5.0	838.7
1980	111.0	4.5	0.0	76.5	90.8	125.1	78.5	266.6	160.2	62.7	1.2	0.0	977.1
1979	3.0	43.5	NA	NA	291.0	NA	NA	182.7	230.0	7.5	0.0	55.7	NA
1978	NA	NA	NA	NA	NA	NA	NA	152.8	193.0	120.2	NA	5.0	NA
AVE.	25.9	11.9	5.9	24.9	94.0	146.3	210.5	174.0	151.2	57.0	8.3	7.8	951.7

Table 77 **Rainfall Data - Amealco I 1988-1991 Lat: 20 deg. 11' 05" Long: 100 deg. 08' 44' Alt: 2,648 m.**

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
1991	14.2	9.8	1.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
*1990	5.2	18.5	14.9	15.5	30.3	1.7	675.4	559.4	462.0	0.0	19.5	NA	1,802.4
1989	0.0	0.0	0.0	4.5	NA	189.5	216.6	336.9	183.9	3.2	0.0	2.1	936.7
1988	NA	NA	NA	NA	NA	NA	277.8	0.0	15.3	0.0	0.0	0.0	NA
AVE.	6.5	9.4	5.3	10.0	30.3	95.6	389.9	298.8	220.4	1.1	6.5	1.1	1,369.6

Table 78 **Rainfall Data -San Miguel Tilax Lat: 20 deg. 08' 32" Long: 100 deg. 04' 00" Alt. 2,420 m.**
1975-1989

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
1989	NA	2.5	NA	NA	NA	100.5	NA	NA	NA	NA	NA	NA	NA
1988	0.0	NA	25.5	8.8	66.3	126.0	NA	NA	NA	0.0	22.0	0.0	NA
1987	0.0	0.0	0.0	28.0	NA	82.0	526.0	128.0	130.2	NA	NA	0.0	NA
1986	0.0	0.0	0.0	37.8	211.0	390.8	157.1	101.0	73.0	108.1	22.2	0.0	1101.0
1985	0.0	0.0	0.0	56.5	77.9	201.2	292.6	154.6	164.5	3.0	2.4	0.0	952.7
1984	11.0	7.8	0.0	0.0	33.8	143.4	NA	177.4	165.1	116.9	NA	0.0	NA
1983	35.9	15.5	11.0	0.0	71.1	60.3	398.1	210.1	254.5	63.8	22.5	0.0	1142.8
1982	0.0	35.7	2.2	23.7	104.8	96.5	158.0	164.2	3.5	31.9	0.0	15.3	635.8
1981	65.5	24.6	NA	49.6	27.5	183.8	244.6	222.2	36.0	116.2	7.0	3.0	980.0
1980	93.3	2.4	0.0	33.4	66.5	99.0	122.9	258.9	NA	45.4	5.3	3.0	730.1
1979	6.5	34.0	1.2	16.0	47.7	68.9	133.7	110.0	90.5	12.0	2.6	51.0	574.1
1978	16.1	24.5	7.0	23.9	86.0	105.5	165.5	157.4	185.3	6.8	9.0	8.5	795.5
*1977	10.2	12.2	8.6	NA	45.0	166.8	153.9	212.2	125.0	29.6	4.8	20.5	788.8
*1976	5.4	0.7	6.6	29.3	70.3	43.0	395.2	253.4	176.2	132.9	20.3	12.1	1145.4
1975	NA	NA	NA	NA	NA	NA	NA	NA	46.1	14.8	0.0	0.0	NA
AVE.	18.8	12.3	5.2	25.6	75.7	133.4	249.8	179.1	120.8	52.4	9.8	8.1	884.6

Table 79 **Rainfall Data - Las Palmillas - 1971-1991**
1971-1991

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
1991	0.0	5.0	0.0	0.0	12.1	134.5	239.0	18.8	171.2	67.9	NA	NA	648.5
1990	2.2	25.9	NA	7.4	42.8	39.4	41.0	NA	124.0	76.5	2.0	4.0	365.2
1989	0.0	0.0	3.0	NA	31.6	52.0	36.4	185.4	37.2	3.3	1.0	NA	349.9
1988	0.0	0.0	0.0	0.0	0.0	0.0	110.0	178.0	33.0	0.0	2.0	0.0	323.0
1987	0.0	NA	0.0	9.0	0.0	77.9	126.0	73.0	54.0	0.0	0.0	0.0	339.9
1986	0.0	3.0	0.0	83.0	85.0	287.0	73.0	164.0	73.6	101.0	50.0	2.0	921.6
1985	4.0	9.0	20.0	72.0	156.0	154.0	155.0	133.0	31.0	4.0	21.0	1.0	760.0
1984	12.0	7.0	2.0	2.0	36.0	172.0	224.0	145.0	144.0	65.0	2.0	0.0	811.0
1983	25.0	7.0	6.0	0.0	89.0	77.0	185.0	90.0	NA	NA	12.0	3.0	494.0
1982	NA	12.0	24.0	32.0	69.0	33.0	43.0	118.0	1.0	133.0	1.0	21.0	487.0
1981	64.0	27.0	12.3	80.0	50.0	120.2	105.0	101.0	9.6	116.9	0.0	4.2	690.2
1980	NA	7.0	0.0	37.0	43.0	57.0	102.0	146.0	48.0	61.1	16.0	2.0	519.1
1979	0.0	25.0	0.0	28.0	45.5	68.0	88.9	75.5	83.6	0.0	9.4	10.4	434.3
1978	16.0	7.0	27.0	11.0	67.8	57.0	106.5	84.0	128.4	68.0	14.0	4.0	590.7
1977	5.0	0.0	0.0	36.0	19.0	140.0	110.0	169.2	174.0	79.0	2.2	14.1	748.5
1976	0.0	3.0	45.0	37.0	69.0	57.0	287.0	55.0	194.0	94.0	24.7	7.0	872.7
1975	39.1	7.0	0.0	0.0	98.1	156.2	168.3	136.0	27.0	3.0	1.0	0.0	635.7
1974	0.0	0.0	49.3	18.0	27.3	85.5	112.1	52.3	134.0	19.9	11.0	12.0	521.4
1973	0.0	0.0	0.0	33.1	67.6	168.8	173.3	111.8	90.9	32.4	0.0	0.0	677.9
1972	7.0	0.0	0.0	16.3	21.2	38.8	103.2	24.7	79.9	21.5	19.9	0.0	332.5
1971	0.0	0.0	15.7	3.0	31.0	232.0	62.5	113.5	160.4	89.7	0.0	13.0	720.8
AVE.	9.2	7.2	10.2	25.2	50.5	105.1	126.2	108.7	89.9	51.8	9.5	5.1	583.0

Table 80 **Factor for Adjusting Amealco I Data**

AVE.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
Am. I	6.5	9.4	5.3	10.0	30.3	95.6	389.9	298.8	220.4	1.1	6.5	1.1	1,369.6
G.Carn.	25.9	11.9	5.9	24.9	94.0	146.3	210.5	174.0	151.2	57.0	8.3	7.8	951.7
Factor	4.0	1.3	1.1	2.5	3.1	1.5	0.5	0.6	0.7	53.4	1.3	7.4	0.7
Am. 90	5.2	18.5	14.9	15.5	30.3	1.7	675.4	559.4	462.0	0.0	19.5	NA	1,802.4
90 Adj.	20.8	23.3	16.7	38.6	94.0	2.6	364.6	325.7	316.9	0.0	24.9	NA	1,228.1
Am. 89	0.0	0.0	0.0	4.5	NA	189.5	216.6	336.9	183.9	3.2	0.0	2.1	936.7
89 Adj.	0.0	0.0	0.0	11.2	NA	289.9	116.9	196.2	126.1	170.9	0.0	15.6	926.8
Am. 88	NA	NA	NA	NA	NA	NA	277.8	0.0	15.3	0.0	0.0	0.0	293.1
88 Adj.	NA	NA	NA	NA	NA	NA	149.9	0.0	10.5	0.0	0.0	0.0	160.4

Table 81 **Factor for Adjusting SMT Data**

AVE.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
SMT	18.8	12.3	5.2	25.6	75.7	133.4	249.8	179.1	120.8	52.4	9.8	8.1	884.6
G.Carn.	25.9	11.9	5.9	24.9	94.0	146.3	210.5	174.0	151.2	57.0	8.3	7.8	951.7
Factor	1.4	1.0	1.1	1.0	1.2	1.1	0.8	1.0	1.3	1.1	0.8	1.0	1.1
SMT 77	10.2	12.2	8.6	NA	45.0	166.8	153.9	212.2	125.0	29.6	4.8	20.5	788.8
77 Adj.	14.1	11.8	9.9	NA	55.9	182.9	129.7	206.1	156.4	32.2	4.1	19.7	822.6
SMT 76	5.4	0.7	6.6	29.3	70.3	43.0	395.2	253.4	176.2	132.9	20.3	12.1	1,145.4
76 Adj.	7.5	0.7	7.6	28.5	87.3	47.1	333.0	246.1	220.4	144.4	17.1	11.7	1,151.5
SMT 79	6.5	34.0	1.2	16.0	47.7	68.9	133.7	110.0	90.5	12.0	2.6	51.0	574.1
79 Adj.	9.0	32.8	1.4	15.6	59.3	75.5	112.7	106.8	113.2	13.0	2.2	49.1	590.7
SMT 78	16.1	24.5	7.0	23.9	86.0	105.5	165.5	157.4	185.3	6.8	9.0	8.5	795.5
78 Adj.	22.2	23.6	8.0	23.3	106.8	115.7	139.5	152.9	231.8	7.4	7.6	8.2	847.0

Table 82 **Factor for Adjusting Las Palmillas Data**

AVE.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
L.Palm.	9.2	7.2	10.2	25.2	50.5	105.1	126.2	108.7	89.9	51.8	9.5	5.1	583.0
G.Carn.	25.9	11.9	5.9	24.9	94.0	146.3	210.5	174.0	151.2	57.0	8.3	7.8	951.7
Factor	2.8	1.6	0.6	1.0	1.9	1.4	1.7	1.6	1.7	1.1	0.9	1.5	1.6
L.P. 89	0.0	0.0	3.0	NA	31.6	52.0	36.4	185.4	37.2	3.3	1.0	NA	349.9
89 Adj.	0.0	0.0	1.7	NA	58.8	72.4	60.7	296.7	62.5	3.6	0.9	NA	557.3
L.P. 88	0.0	0.0	0.0	0.0	0.0	0.0	110.0	178.0	33.0	0.0	2.0	0.0	323.0
88 Adj.	0.0	0.0	0.0	0.0	0.0	0.0	183.4	284.9	55.5	0.0	1.8	0.0	525.5
L.P. 87	0.0	NA	0.0	9.0	0.0	77.9	126.0	73.0	54.0	0.0	0.0	0.0	339.9
87 Adj.	0.0	NA	0.0	8.9	0.0	108.4	210.1	116.8	90.8	0.0	0.0	0.0	534.9
L.P. 84	12.0	7.0	2.0	2.0	36.0	172.0	224.0	145.0	144.0	65.0	2.0	0.0	811.0
84 Adj.	33.9	11.5	1.2	2.0	67.0	239.4	373.4	232.0	242.0	71.4	1.8	0.0	1,275.5
L.P. 75	39.1	7.0	0.0	0.0	98.1	156.2	168.3	136.0	27.0	3.0	1.0	0.0	635.7
75 Adj.	110.3	11.5	0.0	0.0	182.6	217.4	280.6	217.6	45.4	3.3	0.9	0.0	1,069.5
L.P. 74	0.0	0.0	49.3	18.0	27.3	85.5	112.1	52.3	134.0	19.9	11.0	12.0	521.4
74 Adj.	0.0	0.0	28.6	17.8	50.8	119.0	186.9	83.7	225.2	21.9	9.7	18.2	761.7
L.P. 73	0.0	0.0	0.0	33.1	67.6	168.8	173.3	111.8	90.9	32.4	0.0	0.0	677.9
73 Adj.	0.0	0.0	0.0	32.7	125.8	234.9	288.9	178.9	152.8	35.6	0.0	0.0	1,049.5
L.P. 72	7.0	0.0	0.0	16.3	21.2	38.8	103.2	24.7	79.9	21.5	19.9	0.0	332.5
72 Adj.	19.8	0.0	0.0	16.1	39.4	54.0	172.0	39.5	134.3	23.6	17.5	0.0	516.3
L.P. 71	0.0	0.0	15.7	3.0	31.0	232.0	62.5	113.5	160.4	89.7	0.0	13.0	720.8
71 Adj.	0.0	0.0	9.1	3.0	57.7	322.9	104.2	181.6	269.6	98.6	0.0	19.7	1,066.3
LP 91	0.0	5.0	0.0	0.0	12.1	134.5	239.0	18.8	171.2	67.9	NA	NA	648.5
91 Adj.	0.0	8.2	0.0	0.0	22.5	187.2	398.4	30.1	287.7	74.6	NA	NA	1,008.8

Table 83 **Monthly Averages for Aggregated Rainfall Data (mm./mo.)**

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	TOT.
21.6	9.4	6.4	21.2	82.3	143.9	220.2	164.1	164.6	55.9	7.5	9.0	906.1

Figure 5 **Monthly Averages for Aggregated Rainfall Data (mm./mo.)**

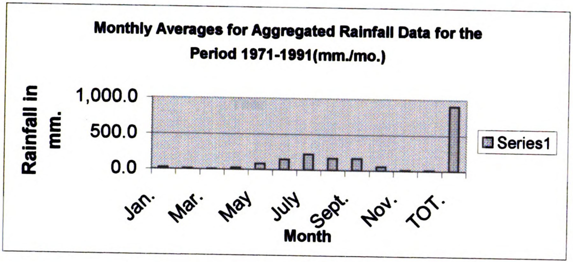


Figure 6 **Yearly Rainfall Totals for Aggregated Data 1971-1991 (mm./mo.)**

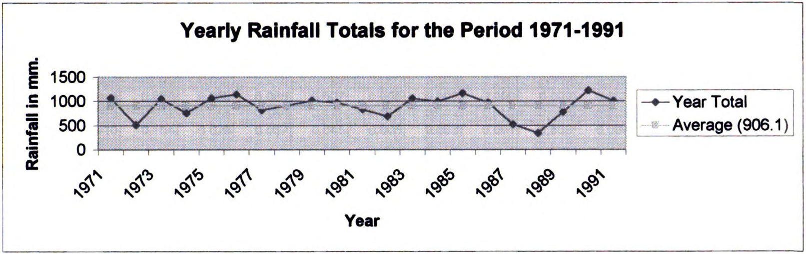


Table 84 **Rainfall Excess in Meters**

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*	Total
1971-72	0.009	0.176	0.030	0.051	0.116	0.037	0.000	0.001	0.001	0.000	0.000	0.001	0.421
1972-73	0.002	0.015	0.060	0.001	0.028	0.000	0.003	0.000	0.000	0.000	0.000	0.005	0.114
1973-74	0.023	0.130	0.184	0.057	0.065	0.005	0.000	0.000	0.000	0.000	0.005	0.002	0.471
1974-75	0.007	0.008	0.045	0.010	0.122	0.001	0.005	0.000	0.059	0.000	0.000	0.000	0.258
1975-76	0.046	0.070	0.080	0.085	0.007	0.005	0.003	0.000	0.000	0.003	0.006	0.009	0.313
1976-77	0.016	0.012	0.168	0.164	0.115	0.031	0.004	0.002	0.003	0.002	0.000	0.003	0.521
1977-78	0.010	0.104	0.028	0.067	0.045	0.005	0.008	0.001	0.003	0.004	0.009	0.002	0.287
1978-79	0.019	0.030	0.042	0.097	0.133	0.068	0.000	0.001	0.002	0.010	0.002	0.006	0.410
1979-80	0.227	0.010	0.029	0.124	0.145	0.000	0.000	0.018	0.058	0.004	0.000	0.027	0.642
1980-81	0.011	0.022	0.009	0.117	0.070	0.009	0.003	0.000	0.022	0.003	0.004	0.007	0.277
1981-82	0.008	0.133	0.021	0.051	0.003	0.014	0.000	0.001	0.000	0.003	0.004	0.001	0.238
1982-83	0.049	0.007	0.059	0.014	0.017	0.041	0.000	0.001	0.003	0.000	0.000	0.000	0.191
1983-84	0.023	0.004	0.234	0.088	0.145	0.002	0.000	0.000	0.001	0.002	0.000	0.000	0.499
1984-85	0.001	0.010	0.252	0.075	0.078	0.010	0.002	0.000	0.000	0.000	0.000	0.001	0.429
1985-86	0.042	0.084	0.111	0.080	0.044	0.018	0.002	0.000	0.000	0.000	0.000	0.003	0.385
1986-87	0.003	0.172	0.076	0.043	0.021	0.024	0.000	0.000	0.000	0.002	0.000	0.001	0.343
1987-88	0.000	0.009	0.092	0.024	0.021	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.149
1988-89	0.000	0.035	0.016	0.067	0.008	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.128
1989-90	0.007	0.033	0.014	0.000	0.031	0.113	0.000	0.000	0.000	0.004	0.005	0.002	0.210
1990-91	0.012	0.002	0.298	0.173	0.203	0.000	0.002	0.001	0.000	0.003	0.000	0.000	0.695
1991-92	0.005	0.066	0.220	0.000	0.159	0.007	0.002	0.001					0.461

Table 85 Monthly Runoff Totals within Catchment Zone in Cu. M. - Pond 1

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
1990-91 (High Year)	924	149	23,307	13,535	15,877	0	155	105	0	213	0	0
Average Year	1,936	4,206	7,696	5,166	5,865	1,454	132	105	592	164	146	277
1972-73 (Low Year)	129	1,135	4,697	111	2,191	3	260	0	0	0	0	362
Capacity - Pond 1	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612	2,612

Figure 7 Monthly Runoff Totals within Catchment Zone in Cu. M. - Pond 1

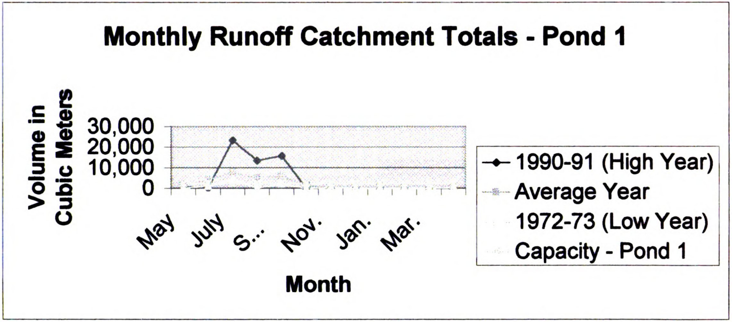


Table 86 **Monthly Runoff Totals within Catchment Zone in Cu. M. - Pond 2**

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
1990-91 (High Year)	554	89	13,984	8,121	9,526	0	93	63	0	128	0	0
Average Year	1,162	2,524	4,617	3,100	3,519	873	79	63	355	98	88	166
1972-73 (Low Year)	78	681	2,818	67	1,315	2	156	0	0	0	0	217
Capacity - Pond 2	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979	1,979

Figure 8 **Monthly Runoff Totals within Catchment Zone in Cu. M. - Pond 2**

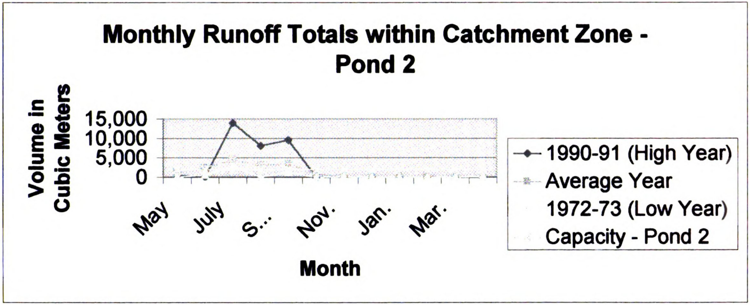


Table 87 Monthly Runoff Totals within Catchment Zone in Cu. M. - Pond 3

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
1990-91 (High Year)	4,066	656	102,552	59,553	69,857	0	682	462	0	938	0	0
Averarge Year	8,520	18,507	33,860	22,730	25,808	6,398	581	462	2,604	722	644	1,217
1972-73 (Low Year)	569	4,993	20,665	488	9,641	13	1,144	0	0	0	0	1,592
Capacity - Pond 3	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125	9,125

Figure 9 Monthly Runoff Totals within Catchment Zone in Cu. M. - Pond 3

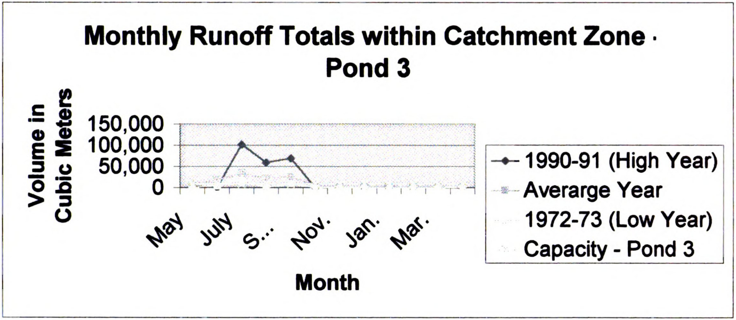
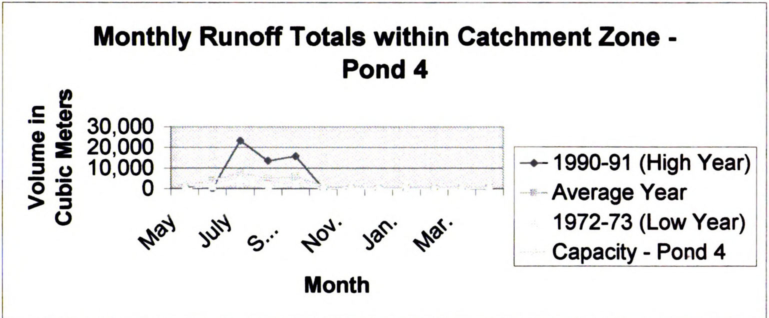


Table 88 Monthly Runoff Totals within Catchment Zone in Cu. M. - Pond 4

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	*Jan.*	*Feb.*	*Mar.*	*Apr.*
1990-91 (High Year)	924	149	23,307	13,535	15,877	0	155	105	0	213	0	0
Average Year	1,936	4,206	7,696	5,166	5,865	1,454	132	105	592	164	146	277
1972-73 (Low Year)	129	1,135	4,697	111	2,191	3	260	0	0	0	0	362
Capacity - Pond 4	2,028	2,028	2,028	2,028	2,028	2,028	2,028	2,028	2,028	2,028	2,028	2,028

Figure 10 Monthly Runoff Totals within Catchment Zone in Cu. M. - Pond 4



the second highest, and September the third. For years of average runoff, there are four months (June-Sept.) where the runoff generated within an individual month is greater than pond capacity – this is true for all four ponds. Thus, in an average year, the runoff of any month between June and September would be enough to fill the ponds.

Ironically, during the year of highest runoff (1990-91), there were only three months (July-Sept.) during which the runoff of a singular month was sufficient to fill the ponds. Because extra rainfall is not necessarily distributed over time, the extra may be lost due to pond overflow. For the year of lowest runoff accumulation (1972-73), July was the singular month where runoff was sufficient to fill the ponds.

This picture of monthly runoff is reassuring as it indicates that, even without considering the cumulative collection of runoff over several months, there are singular months within any given year where enough runoff is generated to fill the study ponds. This is true even for years of low rainfall/runoff. The implication is that, if a pond is altered such that the stored water losses are eliminated, local rainfall is sufficient to generate enough runoff flow to fill the ponds on an annual basis. The challenge then becomes to reduce stored water loss from the ponds.

3.) Comparison of Yearly Runoff Totals to Pond Capacity

A look at annual runoff totals for the 1971-92 period (See Tables 89-92 facing page) reinforces the conclusion that local runoff is sufficient to fill the four study ponds. The runoff data indicate that for all 21 years, annual totals are more than sufficient to fill the ponds. The following figures indicate the percentage of pond capacity generated in runoff for an average year.

Pond 1 – Total annual runoff = 1,061% of pond capacity
Pond 2 – 841%

Table 89 **Yearly Runoff within Catchment Zone in Cu. M. - Pond 1**

Capacity = 2,612 **Yrly. Ave. 1971-1992 = 27,739 Cu. M.**

Year	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Runoff	32,919	8,888	36,809	20,120	24,474	40,720	22,398	32,030	50,119	21,609	18,602
Year	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	
Runoff	14,952	38,981	33,544	30,047	26,815	11,669	9,992	16,397	54,265	37,176	

Table 90 **Yearly Runoff within Catchment Zone in Cu. M. - Pond 2**

Capacity = 1,979 **Yrly. Ave. 1971-1992 = 16,644 Cu. M.**

Year	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Runoff	19,751	5,333	22,086	12,072	14,684	24,432	13,439	19,218	30,071	12,965	11,161
Year	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	
Runoff	8,971	23,388	20,126	18,028	16,089	7,001	5,995	9,838	32,559	22,306	

Table 91 **Yearly Runoff within Catchment Zone in Cu. M. - Pond 3**

Capacity = 9,125 **Yrly. Ave. 1971-1992 = 122,063 Cu. M.**

Year	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Runoff	144,841	39,105	161,961	88,530	107,686	179,170	98,549	140,932	220,524	95,079	81,848
Year	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	
Runoff	65,789	171,515	147,594	132,208	117,984	51,343	43,984	72,147	238,765	163,576	

Table 92 **Yearly Runoff within Catchment Zone in Cu. M. - Pond 4**

Capacity = 2,928 **Yrly. Ave. 1971-1992 = 27,739 Cu. M.**

Year	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Runoff	32,919	8,888	36,809	20,120	24,474	40,720	22,398	32,030	50,119	21,609	18,602
Year	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	
Runoff	14,952	38,981	33,544	30,047	26,815	11,669	9,992	16,397	54,265	37,176	

Pond 3 – 1,337%
Pond 4 – 1,367%

4.) Sensitivity of Runoff Calculations to Error

Before making a final conclusion that local runoff is sufficient to fill the study ponds on an annual basis, it is worthwhile to examine the possibility of error in the calculation of runoff (i.e. the case where actual runoff is less than calculated). To test this possibility, annual runoff was reduced by 50% and compared to the pond capacities. The data (See Tables 93-96 facing page) show that even if the runoff values calculated for this study overstate actual runoff by 50%, annual runoff is still sufficient to fill the ponds on an annual basis. Thus, the runoff calculations performed for this study allow for a 50% margin of error, and it seems safe to conclude that the study ponds do fill with water on a consistent basis.

5.) Evaporation Loss

Tables 97 & 98 (page 180) show the evaporation data taken from the Granja Carnation and San Miguel Tilaxcalte stations. Table 99 (page 181) shows the adjustment factors used to adjust the SMT data. Table 100 (also page181) shows the 21-year aggregated evaporation data.

6.) Comparison of Stored Water Loss

Tables 101-112 (pages 182-184) present a comparison of the three sources of stored water loss. The data show that during years of high, low, and average runoff, infiltration is responsible for approximately 80-90% of annual stored water loss. Evaporation is the next greatest source of loss with about 10-15% of total share. Animal consumption loss is quite minimal with approximately 1-3% of the annual total. (Note:

Table 93 **Yearly Runoff within Catchment Zone of Pond 1 - Reduced by 50%**

Capacity = 2,612 **Yrly. Ave. = 13,870 Cu. M.**

Year	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Runoff	16,459	4,444	18,405	10,060	12,237	20,360	11,199	16,015	25,059	10,804	9,301
Year	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	
Runoff	7,476	19,490	16,772	15,024	13,407	5,834	4,996	8,199	27,132	18,588	

Table 94 **Yearly Runoff within Catchment Zone of Pond 2 - Reduced by 50%**

Capacity = 1,979 **Yrly. Ave. = 8,322 Cu. M.**

Year	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Runoff	9,876	2,666	11,043	6,036	7,342	12,216	6,719	9,609	15,036	6,483	5,581
Year	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	
Runoff	4,486	11,694	10,063	9,014	8,044	3,501	2,998	4,919	16,279	11,153	

Table 95 **Yearly Runoff within Catchment Zone of Pond 3 - Reduced by 50%**

Capacity = 9,125 **Yrly. Ave. = 61,026 Cu. M.**

Year	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Runoff	72,421	19,553	80,980	44,265	53,843	89,585	49,275	70,466	110,262	47,539	40,924
Year	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	
Runoff	32,895	85,758	73,797	66,104	58,992	25,671	21,982	36,074	119,383	81,788	

Table 96 **Yearly Runoff within Catchment Zone of Pond 4 - Reduced by 50%**

Capacity = 2,028 **Yrly. Ave. = 13,870 Cu. M.**

Year	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82
Runoff	16,459	4,444	18,405	10,060	12,237	20,360	11,199	16,015	25,059	10,804	9,301
Year	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	
Runoff	7,476	19,490	16,772	15,024	13,407	5,834	4,996	8,199	27,132	18,588	

Table 97 **Evaporation Data (mm./mo.) - Granja Carnation 1979 - 1989**

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yrly. Tot.
1989	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1986	110	117	159	137	150	118	137	NA	NA	NA	NA	NA	NA
1985	113	106	125	119	155	94	106	127	130	170	130	100	1,478
1984	98	129	156	181	173	143	NA	123	100	128	NA	111	1,341
1983	105	174	187	222	226	195	130	135	115	109	93	70	1,759
1982	142	145	182	220	184	205	165	155	140	130	119	122	1,908
1981	80	93	134	156	206	184	162	148	129	115	113	121	1,638
1980	124	140	220	188	218	181	168	142	161	110	88	94	1,836
1979	141	146	NA	NA	300	NA	NA	124	128	167	123	93	NA
1978	NA	NA	NA	NA	NA	NA	NA	164	NA	141	NA	154	NA
Ave.	114	131	166	175	201	160	145	140	129	134	111	108	1,714

Table 98 **Evaporation Data (mm./mo.) - San Miguel Tilaxcalte 1976-1988**

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yrly. Tot.
1988	56	NA	70	60	66	60	NA	NA	NA	58	67	66	503
1987	112	NA	95	104	NA	73	59	53	54	NA	NA	70	620
1986	133	131	168	174	25	138	150	163	119	130	121	138	1,589
1985	135	136	181	176	166	140	144	134	135	166	137	122	1,772
1984	145	129	168	182	164	145	NA	124	110	143	NA	128	1,440
1983	150	135	190	209	232	189	211	196	139	139	127	117	2,034
1982	118	154	191	181	142	182	171	174	161	147	124	142	1,887
1981	110	NA	113	170	202	180	147	167	154	133	122	110	1,607
1980	128	116	203	166	157	191	191	207	NA	147	155	154	1,817
1979	136	127	216	170	197	170	167	153	131	160	122	94	1,842
1978	134	134	245	193	255	137	134	155	126	151	100	120	1,884

Table 99 **Adjustment Factors and Adjusted Evaporation Data - San Miguel Tilaxcalte**

Fctr.	0.90	0.97	0.96	1.08	1.23	1.08	0.96	0.92	1.00	0.98	0.94	0.96	
Year	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Yrly. Tot.**
1988	52	NA	67	64	81	65	NA	NA	NA	57	63	63	512
1987	103	NA	91	112	NA	79	56	49	54	NA	NA	67	611
1986	121	128	161	187	31	149	144	149	119	127	114	133	1,564
1979	125	124	206	183	241	184	160	140	131	157	115	90	1,857
1978	122	131	235	208	313	148	129	142	127	148	95	116	1,912
1977	128	146	231	NA	244	185	139	142	136	138	106	98	1,695
1976	NA	NA	NA	NA	NA	NA	132	135	149	122	98	94	730

Table 100 **Adjusted Evaporation Data (mm./mo.) - GC & SMT**

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yrly. Tot.
SMT 88	52	NA	67	64	81	65	NA	NA	NA	57	63	63	512
SMT 87	103	NA	91	112	NA	79	56	49	54	NA	NA	67	611
GC/SMT	110	117	159	137	150	118	137	149	119	127	114	133	1,570
1985	113	106	125	119	155	94	106	127	130	170	130	100	1,478
1984	98	129	156	181	173	143	NA	123	100	128	NA	111	1,341
1983	105	174	187	222	226	195	130	135	115	109	93	70	1,759
1982	142	145	182	220	184	205	165	155	140	130	119	122	1,908
1981	80	93	134	156	206	184	162	148	129	115	113	121	1,638
1980	124	140	220	188	218	181	168	142	161	110	88	94	1,836
GC/SMT	141	146	206	183	300	184	160	124	128	167	123	93	1,957
GC/SMT	122	131	235	208	313	148	129	164	127	141	95	154	1,967
SMT 77	128	146	231	NA	244	185	139	142	136	138	106	98	1,695
SMT 76	NA	NA	NA	NA	NA	NA	132	135	149	122	98	94	730
Ave.	110	133	166	163	205	148	135	133	124	126	104	102	1,648

Table 101
Distribution of Total Annual Stored Water Loss by Source - Pond 1

Average Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,855	9.78%
Infiltration	16,693	88.03%
Consumption	416	2.19%
	18,963	

Table 102
Distribution of Total Annual Stored Water Loss by Source - Pond 1

Highest Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,855	13.84%
Infiltration	11,129	83.06%
Consumption	416	3.10%
	13,399	

Table 103
Distribution of Total Annual Stored Water Loss by Source - Pond 1

Lowest Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,855	13.84%
Infiltration	11,129	83.06%
Consumption	416	3.10%
	13,399	

Table 104
Distribution of Total Annual Stored Water Loss by Source - Pond 2

Average Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,264	9.87%
Infiltration	11,379	88.85%
Consumption	164	1.28%
	12,807	

Table 105
Distribution of Total Annual Stored Water Loss by Source - Pond 2

Highest Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,264	10.95%
Infiltration	10,115	87.63%
Consumption	164	1.42%
	11,543	

Table 106
Distribution of Total Annual Stored Water Loss by Source - Pond 2

Lowest Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,264	16.31%
Infiltration	6,322	81.57%
Consumption	164	2.11%
	7,750	

Table 107
Distribution of Total Annual Stored Water Loss by Source - Pond 3

Average Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	5,830	8.32%
Infiltration	64,130	91.49%
Consumption	136	0.19%
	70,096	

Table 108
Distribution of Total Annual Stored Water Loss by Source - Pond 3

Highest Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	5,830	8.32%
Infiltration	64,131	91.49%
Consumption	136	0.19%
	70,097	

Table 109
Distribution of Total Annual Stored Water Loss by Source - Pond 3

Lowest Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	5,830	14.24%
Infiltration	34,980	85.43%
Consumption	136	0.33%
	40,947	

Table 110
Distribution of Total Annual Stored Water Loss by Source - Pond 4

Average Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,440	8.96%
Infiltration	14,401	89.64%
Consumption	225	1.40%
	16,066	

Table 111
Distribution of Total Annual Stored Water Loss by Source - Pond 4

Highest Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,440	13.97%
Infiltration	8,641	83.84%
Consumption	225	2.18%
	10,306	

Table 112
Distribution of Total Annual Stored Water Loss by Source - Pond 4

Lowest Runoff Year

Source	Cu. M./Yr.	% of Tot.
Evaporation	1,440	13.97%
Infiltration	8,641	83.84%
Consumption	225	2.18%
	10,306	

Because the quantities of loss presented here are annual totals, their sum is greater than pond capacity for each respective pond). Thus, it appears that as the farmers have indicated, infiltration is the primary source of stored water loss. For this reason, this study will concentrate on the use of geomembranes to line ponds and not cover them.

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