USE OF AN EVAPOTRANSPIRATION MODEL AND A GEOGRAPHIC INFORMATION SYSTEM (GIS) TO ESTIMATE THE IRRIGATION POTENTIAL OF THE TRASVASE SYSTEM IN THE SANTA ELENA PENINSULA, GUAYAS, ECUADOR

By

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To my Family

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LIST OF OBJECTS

LIST OF ABBREVIATIONS

CEDEGE	Commission for the Development of the Guayas River Basin, Ecuador http://www.cedege.gov.ec
CWR	Crop Water Requirement
CIR	Crop Irrigation Requirement
ESPOL	Polytechnic School of the Littoral, Ecuador http://www.espol.edu.ec
ETo	Reference evapotranspiration
ETc	Actual evapotranspiration
FAO	Food and Agricultural Organization http://www.fao.org
FGDC	Federal Geographic Data Committee http://www.fgdc.gov
GIS	Geographic Information System
GPS	Global Positioning System
IDW	Inverse Distance Weighted
IGM	Geographic Military Institute, Ecuador http://www.igm.gov.ec
ISO	International Organization for Standardization
Kc	Crop coefficient
SEP	Santa Elena Peninsula
USDA	United States Department of Agriculture http://www.usda.gov
WCD	World Commission on Dams http://www.dams.org/

Abstract of Thesis Presented to the Graduate School
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Irrigated agriculture produces more than 40 % of the world food supply, using 20 % of the agricultural land in developing countries. Food production is important, especially in developing countries like Ecuador. The TRASVASE irrigation system was constructed to provide water for irrigation to the Santa Elena Peninsula in Ecuador. However, this project performs below expectations. One of the limitations is that the total area that this irrigation system could irrigate has not been determined. Available geographic, climatic, and soils and land use data were summarized for the Santa Elena Peninsula using a Geographic Information System. The total area that can be irrigated was calculated based on the evapotranspiration concept used by CROPWAT software from UN/FAO. Evapotranspiration is a sum of the water evaporation from the soil and plant surfaces, and transpiration from the plant leaves.

Calculation of evapotranspiration uses weather parameters like air temperature, relative humidity, solar radiation, and wind speed. Taking into consideration the water used by the potable water treatment plants and the water loss thru evaporation and seepage from the canals and dams, total water available for irrigation can be calculated. This total available water divided by the crop water requirement gives the total area that the TRASVASE system could irrigate. To cover a wide range of possible variations in irrigation technology and crops planted in the area, nine scenarios were tested. The variables were three levels of in-field water application efficiency (50 %, 70 %, and 90 %); and three levels of the crop water requirement (high, low, and a mixture of high and low).

Results of this project show that with an in-field application efficiency of 90 % and low-water-requirement crops, 15,506 hectares could be irrigated. However, with 50 % application efficiency and high-water-requirement crops, the area is reduced to 7,700 hectares.

It is obvious that very efficient irrigation technologies must be used in the Santa Elena Peninsula to optimize the use of water. Good management and maintenance of those irrigation systems are also needed. Agricultural production has to be planned to minimize water use and to increase the total area to be irrigated.

CHAPTER 1
LITERATURE REVIEW

Significance of Irrigation in Agriculture

Irrigation is a process that uses more than two-thirds of the Earth's renewable water resources and feeds one-third of the Earth's population (Stanhill 2002). Some 2.4 billion people depend directly on irrigated agriculture for food and employment. Irrigated agriculture thus plays an essential role in meeting the basic needs of billions of people in developing countries (FAO 1996). Although water resources are still ample on a global scale, serious water shortages are developing in the arid and semi-arid regions (Hall 1999).

There is a need to focus attention on the growing problem of water scarcity in relation to food production. The World Food Summit of November 1996, drew attention to the importance of water as a vital resource for future development (FAO 1996). A major part of the developed global water resources is used for food production. The estimated minimum water requirement per capita is 1,200 m^3 annually (50m^3 for domestic use and 1,150 m^3 for food production) (FAO 1996).

Sustainable food production depends on judicious use of water resources as fresh water for human consumption and agriculture become increasingly scarce. To meet future food demands and growing competition for clean water, a more effective use of water in both irrigated and rainfed agriculture will be essential (Smith 2000). Options to increase water-use efficiency include harvesting rainfall, reducing irrigation water losses, and adopting cultural practices that increase production per unit of water.

Irrigation is an obvious option to increase and stabilize crop production. Major investments have been made in irrigation over the past 30 years by diverting surface water and extracting groundwater. The irrigated areas in the world have, over a period of 30 years, increased by 25 % (mainly during a period of accelerated growth in the 1970s and early 1980s) (FAO 1993).

A major constraint to the understanding of the use of water is the difficulty associated with its measurement and quantification. Measurement and data collection of discharge in canals is difficult and fraught with potential errors.

Necessary conditions for the optimal performance of regional water delivery systems include well-defined water rights; infrastructure capable of providing the service embodied in the water rights, and assigned responsibilities for all aspects of system operation (Perry 1995). One or more of those conditions may be missing in some regional systems at the start of irrigation deliveries. In other systems problems may develop over time with changes in land ownership, cropping patterns, and the volume of water available for delivery in the system. Problems with cost recovery and inadequate maintenance also can reduce the efficiency of regional water-delivery systems.

Water use for crop production is depending on the interaction of climatic parameters that determine crop evapotranspiration and water supply from rain (Smith 2000). Compilation, processing, and analysis of meteorological information for crop water use and crop production are therefore key elements in developing strategies to optimize the use of water for crop production and to introduce effective water-management practices. Estimating crop water use from climatic data is essential to, better water-use efficiency.

Because most of the Earth’s irrigated land is in the underdeveloped world (where food, water, and skilled manpower are in short supply), it is important to use the simplest, cheapest, and most practical meteorological method to improve crop water-use efficiency in irrigation. Stanhill (2002) says that in these regions use of standard, correctly sited and maintained evaporation pans operating within a national network can provide the basis for a scheduling method in which the use of empirical crop coefficients is accepted. These coefficients reflect the local economic as well as agronomic, climatologic and hydrological (water quality) situation (Stanhill 2002). However, the literature often contradicts. Hillel (1997) said: “the use of ‘evaporation pans’ has several shortcomings.”

Smith (2000) stated that agro-meteorology would play a key role in the looming global water crisis. Appropriate strategies and policies need to be defined, including strengthening of national use of climatic data for planning and managing of sustainable agriculture and for drought mitigation.

The limitations of currently available methods for measuring rates of evaporation from natural and agricultural surfaces are well known; as is the resulting lack of information (local and global) on this major element in the hydrological cycle. A practical method (suitable for routine use in meteorological station networks) is to use calculations based on other meteorological measurements, like those used by the Penman-Monteith method (Stanhill 2002).

Reference Evapotranspiration

Several definitions of reference evapotranspiration ET_o have been formulated. Jensen (1993) defined ET_o as the rate at which water, if available, would be removed from the soil and plant surface. Pereira et al. (1999) stated that Duke simplified the definition of ET_o to “the water used by a well-watered reference crop, such alfalfa, which fully covers the soil surface.” The modified Penman combination equation is used to compute ET_o, as it is considered to be a satisfactory estimation equation when daily estimates of ET_o are desired (Jensen et al. 1990).

Use of FAO Penman-Monteith to Estimate Reference Evapotranspiration

This approach was introduced by Penman in 1948 to estimate open-water evaporation (Penman 1948); and extended by Monteith in 1965 to directly estimate evaporation from vegetation-covered surfaces (Monteith 1965). It is now the recommended method by the FAO to calculate reference crop evapotranspiration (Allen et al. 1998).

Studies showed the superior performance of the Penman–Monteith approach, in both arid and humid climates, and convincingly confirmed the sound underlying concepts of the method. Based on these findings, the method was recommended by the FAO Panel of Experts (convened in 1990) for adoption as a new standard for reference crop evapotranspiration estimates (Hall 1999).

The use of the Penman-Monteith equation in irrigation practice requires empirical coefficients to modify—in general to reduce but sometimes to increase—the estimates of reference crop evapotranspiration (Stanhill 2002).

Use of FAO Penman–Monteith with limited climatic data. The limited availability of the full range of climatic data (particularly data on sunshine, humidity and wind) has often prevented the use of the combination methods and resulted in the use of empirical methods (which require only temperature, pan, or radiation data). This has contributed to the confusing use of different ET_o methods and conflicting evapotranspiration values. To overcome this constraint and to further use of a single method, additional studies have been undertaken to provide recommendations on the using FAO Penman-Monteith when no humidity, radiation or wind data are available. As a result, procedures are presented to estimate humidity and radiation from maximum/minimum temperature data and to adopt global estimates for wind speed. The availability of worldwide climatic databases further facilitates the adoption of values from nearby stations. Such procedures have proven to perform better than any of the alternative empirical formulas; and will largely improve transparency of calculated evapotranspiration values (Smith et al. 1996).

Actual Crop Evapotranspiration

Procedures for estimating crop evapotranspiration have been well established by Doorenbos and Pruitt (1977), using a series of recommended crop coefficient values (K_c) to determine ET_{crop} (ET_c) from reference evapotranspiration (ET_o), as follows:

$$ET_c = K_c ET_o \tag{1-1}$$

This formula represents the single crop coefficient. Crop evapotranspiration (ET_c) refers to evapotranspiration of a disease-free crop, grown in very large fields, not short of water and fertilizer. Estimation of ET_c is essential for computing the soil water balance and irrigation scheduling. ET_c is governed by weather and crop condition (Smith, 2000). The specific wetting (irrigation) events are taken into account (spikes in Figure 1-1).

Computerized Crop Water Use Simulations

Practical procedures and criteria need to be defined to enhance the introduction and application of effective water use practices for crop production. The introduction of computerized procedures linked to digital databases and geographic information systems (GIS) will greatly enhance the use of appropriate planning and management techniques for water use in irrigated and rainfed agriculture. Computerized procedures greatly facilitate the estimation of crop water requirements from climatic data and allow the development of standardized information and criteria for planning and management of rainfed and irrigated agriculture.

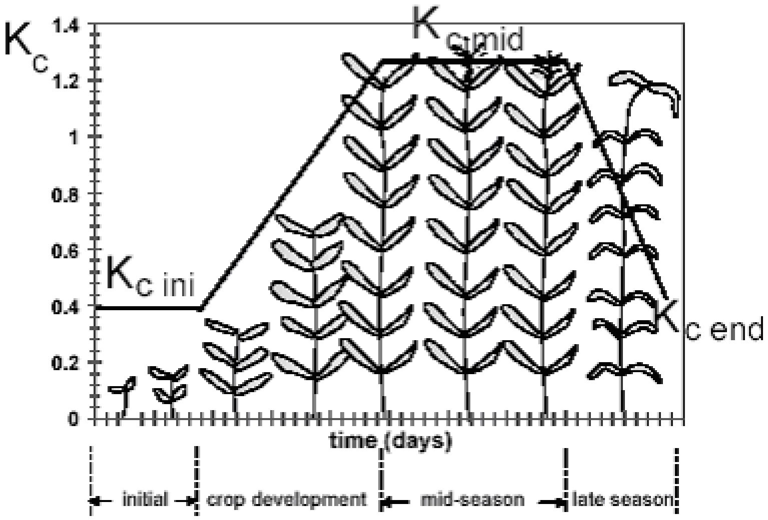

Figure 1-1. Dual crop coefficient curve

Figure 1-1 shows the crop coefficient divided in different stages according to crop development.

The FAO-CROPWAT program (Smith 1992) incorporates procedures for reference crop evapotranspiration and crop water requirements and allows the simulation of crop water use under various climate (CLIMWAT 1994), crop and soil conditions.

As a decision support system CROPWAT's main functions include: (1) the calculation of reference evapotranspiration according to the FAO Penman-Monteith method; (2) crop water requirements using revised crop coefficients (FAO Paper 56, compared to the data from FAO Paper 49) and crop growth periods; (3) effective rainfall and irrigation requirements; (4) scheme irrigation water supply for a given cropping pattern; (5) daily water balance computations (Smith 1992).

Irrigation Efficiency

Classical overall irrigation system efficiency (E_o) is defined as the volume of water used beneficially (net crop evapotranspiration) divided by the volume of water diverted (Keller et al. 1996)

Keller et al. (1996) defines effective efficiency (E_E) as the ratio of net crop evapotranspiration divided by the net volume of water delivered to a field (V_s). The volume of water that becomes usable surface runoff or deep percolation is subtracted from the total volume delivered when calculating the denominator ratio.

Irrigation efficiency has a tremendous impact on agricultural water demands. Understanding how irrigation efficiency fits into estimation of water requirements is essential. Zadalis, et al (1997) consider the effective rainfall in their definition of efficiency. The mean irrigation efficiency for each system is defined by the ratio of the net volume actually used by the crops and the volume released at the head of the main canal:

$$E_E = (ET_c - R_e)/V_s \qquad (1\text{-}2)$$

where ET_c is the estimated water used by crops, R_e is the effective rainfall, and V_s, is the volume of water delivered to each network or canal (Zalidis et al. 1997).

The most common way to express the efficiency of irrigation systems is to subdivide it into conveyance and application efficiencies.

- The conveyance efficiency (Ec), which represents the efficiency of water transport in canals or pipes in the field.
- The field application efficiency (Ea), which represents the efficiency of water application in the field.

The conveyance efficiency (Ec) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals (Brouwer & Prins

1989). In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. When water is conveyed in pipes, Ec mainly depends on pipe leakage and is usually close to 100 % for new systems.

Table 1-1 provides some indicative values of the conveyance efficiency (Ec), considering the length of the canals and the soil type in which the canals are dug. The level of maintenance is not taken into consideration: bad maintenance may lower the values of Table 1-1, by as much as 50 % (Brouwer & Prins 1989).

Table 1-1. Conveyance efficiency (Ec)

Percent Efficiency (%) of conveyance				
(canal length in meters)	Earthen canals			Lined canals
	Sand	Loam	Clay	
Long (> 2000)	60	70	80	95
Medium (200-2000)	70	75	85	95
Short (< 200)	80	85	90	95

The field application efficiency (Ea) mainly depends on the irrigation method and the level of farmer discipline. Some indicative values of the average field application efficiency (Ea) are given in Table 1-2. Lack of discipline may lower the values found in Table 1-2 (Brouwer & Prins 1989).

Table 1-2. Field application efficiency (Ea)

Irrigation methods	Application efficiency (%)
Surface irrigation (border, furrow, basin)	50-60
Sprinkler irrigation	60-80
Drip irrigation	80-up

Once the conveyance and field application efficiency have been determined, the scheme irrigation efficiency (E) can be calculated, using the following formula (Brouwer & Prins 1989):

$$E = \frac{Ec \times Ea}{100} \tag{1-3}$$

with

E = scheme irrigation efficiency (%)
Ec = conveyance efficiency (%)
Ea = field application efficiency (%)

According to FAO a scheme irrigation efficiency of 50–60 % is good; 40 % is reasonable, while a scheme Irrigation efficiency of 20–30 % is poor. It should be kept in mind that the values mentioned above are only indicative values (Brouwer & Prins 1989).

Water productivity increases with improvements in agronomic practices and in water supply and management, both regionally and at the farm level. Water supply reliability also is important, as optimal investments in seeds, fertilizer, and land preparation are less likely to be made when the timing of farm level water deliveries is uncertain (Brouwer 1988).

Improving agricultural water efficiency is particularly important for improving the productivity of large irrigation schemes. The recent promotion of participatory irrigation management or turnover needs to be supported by other measures such as technological innovations, for example, the development of effective water metering of canal systems to enable cost recovery measures to be introduced (Brouwer 1988).

Under irrigated conditions, priorities need to be set for reducing losses of irrigation water and for increasing effectiveness of irrigation management. Considerable amounts of water diverted for irrigation are not effectively used for crop production. It is estimated that, on average, only 45 % is used by the crop, with an estimated 15 % lost in the water conveyance system, 15 % in the field channels and at least 25 % in inefficient field applications (FAO 1994). This number depends on the type of irrigation system. For example, in Arizona, farmers have increased irrigation efficiency from 50–60 % in the 1980s to 95 % in 1995 by adopting sub-surface drip methods. This change in technology results in other benefits such as reduced power consumption, reduced fertilizer and herbicide use and higher yields (Wichelns 2001).

Irrigation Techniques

An adequate water supply is important for plant growth. When rainfall is not sufficient, the plants must receive additional water from irrigation. Various methods can be used to supply irrigation water to the plants. Whatever irrigation method is being chosen, its purpose is always to attain a better crop and a higher yield.

Surface irrigation. Surface irrigation is the application of water by gravity flow to the surface of the field. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders).

Sprinkler irrigation. Sprinkler irrigation is similar to natural rainfall. Water is pumped through a pipe system and then sprayed onto the crops through rotating sprinkler heads (Izuno & Haman 1987).

Micro irrigation. Consists of drip irrigation and micro-sprinkler systems.

Drip irrigation. With drip irrigation, water is conveyed under pressure through a pipe system to the fields, where it drips slowly onto the soil through emitters or drippers that are located close to the plants. Only the immediate root zone of each plant is wetted. Therefore this can be a very efficient method of irrigation. Drip irrigation is sometimes called trickle irrigation (Izuno and Haman 1987).

Microsprinkler. Also known as micro-spray, is an irrigation method that falls into the trickle category, characterized by the application of water to the soil surface as a small spray or mist. Discharge rates are generally less than 30 gal/hr (Izuno and Haman 1987).

Application of GIS to Irrigation Management

GIS have potentially considerable application to irrigation water management, especially in regions where there are poorly defined procedures for irrigation water management data collection, processing and analysis. The possibility of using GIS to identify crop areas, plan irrigation schedules and quantify performance offer exciting possibilities for research (Ray and Dadhwal 2001).

The tools necessary to create a good GIS in irrigation are the availability of weather data and how it is spatially distributed over the study area. Also important are the techniques to be used to interpolate the climatic data, evapotranspiration, and other calculated variables.

The availability of weather data of acceptable spatial resolution for large-scale irrigation scheduling is an important factor to consider in planning the development and management of irrigation information systems throughout the world (Hashmi et al. 1994).

The spatial distribution of the available weather data is important. It is of special concern in developing countries where the availability of weather stations is limited. The recommended maximum distance between points (weather stations) for least dense networks is 150–200 km, for the intermediate network, 50–60 km for the densest network, 30km (Gandin 1970). Once the data is collected and analyzed using statistics, a surface map can be created using GIS.

There are many interpolation methods; however, inverse-square-distance interpolation technique appears to be the most accurate method of interpolation irrespective of number of data points. Hashmi et al. (1994) has also used the inverse-square-distance approach to interpolate ET values.

GIS Data Quality Analysis

An important step when working with GIS is data quality analysis. The International Organization for Standardization supplies an acceptable definition of data quality using accepted terminology from the quality field. The International Organization for Standardization (ISO) is a federation of national standards bodies. ISO's working groups from most of the world's nations forge international agreements, which are published as International Standards. These standards are documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose. Like other ISO standards, ISO quality standards are frequently updated to reflect advances in quality methodology.

Among the many ISO standards is ISO 8402: Quality Management and Quality Assurance Vocabulary. ISO 8402 provides a formal definition of quality as: “The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs” (Marcey, et al. 1998). Thus, data can be defined to be of the required quality if it satisfies the requirements stated in a particular specification and the specification reflects the implied needs of the user. Therefore, an acceptable level of quality has been achieved if the data conforms to a defined specification and the specification correctly reflects the intended use.

Structured analysis of these characteristics, together with careful planning, should provide a data quality assessment that reveals key data quality problems, root causes for the problems, and solutions for improving both conformance and utility.

Data Quality Attributes

A set of characteristics, or data quality attributes, is required for the objective and measurable assessment of data quality. Commonly used attributes to measure data quality include accuracy, completeness, consistency, reliability, timeliness, uniqueness, and validity (Chrisman, & McGranaghan 2000).

- Among other technical issues in GIS, accuracy is perhaps the most important, it covers concerns for data quality, error, uncertainty, scale, resolution and precision in spatial data and affects the ways in which it can be used and interpreted
- All spatial data is inaccurate to some degree but it is generally represented in the computer to high precision

Data Quality Components

Recently a National Standard for Digital Cartographic Data (http://www.fgdc.gov/) was developed by a coordinated national effort in the U.S. (Chrisman, & McGranaghan 2000).

- This is a standard model to be used for describing digital data accuracy
- Similar standards are being adopted in other countries

This standard identifies several components of data quality:

- Positional accuracy
- Attribute accuracy
- Logical consistency
- Completeness
- Lineage

Accuracy

Defined as the closeness of results, computations or estimates to true values (or values accepted to be true). Since spatial data is usually a generalization of the real world, it is often difficult to identify a true value, and we work instead with values that are accepted to be true, e.g., in measuring the accuracy of a contour in a digital database, we compare to the contour as drawn on the source map, since the contour does not exist as a real line on the surface of the earth.

The accuracy of the database may have little relationship to the accuracy of products computed from the database, e.g. the accuracy of a slope, aspect or watershed computed from a Digital Elevation Model (DEM) is not easily related to the accuracy of the elevations in the DEM itself.

Attribute Accuracy, defined as the closeness of attribute values to their true value, has to be noted that while location does not change with time, attributes often do. Attribute accuracy must be analyzed in different ways depending on the nature of the data

Positional Accuracy

Defined as the closeness of locational information (usually coordinates) to the true position. Conventionally, maps are accurate to roughly one line width or 0.5 mm, equivalent to 12 m on 1:24,000, or 125 m on 1:250,000 maps. To test positional accuracy one of the following options can be used as an independent source of higher accuracy: a larger scale map, the Global Positioning System (GPS), raw survey data, internal evidence.

GIS Data Entry

GIS data typically are created from hard-copy source data. The process often is called "digitizing," because the source data are converted to a computerized (digital) format. Human digitizers can compound errors in source data as well as introduce new errors (Korte 2000). Although manual digitizing is used less often today, it was the predominant digitizing method in the 1980s. In this process maps are affixed to digitizing tables, registered to a GIS coordinate system and "traced" into a GIS (Korte 2000). Here also are many opportunities for error, because the process is subject to visual and mental mistakes, fatigue, distraction and involuntary muscle movements.

In addition, the "set up" of a map on a digitizing table or a scanned raster image can produce errors.

Source Data

Only recently has it become commonplace to collect GIS data directly in the field. Data collection can be done using field survey instruments that download data directly into GIS's or via GPS receivers that directly interface with GIS software on portable PC's. These techniques can eliminate the need for GIS source data (Korte 2000).

During the last 20 years, GIS data most often have been digitized from several sources, including hard-copy maps, rectified aerial photography and satellite imagery. Hard-copy maps (e.g., paper, vellum and plastic film) may contain unintended production errors as well as unavoidable or even intended errors in presentation (Korte 2000).

Controlling GIS Errors

GIS data errors are almost inevitable, but their negative effects can be kept to a minimum. Many errors can be avoided through proper selection and "scrubbing" of source data before they are digitized. Data scrubbing includes organizing, reviewing and preparing the source materials to be digitized. The data should be clean, legible and free of ambiguity. "Owners" of source data should be consulted as needed to clear up questions that arise (Marcey et al. 1998).

Perceptions about Irrigation

Irrigation is perceived by some to be costly, and thus financially and economically questionable due to low world prices for the grain crops most commonly found on irrigated land. It has also been criticized as environmentally unfriendly due to water logging, soil salinization and unsatisfactory resettlement programs. To some extent irrigation suffers from excessive expectations. For example, a review of World Bank experience (Jones 1995) shows that irrigation projects yielded overall positive economic rates of returns with an average of 15 %, higher than the opportunity cost of capital and greater than the average for other non-irrigated agricultural projects. The actual achievements were however, lower than the rates of return predicted at appraisal.

The need to manage water holistically has become a familiar message to all working in water resources. This has helped to focus on the cross-cutting nature of the resource and the need to optimize allocation between different users that depend on water for irrigation, drinking water supply, industry, power and between users and the environment.

CHAPTER 2
INTRODUCTION AND PROJECT AREA REVIEW

Introduction

Large dams and irrigation projects such as the TRASVASE in the Santa Elena Peninsula, Ecuador consists of a nested set of sub-systems involving a dam as source of supply, an irrigation system (including canals and on-farm irrigation application technology), an agricultural system (including crop production processes), and a wider rural socio-economic system and agricultural market (WCD 2002). The performance indicators for large dam irrigation projects include:

- Physical performance on water delivery, area irrigated and cropping intensity;
- Copping patterns and yields, as well as the value of production

Irrigated Area

Large dam projects usually fall short of area actually irrigated, and to a lesser extent the intensity with which areas are actually irrigated. Poor performance is most noticeable during the earlier periods of project life, as the average achievement of irrigated area targets compared with what was planned for each period increases over time from around 70 % in year five to approximately 100 % by year 30 (WCD 2002).

The under achievement of targets for irrigated area development for large dams has a number of causes. Institutional failures have often been the primary causes, including inadequate distribution channels, overly centralized systems of canal administration, divided institutional responsibility for main system and tertiary level system, and inadequate allocation of financing for tertiary canal development. Technical causes include delays in construction, inadequate surveys and hydrological assumptions, inadequate attention to drainage, and over-optimistic projections of cropping patterns, yields and irrigation efficiencies. Under achievements includes also the late realization that some areas were not economically viable. In addition, a mismatch between the static assumptions of the planning agency and the dynamic nature of the incentives that govern actual farmer behavior has meant that projections quickly become outdated (WCD 2002).

Lower yields are often observed for crops specified in planning documents that emphasize food grain production for growing populations - than for the crops actually selected by farmers. This occurs as farmers respond to the market incentives offered by higher-value crops such as seasonal or longer-term orchard based crops and allocate available resources to these crops. This implies higher-than-expected gross value of production per unit of area, with the caution that such increases have varied with the long-term real price trend of the relevant agricultural commodities (Vermillion 1997).

But when changes in cropping patterns are combined with shortfalls in area developed and cropping intensity, the end result is often a shortfall in agricultural production from the scheme as a whole. Gross value of production is higher where the shift to higher-value crops offsets the shortfall in area or intensity targets.

Lower than expected crop yields have been caused by agronomic factors, including cultivation practices, poor seed quality, pest attack and adverse weather conditions, and by lack of labor or financial resources. Physical factors such as poor drainage, uneven or unsuitable land, inefficient and unreliable irrigation application, and salinity also hinder agricultural production. The efficiency of water use affects not only production but also demand and supply of irrigated water (WCD 2002).

A general pattern of shortfalls and variability in agricultural production from irrigation projects in developing countries is also revealed by other sources. In the 1990 World Bank OED study on irrigation cited earlier, 15 of 21 projects had lower than planned agricultural production at completion. Evaluations of 192 irrigation projects approved between 1961 and 1984 by the World Bank indicated that only 67 % performed satisfactorily against their targets.

Agriculture and Irrigation

Efforts to promote sustainable water management practices have necessarily focused on the agricultural sector as the largest consumer of freshwater. Governments have several objectives in deciding the nature and extent of inputs in agriculture. These include achieving food security, generating employment, alleviating poverty and producing export crops to earn foreign exchange. Irrigation represents one of the inputs to enhance livelihoods and achieve economic objectives in the agricultural sector with subsequent effects for rural development (Vermillion 1997).

Irrigated agriculture has contributed to growth in agricultural production worldwide, although inefficient use of water, inadequate maintenance of physical systems and institutional and other problems have often led to poor performance. Emphasis on large-scale irrigation facilitated consolidation of land and in some cases brought prosperity for farmers with access to irrigation and markets (World Bank 1990).

In the absence of good quality control and effective maintenance the canal linings often have not achieved the predicted improvements in water savings and reliability of supply. In most irrigation systems, particularly those with long conveyance lengths, a disproportionate amount of water is lost as seepage in canals and never reaches the farmlands.

Inadequate maintenance is a feature of a number of irrigation systems in developing countries. An impact evaluation of 21 irrigation projects by the World Bank concluded that a common source of poor performance was premature deterioration of water control structures. Often poor maintenance reduces irrigation potential and affects the performance of systems (World Bank 1990).

On-Farm Technologies

A number of technologies exist for improving water use efficiency and, hence, the productivity of water in irrigation systems. Sprinkler system and micro-irrigation methods, such as micro-sprinkler and drip systems, provide an opportunity to obtain higher efficiencies than those available in surface irrigation. For these pressurized systems, field application efficiencies are typically in the range of 70–90 % (Cornish 1998). The output produced with a given amount of water is increased by allowing for more frequent and smaller irrigation inputs, improved uniformity of watering and reduced water losses.

Policy

Policy and management initiatives are fundamental to raising productivity per unit of land and water and increasing returns to labor. They are often interlinked and require political commitment and institutional co-ordination. Agricultural support programs tend to be developed and implemented in relative isolation from irrigation systems. Typically there is weak co-ordination between agencies responsible for agricultural activities (such as extension services, land consolidation, credit and marketing) and those responsible for irrigation development. Price incentives are also inadequate to raise productivity and the outcome is a significant gap between potential and actual yields. In the absence of better opportunities from agriculture, many farmers seek off-farm employment. Incentives to enhance production are necessary and can result from a more integrated set of agricultural support measures and the involvement of joint ventures that provide capital resources and market access to smallholder farmers. Appropriate arrangements need to be introduced for such joint ventures to ensure an equitable share of benefits (WCD 2002).

One of the major contributors to poor performance of large irrigation systems is the centralized and bureaucratic nature of system management, characterized by low levels of accountability and lack of active user participation. The structure of farmer involvement varies from transfer of assets to a range of joint-management models. As yet, there is no general evidence to suggest that irrigation performance has improved as a result of transfer alone, although there are promising examples indicating that decentralization may be a required, but not sufficient measure to improve performance (Vermillion 1997). Experience has shown that in order to be effective, a strong policy framework is required, providing clear powers and responsibilities for the farmers' organizations (Bandaragoda 1999). Water rights and trading are highly contentious issues. Win-win situations occur for farmers when they trade a part of their water to replace lost income while at the same time being able to finance water use efficiency gains from their remaining water allocation. The formulation of national policies and strengthening of the national capacities to implement effectively such national policies in better water use is essential (Smith 2000).

Actual Situation and Projections

The construction of the TRASVASE irrigation system in the Santa Elena Peninsula (SEP) was designed to intensify the agricultural use of the land in this Ecuadorian region, but after several years of functioning the improvement is not as significant and viable as expected.

The construction of the TRASVASE was started in 1989 by CEDEGE[1]. After being operative for nine years, the project has not come close to the expected land use. Less than 25 % or 6,512 hectares are being under agricultural production in the Santa Elena Peninsula. According to CEDEGE projections the total land capacity of the TRASVASE irrigation system is 23,066 hectares (CEDEGE 2001), but producer's organizations do not think that the theoretical number given by CEDEGE is the real area that can be irrigated with available water. These organizations of producers say that 16,000 ha to 17,000 ha will be the maximum area that the TRASVASE project could irrigate at any time (El Comercio 2001). The analysis of the irrigation capacity is one of the main points of this research.

Figure 2-1. Canal in construction, TRASVASE Santa Elena

Some factors can be cited to try to identify the problems that have caused slow progress of the TRASVASE project. The climate variability, soil composition, land tenure, and commercialization problems are among the principal constrains.

The Peninsula has surprisingly reduced solar radiation. It is estimated that the area has less than 600 hours per year of total solar radiation. The relatively frequent and strong El Niño effect, with the last one in 1997, and the next one expected in Ecuador by the

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[1] CEDEGE, Comision de Estudios para el Desarrollo de la Cuenca del Rio Guayas, in English, Commission for the Development of the Guayas River Basin.

rainy season of 2002–2003, has also a strong impact on agricultural production. Other problem associated with the climate in the peninsula is the high relative humidity (RH) that results in the spread of fungi and bacteria that attack the crops in the Peninsula.

Soils in the Santa Elena Peninsula are of marine origin, mostly semiarid and of low natural fertility, with high clay content. All those factors require especial soil management techniques that are not always followed by the agricultural producers in the SEP due to their high cost. There are other lesser soil problems related to contents of lithium, sodium, and potassium (CESUR 1995).

Characteristics of the Santa Elena Peninsula

Administrative Jurisdiction

Administratively, the Santa Elena Peninsula is included within the Guayas province. The area under this administration is 6,050 km^2, and represents about 30.5 % of the Guayas province (19,841 km^2) and 2.13 % of the total area of the Republic of Ecuador (CEDEX 1984).

Geography

Ecuador is traditionally divided into four natural regions, a scheme that is followed in this document:

The Pacific coastal region (in Ecuador called the costa) includes the lower, western slopes of the Andes (below 1000 m elevation).

The Andes Mountains above 1,000 m, which occupy the central portion of the country, know as the “Sierra”. Amazon lowlands east of the Andes, are referred to as the “Oriente”, including the lower, eastern slopes of the Andes up to 1,000 m. The Galapagos Islands, is the last region, is a volcanic archipelago in the Pacific Ocean 1,000 km west of the mainland (CESUR 1995).

The coastal region of Ecuador is about 150 km wide from the base of the Andes to the Pacific coastline. A relatively low coastal range of mountains extends parallel to and just inland from the coast, from the city of Esmeraldas in the north to Guayaquil in the south, a distance of about 350 km. The summits of the coastal mountains are mostly between 400 and 600 m elevation, but a few isolated peaks are above 800 m. The coastal range is fairly continuous throughout its length, but is known by different local names: from north to south Mache, Chindul, Jama, Colonche, and Chongón (CESUR 1995).

Between the coastal range and the Andes, south of equator, is the broad, nearly level Guayas River basin. At the mouth of the Guayas River lies Guayaquil, Ecuador's largest city and principal port. The estuary of the Guayas River empties into the Gulf of Guayaquil, the largest embayment of the Pacific Ocean on the South American coast. The Santa Elena Peninsula extends west and south of Guayaquil (CESUR 1995).

Figure 2-2. Landscape of the Santa Elena Peninsula

The Santa Elena Peninsula (SEP) is located at the southwest of the Guayas hydrographic basin, in the Ecuadorian Coast, west of Guayaquil. The main coordinates of the SEP are Latitude 2^{o} 12' South, Longitude 79^{o} 53' West (Figure 2-3). Its boundary is to the north the Manabí province, to the south and west is the Pacific Ocean and to the east is the Guayas River basin, which is separated by the Chongón-Colonche mountain range (CEDEX 1984).

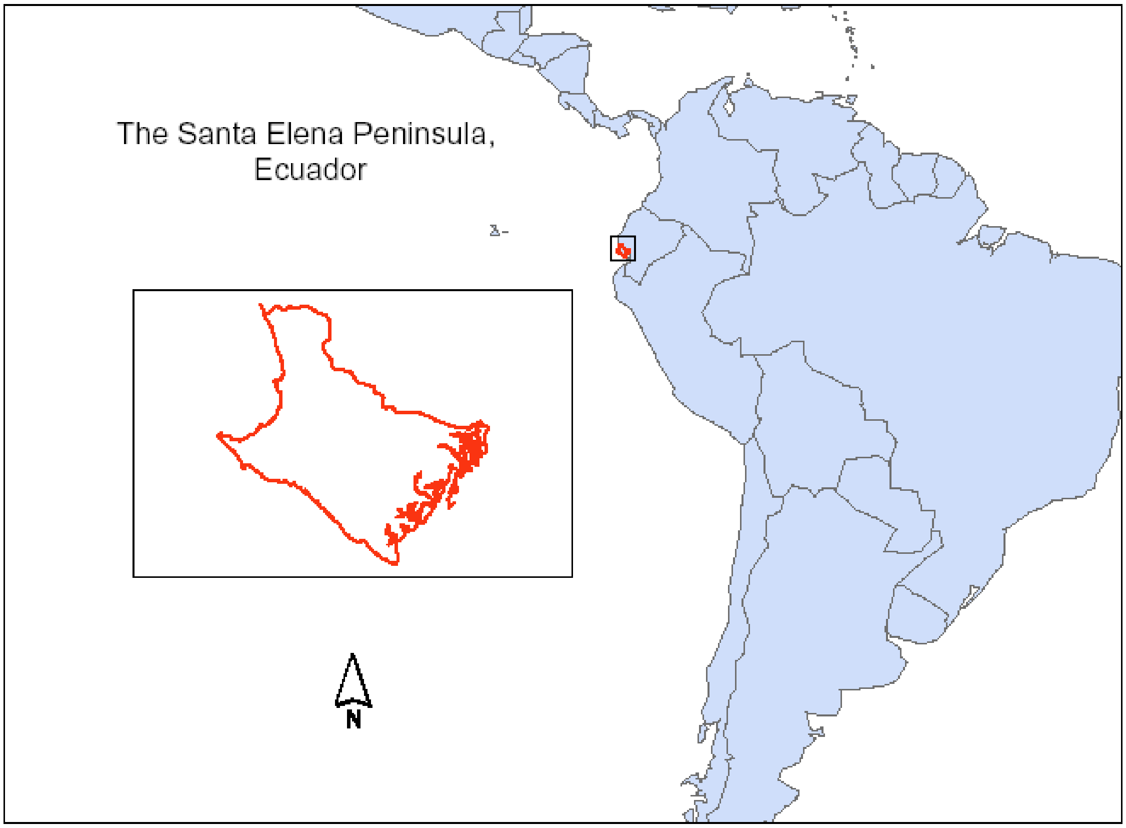

Figure 2-3. Location of the Santa Elena Peninsula

Hydrology

Most of the description of the Santa Elena Peninsula was made by the Center for Study and Experimentation in Public Works, in Spanish, ‘Centro de Estudio y Experimentacion de Obras Publicas’ (CEDEX), with base in Spain.

Figure 2-4. Javita River, an intermittent river at SEP.

The Chongón-Colonche mountain range divides the hydrologic system of the Santa Elena Peninsula (SEP) from the Guayas River basin, specifically from the Daule River sub-basin. The minor watersheds created by the Chongón-Colonche mountain range are indicated in the Table 2-1 (CEDEX 1984).

Table 2-1. Minor watersheds

Minor Watersheds in the Santa Elena Peninsula				
Basin	Area (km^2)	Area (%)	SEP (%)	Regime
Olón	53.29	1.4	0.9	Permanent
Manglaralto	65.98	1.7	1.1	Permanent
Atravezado	81.88	2.1	1.4	Permanent
Valdivia	137.52	3.5	2.3	Permanent
Grande	161.29	4.1	2.7	Intermittent
Javita	800.00	20.6	13.3	Intermittent
Zapotal	1,050.80	27.1	17.4	Intermittent
Grande	631.42	16.2	10.4	Intermittent
Chongón	588.00	16.1	9.7	Intermittent
# 20	517.61	8.2	5.2	Permanent
Total	3,887.79	100	64	

Table 2-2. Basins that start in the Coastal Mountain Range

Coastal Mountain Range Basins				
Basin	Area (km2)	Area (%)	SEP (%)	Regime
La Mata	80.24	3.7	1.3	Ephemeral
Asagmanes	166.40	7.7	2.8	Ephemeral
Salado	310.71	14.4	5.2	Ephemeral
Engabao	140.45	6.5	2.3	Ephemeral
Zona Engunga	362.70	16.7	6.1	Ephemeral
El Mate	319.80	14.8	5.5	Ephemeral
San Miguel	295.21	13.6	4.9	Ephemeral
Arenas	152.32	7.1	2.5	Ephemeral
# 18	179.06	8.3	3.0	Ephemeral
# 19	154.82	7.2	2.6	Ephemeral
Total	3,887.79	100	64	

Climate

A large variety and range of climatic regimes are found in Ecuador, and this variety has a major effect on the extent of the diverse flora of the country. The climatic regimes found in Ecuador are influenced by its geographical position astride the equator, the general circulation of the atmosphere, the position and movements of the ocean currents, and by orographic effects produced by the abrupt topography of the Andes as well as the smaller coastal ranges.

The climatic characteristics in the Santa Elena Peninsula (SEP) are very specific. This is especially true for conditions in the adjacent Guayas River area, especially regarding the precipitation. The main factors affecting the climate conditions in the SEP are two currents of the Pacific Ocean: the Humboldt “cold current” and El Niño “warm current” and the displacements of water and air at the inter-tropical convergence zone. Between the months of January and April, the warm current of El Niño moves from Panama to the South along the Pacific coast and close to the SEP encounters the cold waters of the Humboldt Current. This encounter results in rapid cooling of the air, releasing the moisture when colliding with the mountains (Cañadas 1983). The Ecuadorian Andes create a bigger barrier increasing the effects of the inter-tropical convergence zone. The temperatures on the Peninsula are characteristically very constant all year around. The winds come mostly from the South.

Meteorological Data

The location of the weather stations in the Peninsula is presented in the Chapter 3 (Figure 3-1). The registered parameters are: precipitation, temperature, relative humidity, cloud coverage, evaporation (*A* Pan), and wind speed. However, not all this data is complete for all the stations.

Temperature

Due to Ecuador’s position on the equator, the day length changes very little throughout the year every day has about 12 hours of sunlight, varying no more than about 30 minutes at any point in the country. On the equator, the total amount of solar radiation reaches a maximum at the equinoxes; this is only 13 % higher than the minimum amount of radiation intercepted at the solstices. A consequence of this relative annual constancy in solar radiation is the low seasonal variation in mean air temperature at the equatorial latitudes. From month to month, the mean temperatures at all sites in Ecuador are relatively constant; monthly means do not vary more than 3 °C at any site, and at many sites vary less than 1 °C. In contrast, the daily fluctuations in temperature over 24-hour periods are much more pronounced; the circadian cycle of temperature change is therefore much more important than the annual change in mean temperature. Daily temperature fluctuation at mid-to upper elevations in the Andes is often 20 °C or more. In the lowlands, the daily fluctuation in temperature is generally much less, closer to about 10 °C. The daily maximum and minimum do have significant annual variation at some sites, for example, at high elevations freezing temperatures are more prevalent during the dry season due to clear skies (Sarmiento 1986).

Temperature in Ecuador varies rather predictably with altitude. At sea level in coastal Ecuador, the mean annual temperature is about 25 °C. On moist tropical mountains, following the adiabatic lapse rate, temperature decreases at about 0.5 °C for each increase of 100 m in altitude. The lapse rate, as determined from climatic records at various elevations, is slightly different for the western slopes versus the eastern slopes of the Andes (Cañadas 1983).

The average annual temperature is between 23.1 ^{o}C for Salinas and 25.7 ^{o}C for El Azúcar where the coastal influence is smaller. From the available historical data, the maximum value recorded was 36 ^{o}C in Playas (February) and a minimum of 15.6 ^{o}C in the same station (October). It is appropriate to note that the rainy season is from January to April and this is also the time of the highest temperatures. Here also, daily variations in temperature are more significant than the monthly variations. However, daily variation on average is no larger than 5 ^{o}C. More detailed information of data from the weather stations can be found in Chapter 3, Weather Data.

Precipitation

In contrast to the constancy of temperature regimes in Ecuador, rainfall regimes vary enormously from place to place, in both the annual amount of precipitation and in the patterns of seasonal distribution of rainfall. Different patterns of rainfall are found in the Coastal, Andean, and Amazonian regions of continental Ecuador, and in the Galapagos Islands; variation also occurs from north to south in each main geographical region, and on a local scale according to topography and other factors.

The Inter Tropical Convergence Zone (ITCZ) shifts from a position at about 10 °N latitude at the June solstice, to about 5 °S latitude at the December solstice. Therefore, the ITCZ passes over Ecuador twice during the year on its northward and southward oscillations. The shifts in the ITCZ produce a bimodal distribution of rainfall at Andean localities in Ecuador, with two rainy periods and two drier periods during the year. In the coastal region of Ecuador, annual rainfall patterns are under the influence of the two principal ocean currents in the Pacific, near the shore of northwestern South America (Cañadas 1983). These include the cold Humboldt Current, which flows northward along the coast of Chile, Peru, and southern Ecuador, and turns eastward at about the equator and flows past the Galapagos Islands. The second is the warm equatorial current that flows southward from the Gulf of Panama, along the Pacific coast of Colombia, and meets the Humboldt Current near the equator along the north-central coast of Ecuador (Cañadas 1983).

The Humboldt Current brings arid conditions to the adjacent coast, as the cool oceanic air passes over the relatively warmer landmass. Another effect of the Humboldt Current is the overcast skies—the low clouds, known locally as “garua” (Figure 2-6)—that form a layer about 600 m above sea level and cover most of western Ecuador throughout the day during the dry season (Sarmiento 1986).

The warm equatorial current that bathes the northwest coast of Ecuador brings with it moist air and rainfall. During most years, the warm equatorial current pushes farther to the south of the equator for a few months, December to April (Figure 2-5) generally, bringing rainfall and warm, moist air to the areas of the central and southern Ecuadorian coast that are under the influence of the dry, cool Humboldt Current the remainder of the year. This phenomenon is known locally as *El Niño* (the Christ Child) because the annual rains usually begin in mid- to late December, around Christmas (Cañadas 1983).

Due to the annual southward incursion of the warm equatorial current, most of coastal Ecuador, as well as the Galapagos Islands, have a unimodal pattern of precipitation, with one rainy season extending from December to April, and a long dry season from May to December. The length and intensity of the dry season vary at different sites in the coastal region (Sarmiento 1986).

The most arid region within the Santa Elena Peninsula is the zone of Santa Elena, where the city Salinas shows an annual average precipitation of only 112 mm, 96 % of which is concentrated in the period from January through April. The topography around Salinas constitutes of valleys and small hills, no higher than 100 m (CEDEX 1984).

The North section of the SEP is mountainous, with a medium elevation of 600 m. The effect of the mountain range makes the precipitation increase considerably. The effect of the humid winds coming from the ocean results in the more uniform distribution of the rains throughout the year. In El Suspiro, at 456 m of elevation, the average amount of rainfall for the January-April period is approximately 60 % of the annual total (CEDEX 1984).

In the region from Nuevo River to the Chongón River, where the Chongón-Colonche mountain range has altitudes from 200 to 500 m, the weather stations have registered precipitation of approximately 550 mm. The presence of the mountain range in this zone adds for higher rainfall. The rainfall in the January – April period represents 85 % of the annual total (CEDEX 1984).

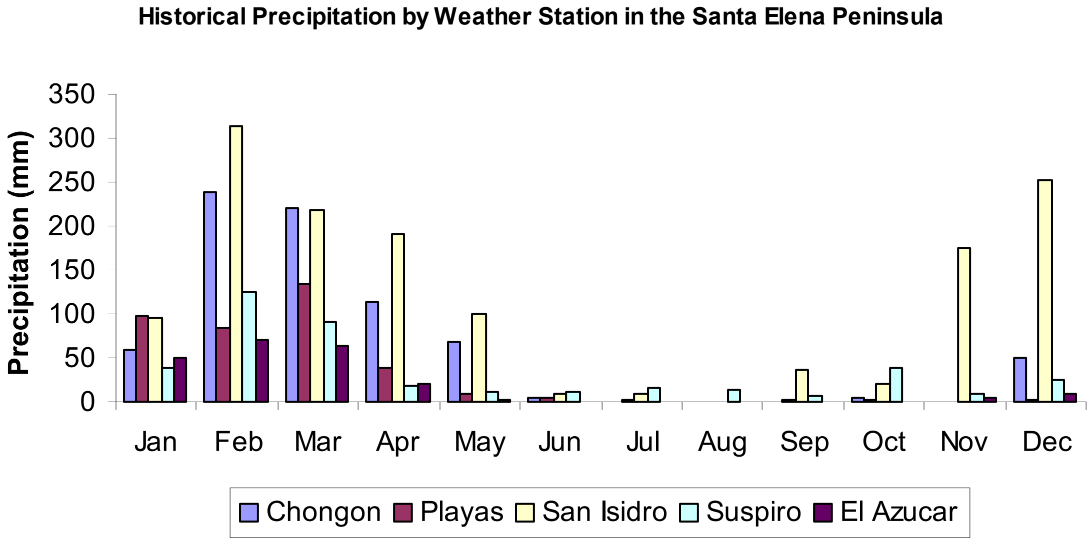

Figure 2-5. Historical average precipitation in the Santa Elena Peninsula

According to the precipitation pattern (Figure 2-5) for five weather stations in the Santa Elena Peninsula the months that require supplementary irrigation are from May thru November. The period for which weather is available for each location is presented in Appendix B.

In the Cerecita’s savanna the effect of the orography is less accentuated, however the precipitation is greater than in the areas located to the South and Southwest of this savanna. The average rainfall over Cerecita is 463 mm, with 91 % captured in the period from January to April (CEDEX 1984).

The semi-arid zone from Colonche to Progreso is a valley; this is not affected by the orographic precipitations. In Figures A-1, A-2, and A-3 (Appendix A), the isohyets (isohyet is a line drawn on a map connecting points that receive equal amounts of rainfall) for the region are presented.

At irregular intervals, but averaging about every seven years, the El Niño phenomenon is much stronger than normal along the Pacific coast of South America. During “El Niño” years, the warm equatorial waters push much farther south into coastal Peruvian waters, displacing the cold Humboldt Current, bringing heavy rains to the Peruvian desert as well as coastal Ecuador. The warm water conditions may last for more than a year before the Humboldt Current again brings dry weather to the coast. The heavy rains associated with El Niño cause flooding in coastal Ecuador and destroy roads, bridges, houses, and crops. The last two major El Niño events were during 1982–1983 and 1997–1998.

Relative Humidity

The weather in the Santa Elena Peninsula is highly modified by the relative humidity (Figure 2-6). This relative humidity is presented in the form of fog and low clouds that cover the skies over the Peninsula most of the year (rainy and dry seasons).

Winds

The highest winds speeds were registered in Salinas, where the monthly average for each year surpass the 300 km/day, except in February and April.

The dominant winds came from the Southwest, with a frequency of 50 %, followed by the winds coming from the West. The winds from the North are least frequent.

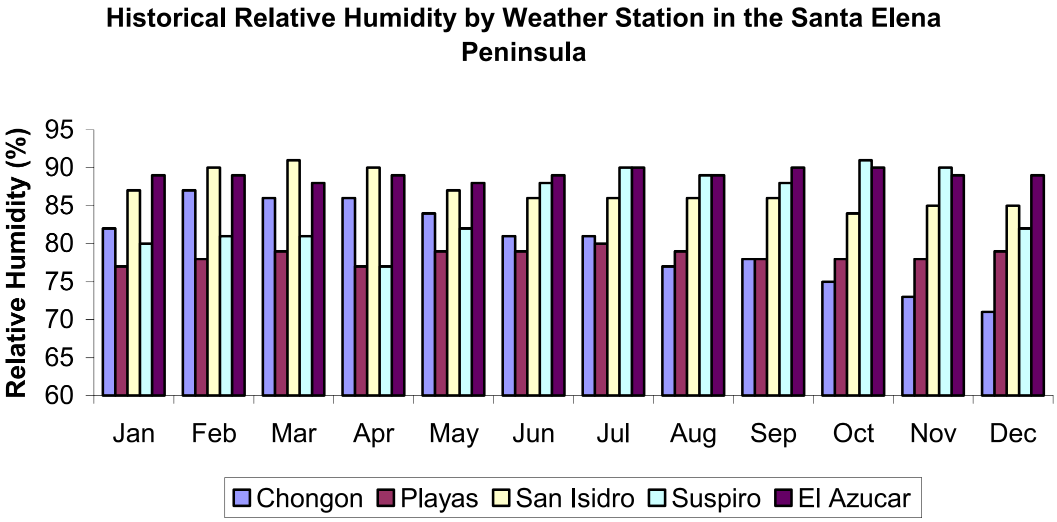

Figure 2-6. Historical average relative humidity in the Santa Elena Peninsula

Sunshine

This term refers to the number of hours of effective sunshine impacting the Earth surface, also described as the impact of the rays from the sun. Sunshine varies respect to the Latitude of the location. At the Equator the average sunshine should be 12 hours per day all year around. However, cloudiness in the Santa Elena Peninsula affects negatively the amount of hours of light impacting the soil, reducing evaporation and photosynthesis.

Climatic Classifications

Papadakis Climatic Classification

The Papadakis method considers characteristics of the winter and summer, the temperature regime and the humidity balance to classify the climates (Figure 2-3.).

In Table 2-3, the classification is listed, showing that the Santa Elena Peninsula (SEP) is divided in to three climatic zones: desert-monsoon in Salinas, going through the semi-arid-monsoon of Playas, Ancón and Azúcar; into the dry-monsoon of Manglaralto.

Table 2-3. Climate types

Weather Station	Climate Type
Playas	Tropical, equatorial, semiarid, (Eq, mo) with 9 dry months.
Azúcar	Tropical, equatorial, semiarid, (Eq, mo) with 10 dry months.
El Suspiro	Tropical, equatorial, semiarid, (Eq, mo) with 10 dry months
Chongón	Tropical, equatorial, warm, (Eq, mo) with 8 dry months
San Isidro	Tropical, equatorial, semiarid, (Eq, mo) with 10 dry months

* (CEDEX 1984)

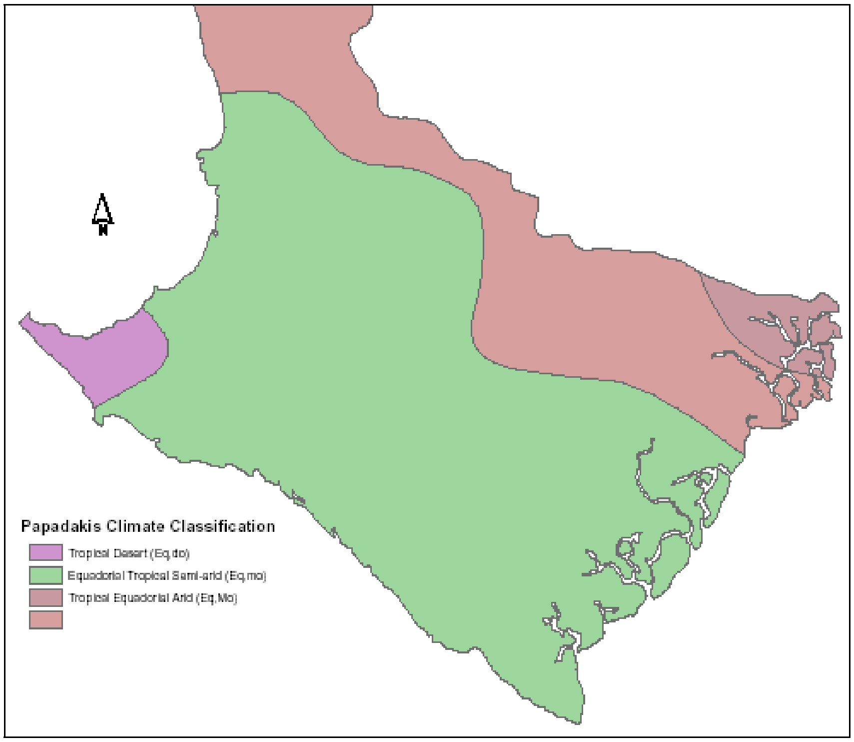

Figure 2-7. Papadakis climate classification

Köppen Climatic Classification

Dr. Vladimir Köppen of Austria devised a climate classification system in 1918 based on the average annual temperature and total precipitation data for areas around the world. It was the most widely used and recognized climate classification system for many decades. Most revised climate classification systems are based on Dr. Köppen’s initial system (CEDEX 1984). A shorthand version was produced using letters to designate 5 broad climatic groups, with further subdividing in subgroups distinguished by seasonal characteristics of temperature and precipitation.

Table 2-4. Köppen climate classification for the SEP

Weather Station	Avg. annual Temp °C	Avg. Temp. coldest month (t_1)	Avg. Temp. warmest month (t_{12})	Precip. (P)(mm)	K/2 =1/2(20tm +280)	Climatic Formula
Playas	24.3	22.0	26.5	362.3	383	BWh'ai-desert
Chongón	25.3	23.9	26.6	1118.9	393	AW tropical-savannah
Azúcar	25.7	24.3	27.5	278.0	397	BWh'ai-desert
El Suspiro	23.4	21.4	26.1	530.3	374	AW tropical-savannah
San Isidro	23.1	20.8	26.0	245.9	371	BWh'ai-desert

A = tropical rainy climate, average temp > 18 °C – no rainy season, large annual rainfall – ppt > evap
B = dry climate, evap > ppt – no surplus water = no perennial streams
AW = prairie
BW = desert
TS = savannah
h' = medium annual temperature > 18 °C (dry and warm climate)
a = medium temperature of the warmest month > 22 °C
i = annual temperature variation (t_{12}-t_1) < 5 °C\

To determine the boundaries of each of the climate types, Köppen uses temperature and precipitation points. Average temperatures of the coldest (t_1) and warmest (t_{12}) months are needed to define the limits among the different climates. Köppen's "climatic formula" is a brief description of the climate, especially air temperature and precipitation, including seasonal tendencies of these variables (CEDEX 1984).

From the *BW* climate (desert), with very scarce precipitation year-round, gradually moves to the *BS* (steppe) with a rainy season that allows fast vegetation growing. From the steppe it goes to the *AW* or prairie where the rainfall concentrates during the summer but few are scattered year around; resulting in a tropical savannah.

Soils

Marine sediments are the parental material of the Santa Elena Peninsula (SEP) soils. Where this parental material stayed "*in situ*" it created "residual" soils in hills; but if it was deposited in lower lands, it created "alluvial" soil in the valleys.

Based on the United States Department of Agriculture (USDA) soil classification the following soil orders were obtained for the SEP.

Table 2-5. Soils

Units	Area (ha)
Individual Units	
Entisols	149,615
Inceptisols	99,695
Aridisols	99,075
Vertisols	12,442
Alfisols	4,905
Mollisols	1,070
Associated units	
Aridisols/Aridisols	67,288
Inceptisols/Inceptisols	55,230
Inceptisols/Vertisols	13,910
Vertisols/Aridisols	9,630
Aridisols/Vertisols	10,500
Inceptisols/Mollisols	7,425
Aridisols/Entisols	13,065
Inceptisols/Entisols/Aridisols	3,180
Total	546,970

The Entisols, Inceptisols and Aridisols orders account for approximately 95 % of the area of the SEP.

It can be said that in general the soils in the Santa Elena Peninsula have a great variability in texture, ranging from clay to silt, and they are more superficial in the hills than in the valleys. In the hills and mountains the parental material can be found just a few centimeters below the surface. The erosion is very high in the hills and mountains; this is especially due to the deforestation and destruction of the vegetation cover.

Following is a more detailed description of the soils units in the Santa Elena Peninsula:

Residual Soils

Residual soils were developed “in situ” from marine clays, they are the oldest soils in the Peninsula and can be found in hills and mountains. The residual soils are less thick when the slope increases. These soils have been classified in the four following units (CEDEX 1984):

- Soils with Cambic horizons, normally found in locations with high slopes (> 20 %). They have a superficial horizon A from 10 to 20 cm with silt and clay contents, sometimes it consists totally of clay. The next horizon is cambic B with a thickness from 20 to 30 cm its texture has high variability. The C layer is similar to the parental material.

- All these soils correspond to the Typic Ustropepts and Typic Cambortid, however, if the clay content is greater than 35 % in the first 50 cm they are classified as Vertic. Very eroded soils can be classified as Paralithic and Lihic depending if is the horizon C or the parental material the one that shows in the first 50 cm.

- Soils with Argilic horizons, located in small hills with slopes less than 10 %. The A_2 superficial horizon is very eroded with 1–5cm; it contains silt and clay. The next is the Bt layer from 15 to 25 cm; in some cases with gravel and rocks (10 cm diameter). They correspond to the Vertic Paleargid and Vertic Paleustalf.

- Soils with high content of clay can be found in low hills and some times in high mountains for which the parental material is marine clay. They show cracks up to 80 cm deep and 2 cm wide, and their horizons are considered clay up to 70 cm with black spots coming from carbonates. The C-horizon also has a high content of clay. These soils are classified as Pellusters, Chromusters and Torrerts.

- Soils without defined horizons are located in degraded, rocky zones and also regions with strong slopes, and are grouped in the Ustorthens and Torriorthents units.

Aluvial Soils

- Sandy non-saline soils, located close to the sea and in some riverbeds. Classified as Ustipsamment and Torripsamment.

- Non-saline soils with contents of silt and clay (40 %) correspond to the Ustifluvents and Torrifluvents units.

- Saline soils located in the mangroves close to the sea and in some rivers. Soils with more that 15 % of interchangeable sodium, Entisols.

CHAPTER 3
WEATHER DATA ANALYSIS FOR CROPWAT MODEL

Air temperature and soil temperature, along with water availability and soil, and relative humidity are key factors for agriculture and forestry systems. Under many situations temperature is the factor that determines which crops or trees can be grown in a given area, seed germination, growth rates, rates of maturation or ripening, and yield.

At a global scale, the major pattern of vegetation is defined by latitudinal gradients. At continental and regional scales, elevation modifies the latitudinal gradients according to adiabatic lapse rates. Because of the large area and coarse spatial resolution of these scales, temperature regimes appear smooth and simple interpolation can be adequate for characterizing patterns.

Most simulation models assume homogeneous conditions over the space they are representing. In fact, general conditions often do not exceed more than a few kilometers square. The weather data across the SEP was difficult to interpolate over several square kilometers between weather stations (Ashrat et al. 1995).

Several interpolation procedures are available, ranging from simple linear interpolation techniques and triangulated networks, to more sophisticated distance weighing or kriging techniques. It must be remembered that the only information used by any interpolation procedure is the location of known values (van der Goot 1997). Most of the weather data information that is used in this project was provided by CEDEGE. For this project the weather data available comes from 5 different weather stations, the parameters recorded are (Appendix B, Table B-1):

- Maximum and minimum air Temperatures, in Celsius degrees (°C)
- Maximum and minimum Relative Humidity (RH), in percentage (%)
- Wind speed (m/s)
- Sunshine (hours/day)

The periods for which the data are available are listed in Appendix B (Table B-1) In addition to limited years of data, all the stations have some missing data for different periods of time. Because of these missing data several methods to fill those gaps were analyzed. Solar radiation and wind speed was also provided from some weather stations but they had too many missing data points to be useful.

Weather Stations Distribution

The maximum distance between points for least dense networks of weather stations is 150–200 km, for intermediate networks is 50–60 km and for most dense networks is around 30 km (Gandin 1970). In the Santa Elena Peninsula (SEP) the distances between the stations are shown in Table 3-1. Considering the above recommendations, the distribution of weather stations in the SEP can be considered an intermediate network.

Table 3-1. Distances among stations (m) and elevation (mmsl)

Station name	El Azúcar	Playas	Chongón	San Isidro	El Suspiro	mmsl
El Azúcar	-	27,000	4,560	35,500	56,000	35
Playas	-	-	72,200	57,000	70,350	24
Chongón	-	-	-	32,500	54,500	41
San Isidro	-	-	-	-	25,000	35
El Suspiro	-	-	-	-	-	35

The spatial location of the weather stations is shown in Figure 3-1. Spatial distribution is not very good, but at least, there are weather stations in each of the ecologic zones of the Santa Elena Peninsula. The small differences in elevation over the main sea level among stations permits the use of more simple interpolation methods (Table 3-1). In flat areas such as the Santa Elena Peninsula the effect of elevation will be a small factor when interpolating the weather data. However, since this is a coastal area the effect of the wind and ocean is accounted for in the CROPWAT software to calculate evapotranspiration.

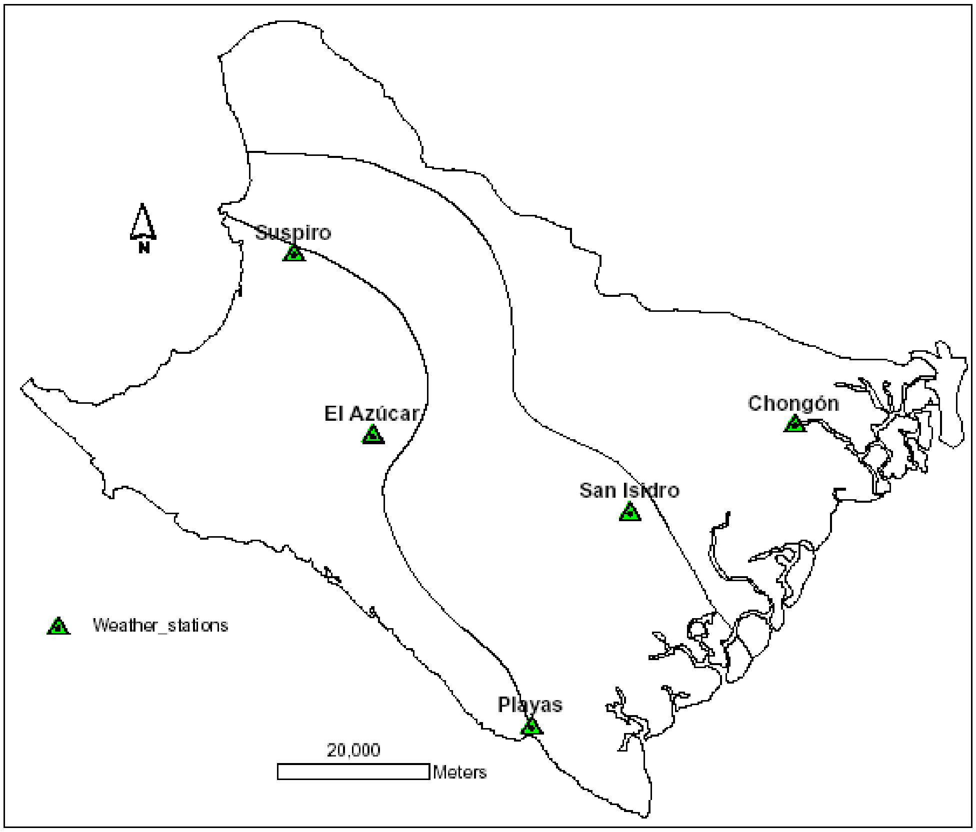

Figure 3-1. Weather stations

Estimating Missing Climatic Data

The calculation of the reference evapotranspiration (ET_o) with the Penman-Monteith method requires mean daily, ten-day or monthly maximum and minimum air temperature (T_{max} and T_{min}), actual vapor pressure (e_a), net radiation, and wind speed measured at 2 m. If some of the required weather data are missing or cannot be calculated, it is strongly recommended that the user estimates the missing climatic data with one of the following procedures and use the FAO Penman-Monteith method for the calculation of ET_o.

Estimating Missing Humidity Data

Where humidity data are lacking or are of questionable quality, an estimate of actual vapor pressure, e_a, can be obtained by assuming that dew point temperature (T_{dew}) is near the daily minimum temperature (T_{min}). This statement implicitly assumes that at sunrise, when the air temperature is close to T_{min}, that the air is nearly saturated with water vapor and the relative humidity is nearly 100%. If T_{min} is used to represent T_{dew} then (Allen, et al. 1998):

$$e_a = e^{\circ}(T_{min}) = 0.611 \exp\left[\frac{17.27\, T_{min}}{T_{min} + 237.3}\right] \tag{3-1}$$

The relationship T_{dew} » T_{min} holds for locations where the cover crop of the station is well watered. However, particularly for arid regions, the air might not be saturated when its temperature is at its minimum. Hence, T_{min} might be greater than T_{dew} and a further calibration may be required to estimate dew point temperatures. After sunrise, evaporation of the dew will once again humidify the air and will increase the value measured for T_{dew} during the daytime (Allen, et al. 1998).

Estimating Missing Radiation Data

Net radiation measuring devices, requiring professional control, have not been used in the agro meteorological stations managed by CEDEGE. In the absence of a direct measurement, long wave and net radiation can be derived from more commonly observed weather parameters, i.e., solar radiation or sunshine hours, air temperature and vapor pressure.

Solar radiation data can be derived from air temperature differences, the difference between the maximum and minimum air temperature is related to the degree of cloud cover in a location. Therefore, the difference between the maximum and minimum air temperature (T_{max} - T_{min}) can be used as an indicator of the fraction of extraterrestrial radiation that reaches the earth's surface, principle that has been used by Hargreaves and Samani to develop estimates of ET_o using only air temperature data (Allen, et al., 1998).

The Hargreaves' radiation formula, adjusted and validated at several weather stations in a variety of climate conditions, becomes:

$$R_s = k_{Rs}\sqrt{(T_{max} - T_{min})}R_a \qquad (3\text{-}2)$$

where
R_a = extraterrestrial radiation (MJ m^2/d),
T_{max} = maximum air temperature (°C),
T_{min} = minimum air temperature (°C),
k_{Rs} = adjustment coefficient (0.16–0.19) (°$C^{-0.5}$).

The square root of the temperature difference is closely related to the existing daily solar radiation in a given location. The adjustment coefficient k_{Rs} is empirical and differs for “interior” or “coastal” regions:

- For 'interior' locations, where land mass dominates and air masses are not strongly influenced by a large water body, k_{Rs} = 0.16;
- For 'coastal' locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body, k_{Rs} = 0.19.

The fraction of extraterrestrial radiation that reaches the earth's surface, R_s/R_a, ranges from about 0.25 on a day with dense cloud cover to about 0.75 on a cloudless day with clear sky. CROPWAT uses the location (coordinates) of each weather station to find the best coefficient for each station.

The temperature difference method is recommended for locations where it is not appropriate to import radiation data from a regional station, either because homogeneous climate conditions do not occur, or because data for the region are lacking.

Missing Wind Speed Data

Importing wind speed data from a nearby station, as for radiation data, relies on the fact that the airflow above a 'homogeneous' region may have relatively large variations through the course of a day but small variations when referring to longer periods or the total for the day. Data from a nearby station may be imported where air masses are of the same origin or where the same fronts govern airflows in the region and where the relief is similar.

When importing wind speed data from another station, the regional climate, and trends in variation of other meteorological parameters and relief should be compared. Strong winds are often associated with low relative humidity, and light winds are common with high relative humidity. Thus, trends in variation of daily maximum and minimum relative humidity should be similar in both locations. Imported wind speed data can be used when making monthly estimates of evapotranspiration.

In the case of the Santa Elena Peninsula (SEP) a correlation comparison was made among all the weather station available in the area, but none of them show a good correlation coefficient ($R^2 > 0.70$), and because of that no data were used from one station to another.

As the variation in wind speed average over monthly periods is relatively small and fluctuates around average values, monthly values of wind speed may be estimated. The 'average' wind speed estimates may be selected from information available for the regional climate, but should take seasonal changes into account.

Where no wind data are available within the region, a value of 2 m/s can be used as a temporary estimate. This value is the average over 2000 weather stations around the globe.

For this project the wind data came from historical data from the available weather stations. This data had some gaps, however, once the wind speed data were used in CROPWAT using both the FAO world average and the available data the latest produced values closer to the reality of the zone.

Minimum Data Requirements

Many of the above procedures rely upon maximum and minimum air temperature measurements. Unfortunately, there is no dependable way to estimate air temperature when it is missing. Therefore it is assumed that maximum and minimum daily air temperature data are the minimum data requirements necessary to apply the FAO Penman-Monteith method.

Estimating Weather Data Sets for the Santa Elena Peninsula

To find a way to complete the missing meteorological data for the "Chongón" (used as an example) weather station, two methods were used. The first one is Regression Analysis, and the second one is Compositional Data. The results were tested against each other to find which one fits better to this situation.

One month (March) with 31 observations of weather data from each one of the five (5) stations was used to test the available methods to estimate missing weather data. The variables to be used are Maximum Temperature (Tmax) and Minimum Temperature (Tmin), and Maximum Humidity (Hmax) and Minimum Humidity (Hmin). In this document the Maximum Temperature is used as an example of what was done with all datasets.

Regression Analysis

Quite often data sets containing a weather variable Y_i observed at a given station are incomplete due to short interruptions in observations. When data are missing, it may be appropriate to complete these data sets from observations X_i from another nearby and reliable station. However, to use portions of data set X_i to replace data set Y_i, both data sets X_i and Y_i must be homogeneous. The procedure of completing data sets is applied after the test for homogeneity and needed correction for no homogeneity has been performed (Allen et al. 1998). The substitution procedure proposed herein consists of using an appropriate regression analysis.

Procedure:

1. Select a nearby weather station for which the data set length covers all periods for which data are missing (in this case, data from three stations were tested to find if the data of one of those have any relationship with the Chongón weather station data).

2. Characterize the data sets from the nearby station (Azúcar, Suspiro, Playas), X_i, and of the station having missing data (Chongón), Y_i, by computing the mean $\overline{x}$ and the standard deviation S_x for the data set X_i:

$$\overline{x} = \sum_{i=1}^{n} x_i / n \tag{3-3}$$

$$s_x = \left(\sum_{i=1}^{n} (x_i - \overline{x})^2 / (n-1) \right)^{1/2} \tag{3-4}$$

and the mean Y and standard deviation S_y for data set Y_i:

$$\overline{y} = \sum_{i=1}^{n} y_i / n \tag{3-5}$$

$$s_y = \left(\sum_{i=1}^{n} (y_i - \overline{y})^2 / (n-1) \right)^{1/2} \tag{3-6}$$

for the periods when the data in both data sets are present (in this case March 2001), where x_i and y_i are individual observations from data sets X_i and Y_i, and n is the number of observations in each set.

3. Perform a regression of y (Play_Tmax, Azu_Tmax, and Sus_Tmax) on *x* (Cho_Tmax) for the periods when the data in both data sets are present (March, 2001):

$$\hat{y}_i = a + bx_i \tag{3-7}$$

with

$$b = \frac{\mathrm{cov}_{xy}}{s_x^2} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

$$a = \bar{y} - b\bar{x}$$

where *a* and *b* are empirical regression constants, and cov_{xy} is the covariance between X_i and Y_i. Plot all points x_i and y_i and the regression line for the range of observed values. If deviations from the regression line increase as *y* increases then substitution is not recommended because this indicates that the two sites have a different behavior relative to the particular weather variable, and they may not be homogeneous (Allen et al, 1998). Another nearby station should be selected.

4. Compute the correlation coefficient *r*:

$$r = \frac{\mathrm{cov}_{xy}}{s_x\, s_y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\left(\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2\right)^{1/2}} \tag{3-8}$$

Both a high r^2 ($r^2 > 0.7$) and a value for b that is within the range ($0.7 < b < 1.3$) indicate good conditions and perhaps sufficient homogeneity for replacing missing data in the incomplete data series (Allen et al, 1998). These parameters r^2 and b can be used as criteria for selecting the best nearby station.

5. Compute the data for the missing periods k = n+1, n+2..., m using the regression equation characterized by the parameters a and b, thus

$$\hat{y}_k = a + bx_k \tag{3-9}$$

6. The complete data set with dimension m will now be

$$Y_j = y_i \ (j = i = 1,...,n)$$

$$Y_j = \hat{y}_k \ (j = k = n + 1, n + 2,...,m)$$

Results: After running the regression analysis of Chongón versus each one of the other three stations the output in Table 3-2, was obtain.

Table 3-2. Regression analysis method

Station	r^2	F
Azúcar (Figure 3-2)	0.0718	2.2443
Suspiro (Figure 3-3)	0.0145	0.4262
Playas (Figure 3-4)	0.0801	2.5257

The result can also be look at in the scatter plots created for each of the comparisons among the weather stations (Figures 3-2 to 3-4).

Since at least an r^2 of 0.7 is needed, the data from any of these stations cannot be used to complete the missing data from Chongón weather station. It was concluded that there is no relation between Chongón and any other existing weather station in the area.

Compositional Data

Any vector *x* with non-negative elements $x_1, \ldots, x_D$ representing proportions of some whole is subject to the obvious constraint

$$x_1 + \ldots + x_D = 1$$

Compositional data, consisting of such vectors of proportions, play an important role in many disciplines and often display appreciable variability from vector to vector. This concept can be used to estimate missing weather data (Aitchison, 1986).

Procedure:

1. Find the daily average for a given variable (Maximum Temperature, Tmax) from many years of a given month (this month will be May).

2. For each daily value calculate the percentage value compared to “one” (one equals the sum of the daily values for a given month).

3. Once these values are calculated new values can be created for May 2001, by multiplying the number for the day with the missing data (obtained in step 2) by the sum of the daily data of May 2001 (sum = 846).

Table 3-3. Creating new values

Cho_avg_may	%	Cho_may	Cho_crt_may
31.4	0.031126	*	26.3
Formulas:	= (31.4*1.0)/1008.8	Missing daily value	= 0.031126*846

4. Now a regression analysis is used to test how these new values fit to the weather data.

Results: The compositional data method gives an r2 of 0.46 and a F value of 25.13 for the Chongón station for May 2001 with 3 days of “created” data compared with the daily historic values for this month. A better r^2 value was obtained, but it did not meet the $r^2 = 0.7$ mark.

Using Data from Other Years to Replace Missing Meteorological Data

Special means were employed to maintain serially complete files of weather data when long segments of missing meteorological data were found. The majority of these situations occurred at stations that were not operated during the evening or on weekends, but in some instances a station would be shut down for several weeks or even longer. When these situations occurred, the gaps in the data were filled with data from other years, for the same days of the year. Averaged data from other years for the same time periods were selected to fill the gap.

Conclusion

Since none of the statistical methods tried to complete the missing weather data for the weather stations in the Santa Elena Peninsula were successful, the only option available was to use the data from other years from the same station to complete the missing data, and make all computation just with the currently available data. When possible and available, better weather data should be used to calculate crop water use.

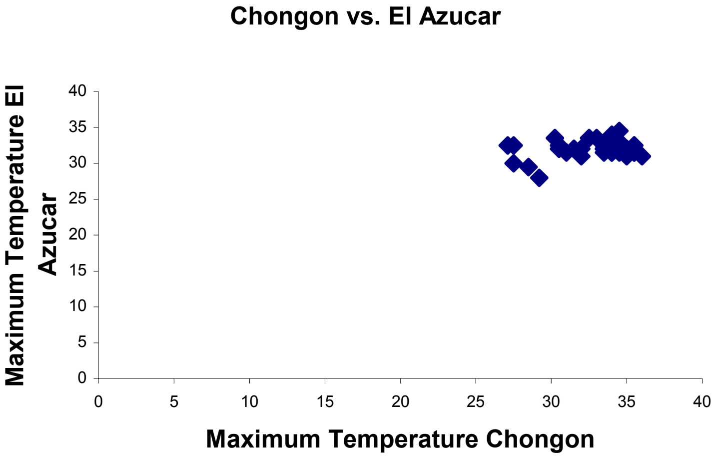

Figure 3-2. Chongón vs. El Azúcar

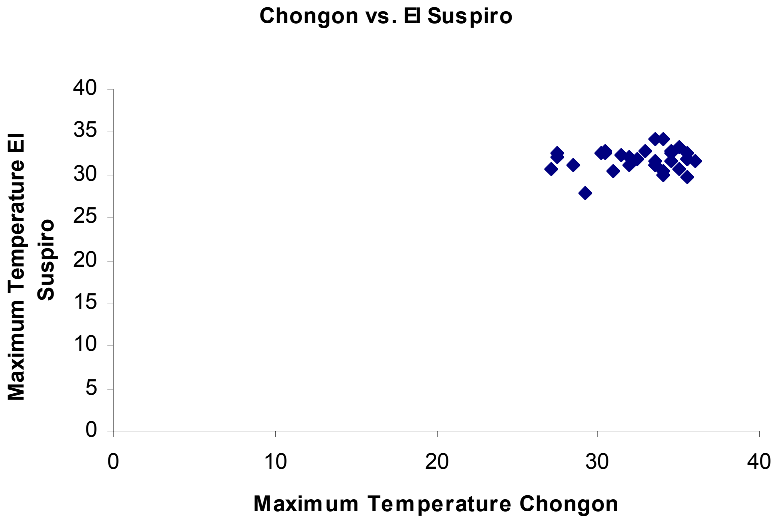

Figure 3-3. Chongón vs. El Suspiro

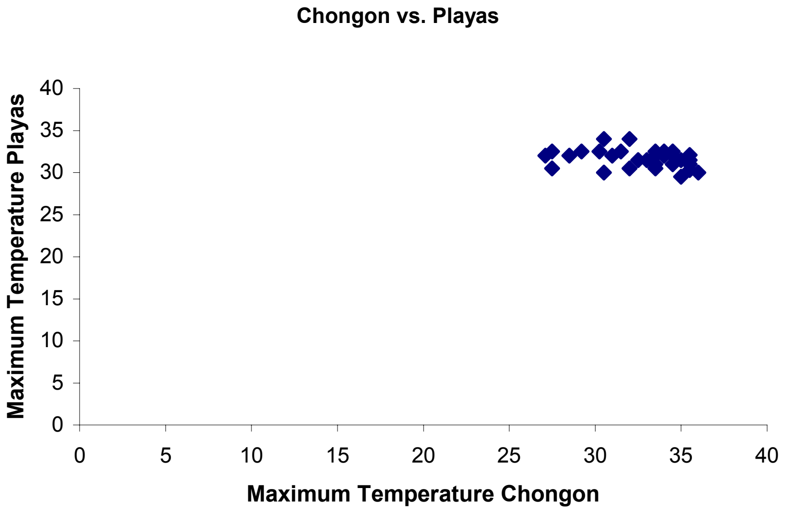

Figure 3-4. Chongón vs. Playas

CHAPTER 4
GEOGRAPHIC INFORMATION SISTEM

Introduction

Geographic Information System (GIS) technology is about 30 years old. However for the most part, it is still often used just to make maps. However, GIS can do much more. Using GIS databases, more up- to-date information can be obtained or information that was unavailable before can be estimated and complex analyses performed. This information can result in a better understanding of a place, can help make the best choices, or prepare for future events and conditions (Mitchel 1999).

Many countries and organizations are still building their GIS databases, as in the case of Ecuador and more specifically CEDEGE. This process of creating GIS databases has been difficult and cumbersome. Now, new easy to use software employing graphic interfaces is removing that obstacle.

The most common geographic analyses that can be done with a GIS are (McCoy & Johnston 2001):

- Mapping where things are
- Mapping the maximum and minimum values
- Mapping density
- Finding what is inside (intersection analysis)
- Finding what is nearby (proximity analysis)
- Mapping change (overlay analysis)

The steps for a good geographic information system analysis are (McCoy & Johnston 2001):

Stating the problem. Stating the problem defines what information is needed, and it is often in the form of a question. Being as specific as possible about this statement will help when trying to decide how to approach the analysis, which method to use, and how to present the results. Other factors that influence the analysis are how it will be used and who will use it.

Understanding the data. The type or data and features to be used in the project will help determine the specific method to be used.

Choosing a method. There are almost always two or three ways of getting the information that is needed. Often one method is quicker and gives more general information. Others may require more detailed data and more processing time and effort, but provide more precise results. To decide which method to use the level of precision to answer the problem has to be again evaluated.

Processing the data. Once the method has been selected, the necessary steps in the GIS have to be performed.

Reviewing the results. The results of the analysis can be displayed as a map, values in a table, or a chart. It has to be decided which information to include in the maps, and how to group the values to best present the information. Looking at the results will help in the decision making process, deciding what information is valid or useful, or whether the analysis should be rerun using different parameters or even a different method. GIS makes it relatively easy to make these changes and create new output. The results using different methods can be compared to decide which one presents the most needed information and produces it in an efficient way.

Mapping Systems

The mapping systems today range from display only systems like electronic atlases to full featured geographic information systems. The dividing lines between one type of system and the next are not sharply defined. The systems do differ in a number of important ways: how they link geographic locations with information about those locations (topology and relational database management), the accuracy with which they specify geographic locations (positional accuracy), the level of analysis they perform, and the way they present information as graphic drawings (Mitchel 1999).

Electronic atlases, for instance, allow displaying pictures of geographic areas on the computer screen. They provide limited information about the geographic areas, and limited ability to alter the graphics. Without any tools for analyzing the information, these systems are most useful for providing graphics that can be used in presentations and reports. They can also be used as reference tools (Mitchel 1999).

Unlike electronic atlases, thematic mapping systems have the capacity to create graphic displays using information stored in spreadsheet or database. These systems are especially useful for creating graphic presentations. Each map produced is based on a theme, such as population or income, and uses color, patterns, shading, and symbols of various sizes to show the relative value of the information stored for that theme, at each geographic location.

Street-based mapping systems are more sophisticated than electronic atlases and thematic mappers. They relationally link information to geographic locations. Street-based mapping systems can display address locations on street maps as points, and can plan travel routes via topological information.

More sophisticated mapping systems can import database or spreadsheet files or provide direct access to outside information sources. Some mapping systems let the user create and manage tabular information, use tabular information to create charts and graphs, and even analyze information statistically.

ArcGIS

ArcGIS (Environmental Systems Research Institute, ESRI®) desktop is a group of tools to develop and edit digital maps, and also allow some modeling (Breslin 1999). The tools used in this project are described in this section (Ormsby 2001).

ArcMap. It is an application for displaying maps and investigating them, for analyzing, maps to answer geographic question and producing maps that make analysis persuasive. In ArcMap, maps can be made from layers of spatial data, colors and symbols, query attributes can be selected, analyze spatial relationships analyzed, and map layouts designed. The ArcMap interface contains a list of the layers in the map, a display area for viewing the map, and menus and tools for working with the map.

ArcCatalog. This tool is used to browse spatial files on the computer's hard drive, on a network, or on the Internet. The program can be used to search the spatial data, preview it, and add it to ArcMap. ArcCatalog also has tools for creating and viewing metadata (information about spatial data, such as who created it and when, its intended use, its accuracy, etc).

Spatial analyst. It is an application used to create raster (cell-based) surfaces, query them, and do overlay analysis on them. It can also be used to derive new surfaces from other raster or vector layers. For example, a slope surface can be derived from an elevation surface or a population density surface from population points.

Geostatistical analyst. It is a tool that can create continuous surfaces from a small number of points by predicting the values of unsampled locations.

ArcPress. This is an application that improves map printing speed and renders high-quality maps without requiring additional memory or hardware.

Original Maps

The Instituto Geografico Militar (IGM) publishes the official maps of Ecuador. Topographic maps of the country at 1:1,000,000 and 1:500,000 scales are available, and a series of topographic sheets at 1:50,000 scale, published gradually during the past 20 years, now covers most of the country, except remote areas of the Amazon basin and parts of the Andean slopes. The IGM has also published thematic maps at 1:1,000,000 scale, including geologic, soils, bioclimatic, and life zones maps. A branch of the IGM, the "Centro de Levantamientos Integrados de Recursos Naturales por Sensores Remotos" (CLIRSEN), that operates a Landsat and SPOT satellite image receiving station near the Cotopaxi volcano, carries out geographic and natural resources studies using remote sensing data, and sells the satellite imagery to other users.

Soils

The original layer containing the different types of soils in the Santa Elena Peninsula (SEP) contain a large number of various soils that was too complex to use in a model using CROPWAT. This original map is presented in Figure 4-1, a complete view of this map is shown in Figure A-4.

CROPWAT model from FAO/UN (Food and Agricultural Organization of the United Nations) uses only three soil texture groups of clay, silt, and sand to calculate irrigation schedules.

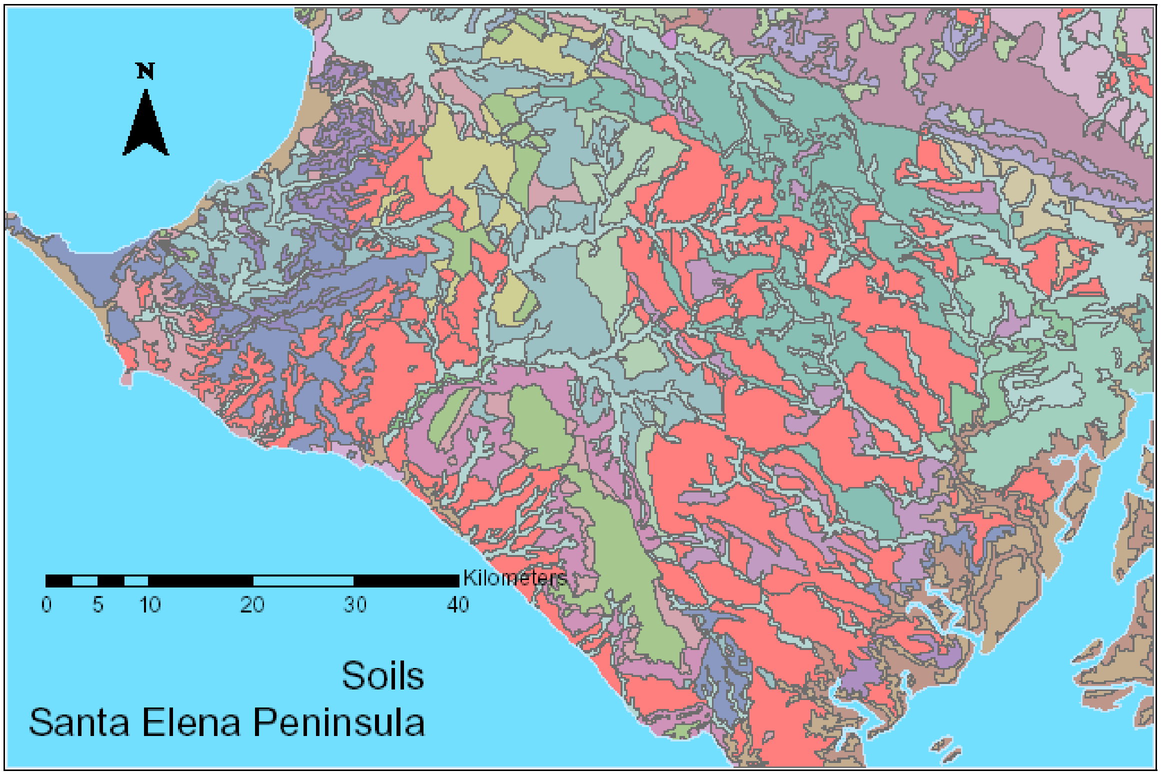

Figure 4-1. Soil types on Santa Elena Peninsula, original map

Ecological Zones

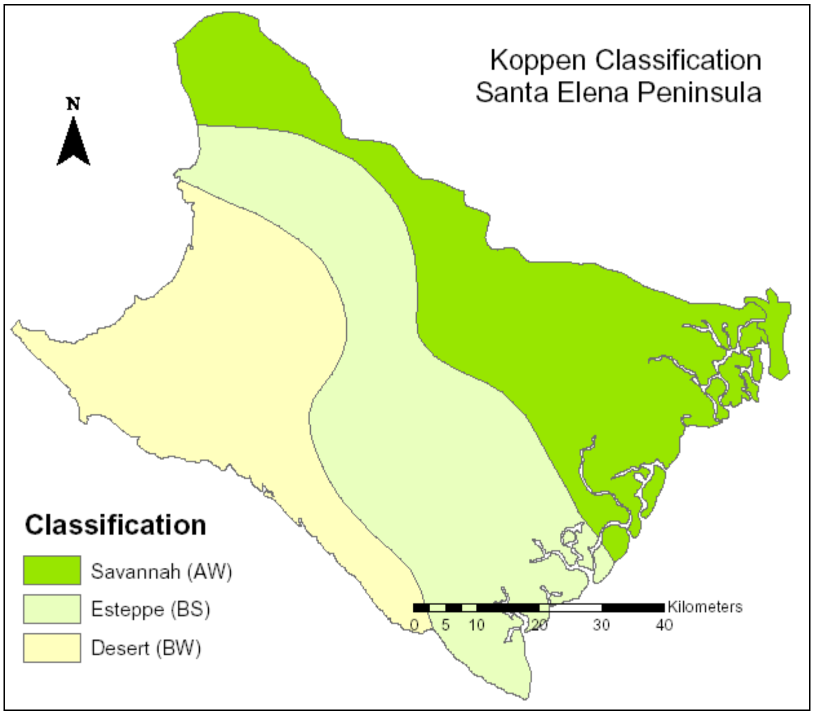

Figure 4-2. Köppen climate classification of Santa Elena Peninsula

The Peninsula was subdivided into three zones (Figure 4-2) based on the climate data presented in Chapter 2.

According to the Köppen method the Santa Elena Peninsula has the following ecological zones: Desert, Steppe, Savannah.

Dams

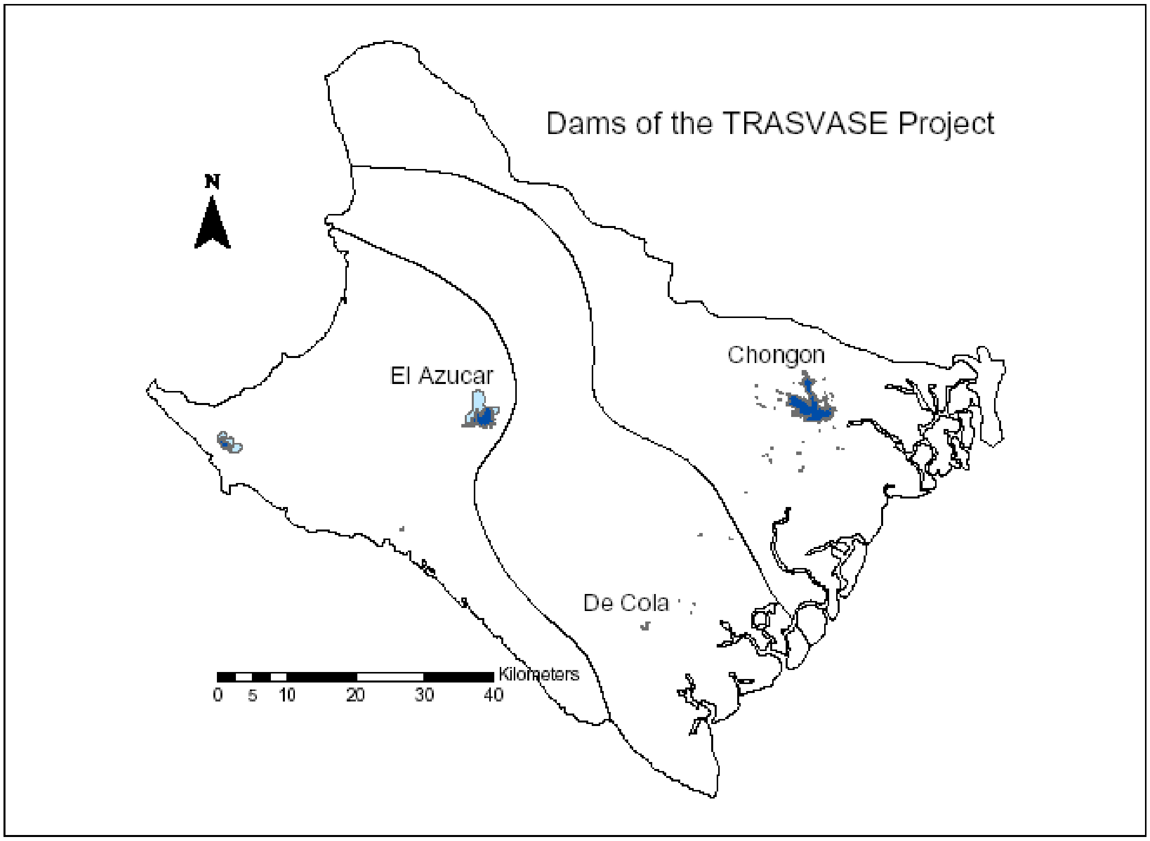

Figure 4-3. Dams location on Santa Elena Peninsula

The geographic location and area of the main dams that constitute the TRASVASE irrigation system is presented on the layer in Figure 4-3. The information in this layer was used to calculate the capacity of the system, evaporation and their storage efficiencies.

The three dams that are presented in Figure 4-3 that are part of this project are: Chongón, El Azúcar, and De Cola. Also, the projected areas for El Azúcar and Velasco Ibarra dams are shown in this layer.

Canals

A layer containing geographic locations of the canals, length and materials used in their construction is also available and is presented in Figure 4-5. This layer also contains roads and drainage information that will not be used in this project.

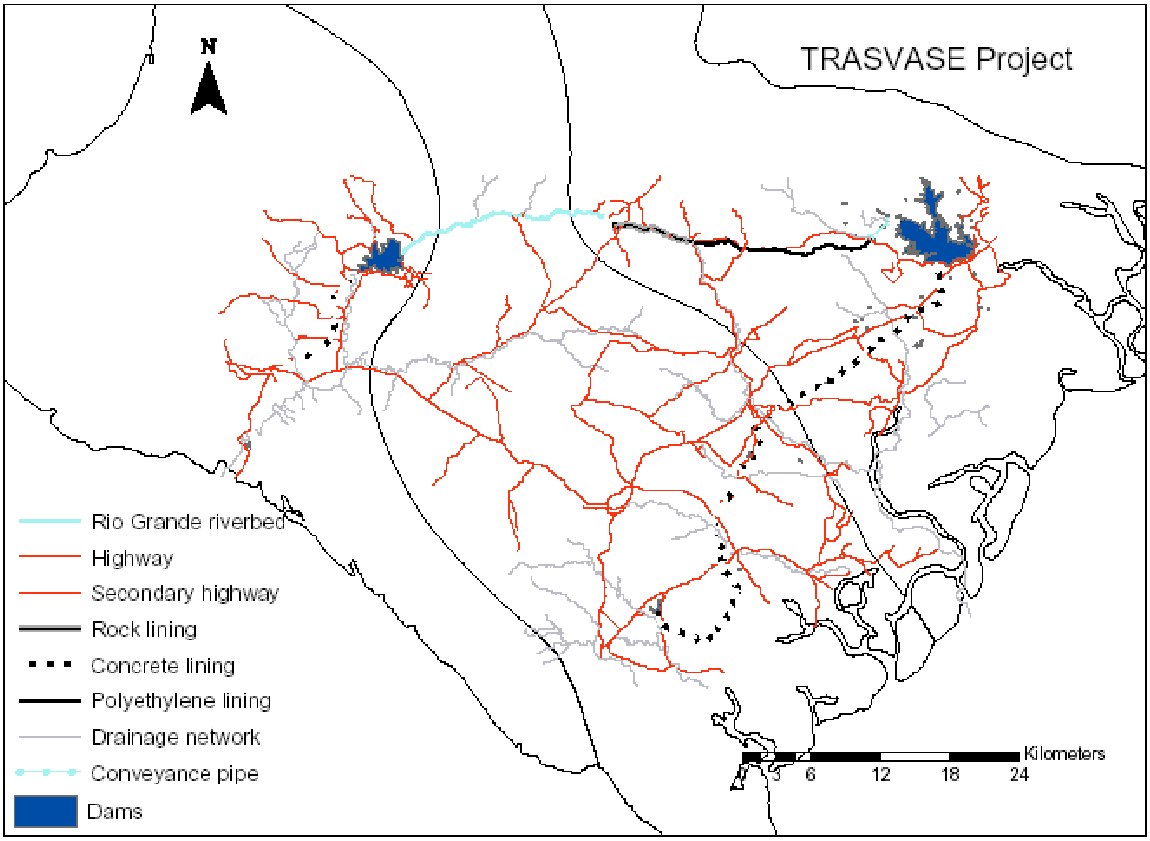

Figure 4-4. Canals and other features

Data Quality Problems with the Santa Elena Peninsula Data Set

Data quality problems in the data set available from the Santa Elena Peninsula during the creation of the geographic information system (GIS) for this area. Lineage, unclosed polygons, lines that overshoot or undershoot junctions, labeling problems, missing metadata, and maps in different projection systems.

Lineage

It is important to create a record of the data sources and of the operations that created the database:

- How was it digitized, from what documents?
- When was the data collected?
- What agency collected the data?
- What steps were used to process the data?

The matching of final results, after calculation, can be a good indicator of the initial data accuracy. In the case of the data for the Santa Elena Peninsula even when one institution digitized the maps, the original “hard copy” maps came from multiple agencies and in different projections and scales. This made the process of interpolation very difficult and introduced an imbedded error. Some of the agencies that collected and digitized the data for the SEP are: ESPOL, CEDEGE, and IGM. This resulted in a set of data with different projections, scales, and different information in the metadata.

In addition the weather and agricultural databases (CEDEGE, ESPOL) have certain problems. One major problem is that these databases do not describe the time when the information was gathered and how the data was collected. The most serious errors resulted from the missing data, especially weather data.

Accuracy

Overshoots and undershoots may be used as a measure of positional accuracy. These are presented in few layers for this project, but most of the errors occur in the elevation contours, and the hydrology maps (Figure 4-5) where logical consistency errors are also presented.

Logical consistency refers to the internal consistency of the data structure, particularly it applies to topological consistency related to the polygon closure and polygon labeling.

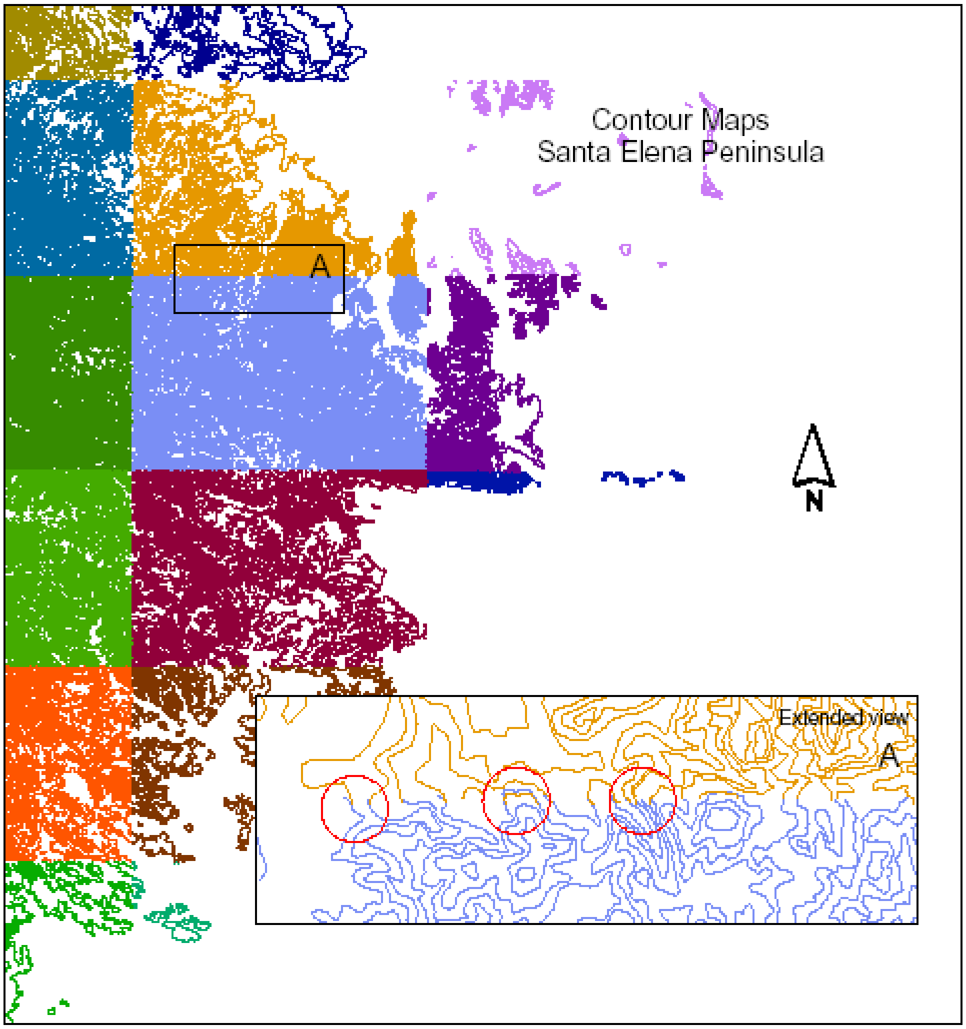

Figure 4-5. Errors in the hydrology maps of the SEP

Many of the polygons in the maps that were available for the Santa Elena Peninsula have more than one label. One example is the ecological zones map, where up to three labels can be found. Some labels are not accurate or longer than required. Large descriptions of each attribute in the table make it difficult to read and interpret the labels, and are difficult to place in the map itself. All of that required significant changes during data preparation. To correct these errors the databases related to each of the maps presenting this type of error (Köppen, Papadakis, ecological zones soils, canals) were edited, adding or subtracting data fields as needed to create layer suitable for use in a GIS.

Map scale is the other source of error. Cartographers and photogrammetrists work to accepted levels of accuracy for a given map scale. Locations of map features may disagree with actual ground locations, although the error likely will fall within specified tolerances. Scales from 1:5,000 to 1:50,000 are found for the maps available for the SEP and the combination of different scales added error to the final maps produced for this project. Although it is not possible to eliminate this error it should be recorded in the metadata for future reference, this was done for all the maps produced, using ArcCatalog.

Precision

The accuracy and precision errors can be located in the Santa Elena Peninsula data, overlapping the soils map, and the ecological zones (Köppen) layer (red line) shows the difference between the two maps.

A shift to the northwest in the ecological zones layer can be identified. Georeferencing between this vector layers was used to correct the ecological zones layer. The soil layer was used as a reference layer because all its metadata were known and correct.

Completeness

Completeness is the degree to which the data exhausts the universe of possible items: are all possible objects included within the database? In the case of the data available for this project this aspect relates to a “logical consistency”. Basically, it does not matter if there is a lot of information in a database if that information cannot be used in an efficient manner.

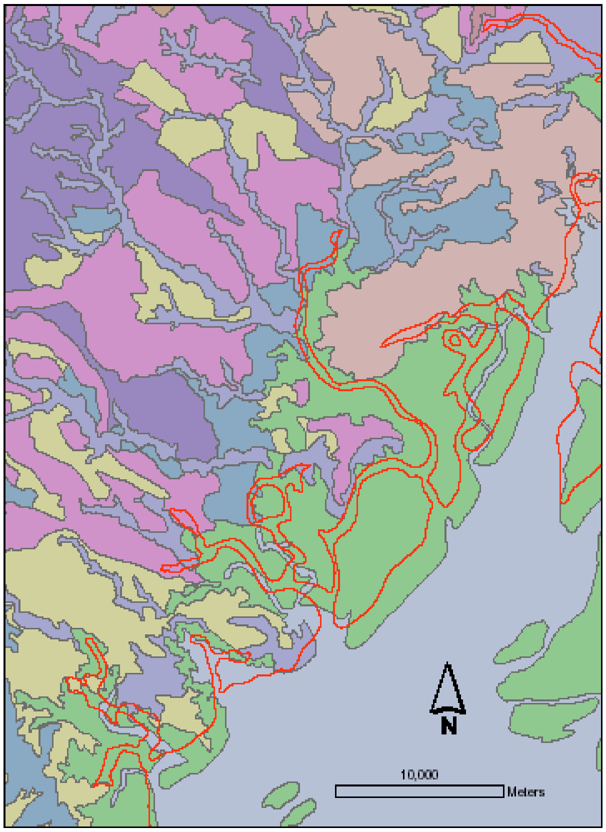

Figure 4-6. Overlap error

Metadata Errors

Coordinate transformation introduces error, particularly if the projection of the original document is unknown, or if the source map has poor horizontal control. The digital maps of the SEP were that the maps were in different projections or did not have any stated projection; however this is not something difficult to correct. ArcGIS contains a feature that allows setting the desired coordinate system for a map. The coordinate system selected for the maps of the SEP was the Universal Transverse Mercator (UTM) Zone 17 South. It is important to note that bad metadata can be a source of spatial error, especially when trying to overlay different layers. The most accepted standard for metadata is giving by the Federal Geographic Committee (2000) in the Content Standard for Digital Spatial Metadata.

Manual Digitizing

Manual digitizing was the method predominantly used to create the digital maps of the different attributes for the Santa Elena Peninsula (SEP). This digitizing method can introduce more errors in the final product, especially when done without proper trained people and without supervision and quality control (Figure 4-5). The digitizing process was made in ESPOL (Polytechnic School of the Littoral) Guayaquil, Ecuador, in most of the cases by students and people with little practice in digitizing.

Source Data for the Santa Elena Peninsula

The main problem with the SEP maps is related to many different data sources. Starting with maps created by various national and international agencies, and digitized in different manners. Several databases (climatic, agricultural production, water use, water consumption, etc.) the collected with unknown methods by different institutions. In addition, there was difficulty to compare this data against other sources because of the few studies completed in the area of the Peninsula.

Controlling GIS Errors

Data entry procedures should be thoroughly planned, organized and managed to produce consistent, repeatable results. Nonetheless, a thorough, disciplined quality review and revision process also is needed to catch and eliminate data entry errors. All production and quality control procedures should be documented, and all personnel should be trained in these procedures. Moreover, the work itself should be documented, including a record of what was done, who did it, when was it done, who checked it, what errors were found, and how they were corrected. GIS data should not be provided without metadata indicating the source, accuracy and specifics of how the data were entered.

GIS Layers Created or Edited for the Project from the Original Maps

Soils

The new soil map divides all the soils into three groups (silt, sand and clay). The distribution of these soils within the Peninsula is presented in Figure 4-7. The "merge" tool in the "Geoprocessing" wizard from Arc View 3.2 was used to simplify this layer. The original soil map is presented in Figure 4-1.

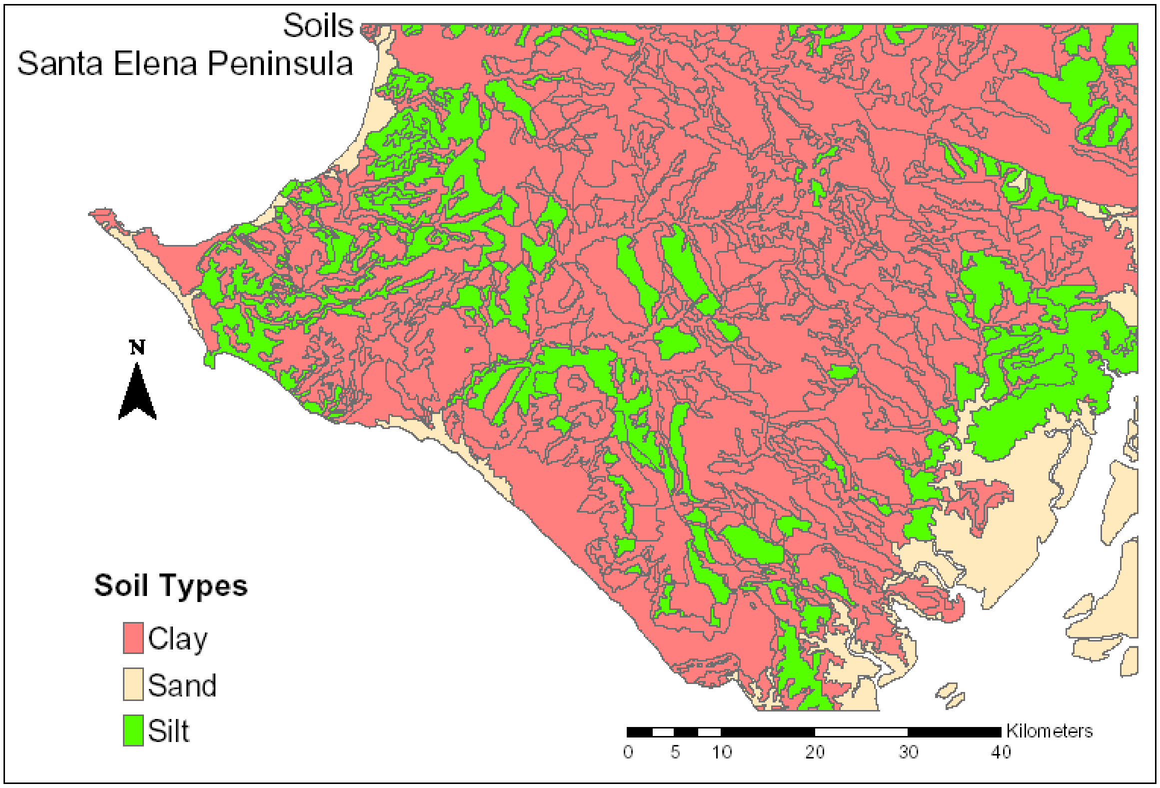

Figure 4-7. Main soil types layer created for the Santa Elena Peninsula

Ecological Zones

This layer shows the ecological division in the Santa Elena Peninsula. According to the Köppen method the Peninsula is divided in desert, steppe and savannah.

The canals of the TRASVASE irrigation system cross the different ecological zones. The "clipping" geoprocessing tool available in Arc View 3.2 was used to clip the canals to the ecological zones (Figure 4-8).

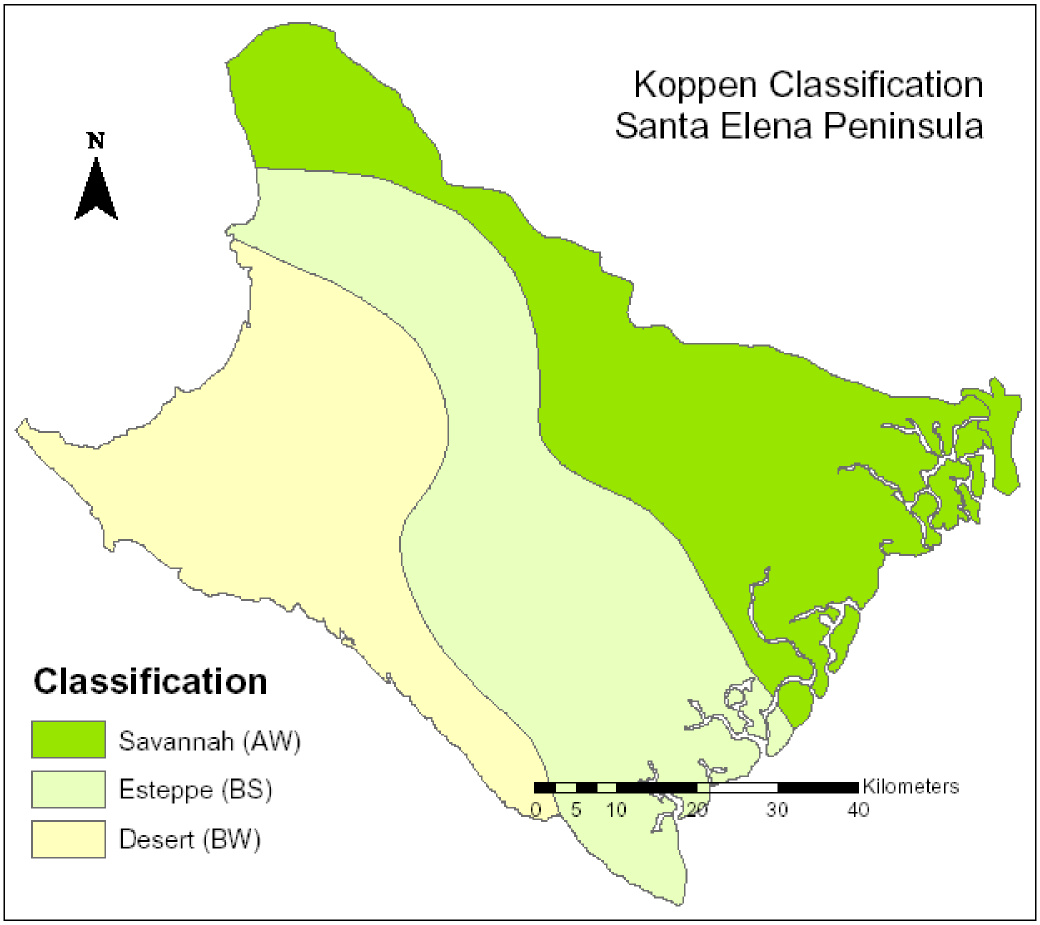

Figure 4-8. Ecological zones

Canals

This figure represents several layers; ecological zones, canals, and the dams in the area of interest.

The roads, and drainage lines were deleted to create this layer. The layers were also clipped using the Köppen Ecological Zones. The different materials of the canals where maintained but join in one canal per ecological zone, this was done to facilitate the evaporation calculation in the later phase on in the project.

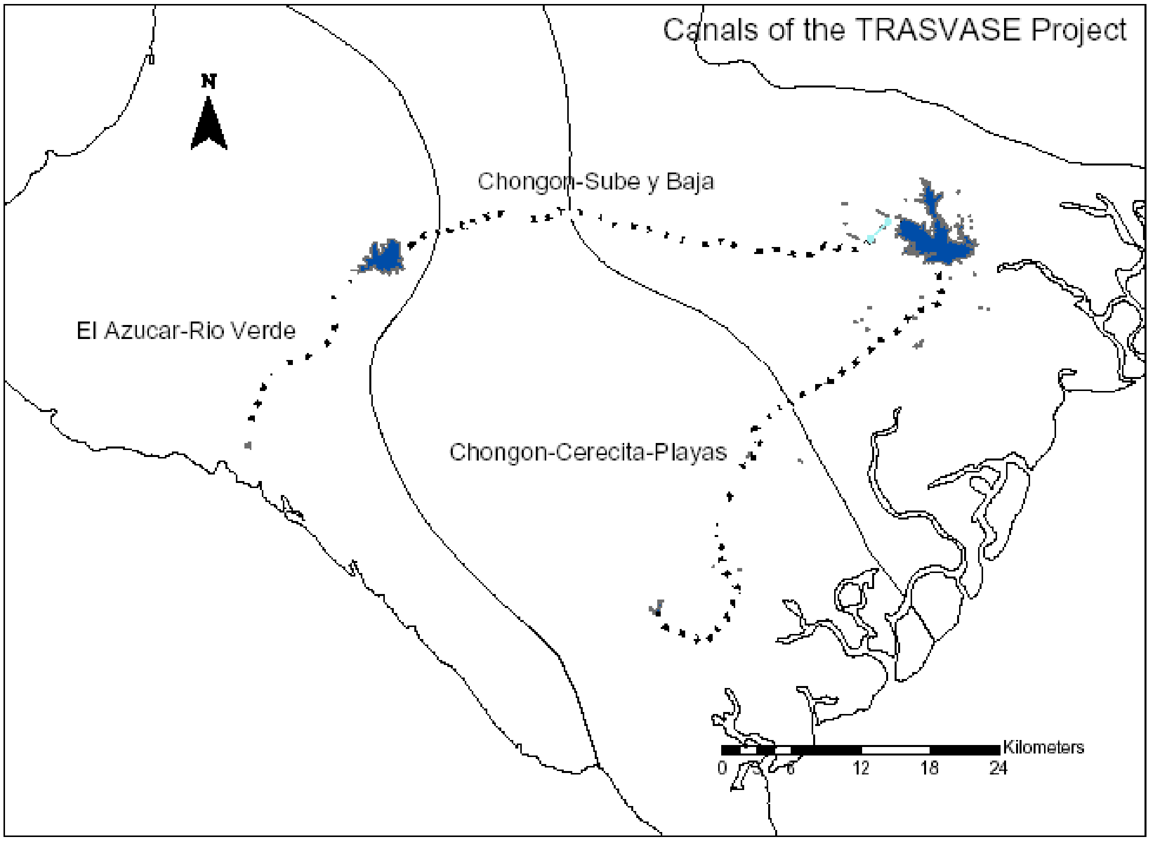

Figure 4-9. Canals

Existing Farm Locations

A layer that shows the geographic locations of most of the farms close to the canals (Figure 4-9) was also created. More detailed maps of the farms locations can be seen in Appendix A (Figures A-5 to A-8). The farms are grouped in five regions: Santa Elena, Chongón, Cerecita, and El Azúcar – Rio Verde. This layer shows the total areas of the farms, however that is not the actual area under agricultural production. As information about crops produced in each farm becomes available, these layers will be used to create maps that will show the total area that can be irrigated in each zone according to the weather parameters and crop water requirements. These concepts will be explained in the following Chapters.

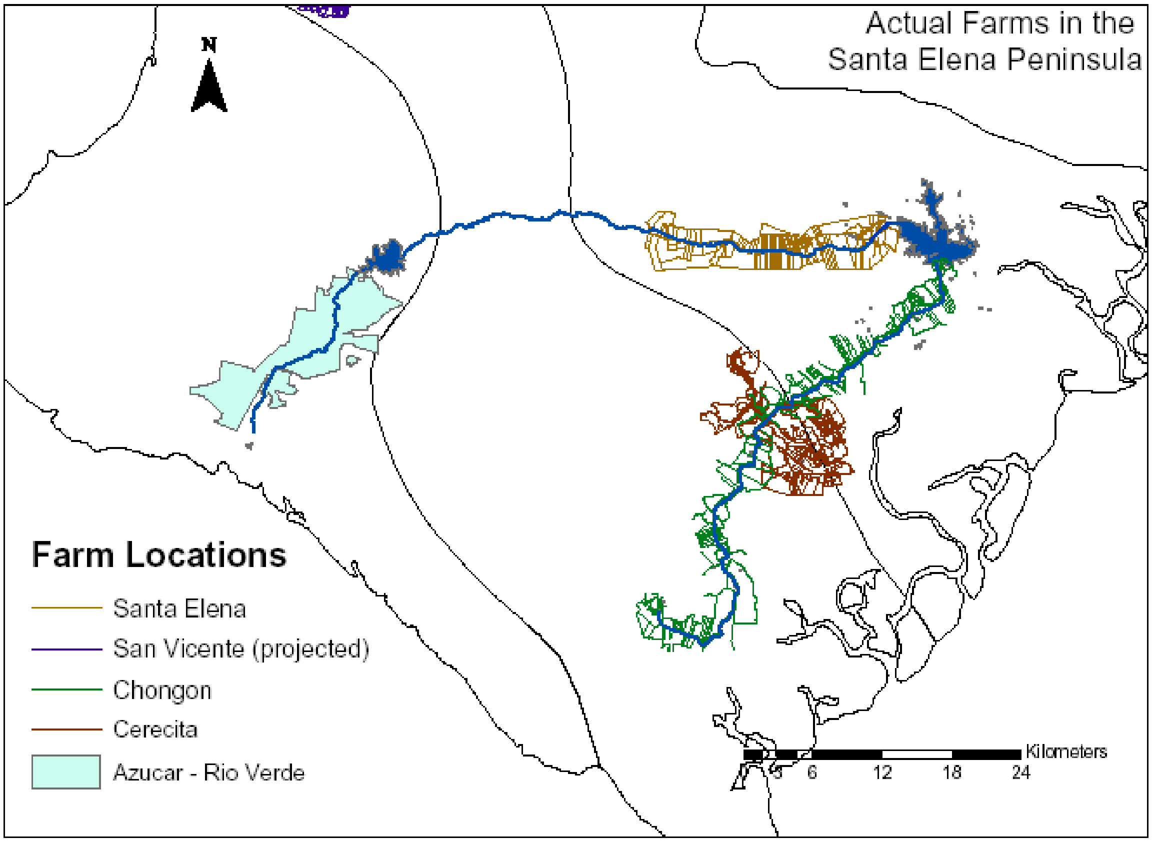

Figure 4-10. Actual farm locations

Weather Stations Location

Known coordinates of each one of the weather stations were used to create a Microsoft Access database. An "ID and Station Name" fields were added for better identification of the stations and to be used to link or join this table with others in Arc View 3.2. With the Access file a shape file was created in Arc View 3.2 so it can be displayed as a layer in the GIS (Figure 2-5 in Chapter 2).

Weather Data

There are a number of commonly used interpolation techniques described in the literature, such as simple average, Thiessen polygon, classical polynomial interpolation, inverse distance, multi quadratic interpolation, optimal interpolation, kriging and others. In this study the inverse distance interpolation technique was chosen for its simplicity.

Researchers have used diverse statistical and geostatistical models to generate temperature surfaces from point sampling locations. The simplest technique uses the nearest measurements. Trend surfaces, inverse distance weighted interpolation (IDW), and thin plate spline, all have been used to interpolate temperature measurements over global, continental, and broad regional scales. These models, assume the underlying surface is smooth as it is the topography found in the Santa Elena Peninsula.

Inverse Distance Interpolation. As is obvious for the name of the interpolation technique, the weighting factor is inversely proportional to the distance. The weights of this interpolation technique are solely a function of the distance between the point of interest and the sampling points.

Table 4-1. Comparison of interpolation methods

Method	Advantages	Disadvantages
Bi-linear interpolation	Simple, conservative	Smoothing
Polynomial trend surface	Designed degree of smoothing	Unstable near edges
Inverse square distance weighting	Preserves high frequencies	Outliers
Kriging (variogram)	Uses variance of data	Directional effects
Spline interpolation	Optimal fit	Strong edge effects
Laplacian fitting	Good fitting, smooth decay at edges	Smoothing

The inverse distance technique does not take advantage of spatial correlation structure explicitly. However, for climate data these correlation structures tend to be linear and it is a good guess to assume that the inverse distance weighting would work fairly well.

The Inverse Distance Weighted interpolation method was used to create the surface maps (Figure 4-11) with the Geostatistical Analysis Tool from ArcGIS for the weather variables: maximum, minimum and medium temperature, and maximum, minimum and medium relative humidity. Examples are the surface maps for the month of January (Figure 4-11).

Inverse Distance Weighted (IDW) interpolation explicitly implements the assumption that places that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location, with values closest to the prediction location having more influence on the predicted value than those farther away (Johnston, et al. 2001). IDW assumes that each measured point has a local influence that diminishes with distance, and weights the point closer to the prediction location greater than those farther away (Johnston, et al. 2001).

$$Z(S_o) = \sum_{i=1}^{N} \lambda_i Z(S_i) \qquad (4\text{-}1)$$

$Z(S_o)$ value to predict for location S_o
N number of measured points
λ weight, these weights will increase with distance
$Z(S_i)$ observed value at the location S_i

The formula to determine the weights is (Johnston, et al., 2001):

$$\lambda_i = d_{io}^{-p} \Big/ \sum_{i=1}^{N} d_{io}^{-p} \qquad (4\text{-}2)$$

$$\sum_{i=1}^{N} \lambda_i = 1$$

As the distance becomes larger, the weight is reduced by a factor of p. The d_{io} value is the distance between S_o and S_i.

The Inverse Distance Weighted method includes a power (p) parameter. This p parameter influences the weighting of the measured location's value on the prediction location’s value; that is, as the distance increases between the measured sample locations and the prediction location, the weight that the measured point will have on the prediction will decrease exponentially (Johnston, et al. 2001). The optimal *p* value is determined by minimizing the root-mean-square prediction error (RMSPE). The RMSPE is a summary statistic quantifying the error of the prediction surface (Johnston, et al. 2001).

After one map for each weather variable was created for each month of the year they were classified into 5 classes because the variation in the data was small. To reclassify those surface maps the Equal Interval method was used. In the Equal Interval method the range of possible values is divided into equal-sized intervals. Because there are usually fewer endpoints at the extremes, the numbers of values are less in the extreme classes. This method is used in data ranges as percentages (relative humidity or temperature) (McCoy, and Johnston 2001).

Creation of Evapotranspiration Surface Maps

For this study, the climatic information used to make interpolation is based on inverse distance weighted method of 5 stations in the Santa Elena Peninsula (SEP). While interpolation of a value at reach cell in the study area using 5 meteorological stations is technically easy, some important questions can be raised. Are the stations representative of the areas around them? How large or small an area do they represent? How does the spatial feature in question change over space? Is it continuous or discontinuous and abrupt?

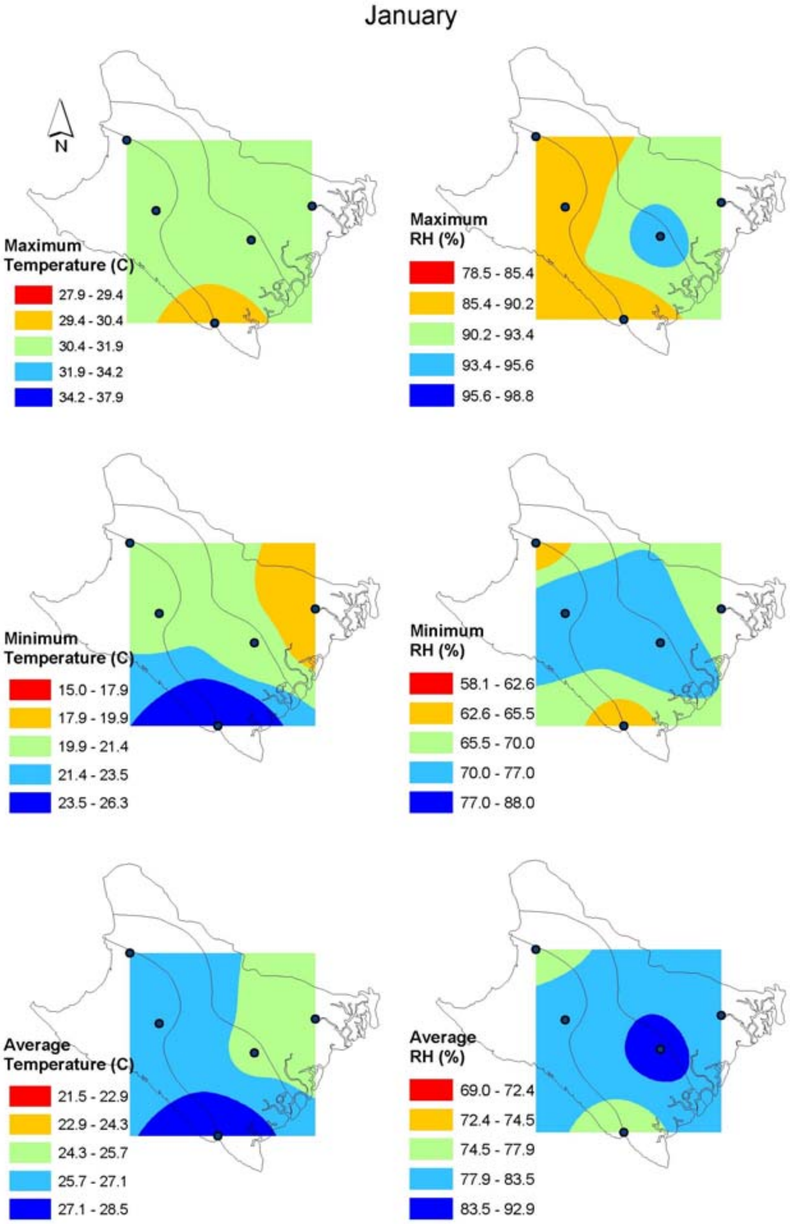

Figure 4-11. Surface maps of weather data for January

Characterization of climate data for a study area typically relies upon a series of measurements at discrete locations. Spatial interpolation of these discrete data into a continuous surface is generally the first step for use with other GIS data layers. These surface maps layers were used to determine relationships between stations and to identify the agricultural production zones affected by each of the weather stations. Weather parameters affect evapotranspiration and as a result they modify irrigation requirements. Later in this document (Chapter 5, Figures 5-9.1 and 5-9.2) reference evapotranspiration surface maps are presented to show the monthly variations within the Santa Elena Peninsula.

CHAPTER 5
WATER AVAILABILITY AND ITS USE IN THE SANTA ELENA PENINSULA

Infrastructure

In the TRASVASE irrigation system the water is used for irrigation and also for human consumption, and as in any irrigation systems there are losses. To calculate the total available water for irrigation the amount used for potable water and the losses of the system have to be calculated.

TRASVASE Santa Elena

Daule – Peripa Dam

This dam (6,000 million cubic meter) works to control floods, regulate water flow, control salinity levels, and produce hydroelectric power. Because of that its name is ‘Proyecto de Propósito Multiple Jaime Roldós Aguilera’, in English, Multi-purpose Project ‘Jaime Roldós Aguilera’ (Figures 5-1 and 5-2).

Figure 5-1. Daule-Peripa Dam

Figure 5-2. Hydroelectric plant, 'Proyecto de Propósito Multiple Jaime Roldós Aguilera'.

The area directly influenced by this project is 50,000 ha in the Daule Valley. Indirectly 42,000 ha are projected to be irrigated in the Santa Elena Peninsula. Another 50,000 ha (500 m3/year) are projected to be irrigated from the same Dam in the Manabi province (CEDEGE 2001).

History of the Project

The Santa Elena Peninsula (SEP) has suffered a water crisis for more than 100 years. Most people agree that deforestation is the main cause, converting what was once tropical forest to a near desert. To mitigate the drought conditions, and to use this land for agricultural production the TRASVASE project was built. In 1992 the first hydraulic structures were put together to start the TRASVASE Daule-Santa Elena.

Following that, the Chongón Dam (Figure 5-3), the Chongón irrigation canal, the Chongón – Cerecita irrigation canal and the irrigation infrastructure in the Chongón, Daular and Cerecita irrigation zones were built; total project covering approximately 5,000 ha (CEDEGE 2001).

Figure 5-3. Chongón Dam

In order to promote the use of most efficient irrigation techniques, and demonstrate the agricultural potential in the SEP, pressurized irrigation systems were installed, at Chongón and Cerecita, consisting of pumping stations, subterranean conveyance pipes, and portable sprinkler systems.

Figure 5-4. Daule pumping station

At the end of 1995 the construction of the Daule-Chongón canal was completed assuring constant water supply to the Chongón Dam, the Chongón-Cerecita-Playas canal and the Daule Pumping Station. Sixty-one kilometers of canals were lined with concrete, and the 6.5 km Cerro Azúl tunnel was finished. It was estimated that this system will allow the irrigation of 15,000 ha of land (CEDEGE 2001).

In 1998 the first part of the project was finished. In that part the water from the Chongón Dam was conducted to El Azúcar Dam and from here to the Río Verde irrigation zone. To accomplish this the following structures were build: the Chongón Pumping Station, a 3 km pressurized conveyance pipeline, and 40 km of canals lined with high-density polyethylene. The El Azúcar Dam was refurbished, and the Cola dam in San Juan (Playas) was built to regulate the water flow.

Table 5-1. Main dams

Dams	Volume (10^6 m^3)		Surface (km^2)		Water level (m)	
	Max	Min	Max	Min	Max	Min
Chongón	273.6	148.5	25.7	16.9	51	45
El Azúcar	53.8	25	14	8.5	45	42
De Cola	2.44	1.4	0.4	0.5	26.5	24.8

In the last part of this project the Sube y Baja Dam, the Sube y Baja-Javita, Afaye-Atahualpa, and Villangota and Azúcar-Zapotal canals will be built.

Other important and complementary projects were constructions of two potabilization plants and wastewater treatment plants in 2000.

Potabilization Plants

The water from the TRASVASE is now also used to supply two water potabilization plants for two of the larger towns in the Peninsula. One of those is the Santa Elena plant (Irrigation Zone I), which supplies water for the cities of Santa Elena and Salinas. The second one provides water to Playas (Irrigation Zone II). The flow water required by the plants are 1.6 m^3/sec and 0.55 m^3/sec respectively (CEDEGE 2001).

Figure 5-5. Zone II potabilization plant

The construction of sanitary canals in the main cities and towns of the Peninsula is included in the CEDEGE plans for the SEP. Also planned are controls for prevention of surface and groundwater contamination.

Transmission Canals

The TRASVASE irrigation system uses canals and pipes to deliver the water to its users. The seepage loss from the canals constitutes a substantial percentage of the usable water. Irrigation canals lose water through seepage and evaporation (Chahar 2000). The seepage loss from canals is governed by hydraulic conductivity of the subsoil, canal geometry, location of water table relative to the canal, and several other factors (Burton et al. 1999).

Figure 5-6. Canal

Transmission canals are used in the TRASVASE system to convey water from the source to a distribution canal. Often the area to be irrigated lies very far from the source, and hence requires long transmission canals.

Figure 5-7. Canal San Rafael, TRASVASE project

Normally, there should be no withdrawal from a transmission canal. In the case of the TRASVASE this occurs because the secondary (delivery) canals have not been completed and water from the transmission canals is used to supply irrigation water to the adjacent land.

The canals of the TRASVASE system are lined with various materials, from reinforced concrete, to polyethylene, to the original material of the riverbed. To calculate the seepage losses of each section of the canal we need to know the characteristics of each of these materials. However, in this study the average number estimated by CEDEGE (7 %) was used for calculation of seepage losses.

Water Loss from the Canals and Dams to Evaporation

The main causes of loss of stored water are seepage through a leaking basin or dam wall, and evaporation from the surface. Many methods have been developed for controlling both, but few are economically attractive (Hudson 1987).

Evaporation from open water can easily reach 7 mm per day in arid or semi-arid countries. This equals 5 cm per week and 20 cm per month (Brouwer, et al. 1992). The amount of water lost by evaporation can be considerable, particularly in reservoirs, which are large and shallow. Therefore, irrigation from shallow lakes and reservoirs should be started as soon as possible after the rainy season.

Evaporation from the dams and canals (Appendix C, Tables C-6 and C-7) has to be calculated based on the available weather data and the surface area of the dams and canals (Tables 5-2 and 5-3) that are part of the TRASVASE irrigation system.

Table 5-2. Approximated surface areas of the canals

Canal	Length (m)	Width (m)	Surface Area (m^2)
Chongón-Cerecita	37,520	8.6	322,672
Cerecita-Playas	18,309	7.7	140,979
Chongón-Sube y Baja	19,600	8.3	162,680
Azúcar-Rio Verde	19,863	12.5	248,288

Table 5-3. Approximated surface areas of the dams

	Surface (m^2*10^4)		
Dams	Max	Min	Average
Chongón	25.7	16.8	21.25
El Azúcar	14	8.5	11.25
De Cola	0.3	0.5	0.40

A well-designed and constructed canal system transports water from the source to the farmers’ fields with a minimum amount of water loss. However, water losses will occur and can seriously reduce the efficiency of water delivery. Water may be lost by seepage, leakage, or both (Hoevenaars, et al. 1992).

Seepage

Water that seeps through the bed and sides of a canal will be lost for irrigation. This so-called “seepage loss” can be significant where a canal is constructed from material which has a high permeability: water seeps quickly through a sandy soil and slowly through a clay soil, and so canals constructed in sandy soils will have more seepage losses than canals in clay soils. The results of seepage through the sides of a canal can sometimes be very obvious, such as when fields adjacent to a canal become very wet, and even have standing water. Seepage loss through the canal bed is difficult to detect because water goes down and does not appear on the nearby ground surface (Hoevenaars et al., 1992).

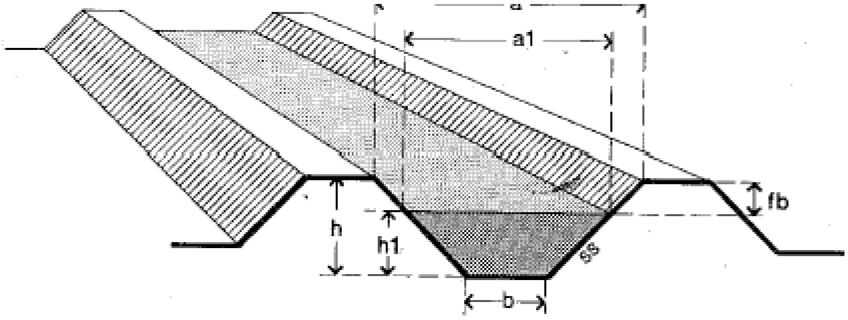

Figure 5-8. Trapezoidal canal

Leakage

Water may also be lost by leakage. This water does not seep, but flows through larger openings in the canal bed or sides (Hoevenaars, et al. 1992).

- Seepage around structures, leading to severe leakages
- Gates which are not tightly sealed
- Cracked concrete canal linings, or joints that are not tightly sealed
- Torn asphalt or plastic lining

Leakage often starts on a small scale, but the moment that water has found a way through a canal embankment a hole will develop through which water will leak. If the leakage is not stopped in time, the tunnel becomes larger and the canal bank may be washed away at a certain moment. In the case of a lined canal, the canal foundation may be undermined after some time and the canal will collapse.

Table 5-4. Canal description

Canal	Length (m)	Q (m^3/sec)	Lining
Daule-Chongón (tunnel)	32,723	44	Concrete
Chongón-Cerecita	24,494	12	Concrete
Cerecita-Playas	31,741	9	Concrete
Chongón-Sube y Baja	19,600	9.2	Polyurethane
Azúcar-Rio Verde	19,863	5.5	Polyurethane

Irrigation Efficiency

The application efficiencies considered for this project were within those defined by FAO (Table 1-2). The in-field irrigation efficiency values considered were 50 %, 70 % and 90 %. Using an ample range of efficiencies assures the inclusion of a wide range of conditions where irrigation is applied to the field.

Irrigation Technology used in the Santa Elena Peninsula

In the period 2000–2001 CEDEGE conducted a survey to the agricultural producers in the SEP. The results from this survey show the adoption of the latest irrigation technology by large farmers that have the capital to implement the technology (Tables 5-5 to 5-7).

Table 5-5. Chongón-Daular-Cerecita pressurized system, Zone I (2001)

System	Area %
Drip	19.17
Sprinkler	18.63
Microsprinkler	9.89
Water hose	11.41
Other	2.28
Not using irrigation	38.02

In this zone consisting of 2,780 ha cultivated (Table 5-5) the percentage of farmers not using any type of irrigation system is highest compared to the other regions. This corresponds to the area owned by small farmers.

Table 5-6. Chongón-Cerecita-Playas canal, Zone I (2001)

System	Area %
Drip	27.78
Sprinkler	8.89
Microsprinkler	21.11
Water hose	11.11
Not using irrigation	31.11

More than half (57 %) of the area in this zone of 3,175 ha under agricultural production (Table 5-6) is covered by irrigation systems that theoretically will have a field application efficiency of 70 % of higher.

Table 5-7. El Azúcar-Río Verde canal, Zone II (2001)

System	Area %
Drip	35.4
Sprinkler	7.96
Microsprinkler	3.54
Surface	13.27
Not using irrigation	39.82

The conditions in this area (565 ha cultivated) (Zone II) differ from the previous two areas (Zone I) because in Zone II the water is scarcer and the irrigation systems used should be more efficient to overcome that deficit. This can explain the higher use of drip systems over sprinklers.

Water Consumption

CROPWAT is meant as a practical tool to help agro-meteorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies and more specifically, the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation.

Calculations of crop water requirements (CWR) and irrigation requirements are carried out with inputs of climatic and crop data. Standard crop data are included in the program and climatic data can be obtained for 144 countries through the CLIMWAT database. Ecuador is included in this database, however, the data for the Santa Elena Peninsula is for weather stations that do not represent accurately the weather in this area.

The development of irrigation schedules and evaluation of rain fed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided for the model.

Reference Evapotranspiration Surface Maps

The first step to calculate CWR is to calculate reference evapotranspiration (ET_o). The process starts by entering historical average weather data for the Santa Elena Peninsula into CROPWAT (FAO/UN). This is a process that requires careful quality control since each value has to be entered manually into the system, and errors are easily made. All weather data (maximum and minimum temperatures and relative humidity, available wind speed data, and sunshine) for each station was introduced to the CROPWAT database. Missing parameters like wind speed data (for some months and stations) and solar radiation were calculated using the same program. Once all the data was complete, the reference evapotranspiration was calculated using the Penman-Monteith method.

To create the ET_o surface maps, the output from CROPWAT had to be entered to an ArcMap (ESRI) database to georeference the ET_o data set. Inverse distance weighting (IDW) interpolation method (Chapter 4) was selected to interpolate the reference evapotranspiration data between the weather stations.

The average monthly surface maps of ET_o for the Santa Elena Peninsula (Figures 5-9.1 and 5-9.2) present the variation in reference evapotranspiration in the months of June to November considered to be the dry season, and December to April (or May) considered to be the wet season.

These ET_o maps plus the precipitation distribution data (Chapter 2) were used later on in this project (Chapter 6) to determine the crops irrigation requirements in different irrigation zones.

Crop water requirement (CWR). A specific crop grown in a sunny and hot climate needs more water per day than the same crop grown in a cloudy and cooler climate. The highest crop water needs are thus found in areas that are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind (Brouwer & Heibloem 1985).

The crop type impact on the crop water need is important in two ways:

- The crop type influences on the **“**daily water needs” of a fully-grown crop
- Duration of the total growing season depends on the crop.

Data on the duration of the total growing season of the various crops grown in an area can best be obtained locally. These data may be obtained from, for example, the seed supplier, the Extension Service, the Irrigation Department or Ministry of Agriculture.

Table 5-8. Crop growing period

Crop	Total growing period (days)	Crop	Total growing period (days)
Banana	300-365	Onion green	70-95
Bean green	75-90	Onion dry	150-210
Bean dry	95-110	Pepper	120-210
Citrus	240-365	Potato	105-145
Cucumber	105-130	Rice	90-150
Grain/small	150-165.	Sorghum	120-130
Maize sweet	80-110	Soybean	135-150
Maize grain	125-180	Squash	95-120
Melon	120-160	Sunflower	125-130
		Tomato	135-180

* Modified from Irrigation Water Management, Training manual no. 3, FAO

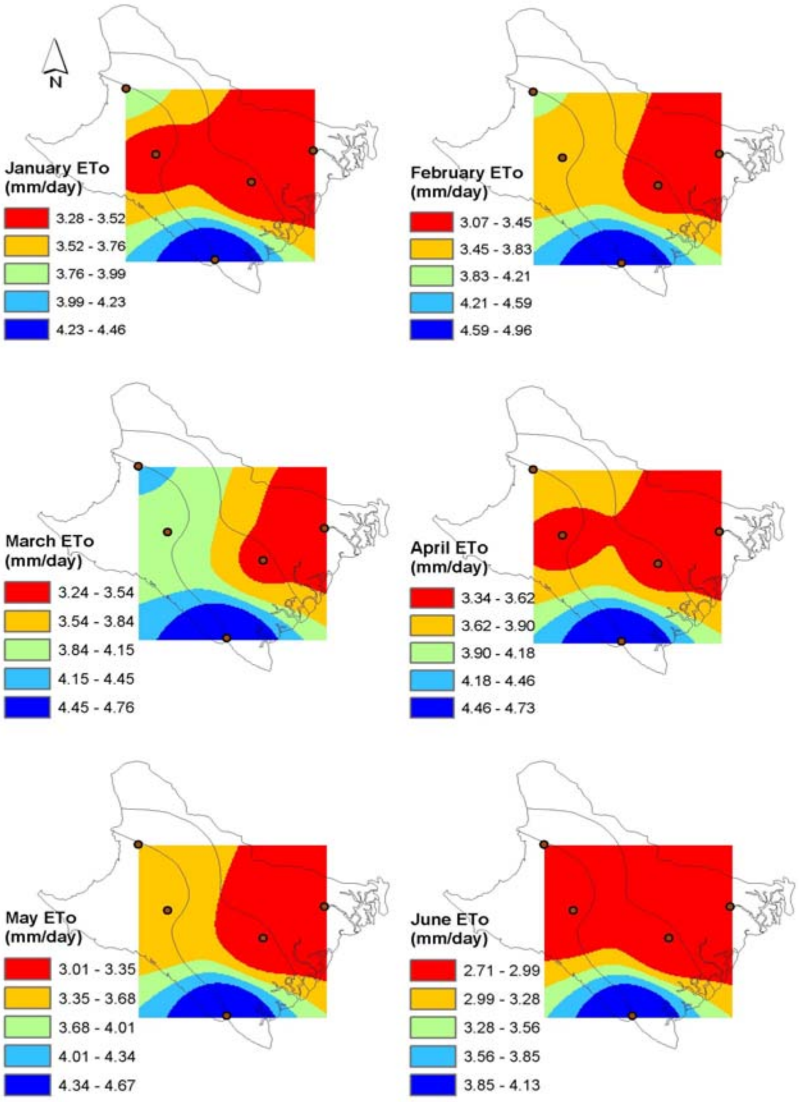

Figure 5-9.1. Average reference evapotranspiration for the SEP I

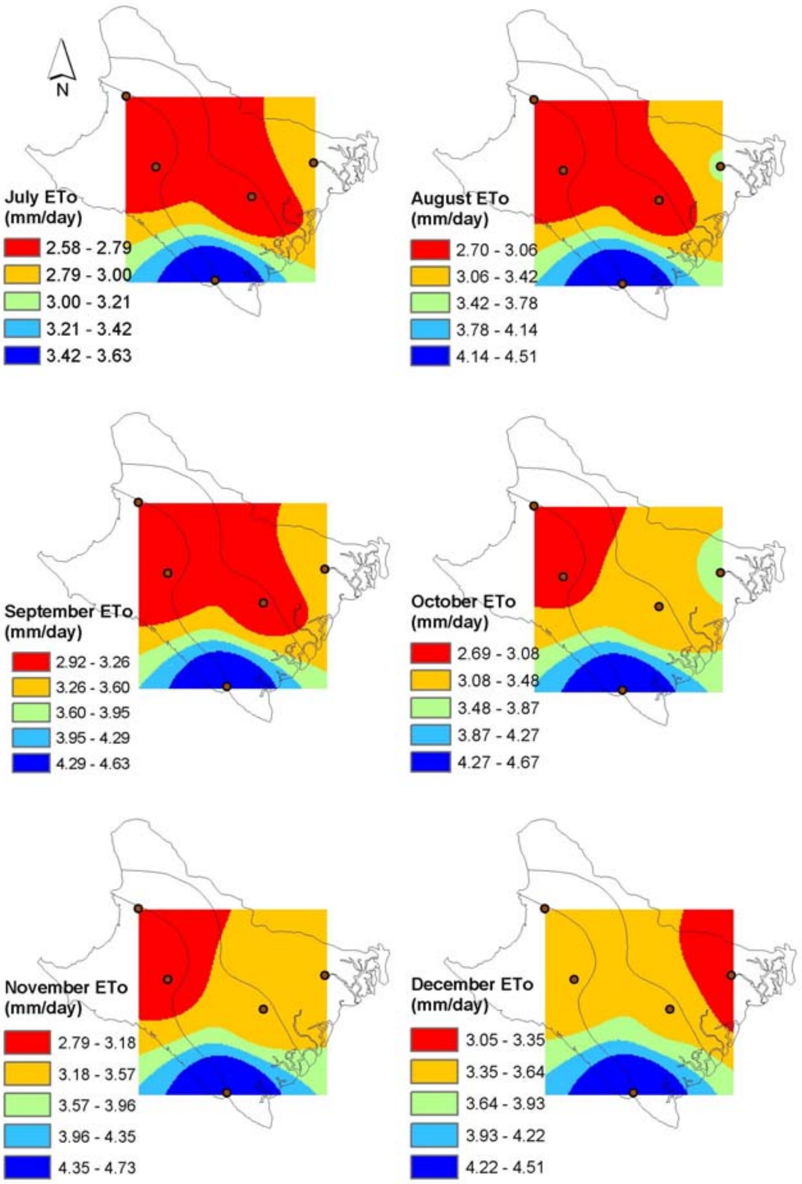

Figure 5-9.2. Average reference evapotranspiration for the SEP II

When the plants are very small, the evaporation from the soil will be more important than the transpiration. When the plants are fully-grown, the transpiration is a larger component of total water loss than the evaporation. At planting and during the initial stage, the evaporation is more important than the transpiration and the evapotranspiration or crop water need, during the initial stage, is estimated at 50 percent of the crop water need during the mid - season stage, when the crop is fully developed. During the so-called crop development stage, the crop water need gradually increases from 50 percent of the maximum crop water need. The maximum crop water need is reached at the end of the crop development stage, which is the beginning of the mid-season stage.

To estimate the water use of the cultivated area in the Santa Elena Peninsula (SEP) some concepts have to be defined first to understand the calculations made to obtain the crop water requirement (CWR) values. To calculate these values the CROPWAT software from FAO was used.

Crop coefficients. While reference crop evapotranspiration (ET_o) accounts for variations in weather and offers a measure of the evaporative demand of the atmosphere, crop coefficients account for the difference between the crop evapotranspiration (ET_c) and ET_o.

Because evapotranspiration (ET) is the sum of evaporation (E) from soil and plant surfaces and transpiration (T), which is vaporization that occurs inside of the plant leaves, it is often easier to consider them together as ET (Stroosnijder 1987). When not limited by water availability, both transpiration and evaporation are limited by the availability of energy to vaporize water. Therefore, solar radiation interception by the foliage and soil has a big effect on the ET rate (Allen et al. 1998).

Table 5-9. Crop coefficients

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height
Small Vegetables	0.7	1.05	0.95	
Garlic		1.00	0.70	0.3
Onions				
dry		1.05	0.75	0.4
green		1.00	1.00	0.3
Vegetables - Solanum Family (Solanaceae)	0.6	1.15	0.80	
Sweet Peppers (bell)		1.05	0.90	0.7
Tomato		1.15	0.70-0.90	0.6
Vegetables - Cucumber Family (Cucurbitaceae)	0.5	1.00	0.80	
Cantaloupe	0.5	0.85	0.60	0.3
Cucumber				
Fresh Market	0.6	1.00	0.75	0.3
Pumpkin, Winter Squash		1.00	0.80	0.4
Watermelon	0.4	1.00	0.75	0.4
Roots and Tubers	0.5	1.10	0.95	
Potato		1.15	0.75	0.6
Legumes (Leguminosae)	0.4	1.15	0.55	
Beans, green	0.5	1.05	0.90	0.4
Perennial Vegetables (with winter dormancy and initially bare or mulched soil)	0.5	1.00	0.80	
Asparagus	0.5	0.95	0.30	0.2-0.8
Cereals	0.3	1.15	0.4	
Maize, Field (grain) (field corn)		1.20	0.60-0.35	2
Maize, Sweet (sweet corn)		1.15	1.05	1.5
Rice	1.05	1.20	0.90-0.60	1
Forages				
Grazing Pasture				
Extensive Grazing	0.30	0.75	0.75	0.10
Tropical Fruits and Trees				
Banana				
1st year	0.50	1.10	1.00	3
2nd year	1.00	1.20	1.10	4
Cacao	1.00	1.05	1.05	3
Coffee				
bare ground cover	0.90	0.95	0.95	2-3

with weeds	1.05	1.10	1.10	2-3
Pineapple				
bare soil	0.50	0.30	0.30	0.6-1.2
with grass cover	0.50	0.50	0.50	0.6-1.2

*continuation Table 5-9

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height
Grapes and Berries				
Grapes				
Table or Raisin	0.30	0.85	0.45	2
Wine	0.30	0.70	0.45	1.5-2
Fruit Trees				
Avocado, no ground cover	0.60	0.85	0.75	3
Citrus, no ground cover				
70% canopy	0.70	0.65	0.70	4
50% canopy	0.65	0.60	0.65	3
20% canopy	0.50	0.45	0.55	2
Citrus, with active ground cover or weeds				
70% canopy	0.75	0.70	0.75	4
50% canopy	0.80	0.80	0.80	3
20% canopy	0.85	0.85	0.85	2

Based on Tabulated K_c (Table 12), Paper # 56 FAO (Allen et al. 1998).

As a crop canopy develops, the ratio of T to E increases until most of the ET comes from T and E is a minor component. This occurs because the light interception by the foliage increases until most light is intercepted before it reaches the soil.

Commercial irrigation schedules typically begin their computation with published regional crop coefficients. These coefficients, when multiplied by reference crop evapotranspiration, are used to calculate crop evapotranspiration. These regional crop coefficients are based on a certain reference crop, soil type and irrigation management practice. In conventional agriculture irrigation scheduling, crop coefficients can be modified as needed during the growing season, because there is constant feedback based on field observations of crop and soil conditions.

Agricultural Production in the Santa Elena Peninsula

Ecuador, with its climatic conditions, could be completely self-sufficient in food production and even produced for export. However, today most of the subtropical fruits (deciduous, grapes, citrus, etc.) are imported from Chile or California. Many areas of the country are considered very dry (less than 500 mm of water a year) and are therefore not included in the agricultural production cycle. Ecuador has several state water projects that were built many years ago, however, most are not in operation.

According to CEDEGE (2001) the TRASVASE Daule-Santa Elena Project is the largest and most modern irrigation project in Ecuador. Until 1994 there was no source of water for irrigation in the SEP and the few wells sunk had a low capacity and were mostly saline. On completion of the first part of the project, about 15,000 hectares were brought into the production potential and today, with completion of the second part, the entire 40,000 hectares are suited for irrigated crops. However, in 1995, a total of about 2,000 hectares were under cultivation and the farmers of the peninsula (large and small) did not in fact know where to invest and how to utilize the potential of the zone.

The agricultural production in the Santa Elena Peninsula has been limited to few crops. Even those few crops were planted without any suitability study. Crops like mangos were planted in zones with heavy soils, and pronounced slopes often without a good drainage. In other farms, cocoa trees were planted in flat and low land, and then "El Niño" came in 1997, flooding most of the area and killing the plantations. Stories like these can be found throughout the Peninsula. In addition, poor market study and lack of governmental policies to control the planted area affected the price in the international markets, because of an excessive offer of the product (Mango, Onion, Passion Fruit).

The large farms in the Santa Elena Peninsula are mainly focused towards export products, and only the excess or products that do not meet the international standards are left for the local (internal) market. The main market for onion is Colombia and Peru, while passion fruit is transformed into concentrate and exported to the U.S. and European markets. Tomato is used by the local industry, and pineapple is exported as fresh and canned fruit. Bananas were first planted in the SEP because it was thought that the dry conditions in the area would help to control the fungus *Mycosphaerella fijinsis* or Sigatoka. But even though the Santa Elena Peninsula is considered a dry area because of the soil characteristics and the reduced rainfall, it has a high relative humidity (average > 80 %), and relative humidity promotes the development of fungus. As a result, the banana planted area is being reduced. Plantain is far more resistant and resilient than banana to Sigatoka. Yields from 5 crops (Figure 5-10) were obtained from CEDEGE in 2001.

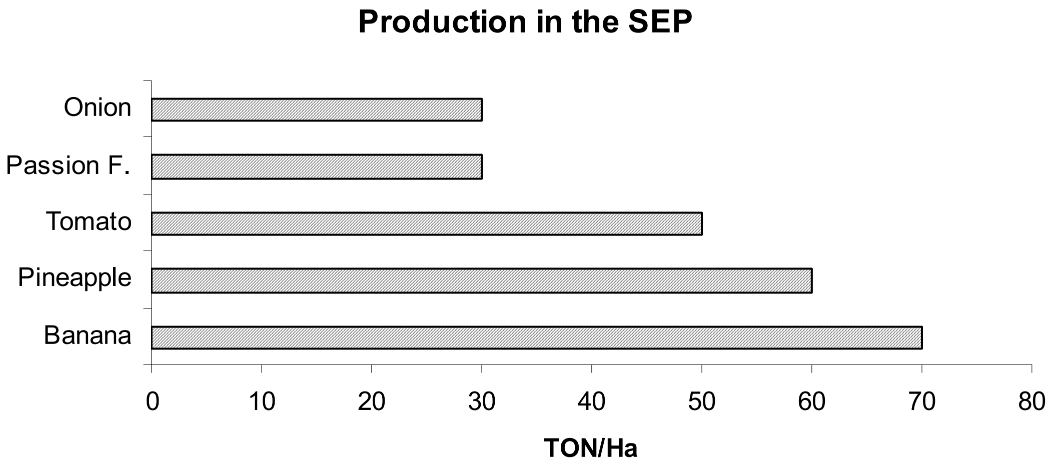

Figure 5-10. Agricultural Production in the Santa Elena Peninsula

In 2000 CEDEGE conducted a survey to the farmers using water from the TRASVASE project in the areas adjacent to the canals, dams, and covered by the pressurized irrigation zones, the results about land use are presented in Table 5-10. The data for 200o is the actual area under production, and the data for 2001 are the estimated increase in area.

Table 5-10. Crops planted and projected increase in the Santa Elena Peninsula

	Crops planted and projected in the Santa Elena Peninsula					
	Zone I				Zone II	
	Chongón-Daular		Chongón-Playas		El Azúcar-Rio Verde	
Crops	2000	2001	2000	2001	2000	2001
Asparagus					20	
Avocado	5		22	40		
Banana	60					
Beans	4					8
Black Pepper					1	
Cassava	6					
Plum	11					
Citrus	74		2		26	
Cocoa	241	127	492	60	2	54
Corn	364	155	244	168	263	
Cotton			16			
Cucumber		14				1
Flowers	21					
Grape	8		6		7	
Grass	198	22	5	20	8	
Green pepper		11			19	19
Guava	24		201	100		
Guanabana			28	40		
Hot pepper			24	4		
Lime	451	20	178			
Mango	852	89	1343	171		
Melon		51		15		12
Onion	75	213		70	132	38
Palm			4			
Papaya	10	13	16		50	
Pineapple			45			
Pitahaya					10	
Plantain	184	25	388		6	
Rice	44	8	9			
Soya						8
Teak	105		100			
Tobacco			10			
Tomato	5					15
Watermelon	23	14		12		14
Wheat						11
Other	19		37	14	17	

CHAPTER 6
METHODOLOGY

Water available from the TRASVASE project is mainly utilized for irrigation. One of the objectives of this project was to determine the total area that can be irrigated using this water. The extent of irrigated land was determined by calculating the crop water requirement of crops grown in the area using CROPWAT, a model developed by FAO/UN. This model requires monthly averages of weather parameters that were calculated from the available data from the Santa Elena Peninsula.

CROPWAT was reviewed in Chapter 5. To calculate water requirement (CWR) for each crop the required data are: evapotranspiration, crop coefficients, crop area, and planting dates.

Weather data for the CROPWAT were based on the monthly averages calculated from the data provided by CEDEGE. The variables (Figure C-1) entered were average temperature (^{o}C), average relative humidity (RH), average wind speed (m/s or km/day), and daily average sunshine (hr/day). Built into the CROPWAT are the processes to calculate 'missing' weather parameters as explained in "Estimating missing climatic data" section in Chapter 3. This technique was used to calculate the solar radiation (MJ/m^2/d).

Evapotranspiration

CROPWAT calculates the evapotranspiration (ET_o) values for each month for every weather station in the Santa Elena Peninsula based on the provided weather data. These evapotranspiration values (ET_o) are presented in Appendix C (Tables C-1 to C-5).

A revised method for estimating reference crop evapotranspiration, adopting the approach of Penman-Monteith as recommended by the FAO Expert Consultation in Rome is used in this model. Further details on the methodology are provided in the Irrigation and Drainage Paper No 56: "Crop Evapotranspiration" (Allen, et al. 1998).

Open Water Evaporation

In Tables 5-1 and 5-3 the approximated surface areas based on available dimensions for all canals and dams in the TRASVASE project are presented. Average evapotranspiration values calculated using CROPWAT for the same zones used to calculate crop water requirement (CWR), were used to estimate the evaporation from the canals and dams. The open water evaporation per month has been calculated with the following equation developed by Smith (1996):

$$E = k_w * ET_o \tag{6-1}$$

where:

E: Open water evaporation
ET_o: Penman Monteith reference evapotranspiration
k_w: correction factor for open water evaporation

Reference evapotranspiration values came from CROPWAT, and the correction factor used for open water evapotranspiration is 1.3, based on Smith (1996) and recommended by FAO as a global average for open water evaporation when local data is not available. The value of 1.3, therefore, is an arbitrary value valid only under average conditions.

The monthly evaporation values for each canal, and dam are presented in Appendix E (Tables E-1 and E-2 respectively). Since evaporation is directly proportional to the evapotranspiration data these values are the highest in the month of April followed by

November for all the weather stations. The monthly changes in evaporation in cubic meters from the different canals are presented here (Figure 6-1).

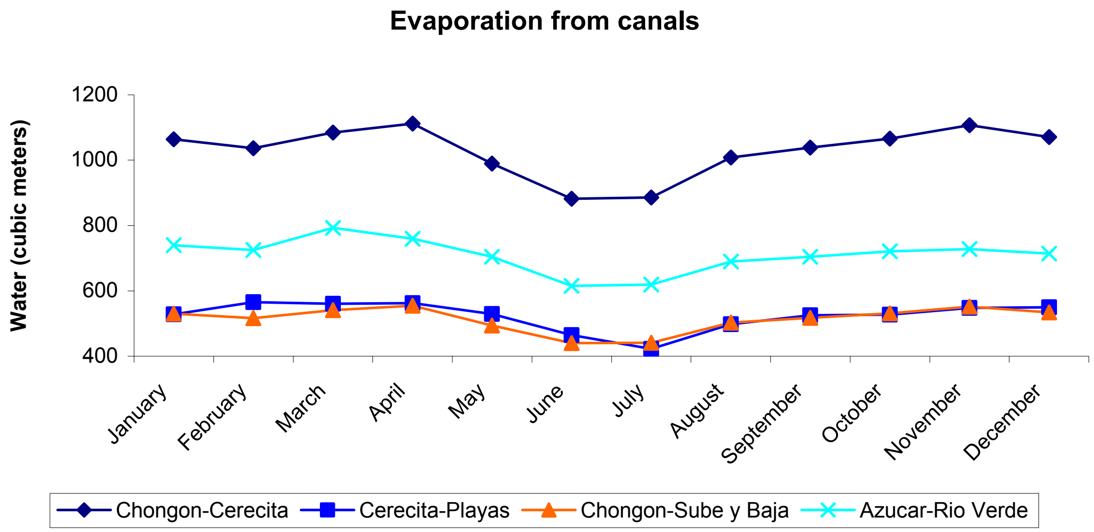

Figure 6-1. Evaporation from canals of the TRASVASE system

Crop Water Requirement

Once crop water requirements (CWR) were calculated, for the known location of the weather stations, the average values were calculated for the areas surrounding the specific canals and dams.

These areas were: Chongón-Cerecita canal influenced by the Chongón and San Isidro weather stations, Cerecita-Playas canal under the influence of the San Isidro and Playas stations, and De Cola dam influenced by Playas weather station. Chongón dam under the Chongón station, and Chongón-Sube y Baja canal is influenced by Chongón and El Azúcar weather stations, El Azúcar dam is under the influence of El Azúcar weather station as it is the El Azúcar-Rio Verde canal.

Table 6-1. Chongón-San Isidro, Zone I, crop water requirements (CWR)

Crop Water Requirements (CWR) Chongón-San Isidro, Zone I (mm)												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avocado	63.2	73.9	84.2	78.6	74.9	70.7	75.2	72.9				
Asparagus							63.4	79.5	90.9	61.1		
Plantain	50.8	50.7	49.5	57.2	100.7	93.0	97.3	97.1	15.7			
Citrus	71.2	71.1	69.4	66.5	84.3	60.3	59.2	59.7	62.1	64.8	66.7	58.1
Grapes-t	40.6	40.6	39.6	38.0	49.7	55.3	74.0	77.6	81.2	84.8	82.2	45.7
Mango	91.1	91.2	89.2	88.8	122.0	95.4	97.3	100.5	103.7	104.3	99.5	78.7
Onion					74.1	77.9	92.9	92.2	38.7			
Pineapple	49.1	40.3	29.7	28.5	19.1							
Potato	57.5	89.2	114.0	100.5	24.9							
Melon								55.4	89.5	105.0	91.5	
Watermelon								54.9	68.6	100.0	89.0	
S-Pepper								74.7	85.2	105.0	102.0	
B-Pepper	62.6	77.0	102.4	98.5	74.1	77.9	92.9	91.0				

*t = table, S= sweet, B=black

Table 6-2. San Isidro-Playas, Zone I, crop water requirements (CWR)

Crop Water Requirements (CWR) San Isidro-Playas, Zone I (mm)												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avocado	77.7	91.5	104.7	97.3	78.1	85.1	89.4	86.0				
Asparagus							75.5	93.8	107.2	72.2		
Plantain	62.5	62.7	61.5	70.8	123.1	111.8	115.7	114.6	18.5			
Citrus	87.5	87.9	86.2	82.3	103.1	72.5	70.3	70.4	58.8	76.6	79.2	69.2
Grapes-t	50.0	50.2	49.2	47.0	60.7	66.5	88.0	91.6	95.7	100.2	97.6	54.4
Mango	112.1	112.8	110.8	109.9	149.1	114.9	115.7	118.6	123.5	123.3	119.3	93.8
Onion					90.6	93.7	110.4	108.8	45.6			
Pineapple	60.3	49.8	36.9	35.3	21.2							
Potato	70.7	110.2	141.6	124.4	30.6							
Melon								65.4	105.5	124.1	108.6	
Watermelon								64.8	100.9	118.2	105.7	
S-Pepper								88.2	100.4	124.1	121.1	
B-Pepper	76.9	95.3	127.2	121.9	90.6	93.7	110.4	107.5				

Monthly crop water requirements (mm) were calculated for 13 crops: avocado, asparagus, citrus, grapes, mango, melon, onion, pineapple, plantain, potato, black pepper, sweet pepper, and watermelon. The calculations were done for three areas: Chongón-San Isidro, San Isidro-Playas, and Chongón-El Azúcar.

Table 6-3. Chongón-El Azúcar, Zone II, crop water requirements (CWR)

Crop Water Requirements (CWR) Chongón-El Azúcar, Zone II (mm)												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avocado	64.0	75.7	87.4	81.9	77.8	72.6	76.0	72.6				
Asparagus							64.2	79.3	89.6	61.5		
Plantain	51.5	51.9	51.4	59.7	104.6	95.4	98.4	96.7	15.5			
Citrus	72.1	72.7	72.0	69.3	87.6	61.9	59.8	59.4	61.2	63.6	65.6	57.7
Grapes-t	41.2	41.5	41.1	39.6	51.6	56.7	74.8	77.3	80.1	83.1	81.0	45.2
Mango	92.7	93.5	92.5	92.5	126.7	98.0	98.4	100.2	102.1	102.4	97.9	78.1
Onion					77.0	79.9	93.9	91.8	38.2			
Pineapple	49.7	41.2	30.8	29.7	9.6							
Potato	58.3	91.5	118.8	104.8	25.9							
Melon								55.2	88.2	103.0	90.1	
Watermelon								54.7	67.3	98.1	87.7	
S-Pepper								74.5	83.9	103.0	102.1	
B-Pepper	63.4	78.9	106.2	102.7	77.0	79.9	93.9	90.7				

CROPWAT was used to calculate reference evapotranspiration (ET_o) for each weather station (Appendix C); crop information was used to calculate actual crop evapotranspiration for 13 crops under consideration (Appendix E). This crop data consists of crop coefficient, date when the crop is planted on the field, and percentage of the total area occupied by the crop. In this case the program was run for each crop and the area covered for each crop was considered 100 % of the total area. The crop coefficients came from those already into the CROPWAT database (CLIMWAT 1994) and for those not in CLIMWAT the crop coefficients where entered from the data in Table 5-12 also obtained from FAO/UN. The planting dates for each crop were entered following the recommendations of ESPOL (Polytechnic School of the Littoral, Guayaquil) (Appendix D) that takes into consideration seasonal effects and in some other cases market advantages.

Crop Irrigation Requirement

Crop irrigation requirement (CIR) is the total water needed for the crop (CWR) multiplied by an in-field irrigation application efficiency factor. These irrigation application efficiency factors were taken from the estimates given by FAO (Table 1-2). The values used for application efficiency in this study are 50 %, 70 % and 90 % efficiency. Fifty percent application efficiency represents a well-managed surface irrigation system or poor maintained and administered sprinklers or micro-irrigation systems. Seventy percent efficiency could be well maintained and managed sprinklers systems, or poorly managed micro-irrigation systems. Ninety percent efficiency represents well-managed and maintained micro-irrigation systems.

Various scenarios were analyzed. Calculations of water requirement for land planted with crops with high irrigation requirements, low irrigation requirements, and a mixture of high and low irrigation requirement were made to be used in this project, for each of the efficiencies described above. These data are presented in Appendix F.

Scenarios

To facilitate the calculation of the total water resource for certain types of production, and to follow Köppen ecological classification and the climatic parameters associated with each classification (Chapter 2, Climatic Classification Section), the TRASVASE system was divided in two main zones (Figure 6-2).

Zone I: Chongón-Cerecita, Cerecita-Playas canals, Daular, Cerecita, and Chongón irrigation zones, Zone I (Playas, Table 5-2) potabilization plant, and the Chongón, San Isidro, and Playas weather stations. Zone II: Chongón-Sube y Baja, El Azúcar-Rio Verde canals, El Azúcar and Chongón dams, Zone II (Santa Elena, Table 5-2) potabilization plant, and Chongón, and El Azúcar weather stations.

A map using ArcMap (ESRI) was created to show the two zones, the yellow areas represent Zone I, and the green areas represent Zone II (Figure 6-2).

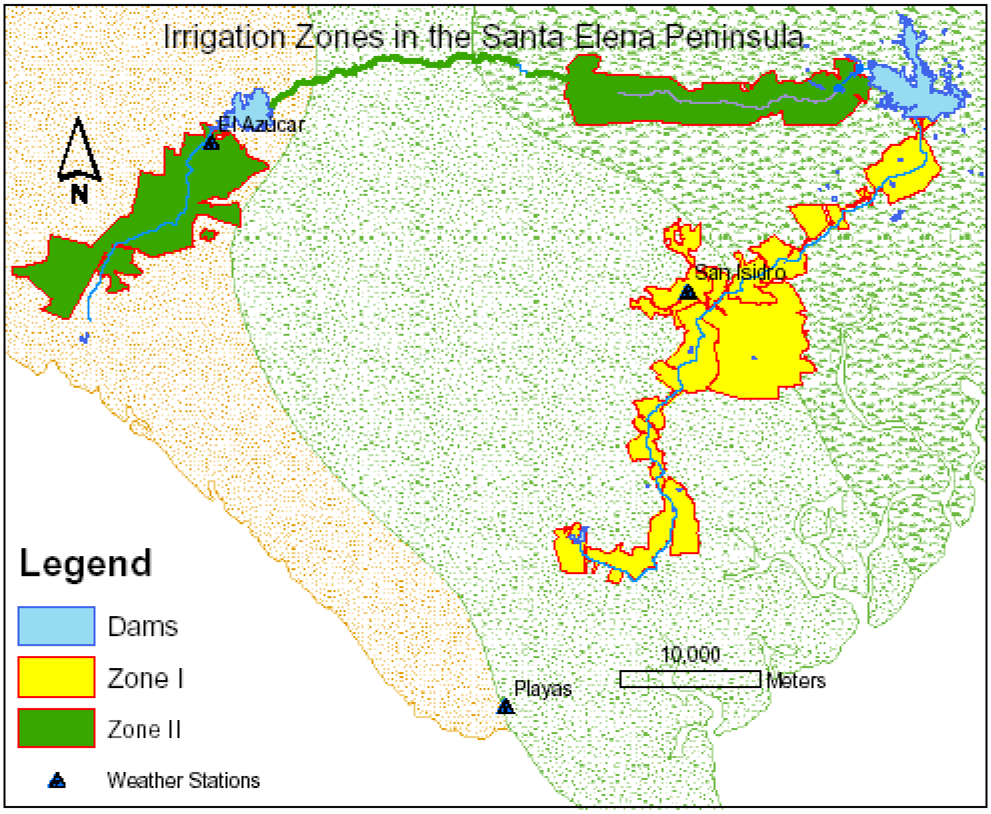

Figure 6-2. Irrigation zones in the Santa Elena Peninsula

Nine scenarios were created to calculate the water available for agricultural production and the area that can be irrigated with that amount of water. The water inputs into the system were: water from the dams. The water available for irrigation was calculated by subtracting seepage losses of the system; water used in the water treatment plants, and evaporation losses from the canals and dams. The only changing parameters among the scenarios are crop types and the types of irrigation system that affects in-field efficiency.

Scenario A, a surface irrigation system with an in-field efficiency of 50 %, and all the 13 crops with available crop water requirement (CWR) data. These 13 crops are:

avocado, asparagus, citrus, grapes, mango, melon, onion, pineapple, plantain, potato, black pepper, sweet pepper, and watermelon; evenly distributed to cover 100 % of the area, the same procedure was repeater for scenarios *B* and *C*.

Scenario B, a sprinkler irrigation system with an in-field efficiency of 70 %, all the 13 crops with available crop water requirement (CWR) data.

Scenario C, a micro-irrigation system with an in-field efficiency of 90 %, all the 13 crops with available crop water requirement (CWR) data.

Scenarios *A, B*, and *C*, all assume 100 % replacement of evapotranspiration in the month (August) of the highest evapotranspirational demand.

Scenario AA, surface irrigation system with an in-field efficiency of 50 %, avocado, plantain, citrus, grapes, and mango, considered as high water requirement crops (CWR). These crops are in this group for their monthly evapotranspirational demand and also because the extended growth period they have. The same crops are used in scenarios BA, and CA.

Scenario BA, sprinkler irrigation system with an in-field efficiency of 70 %, and high water requirement crops (CWR).

Scenario CA, micro-irrigation system with an in-field efficiency of 90 %, and high water requirement crops (CWR).

Scenarios AA, BA, and CA, all assume 100 % replacement of evapotranspiration in the month (August) with the highest evapotranspirational demand.

Scenario AB, surface irrigation system with an in-field efficiency of 50 %, asparagus, melon, onion, potato, black pepper, sweet pepper, and watermelon are considered low water requirement crops (CWR), these crops have a short growth period and their evaporatranspirational demand is relatively small compared to those crops considered as high irrigation requirement crops. These low water requirement crops are used in scenarios BB, and CB.

Scenario BB, sprinkler irrigation system with an in-field efficiency of 70 %, and low water requirement crops (CWR).

Scenario CB, micro-irrigation system with an in-field efficiency of 90 %, and low water requirement crops (CWR).

Scenarios AB, BB, and CB, also assume 100 % replacement of evapotranspiration in the month (August), the month with the highest water requirement.

To calculate the output of the different scenarios quickly a spreadsheet program was developed using Excel®. The program is based on the crop water requirement data produced by CROPWAT. Inputs required by the program are crop area (percentage of total area), and in-field irrigation efficiency (i.e. 50 % surface irrigation, 70 % sprinklers, and 90 % micro-irrigation). The output is given in millimeters (mm) of water per month for each one of the crops selected. To select a given crop an area (percentage have to be entered in the spreadsheet, to deselect a crop a zero (0) has to be entered for that specific crop.

CHAPTER 7
RESULTS AND DISCUSSION

The results for this project are based on the multiple scenarios described in ‘Methodology’ (Chapter 6). In this Chapter, the outcome of each scenario will be discussed and compared to the other scenarios.

As presented in Chapter 2, there are two months (April and August) with the highest evapotranspiration values. However, April is at the end of the rainy season and will still receive some rainfall (Figure B-1) and only supplemental irrigation may be required at this time. In addition, heavy soil texture (clays) (Figure 4-5) results in some water retention that can be used by the crops at the beginning of the dry season lowering irrigation requirement.

The month of August is in the dry season with at least two dry months before it. During this time all the available water likely comes from irrigation. As a result, August is clearly the month of the highest irrigation demand and is used in this study to determine the maximum area that can be irrigated with the water from the dams of the TRASVASE system.

A complete explanation of how these results were obtained is presented for the following scenario (Scenario *A).* The total irrigated area consists of Zone I and II. For Zone II (Table 7-1) the water comes from the El Azúcar-Rio Verde and Chongón-Sube y Baja canals, and El Azúcar dam (Table 7-1). There are 13 crops (avocado, asparagus, citrus, grapes, mango, melon, onion, pineapple, plantain, potato, black pepper, sweet pepper, and watermelon) planted in the zone. These crops represent a mixture of crop irrigation requirement (CIR) from high to low. However, not all the crops are growing during the month of August according to the recommendations by ESPOL and CEDEGE. In-field irrigation efficiency (application efficiency) is assumed to be 50 % with 100 % evapotranspiration replacement. Fifty percent efficiency indicates surface irrigation or poor management of pressurized irrigation systems. Zero (0) precipitation in the area is assumed.

Table 7-1. Scenario *A*, Zone II

Evaporation from		Water Lost m^3
Canals:	Chongón - Sube y Baja	502
	El Azúcar - Rio Verde	690
Dams:	El Azúcar	41,828
Potabilization	Zone II	1,073,600
Seepage losses from canals: 7%		210,000
	TOTAL water lost	1,326,620

		Available Water m^3	CIR/zone m^3/ha
Irrigation Zones	El Azúcar	2,000,000	1,080
Canals	Chongón - Sube y Baja	1,000,000	1,080
	El Azúcar - Rio Verde	2,000,000	1,080
TOTAL available water		5,000,000	

Area that can be irrigated at 50% application efficiency is 3,401ha.

The amount of water that is available for irrigation is calculated as a difference between total water available from the dams and various losses in the system. The losses in Zone II include: potabilization plant, seepage losses from the canals, and evaporation from the canals and the dams. The difference between available water and losses is divided by the monthly crop irrigation requirement (CIR) value (Table F-3) that was multiplied by the application efficiency factor (0.5 for 50 % efficiency, in this case). The parameters in each scenario can be defined as follows: evaporation (canals and/or dams) refers to the potential evaporation from an open water body (Appendix C, Tables C-6 and

C-7) expressed in cubic meters (m^3). Potabilization is the water used in the water treatment plants (Zones I and II, defined in Chapter 6) estimating 12 working hours per day for 30 days. Seepage losses (Chapter 5) are calculated for the canals in each zone using 7 % (a value provided by CEDEGE[2]). Available water is the total water available from the dams in cubic meters (m^3) minus losses in canals or conveyance losses in pressurized irrigation systems. Crop irrigation requirement or CIR (Appendix F. Tables F-1 to F-3) is expressed in cubic meters (m^3). The total area that can be irrigated is calculated in hectares (1 ha = 10,000 m^2) from the water available from the system and the CIR.

Table 7-2. Scenario A, Zone I

Evaporation from		Water Lost m^3	
Canals:	Chongón - Cerecita	1,064	
	Cerecita-Playas	528	
Potabilization	Zone I	712,800	
Seepage losses from canals: 7%		350,000	
	TOTAL water lost	1,064,392	
		Available Water m^3	CIR/zone m^3/ha
Irrigation Zones	Chongón	648,000	1,080
	Daular I	617,040	1,080
	Daular II	816,480	1,080
	Cerecita I	479,520	1,080
	Cerecita II	1,089,360	1,080
Canals	Chongón - Cerecita	2,500,000	1,080
	Cerecita-Playas	2,500,000	1,280
	TOTAL available water	8,044,872	

Area that can be irrigated at 50% application efficiency is 6,662ha.

The same procedure was conducted for Scenario *A* Zone I (Table 7-2). The differences are in the water sources, Chongón-Cerecita, Cerecita playas canals, and

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[2] CEDEGE, Comision de Estudios para el Desarrollo de la Cuenca del Rio Guayas, in English, Commission for the Development of the Guayas River Basin.

conveyance pipe systems for Chongón, Daular I and II, Cerecita I and II irrigation. The losses are seepage from the canals, evaporation from canals, and the water used in the Zone II potabilization plant.

In **Scenario *A*,** the areas calculated for Zones I and II were added to calculate the 'total' area that could be irrigated under the given conditions for this scenario (Chapter 6, Scenario *A*). The total area becomes 10,063 ha for the month of August that is the month with the highest evapotranspiration. If some water stress would be permitted, for example 80 % or 90 % replacement, more area could be irrigated. Depending on the planting schedule, more area might be irrigated in other months than August since the calculations were performed for the month with the highest crop irrigation requirement (CIR).

Table 7-3. Total area that can be irrigated under different scenarios

Area that can be irrigated by scenario (ha)						
Scenario	Zone I	Zone II	Total Area	Efficiency (%)	Crop water requirement	Water replacement (%)
A	6,662	3,401	10,063	50	Mix: high and low	100
B	7,683	3,950	11,633	70	Mix: high and low	100
C	9,049	4,650	13,699	90	Mix: high and low	100
AA	4,961	2,739	7,700	50	High	100
BA	5,847	3,161	9,008	70	High	100
CA	6,912	3,733	10,645	90	High	100
AB	7,382	3,988	11,370	50	Low	100
BB	8,519	4,603	13,122	70	Low	100
CB	10,064	5,442	15,506	90	Low	100

All the scenarios follow the same procedures. The only differences are the crops used to calculate crop irrigation requirement and the levels of in-field irrigation efficiency.

The results from the other scenarios are summarized in Table 7-3. The parameters to be considered in this discussion are the irrigation efficiency, and the water requirement

(Tables 6-1 to 6-3) by crops in each scenario. The crop irrigation requirements (CIR) calculated for the scenarios are presented in Appendix F.

Scenario *B* has the same crops as Scenario *A*. The difference is the in-field efficiency of the irrigation system is increased from 50 % to 70 %. Under these conditions the total irrigable area increases by almost 1,600 ha to 11,633 ha. This is a good indicator how important are the changes in irrigation technology and irrigation management skills to improve the application efficiency of the irrigation systems in the Santa Elena Peninsula.

Scenario *C* has the same 13 crops (Appendix E) as scenarios *A* and *B*, but is assuming a high application efficiency (90 %) of the irrigation system. This positively affects the area that can be irrigated for Zone I as well as for Zone II reaching a maximum of 13,699 ha.

These three scenarios are calculated for August, the month with the highest crop irrigation requirement. This means that for other months with a smaller CIR there is some excess water in the system and this should be considered when planning the planting chronogram for the entire season (year).More area can be irrigated during months with less total crop irrigation requirement, and annual crops with short growing season can be planted at that time to take advantage of this excess water. For perennial crops the area is constant. In some cases, or in the first few years of the plantation, intercropping systems can be used in some fields. That will allow more agricultural production within the same area and better use of available water.

Scenario *AA* uses high irrigation requirement crops (CIR) avocado, plantain, citrus, grapes, and mango; a low in-field irrigation efficiency of 50 % that can be considered as surface irrigation. According to the data obtained by ESPOL[3] (Tables 5-7 to 5-9) up to 13 % of the farmers use an irrigation system with this efficiency (50 %) in the El Azúcar-Rio Verde area (Zone II). Almost 30 % less area can be irrigated under this scenario as compared to Scenario *A*. This area reduction may be required, if the majority of the area within the TRASVASE irrigation system is dedicated to the crops with high water requirement, under low efficiency irrigation.

Scenario *BA* is a scenario with the same crops as Scenario *AA* but with an efficiency increased to 70 %. That gives almost a 20 % increase in total area (9,008 ha) compared to the previous scenario. A mixture of high efficiency (micro-irrigation) and low efficiency (surface) irrigation methods can create a 70 % overall efficiency. The entire area irrigated using well design and managed sprinkler systems would also result in similar application efficiency.

Scenario *CA* considers the following combination of parameters: 90 % in-field efficiency, 100 % replacement of water lost, and high CIR crops. The total area that can be irrigated increases to 10,645 ha, similar to that achieved under Scenario *A*, using all 13 crops instead of just 5 with high irrigation requirement (CIR) as in this scenario. However, scenario *A* assumed lower application efficiency.

Scenario *AB* is a scenario that uses crops with low water requirements (asparagus, melon, onion, potato, black pepper, sweet pepper, and watermelon), and irrigation efficiency of 50 %. Even using a low efficiency or poor managed irrigation system, the low water consumption by the crops compensates the high losses increasing the total area that can be irrigated under this scenario to 11,370 ha (Table 7-3). This area is greater that

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[3] ESPOL, Escuela Superior Politecnica del Litoral, in English, Littoral Polytechnic School.

the one for Scenario *CA* that considered a highly efficient irrigation system and the crops with high water requirements.

Scenario *BB*, considers a 70 % efficiency irrigation system and low water consumption crops, with zero precipitation, and low CIR crops. According to ESPOL among the different irrigation zones the use of systems with this application efficiency varies from 10 % to 20 % (Tables 5-7 to 5-9). Sprinkler irrigation systems are considered to be in this application efficiency (70 %) range.

Scenario *CB* consists of asparagus, melon, onion, potato, black pepper, sweet pepper, and watermelon (low water requirement crops), 90 % in-field irrigation efficiency, and assumes 100 % replacement of water lost to evapotranspiration, with no precipitation. The total area that can be irrigated reaches 15,506 ha (Table 7-3). Of all the scenarios this one permits the irrigation of the largest amount of land.

CEDEGE considers that the total area that can be irrigated is 23,066 ha for the entire TRASVASE project (Chapter 2, Actual Situation and Projections). This is 7,560 ha (48 %) more that the last, most conservative scenario (*CB*).

Table 7-4. Areas that could be irrigated during dry season in the SEP, Scenario *A*

	Areas that could be irrigated (ha)		
		Scenario A	
Month	Zone II	Zone I	Total
June	7,245	14,504	21,749
July	5,992	11,195	17,187
August	4,626	8,568	13,194
September	6,290	12,123	18,413
October	6,411	11,703	18,114
November	7,512	13,713	21,225

The total areas that could be irrigated during the dry season (June, July, August, September, October, November) in the Santa Elena Peninsula and compared to the values to the values given by CEDEGE and the farmers (Chapter 2) are given in Figure 7-4.

June and November are close to the numbers given by CEDEGE (Table 7-5). However, especially for August the crops will be subject of stress if the same area (23,066 ha) is maintained in this month.

In Figure 7-1 the buffers created at each side from the canals represent the areas that could be irrigated under different circumstances.

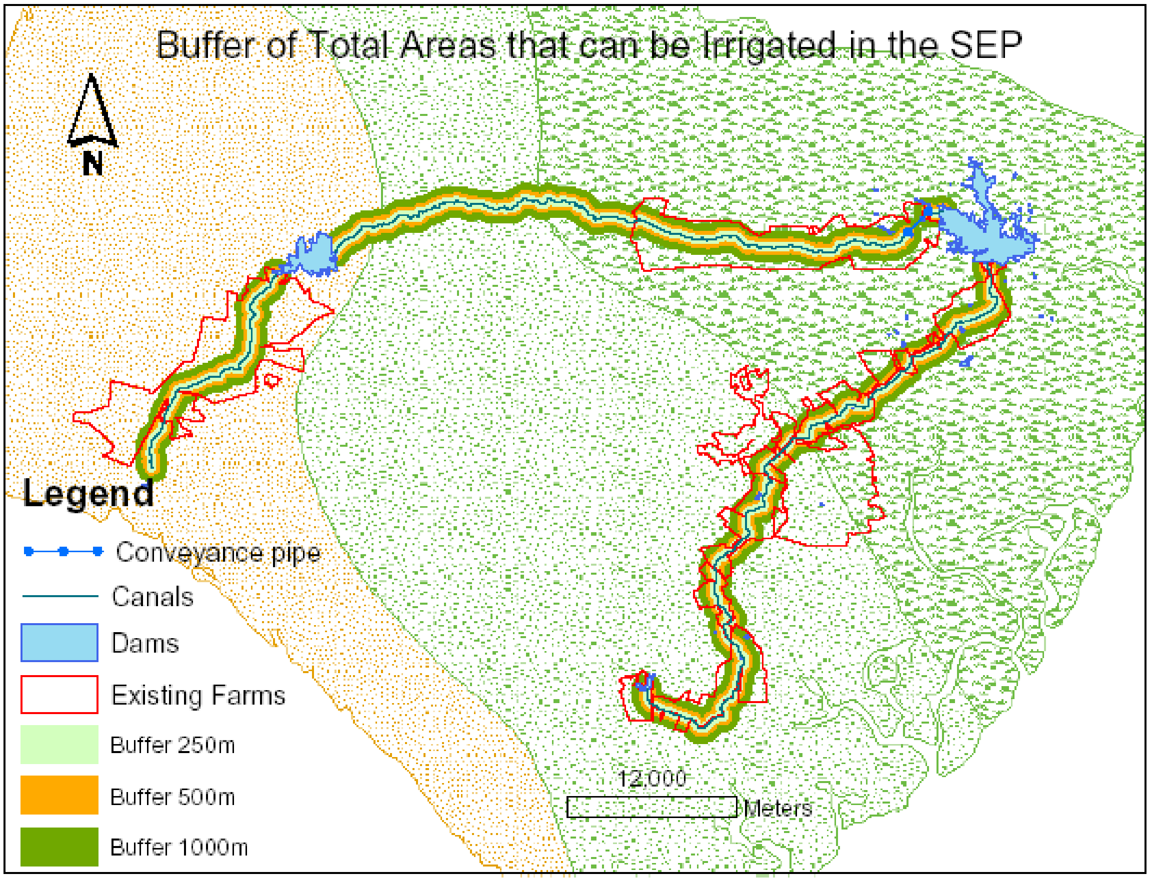

Figure 7-1. Buffers from the canals in the Santa Elena Peninsula

Apart of water limitation there are other limiting factors such as the cost of conveying water far away from the main canals and also the higher losses associated with this process.

The areas that theoretically could be irrigated assuming different buffers at each side of the canals are presented in Table 7-5, comparing those values to three of the scenarios for this project. The three selected scenarios represent 70 % application efficiency and three crop selections (Table 7-6).

Table 7-5 Areas covered by different buffers of the canals in the SEP

Buffer Size (Meters at each side of the canal)	Area (ha)	Areas by scenario (ha)
250	7,600	B- 11,633
500	15,200	BA- 9,008
1,000	30,400	BC- 13,122

Comparing the values given by CEDEGE, the associations of farmers, and the values obtained in this project (Table 7-6), it can be noticed that the values calculated (Chapter 7) in this project are closer to those given by the farmers association, and are approximately 50% of the area that can be irrigated according to CEDEGE estimates.

Table 7-6. Comparison of areas that could be irrigated according different sources

<table>
<tr><td colspan="6">Comparison of areas that could be irrigated according different sources</td></tr>
<tr><td colspan="3" rowspan="3">(Chapter 2)</td><td colspan="3">(Chapter 7)</td></tr>
<tr><td colspan="3">70% application efficiency</td></tr>
<tr><td colspan="3">Scenarios (ha)</td></tr>
<tr><td>CEDEGE Predicted (ha)</td><td>Farmers Assoc. Predicted (ha)</td><td>Actual Production (ha)</td><td>B
Mix of crops</td><td>BA
High irrigation Requirement</td><td>BC
Low irrigation Requirement</td></tr>
<tr><td>23,000</td><td>16,000-17,000</td><td>6,900</td><td>11,633</td><td>9,008</td><td>13,122</td></tr>
</table>

The question is whether the values obtained in this project are better than those given by CEDEGE. To assess that, the data and procedures used in this project had to be analyzed.

CEDEGE used data from the same weather stations as used for this project, but also included the stations of Salinas and Guayaquil. Salinas is located in the driest area of the Peninsula and in the shoreline. The Guayaquil weather station is located in Guayaquil's International Airport. Because of the use of these two weather stations extreme data can be introduced in the calculation of evapotranspiration (ET_o). Also, when the TRASVASE system was originally planned, the two water treatment plants were not included in the original plan. The total area to be irrigated after the water treatment plants where included in the system was not re-calculated to correct for the water lost. These water treatment plants alone use approximately 1,700,000 cubic meters of water per month, assuming 12 hours of operation per day. This amount of water would allow us to irrigated additional 1,150ha for scenario *B*, 920ha for scenario *BA*, and 2,160ha for scenario *BC*.

In this project different procedures were used to calculate missing values of solar radiation and wind speed (Chapter 3). The use of those procedures can result in slight overestimation of the radiation values and at the end would affect the reference evapotranspiration data obtained in this project (Appendix C). The wind speed data were estimated for all stations. However, calculating reference evapotranspiration using zero wind speed, the variation in ET_o is less than 0.4mm/day in average for most of the weather stations, except those closest to the sea (Playas, El Suspiro) having a small effect in the actual evapotranspiration. As a result, it can be assumed that an error in wind speed estimation would not have a significant effect on overall ET_o.

The use of 13 crops to calculate the crop and irrigation water requirements is more precise than the single theoretical crop coefficient that CEDEGE used to calculate agricultural water consumption in the Santa Elena Peninsula.

This increases the accuracy of the results obtained in this project compared to those of CEDEGE.

Conclusion

The results of this project are a reflection of the available data. Limitations in number of years of weather data available and the quality of these data affected the final calculations. The assumptions adopted to replace or complete the missing weather data can also inflict some inaccuracy in the final outcome of this work. Some of those assumptions (open water evaporation, crop coefficients) are on a global scale without considering local variations, however, this values are widely accepted and are also used by other institutions working in the Santa Elena Peninsula. Other assumptions (wind speed, solar radiation) do account for local variation reducing the margin of error.

The quality of information provided by CEDEGE regarding the water conveyance capacity of the TRASVASE system, and the losses in the canals has an effect on the estimation of the total area that the irrigation system could maintain under agricultural production, and these data were not verified in this project.

Based on the knowledge of the total area that can be irrigated with the TRASVASE project, plans to stimulate and to increased agricultural production in the Santa Elena Peninsula should be developed. Use of efficient and well-managed irrigation systems will be a key factor to achieve the crop production goals of the TRASVASE project.

Further geospatial, and weather network data and GIS-based planning are needed to refine agricultural planning, particularly for new permutations of crop type, rotation, irrigation efficiency, and water-distribution policies.

Cooperation among institutions is fundamental to increase agricultural production in the SEP. This agricultural production will have to be concordant with the water necessities of the inhabitants of the Peninsula. Reforms in policy and thinking are necessary to produce development in this area. Land tenure problems have to be solved. Equal access to credit and markets is needed for the small farmers in order to produce and compete in the local and international markets. The farmers also need to be organized within communities and have common goals to succeed.

Different experiences in irrigation systems worldwide (Chapter 1) show that not just the engineering part of an irrigation system has to be implemented but also the social, economical and political components need to be considered.

Suggestions for Future Work

This project used all the available data to estimate the total area that could be irrigated with the TRASVASE project in the Santa Elena Peninsula. To implement any study high quality information is needed. More effort has to focus in the collection of high quality information for the Santa Elena Peninsula. For example, the installation of additional weather stations, and improvement in quality of the weather data acquired would be beneficial for further evaluations. The creation of an organization in charge of storage and management all the digital spatial information for the study area is recommended, to avoid the duplication of efforts, to maximize the use of scarce resources and to improve the quality of the data. More precise records of water delivered into the TRASVASE system are necessary for better estimation of water availability data.

More studies related to crop production and water use by crops are needed. The factors affecting the quality of the soil have to be studied. Erosion, salinity, drainage, and soil and water pollution have to be considered in future work. The use of water for aquaculture, especially shrimp farms, has to be measured.

Timber production in the SEP can help to increase the area that could be irrigated by the TRASVASE system, although no practical studies have been conducted in this area, this option has to be considered, as well as studies for other crops.

Erosion can become an alarming problem for the Santa Elena Peninsula since most of the area is deforested and there are little efforts to plant trees or to adopt other practices to reduce erosion. In addition, soils of marine origin in the SEP can cause salinity problems for agricultural production if the farmers do not adopt adequate practices.

Soil and water pollution can be caused by erosion, and salinization, however, over application of chemicals used in agricultural production can also pollute the water and soil. Studies to determine the risks and actual situation in the Peninsula are needed.

All the institutions, public and private, related to the development of the Santa Elena Peninsula should work together with common goals to accelerate the progress of this area.

APPENDIX A
MAPS

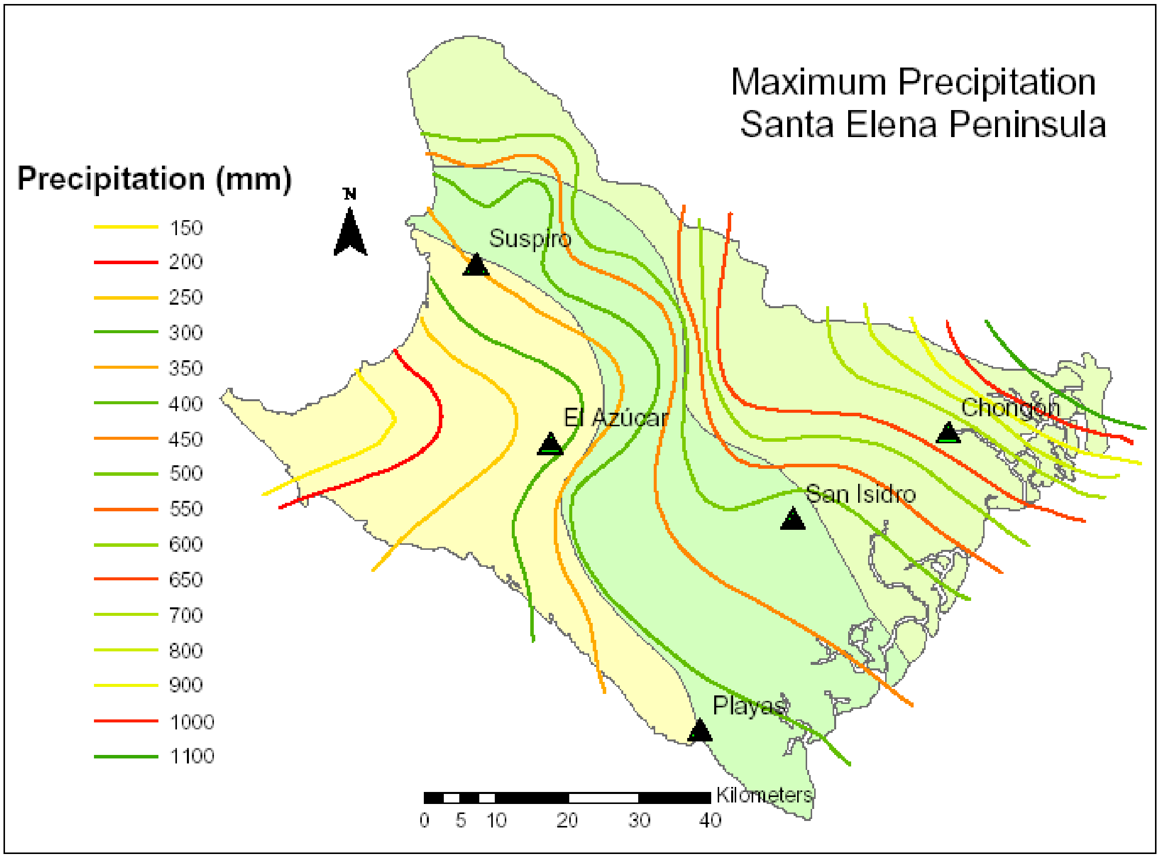

Figure A-1. Maximum annual precipitation isohyets

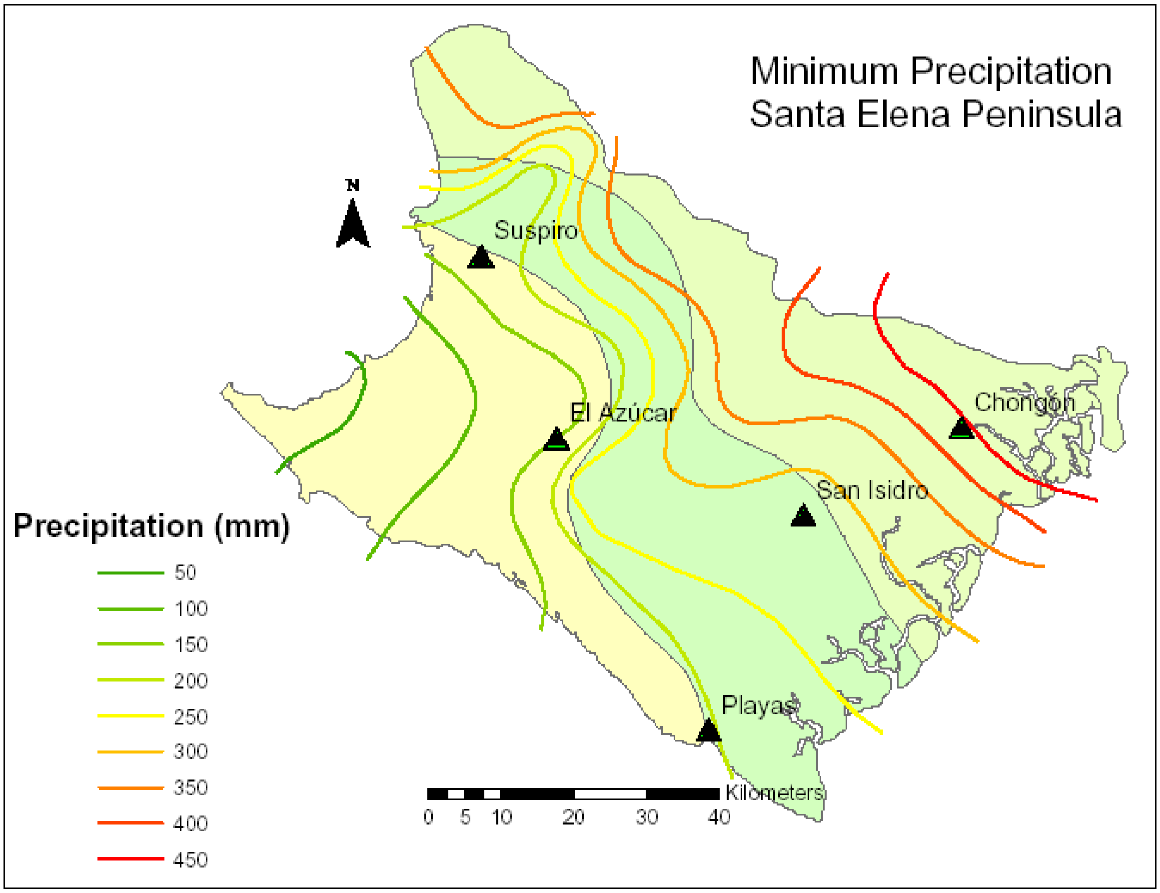

Figure A-2. Minimum annual precipitation isohyets

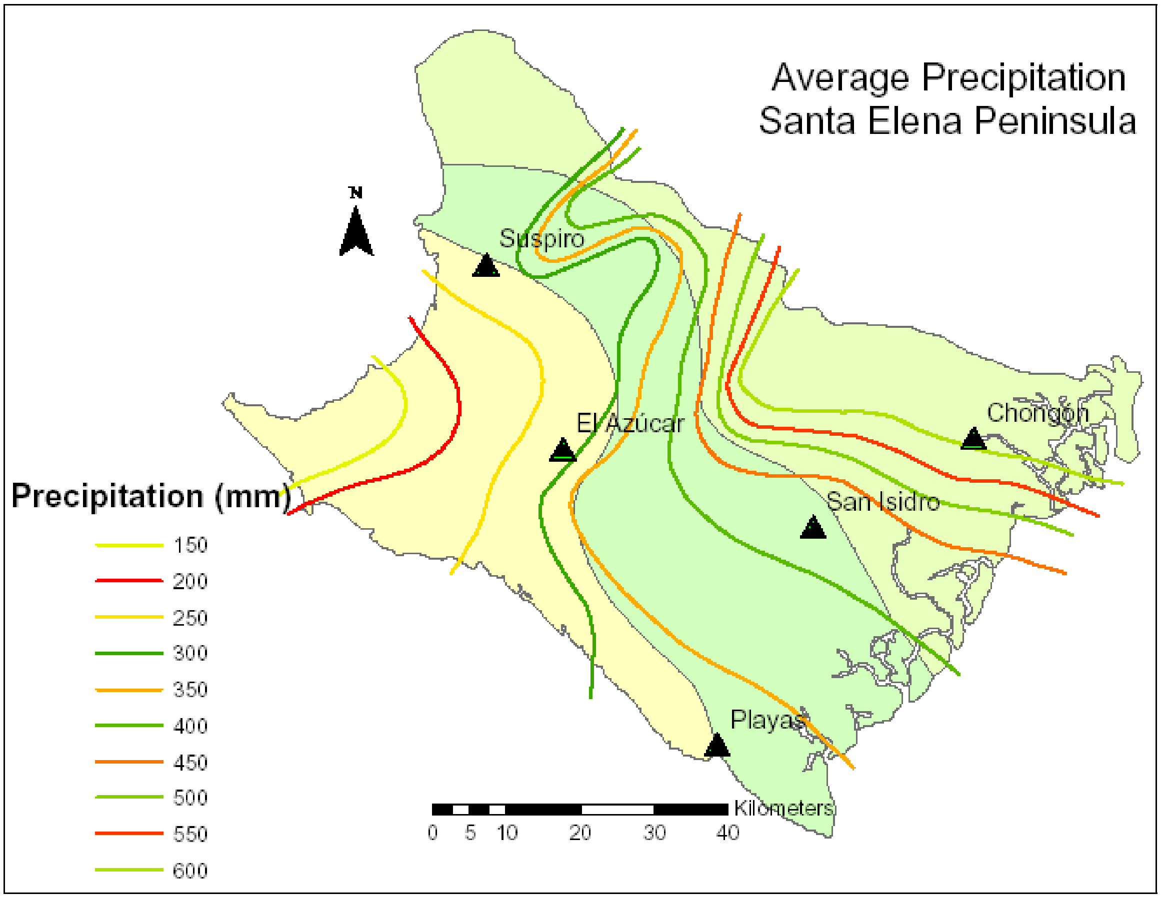

Figure A-3. Average annual precipitation isohyets

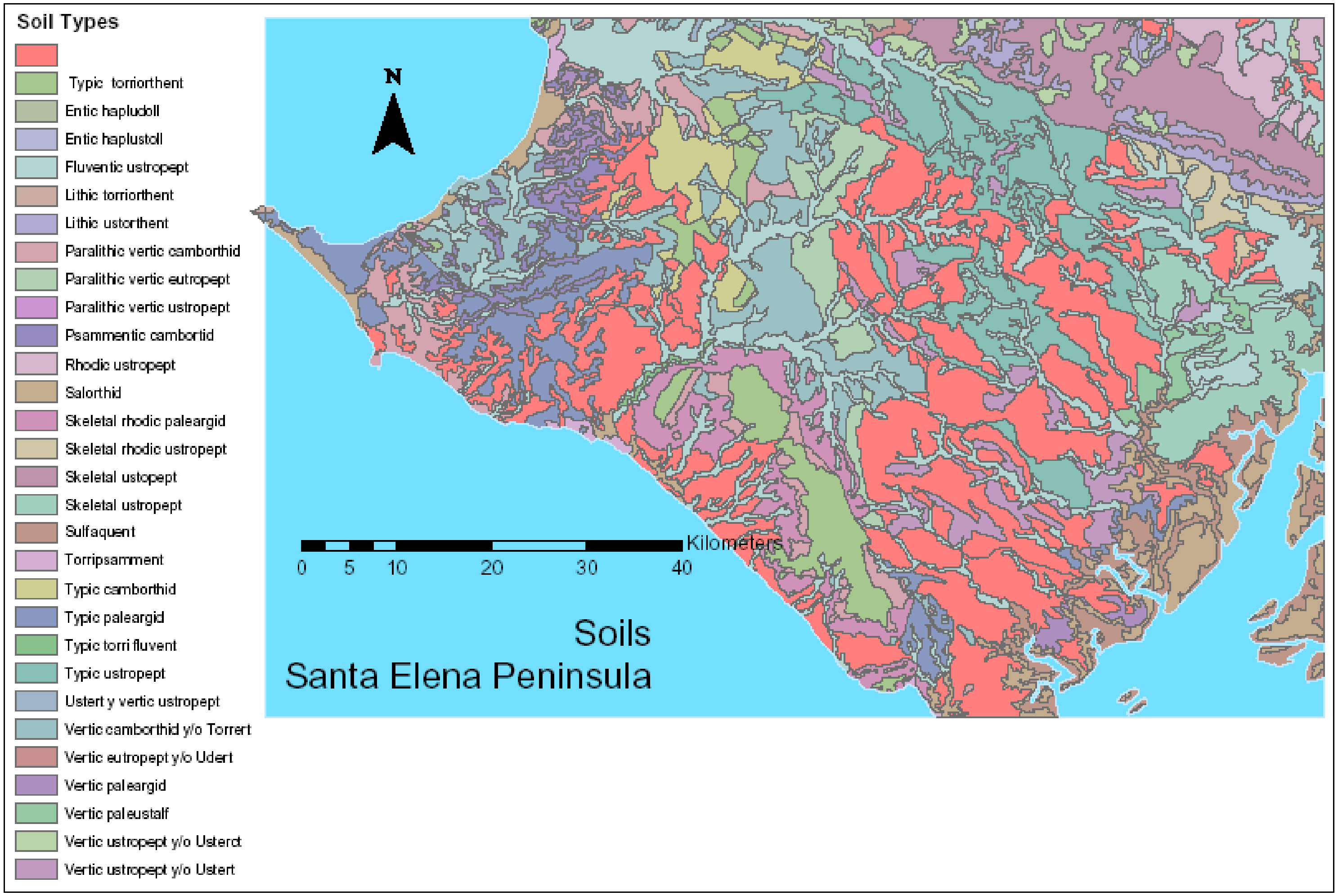

Figure A-4. Complete map of soils in the Santa Elena Peninsula

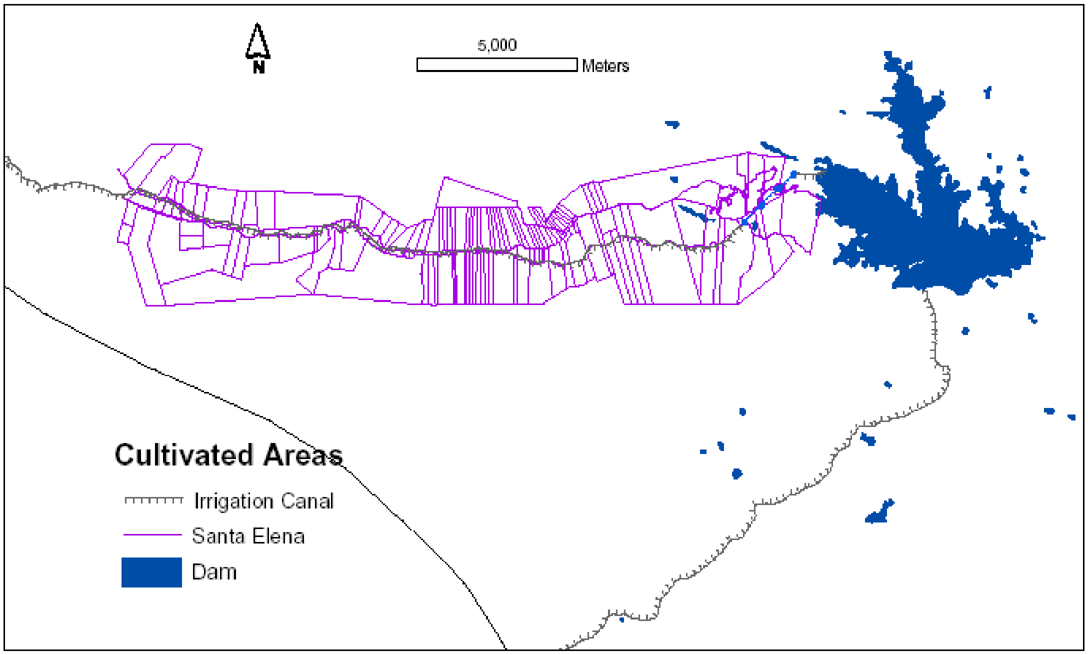

Figure A-5. Santa Elena farms

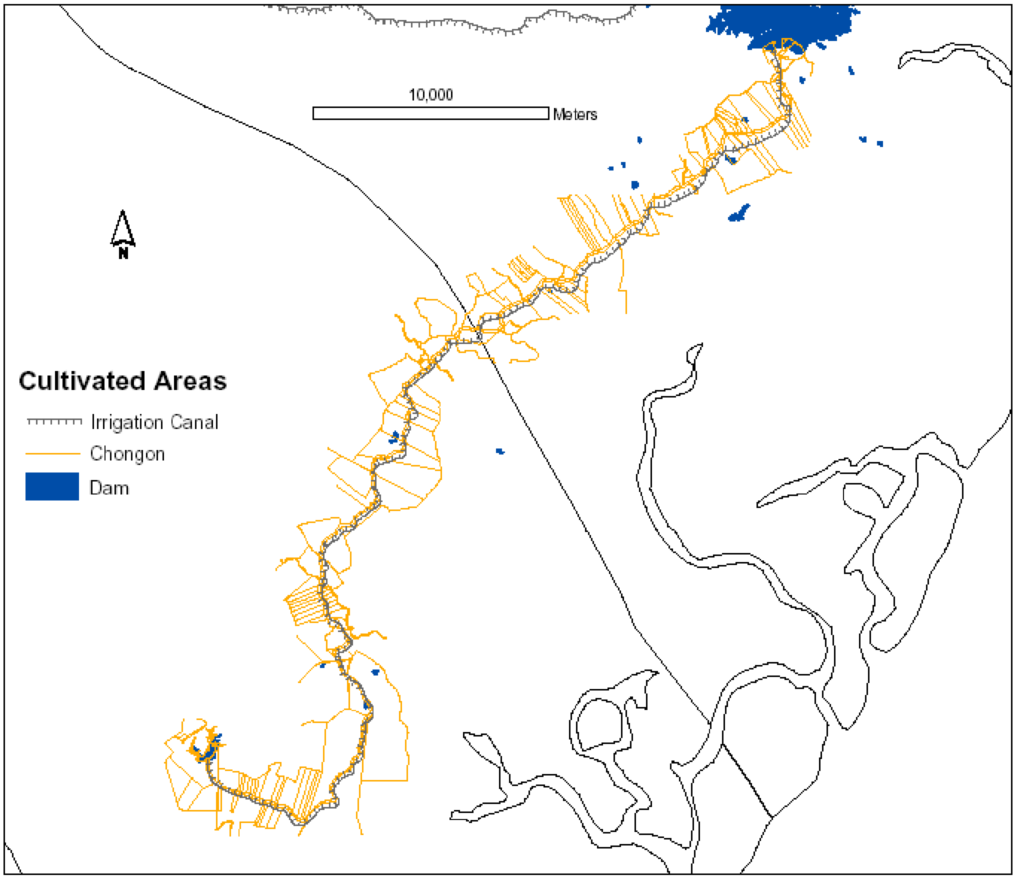

Figure A-6. Chongón farms

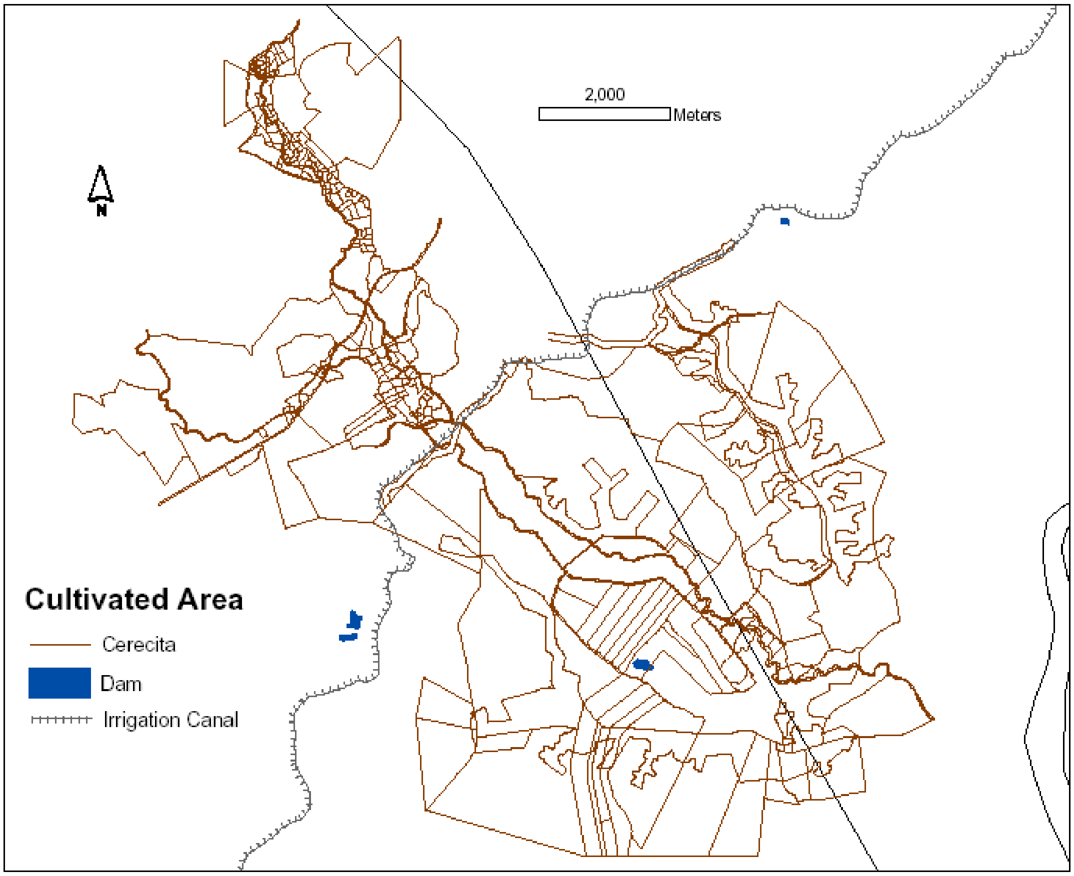

Figure A-7. Cerecita farms

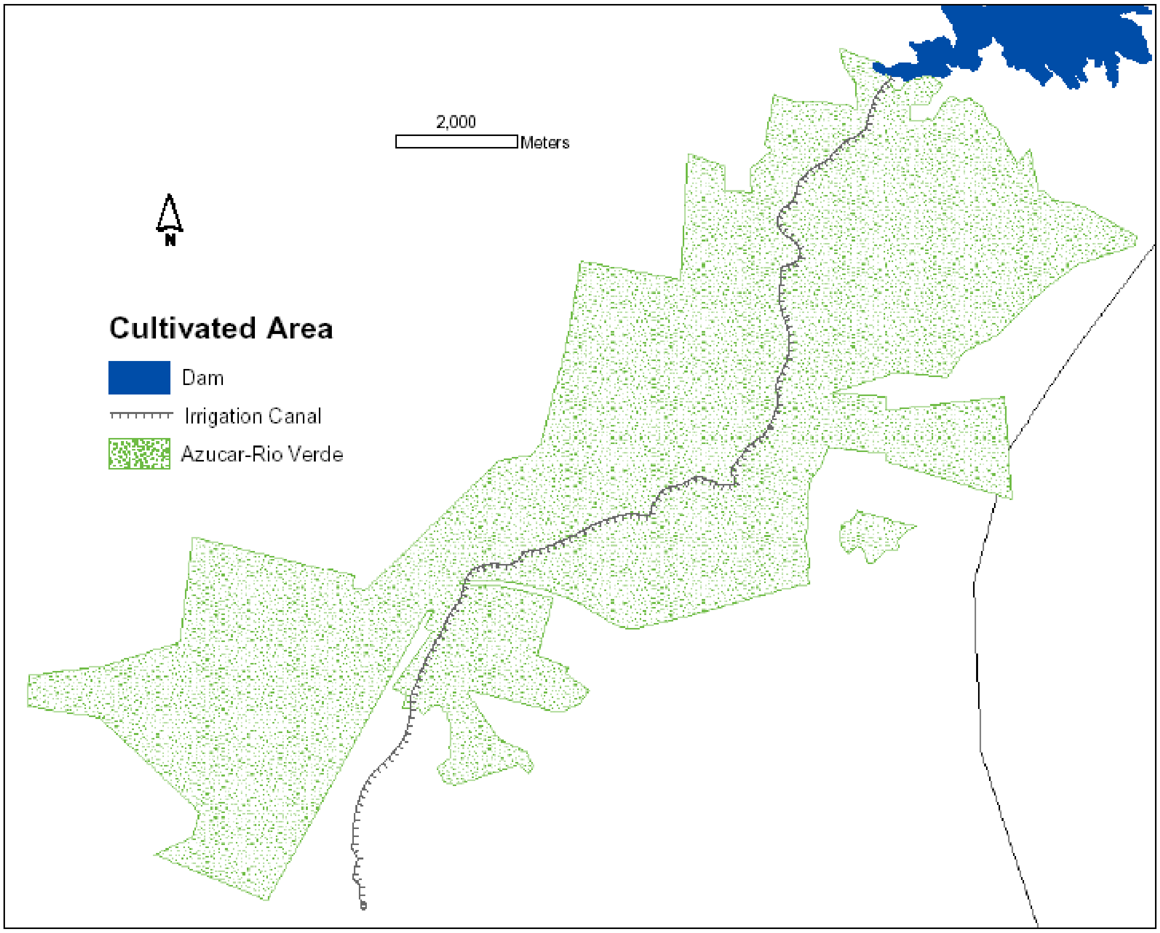

Figure A-8. Azúcar-Rio Verde farms

APPENDIX B
AVERAGE WEATHER DATA

Table B-1. Available weather data sets

	Available Weather Data Sets	
Weather station	Periods	
Chongón	1991-2000	
El Azúcar	1966-1991	1995-2000
Playas	1962-1978	1995-2000
San Isidro	1991-1998	
Suspiro	1962-1969	1991-1996

Chongón weather station is located in the CEDEGE experimental station at 24 m of elevation. The parameters registered in this station are temperature, relative humidity, wind speed, hour of light, precipitation, and evaporation, this data is different from all the others in the Santa Elena Peninsula since this station is close to Guayaquil where more rainfall is found.

Playas weather station is located near to the coastal line. Its climate is influenced by the winds coming from the ocean. The evaporation is highest on this station, and the precipitation is scarce.

El Azúcar weather station is located in the CEDEGE research station in El Azúcar. This station started its operation again in 2000. The parameters collected as the same as those shown in this table that collects historical data for this station.

El Suspiro and San Isidro were under CEDEGE control but they are not operational at this moment.

Table B-2. Chongón weather station

Chongón 1991 - 2000

LATITUDE: 2° 14' S LONGITUDE: 80° 04' E ELEVATION: 24 m

MONTH	TEMPERATURE (°C)	RELATIVE HUM. (%)	WIND (m/sec)	LIGHT PRECIP		EVAP	
	Avg.	Avg.	Day	Night	H/month	mm	mm
January	27.0	82	0.9	1.0	102.4	58.3	71.5
February	27.2	87	0.6	0.5	79.7	238.5	69.7
March	28.1	86	0.7	0.5	99.9	220.2	82.8
April	27.5	86	0.7	0.4	126.8	114.7	80.1
May	26.9	84	0.7	0.5	119.0	68.9	104.8
June	26.5	81	0.9	0.7	81.8	4.2	99.3
July	24.8	81	1.0	0.7	86.6	0.0	97.4
August	24.9	77	1.1	1.0	134.2	1.1	107.7
September	25.3	78	1.2	1.0	89.4	1.7	88.7
October	26.4	75	1.0	1.0	120.2	4.0	90.5
November	26.5	73	1.2	1.0	116.4	1.1	83.3
December	28.0	71	1.0	1.3	74.7	51.5	75.0

- CEDEGE (2001). N/D: no data

Table B-3. Playas weather station

Playas 1963 – 1978

LATITUDE: 2° 37' S LONGITUDE: 80° 23' E ELEVATION: 41m

MONTH	TEMPERATURE (°C)	RELATIVE HUM. (%)	WIND (m/sec)	LIGHT		PRECIP	EVAP.
	Avg	Avg	Day	Night	h/day	mm	mm
January	25.7	77	3.1	N/D	5.3	97.5	N/D
February	26.3	78	3.1	N/D	5.2	83.9	N/D
March	26.6	79	2.9	N/D	5.8	135.7	N/D
April	26.2	77	3.1	N/D	6.5	38.7	N/D
May	25.2	79	3.4	N/D	5.7	10.3	N/D
June	24.0	79	3.4	N/D	4.2	5.6	N/D
July	24.9	80	3.7	N/D	3.6	2.1	N/D
August	22.4	79	4.2	N/D	3.6	1.2	N/D
September	22.3	78	4.3	N/D	3.9	2.5	N/D
October	22.7	78	3.6	N/D	3.6	2.8	N/D
November	23.2	79	4.1	N/D	4.8	0.9	N/D
December	24.3	78	3.9	N/D	6.1	3.2	N/D

- CEDEGE (2001). N/D: no data

Table B-4. El Azúcar weather station

			El Azúcar 1974 - 1991				
	LATITUDE: 2°15´S		LONGITUDE: 80°35´W		ELEVACION: 50m		
MONTH	TEMP. (°C)	RELATIVE HUM. (%)	WIND (m/sec)		LIGHT	PRECIP.	EVAP.
	Avg	Avg.	Night	Day	h/mo	mm	mm
January	25.8	89	N/D	1.4	98.3	49.8	151.8
February	25.9	89	N/D	1.2	100.3	71.3	118.8
March	26.2	88	N/D	1.5	151.5	63.3	138.4
April	26.0	89	N/D	1.2	120.2	20.8	139.2
May	25.3	88	N/D	1.4	139.6	2.2	144.7
June	23.8	89	N/D	1.5	87.4	1.1	115.4
July	23.3	90	N/D	1.6	82.6	0.4	107.7
August	22.9	89	N/D	1.6	89.9	0.2	134.4
September	23.5	90	N/D	1.6	100.6	0.3	137.2
October	23.5	90	N/D	1.7	67.1	1.0	136.0
November	24.1	89	N/D	1.9	85.7	4.4	153.6
December	25.2	89	N/D	1.5	126.6	8.1	149.6

Table B-5. San Isidro weather station

			San Isidro 1991 - 1998				
	LATITUDE: 2°25´S		LONGITUDE: 80°58´W		ELEVACION: 35m		
MONTH	TEMP. (°C)	RELATIVE HUM. (%)	WIND (m/sec)		LIGHT	PRECIP.	EVAP.
	Avg	Avg.	Night	Day	h/mo	mm	mm
January	26.4	87	0.2	0.5	N/D	95	99
February	26.4	90	0.1	0.3	N/D	313	67
March	26.5	91	0.1	0.2	N/D	419	100
April	26.6	90	0.1	0.3	N/D	192	84
May	26.1	87	0.3	0.4	N/D	108	87
June	25.5	86	0.4	0.5	N/D	10	89
July	25.6	86	0.5	0.5	N/D	109	90
August	25.2	86	0.5	0.6	N/D	0	71
September	25.3	86	0.6	0.8	N/D	36	87
October	25.2	84	0.8	0.8	N/D	20	97
November	25.6	85	0.4	0.8	N/D	175	94
December	26.0	85	0.9	0.7	N/D	263	82

- CEDEGE (2001). N/D: no data

Table B-6. Suspiro weather station

Suspiro 1962-1969/1991-1996

LATITUDE: 2°15´S LONGITUDE: 80°35´W ELEVACION: 35m

MONTH	TEMP. (°C)	RELATIVE HUM. (%)	WIND (m/sec)		LIGHT	PRECIP.	EVAP.
	Avg	Avg.	Night	Day	h/mo	mm	mm
January	25.9	80	N/D	N/D	N/D	39	161
February	26.1	81	N/D	N/D	N/D	125	130
March	26.4	81	N/D	N/D	N/D	92	173
April	26.0	77	N/D	N/D	N/D	18	131
May	25.2	82	N/D	N/D	N/D	11	151
June	23.2	88	N/D	N/D	N/D	12	117
July	22.0	90	N/D	N/D	N/D	17	77
August	21.4	89	N/D	N/D	N/D	14	59
September	21.7	88	N/D	N/D	N/D	6	71
October	21.6	91	N/D	N/D	N/D	38	96
November	21.9	90	N/D	N/D	N/D	10	121
December	24.5	82	N/D	N/D	N/D	26	164

- CEDEGE (2001). N/D: no data

APPENDIX C
CROPWAT REFERENCE EVAPOTRANSPIRATION TABLES

Table C-1. Reference evapotranspiration Chongón

```
11/1/2002                                            CropWat 4 Windows
Ver 4.3
***********************************************************************
Climate and ETo (grass) Data (based on 9 years of data)
***********************************************************************
Data Source: C:\CROPWATW\CLIMATE\CHONGON.PEM
-----------------------------------------------------------------------
Country : Ecuador                    Station  : Chongón
Altitude: 24 meter(s) above M.S.L.
Latitude: -2.23 Deg. (South)         Longitude: 80.07 Deg. (East)
-----------------------------------------------------------------------
Month      MaxTemp MiniTemp Humidity Wind Spd. SunShine  Solar Rad. ETo
           (deg.C) (deg.C)    (%)     (Km/d)   (Hours)   (MJ/m2/d(mm/d)
-----------------------------------------------------------------------
January     31.2    19.0     79.5     77.8      3.3        14.3    3.29
February    30.7    19.1     80.1     51.8      2.8        13.9    3.08
March       30.7    19.3     79.2     60.5      3.2        14.6    3.24
April       31.0    19.5     79.6     60.5      4.2        15.5    3.35
May         30.5    19.3     78.3     60.5      3.8        13.9    3.02
June        30.4    18.7     78.9     77.8      2.7        11.8    2.77
July        30.8    18.5     78.9     86.4      2.8        12.1    2.90
August      30.8    20.0     79.0     95.0      4.3        15.1    3.43
September   30.8    19.3     79.5     103.7     3.0        13.9    3.34
October     30.6    19.8     78.2     86.4      3.9        15.5    3.52
November    30.8    19.9     79.1     103.7     3.9        15.2    3.54
December    30.4    19.3     78.1     86.4      2.4        12.7    3.06
-----------------------------------------------------------------------
Average     30.7    19.3     79.0     79.2      3.4        14.1    3.21
-----------------------------------------------------------------------
 Pen-Mon equation was used in ETo calculations with the following
values for Angstrom's Coefficients:            a = 0.25        b = 0.5
***********************************************************************
C:\CROPWATW\REPORTS\CHONGON2.TXT
```

Table C-2. Reference evapotranspiration El Azúcar

```
11/1/2002                                                CropWat 4 Windows
Ver 4.3
**********************************************************************
Climate and ETo (grass) Data Azúcar (based on 30 years of data)
**********************************************************************
Data Source: C:\CROPWATW\CLIMATE\AZUCAR.PEM
----------------------------------------------------------------------
Country : Ecuador                        Station  : Azúcar
Altitude: 35 meter(s) above M.S.L.
Latitude: -2.25 Deg. (South)             Longitude: 80.58 Deg. (East)
----------------------------------------------------------------------
Month     MaxTemp MiniTemp Humidity Wind Spd. SunShine  Solar Rad.  ETo
          (deg.C) (deg.C)    (%)     (Km/d)   (Hours)   (MJ/m2/d)(mm/d)
----------------------------------------------------------------------
January     31.5    21.3     81.4     121.0     3.2         14.1   3.45
February    31.4    21.4     82.5     103.7     3.6         15.1   3.53
March       31.9    21.4     83.4     129.6     4.9         17.2   3.98
April       32.2    20.6     82.3     103.7     4.0         15.2   3.57
May         30.6    20.9     81.9     121.0     4.5         14.9   3.40
June        29.4    19.0     84.9     129.6     2.9         12.1   2.84
July        28.8    19.3     87.2     138.2     2.7         12.0   2.74
August      28.1    18.7     88.3     138.2     2.9         13.1   2.86
September   28.0    19.0     88.8     138.2     3.4         14.5   3.08
October     29.5    19.0     87.5     146.9     2.2         12.9   3.05
November    28.4    19.0     87.5     164.2     2.9         13.7   3.09
December    30.5    20.1     85.9     129.6     4.1         15.3   3.45
----------------------------------------------------------------------
Average     30.0    20.0     85.1     130.3     3.4         14.2   3.25
----------------------------------------------------------------------
 Pen-Mon equation was used in ETo calculations with the following
values for Angstrom's Coefficients:          a = 0.25        b = 0.5
**********************************************************************
C:\CROPWATW\REPORTS\AZUCAR2.TXT
```

Table C-3. Reference evapotranspiration Playas

```
11/1/2002                                            CropWat 4 Windows
Ver 4.3
***********************************************************************
Climate and ETo (grass) Data (based on 21 years of data)
***********************************************************************
Data Source: C:\CROPWATW\CLIMATE\PLAYAS.PEM
-----------------------------------------------------------------------
Country : Ecuador                    Station  : Playas
Altitude: 41 meter(s) above M.S.L.
Latitude: -2.62 Deg. (South)         Longitude: 80.38 Deg. (East)
-----------------------------------------------------------------------
Month      MaxTemp MiniTemp Humidity Wind Spd. SunShine  Solar Rad. ETo
           (deg.C) (deg.C)    (%)     (Km/d)   (Hours)  (MJ/m2/d)(mm/d)
-----------------------------------------------------------------------
January     30.2    25.5     77.1     267.8     5.3        17.4    4.47
February    33.5    28.7     76.7     267.8     5.2        17.7    4.97
March       27.0    5.0      78.1     250.6     5.8        18.7    4.76
April       29.3    23.2     73.1     267.8     6.5        19.0    4.74
May         33.6    29.9     79.0     293.8     5.7        16.6    4.67
June        30.5    24.3     74.3     293.8     4.2        13.8    4.14
July        28.5    23.9     79.0     319.7     3.6        13.2    3.63
August      30.6    25.6     74.0     362.9     3.6        14.1    4.51
September   33.3    28.9     79.7     371.5     3.9        15.3    4.64
October     33.2    26.6     76.5     311.0     3.6        15.1    4.67
November    30.3    25.3     75.3     354.2     4.8        16.7    4.74
December    28.9    24.2     78.2     337.0     6.1        18.4    4.52
-----------------------------------------------------------------------
Average     30.7    24.3     76.8     308.2     4.9        16.3    4.54
-----------------------------------------------------------------------
Pen-Mon equation was used in ETo calculations with the following values
for Angstrom's Coefficients:          a = 0.25        b = 0.5
***********************************************************************
C:\CROPWATW\REPORTS\PLAYAS2.TXT
```

Table C-4. Reference evapotranspiration San Isidro

```
11/1/2002                                            CropWat 4 Windows
Ver 4.3
***********************************************************************
Climate and ETo (grass) Data (based on 7 years of data)
***********************************************************************
Data Source: C:\CROPWATW\CLIMATE\SNISIDRO.PEM
-----------------------------------------------------------------------
Country : Ecuador                    Station  : San Isidro
Altitude: 35 meter(s) above M.S.L.
Latitude: -2.25 Deg. (South)         Longitude: 80.58 Deg. (East)
-----------------------------------------------------------------------
Month      MaxTemp MiniTemp Humidity Wind Spd. SunShine  Solar Rad. ETo
           (deg.C) (deg.C)    (%)     (Km/d)   (Hours)  (MJ/m2/d)(mm/d)
-----------------------------------------------------------------------
January     31.0    20.2     85.3     43.2      4.3        15.8    3.32
February    31.3    20.7     85.3     25.9      4.2        16.1    3.36
March       31.4    20.4     85.8     17.3      4.8        17.1    3.50
April       31.4    20.9     85.6     25.9      5.5        17.5    3.56
May         31.3    20.9     85.1     34.6      4.7        15.2    3.13
June        31.5    20.8     84.8     43.2      3.2        12.5    2.71
July        31.2    20.1     85.2     43.2      2.6        11.9    2.60
August      31.7    20.5     85.1     51.8      2.6        12.6    2.83
September   31.3    20.5     85.0     69.1      2.9        13.8    3.11
October     31.5    20.9     84.7     69.1      2.6        13.5    3.10
November    31.4    20.8     84.7     69.1      3.8        15.1    3.34
December    31.7    20.6     84.5     60.5      5.1        16.8    3.59
-----------------------------------------------------------------------
Average     31.4    20.6     85.1     46.1      3.9        14.8    3.18
-----------------------------------------------------------------------
Pen-Mon equation was used in ETo calculations with the following values
for Angstrom's Coefficients:           a = 0.25        b = 0.5
***********************************************************************
C:\CROPWATW\REPORTS\ISIDRO2.TXT
```

Table C-5. Reference evapotranspiration Suspiro

```
11/1/2002                                            CropWat 4 Windows
Ver 4.3
***********************************************************************
Climate and ETo (grass) Data (based on 13 years of data)
***********************************************************************
Data Source: C:\CROPWATW\CLIMATE\SUSPIRO.PEM
-----------------------------------------------------------------------
Country : Ecuador                    Station  : Suspiro
Altitude: 35 meter(s) above M.S.L.
Latitude: -2.25 Deg. (South)         Longitude: 80.58 Deg. (East)
-----------------------------------------------------------------------
Month      MaxTemp MiniTemp Humidity Wind Spd. SunShine  Solar Rad. ETo
           (deg.C) (deg.C)    (%)     (Km/d)   (Hours)  (MJ/m2/d)(mm/d)
-----------------------------------------------------------------------
January     31.6    20.3     75.3     164.2     3.2        14.1    3.86
February    31.3    21.4     75.6     146.9     3.6        15.1    3.88
March       32.1    21.0     78.3     146.9     4.9        17.2    4.20
April       31.7    20.2     77.0     155.5     4.0        15.2    3.90
May         30.4    21.4     77.0     129.6     4.5        14.9    3.54
June        28.8    19.3     78.3     112.3     2.9        12.1    2.88
July        27.9    18.6     84.7     86.4      2.7        12.0    2.59
August      26.2    17.9     88.0     129.6     2.9        13.1    2.70
September   25.8    17.0     87.3     121.0     3.4        14.5    2.92
October     25.5    17.9     87.5     129.6     2.2        12.9    2.69
November    26.3    18.3     86.3     86.4      2.9        13.7    2.80
December    30.0    20.2     83.5     167.0     4.1        15.3    3.58
-----------------------------------------------------------------------
Average     29.0    19.5     81.6     131.3     3.4        14.2    3.30
-----------------------------------------------------------------------
Pen-Mon equation was used in ETo calculations with the following values
for Angstrom's Coefficients:            a = 0.25        b = 0.5
***********************************************************************
C:\CROPWATW\REPORTS\SUSPIRO2.TXT
```

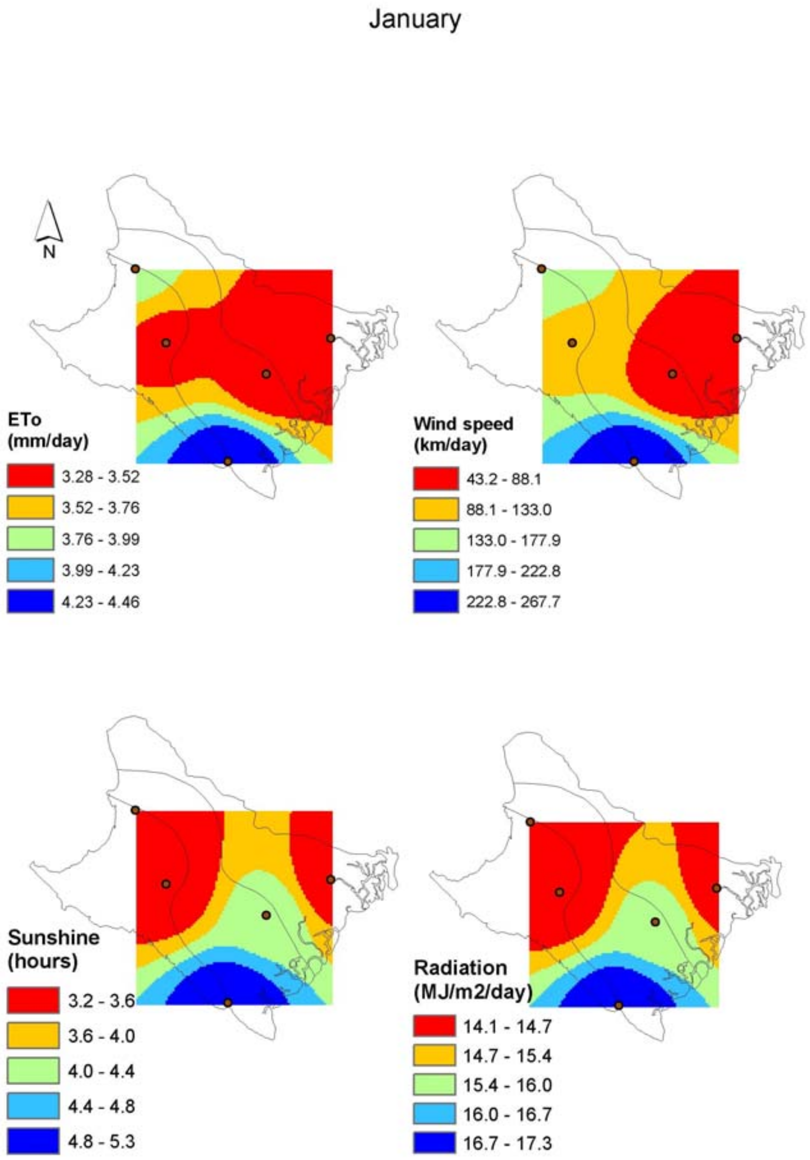

Figure C-1. Surface maps used to create a reference evapotranspiration map

Table C-6. Open water evaporation values per canal

Month	Chongón-Cerecita (m^3)	Cerecita-Playas (m^3)	Chongón-Sube y Baja (m^3)	Azúcar-Rio Verde (m^3)
January	1064	528	531	740
February	1037	565	517	725
March	1085	560	541	792
April	1112	563	555	759
May	990	529	494	705
June	882	465	440	616
July	885	423	441	619
August	1008	498	502	690
September	1038	526	518	705
October	1066	527	531	721
November	1107	548	552	728
December	1070	550	534	714

Table C-7. Open water evaporation from dams

Month	Chongón (m^3)	El Azúcar (m^3)	De Cola (m^3)
January	90,886	50,456	2,324
February	85,085	51,626	2,584
March	89,505	58,208	2,475
April	92,544	52,211	2,465
May	83,428	49,725	2,428
June	76,521	41,535	2,153
July	80,113	40,073	1,888
August	94,754	41,828	2,345
September	92,268	45,045	2,413
October	97,240	44,606	2,428
November	97,793	45,191	2,465
December	84,533	50,456	2,350

APPENDIX D
ECOCROP SELECTION CRITERIA TABLES

The information in ECOCROP permits the identification of 1,710 plant species whose most important climate and soil requirements match the information on soil and climate entered by the user. It also permits the identification of plant species for certain uses. ECOCROP can be used as a library of crop environmental requirements and it can provide plant species attribute files on crop environmental requirements to be compared with soil and climate maps in Agro-ecological zoning (AEZ) databases or Geographical Information System (GIS) map-based display.

A list of 60 crops was selected as potential crops for the SEP following workshops and studies conducted by ESPOL and CEDEGE (2001). Following parameters were considered:

- Crops actually being grow in the Santa Elena Peninsula
- Market analysis for these crops
- Ecology and adaptability to the zone
- Discussion with the agricultural producers

From the list of 60 crops, following a process of elimination using ECOCROP, expert advises from international market consultants, and producers a final list of 20 crops was produced. Thirteen crops from that list are used to calculate water use in this project. In this section the output given by ECOCROP is presented. These 13 crops were selected because were considered the ones with better economical future.

ECOCROP SELECTION CRITERIA (PRODUCTION)

DESCRIPTION

SELECTED CROPS	FORM	TYPE	USES	PRODUCTION SYSTEM	CYCLE (days)	
					MIN	MAX
Psidium guajava L.	Bush	Perennial	Fruit, lumber	ND	150	365
Abelmoschus spp.	Herb.	Annual	Vegetable	ND	50	180
Algarrobo	Bush, tree	Perennial	Medicine. Aromatic, Industry	ND	210	365
Ficus carica L.	Bush, tree	Perennial	Fruit, Medicine. Aromatic, Industry	Garden	120	300
Cucurbita spp.	Climbing	Annual	Fruit, Medicine. Aromatic, Industry, Forages, Vegetable	Garden, commercial	80	140
Annona cherimola	Bush, tree	Perennial	Fruit	Garden, commercial	210	270
Anacardium occidentale	Bush, tree	Perennial	Fruit, Medicine, Industry	ND	190	260
C. sinensis	Tree	Perennial	Fruit	Commercial	180	365
Aloe spp.	Herb.	Perennial	Medicine, Industry	Garden	120	150
Lycopersicon esculentum	Herb.	Annual	Aromatic, Industry, Forages, Vegetable	ND	70	150
Carica papaya L.	Herb.	Perennial	Fruit, Medicine, Aromatic	Garden, commercial	330	365
Cucumis sativus	Herb.	Annual	Fruit, Medicine. Aromatic, Industry, Vegetable	Garden, commercial	40	180
Persea spp.	Tree	Perennial	Fruit, lumber	ND	ND	ND
Citrullus lanatus	Climbing, Herb.	Annual	Fruit, Medicine. Aromatic, Industry	Commercial	ND	ND
C. reticulata	Tree	Perennial	Fruit	Garden, commercial	60	365

Piper nigrum L.	Climbing	Perennial	Medicine, Aromatic	ND	180	270
Allium sativum L.	Herb.	Biannual	Vegetable, Medicine. Aromatic	ND	ND	ND
Ananas comosus Merr.	Herb.	Perennial	Fruit	ND	330	365
Cucumis melo L.	Herb., Climbing	Annual	Fruit, Industry	ND	50	120
Vitis spp.	Bush, Climbing	Perennial	Fruit, Medicine, Industry	Commercial	160	270
C. aurantifolia	Tree	Perennial	Fruit, Aromatic	ND	ND	ND
Asparagus officinalis L.	Herb.	Perennial	Vegetable, Medicine, Industry	Commercial	210	270
Allium cepa	Herb.	Biannual	Vegetable, Medicine, Industry	Garden, commercial	85	175
Musa spp.	Herb.	Perennial	Fruit	ND	ND	ND
Capsicum spp.	ND	ND	ND	ND	ND	ND

SELECTED CROPS	ECOCROP SELECTION CRITERIA (SOIL)							
	SOIL THICKNESS (cm)		SOIL TEXTURE		SOIL pH			
	OPTIM	ABSOLT	OPTIMUM	ABSOLUTE	OPTIMUM		ABSOLUTE	
					MIN	MAX	MIN	MAX
Psidium guajava L.	50-150	20-50	Medium, organic	Heavily, medium, light	5.5	7.5	4	8.5
Abelmoschus spp.	20-50	20-50	Heavily, medium, light, organic	Heavily, medium, light	5.5	7	4.5	8.7
Algarrobo	20-50	20-50	Medium, light	Medium, light	6	7.5	5	9
Ficus carica L.	>150	50-150	Medium	Heavily, medium, light	6	7	4.3	8.6
Cucurbita spp.	>150	20-50	Heavily, medium, light, organic	Heavily, medium, light	5.5	7.5	5	8.5
Annona cherimola	>150	20-50	Medium, light	Heavily, medium, light	7	8	4.3	8.5
Anacardium occidentale	>150	50-150	Medium, light	Heavily, medium, light	4.5	6.5	3.8	8.7
C. sinensis	150	50-150	Medium, light	Heavily, medium, light	5	6	4	8.3
Aloe spp.	50-150	20-50	Light	Medium, light	6.5	7	6	7.5
Lycopersicon esculentum	20-50	20-50	Medium, organic	Heavily, medium, light	5.5	6.8	5	7.5
Carica papaya L.	>150	50-150	Medium, organic	Heavily, medium, light	5.5	7	4.5	8
Cucumis sativus	50-150	20-50	Medium, organic	Heavily, medium, light	6	7.5	4.5	8.7
Persea spp.	>150	>150	Medium	Medium	5	5.8	4.5	7
Citrullus lanatus	>150	50-150	Medium	Light	6	7	5.5	7.5

C. reticulata	>150	50-150	Medium, light	Heavily, medium, light	6	6.8	5.5	8.3
Piper nigrum L.	>150	50-150	Heavily, medium	Heavily, medium, light	6	7	5	7.5
Allium sativum L.	50-150	20-50	Medium, light	Heavily, medium, light	6	6.6	5	8.5
Ananas comosus Merr.	50-150	20-50	Medium, light	Heavily, medium, light	4.5	8	3.5	9
Cucumis melo L.	50-150	50-150	Medium, organic	Heavily, medium, light	6	7.5	5	8.7
Vitis spp.	>150	20-50	Medium, organic	Heavily, medium, light	5.5	7.5	4.5	8.5
C. aurantifolia	50-150	20-50	Medium, light	Heavily, medium, light	5.5	6.5	5	7.5
Asparagus officinalis L.	50-150	50-150	Medium, organic	Medium, light	6	6.7	4.5	8.2
Allium cepa	50-150	20-50	Medium, organic	Organic	6	7	4.3	8.3
Musa spp.	ND	ND	ND	ND	ND	ND	ND	ND
Capsicum spp.	ND	ND	ND	ND	ND	ND	ND	ND

ECOCROP SELECTION CRITERIA (CLIMATE II)

SELECTED CROPS	LATITUD (decimal degrees)				ELEVATION (m)	CLIMATIC ZONE
	OPTIMUM		ABSOLUTE		ABSOLUTE	
	MIN	MAX	MIN	MAX	MAX	
Psidium guajava L.	0	20	0	35	2000	THS, TH, StSa, SbH, SSV, SSI
Abelmoschus spp.	0	35	0	40	1000	THS, TH, StSa, SbH, SSV, SSI
Algarrobo	27	42	25	45	1000	StSa, SbSV, TO
Ficus carica L.	30	50	25	53	1200	THS, TH, StSa, SbH, SSV; SSI, TO, TC, THI, TSI
Cucurbita spp.	10	20	0	50	2000	THS, TH, StSa, SbH, SSV; SSI, TO, TC, THI, TSI
Annona cherimola	0	15	0	25	1000	THS, TH, SSV
Anacardium occidentale	0	25	0	30	1200	THS, StSa, SSV, SSI
C. sinensis	0	40	0	40	2100	THS, TH, StSa, SbH, SHV, SSI
Aloe spp.	20	40	20	40	2000	StSa, SbSV
Lycopersicon esculentum	0	0	0	0	2400	THS; TH; StSr, SbH, SSV, SSI, TO, TC, THI, TSI
Carica papaya L.	0	30	0	32	2100	THS, TH
Cucumis sativus	0	40	0	40	2000	THS; TH; StSr, SbH, SSV, SSI, TO, TC, THI, TSI
Persea spp.	0	42	0	42	2800	THS, TH
Citrullus lanatus	20	43	10	43	1000	THS, TH, SbH, SHV, TO
C. reticulata	0	35	0	45	2300	THS, StSA, SbH, SSV, SSI
Piper nigrum L.	0	15	0	20	2000	THS, TH

Allium sativum L.	0	60	0	60	2200	THS; TH; StSr, SbH, SSV, SSI, TO, TC, THI, TSI
Ananas comosus Merr.	0	25	0	33	1800	THS, TH, SbH
Cucumis melo L.	0	0	0	0	1000	THS; TH; StSr, SbH, SSV, SSI, TO, TC, THI, TSI
Vitis spp.	20	45	0	50	2000	THS; StSr, SSV, TO, TC
C. *aurantifolia*	ND	ND	ND	ND	ND	THS
Asparagus officinalis L.	0	60	0	60	2600	THS; TH; StSr, SbH, SSV, SSI, TO, TC, THI, TSI
Allium cepa	0	60	0	60	2000	THS; TH; StSr, SbH, SSV, SSI, TO, TC, THI, TSI
Musa spp.	ND	ND	ND	ND	ND	ND
Capsicum spp.	ND	ND	ND	ND	ND	ND

ECOCROP SELECTION CRITERIA (CLIMATE I)												
SELECTED CROPS	TEMPERATURE (C)				PRECIPITATION (mm)				RADIATION			
	OPTIMUM		ABSOLUTE		OPTIMUM		ABSOLUTE		OPTIMUM		ABSOLUTE	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
Psidium guajava L.	20	33	10	45	1000	3000	400	5000	High luminosity	Open sky	High luminosity	Cloudy sky
Abelmoschus spp.	20	30	12	35	600	1200	300	2500	Open sky	Open sky	High luminosity	Cloudy sky
Algarrobo	20	32	10	39	400	1000	200	2000	High luminosity	Open sky	High luminosity	Cloudy sky
Ficus carica L.	16	26	4	38	700	1500	300	2700	High luminosity	Open sky	High luminosity	Shadow
Cucurbita spp.	20	30	9	38	600	1000	450	2700	High luminosity	High luminosity	High luminosity	Cloudy sky
Annona cherimola	23	30	11	41	800	1200	570	4000	High luminosity	Open sky	High luminosity	Cloudy sky
Anacardium occidentale	15	35	5	46	750	1600	400	4000	High luminosity	High luminosity	High luminosity	Open sky
C. sinensis	20	30	13	38	1200	2000	450	2700	High luminosity	High luminosity	High luminosity	Open sky
Aloe spp.	18	26	10	30	500	600	300	800	High luminosity	High luminosity	High luminosity	Cloudy sky
Lycopersicon esculentum	20	27	7	35	600	1300	400	1800	Open sky	Open sky	High luminosity	Cloudy sky
Carica papaya L.	21	30	12	44	1500	2500	1000	3000	High luminosity	Open sky	High luminosity	Cloudy sky
Cucumis sativus	18	32	6	38	1000	1200	400	4300	High luminosity	High luminosity	High luminosity	Open sky

Persea spp.	18	40	12	45	500	2000	300	2500	High luminosity	High luminosity	Open sky	High luminosity
Citrullus lanatus	20	35	15	40	500	700	400	1800	Open sky	High luminosity	Cloudy sky	High luminosity
C. reticulata	23	34	12	38	1200	1800	300	4000	High luminosity	High luminosity	High luminosity	Open sky
Piper nigrum L.	22	35	10	40	2500	4000	2000	5500	Open sky	Shadow	Open sky	Shadow
Allium sativum L.	18	30	7	35	750	1600	500	2700	Open sky	Open sky	High luminosity	Cloudy sky
Ananas comosus Merr.	21	30	10	36	800	2500	550	3500	Open sky	Cloudy sky	High luminosity	Shadow
Cucumis melo L.	18	30	9	35	1000	1300	900	2500	High luminosity	High luminosity	High luminosity	Open sky
Vitis spp.	18	30	10	38	700	850	400	1200	High luminosity	High luminosity	High luminosity	Open sky
C. aurantifolia	20	28	12	32	1200	1500	750	2300	High luminosity	High luminosity	High luminosity	Open sky
Asparagus officinalis L.	15	30	6	38	800	1200	500	4000	High luminosity	High luminosity	High luminosity	Cloudy sky
Allium cepa	12	25	4	30	350	600	300	2800	Open sky	Open sky	Cloudy sky	High luminosity
Musa spp.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Capsicum spp.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ECOCROP SELECTION CRITERIA (FERTILITY/DRAINAGE)

SELECTED CROPS	FERTILITY		SALINITY		DRAINAGE		SHORT DAYS
	OPTIM	ABSOLT	OPTIM	ABSOLT	OPTIM	ABSOLT	
Psidium guajava L.	High	Low	<4ds/m	4-10 ds/m	good (dry season)	good (dry season), excessive (very dry)	<12 hr
Abelmoschus spp.	High	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12 hr
Algarrobo	Moderate	Low	<4ds/m	4-10 ds/m	good (dry season)	good (dry season), excessive (very dry)	<12 hr
Ficus carica L.	Moderate	Low	<4ds/m	4-10 ds/m	good (dry season)	good (dry season), excessive (very dry)	<12hr, 12-14 hr, >14 hr
Cucurbita spp.	High	Low	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
Annona cherimola	High	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12 hr
Anacardium occidentale	Moderate	Low	<4ds/m	<4ds/m	good (dry season)	good (dry season), excessive (very dry)	<12hr, 12-14 hr, >14 hr
C. sinensis	Moderate	Low	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
Aloe spp.	Moderate	Low	<4ds/m	<4ds/m	good (dry season)	good (dry season), excessive (very dry)	<12 hr
Lycopersicon esculentum	High	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
Carica papaya L.	High	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season), excessive (very dry)	<12hr, 12-14 hr, >14 hr

Cucumis sativus	High	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
Persea spp.	Moderate	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season)	ND
Citrullus lanatus	High	Low	<4ds/m	4-10 ds/m	good (dry season)	good (dry season), excessive (very dry)	>14 hr
C. reticulata	High	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season), excessive (very dry)	<12 hr, 12-14 hr
Piper nigrum L.	High	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
Allium sativum L.	High	Low	<4ds/m	<4ds/m	good (dry season)	good (dry season)	>14 hr
Ananas comosus Merr.	Moderate	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12 hr
Cucumis melo L.	Moderate	Low	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
Vitis spp.	Moderate	Low	<4ds/m	<4ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
C. aurantifolia	High	Moderate	<4ds/m	<4ds/m	good (dry season)	good (dry season), excessive (very dry)	<12hr, 12-14 hr, >14 hr
Asparagus officinalis L.	High	Moderate	<4ds/m	4-10 ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
Allium cepa	Moderate	Low	<4ds/m	4-10 ds/m	good (dry season)	good (dry season)	<12hr, 12-14 hr, >14 hr
Musa spp.	ND	ND	ND	ND	ND	ND	ND
Capsicum spp.	ND	ND	ND	ND	ND	ND	ND

APPENDIX E
TROPICAL CROPS

Aloe - Aloe spp.

Varieties: Aloe barbadensis, Aloe vera, Aloe arborensis, Aloe saponaria, Aloe ferro, Aloe perryi.

Aloe is an evergreen perennial native to Europe and the Mediterranean. It escaped cultivation and spread throughout the world. It is now found in deserts and jungles, temperate and cold climates. Cultivation is fairly easy; the plant prefers light, sandy, well-drained soil and a very sunny location (Atherton 1997).

Figure E-1. Aloe plantation, Santa Elena Peninsula

Asparagus - Asparagus officinalis L.

Varieties: Many new asparagus varieties are now available. All male hybrids are more productive and do not produce seed which sprouts to become a weed (Phillips 1990).

Soils: Well-drained soils are a must for successful production, and very sandy soils are preferred. Good drainage is important in control for crown rot disease of asparagus. Commercial plantings of asparagus should not be made in soil that is heavier than a sandy loam. An ideal site includes a sandy loam soil with good drainage and aeration, water table below 1.2 m, and a pH of 6.8–7.5. Sites which retain standing water for more than 8 hours after a heavy rain should be avoided (Mullen 1998).

Climate: Asparagus grows best when growing conditions include high light intensity, warm days, cool nights, low relative humidity, and adequate soil moisture. Compared to most other vegetables, asparagus is relatively winter hardy, with higher heat, drought, and salt tolerances (Cantaluppi & Precheur 1993).

Spear initiation and root growth begin when the soil temperature is above 15 degrees C. Sandy soils warm earlier in the spring and encourage early spear production, while irrigation cools the soil and retards spear production. Optimum productivity occurs at 20–25 degrees C in the day and 15–20 degrees C at night. High daytime temperatures during harvest will loosen the spear tip and develop fiber in the stem, both of which reduce crop quality (Phillips 1990).

Cashew Nut - Anacardium occidentale

Cashew, a native of Brazil is a major crop for the tropics. It is a hardy crop, which does well in areas considered relatively dry and marginal for many economic crops. The crop also requires minimal care and skills from the farmer.

The cashew fruit consists of two distinct parts, a fleshy stalk in the form of a pear, also called cashew apple, with a brilliant yellow or red skin, which can measure from 5 to 10 cm; and a nut of greybrownish color, in the shape of a kidney, which hangs from the lower end of the stalk or "apple" and which is the true nut called cashew, very rich in carbohydrates and Vitamin A. Of the stalk or "apple", juices, syrups, preserves, wine or liquors are obtained. But its main commercial use is the cashew nut itself; shelled, roasted and salted forming an ingredient as snack and the confectionery industry (delicacies, chocolate, etc).

Climate: Cashew is hardy and drought resistant, and can grow better in areas with rainfall between 500 mm and 1,500 mm per year. Cashew is well suited to a seasonally wet/dry tropical climate. The area selected for cashew production should be frost-free. Mean daily temperatures of less than 25 °C will limit the growth and productivity of cashew trees. It is generally grown under rain fed conditions on soils of low fertility (Rieger 1990).

Cucumber - Cucumis sativus

Cucumbers are a warm season crop and susceptible to frost damage. Low humidity is favorable to cucumber production because of lower incidences of fruit and foliar diseases. Extremely high temperatures may cause light green fruit color and bitterness in many cucumber varieties.

Climate: Cucumbers are very tender, warm-season plants that grow best in temperatures from 18.3 °C to 23.9 °C with a minimum temperature of 15.6 °C and a maximum of 32.2 °C. Cucumber seeds germinate in soils at temperatures from 15.6 °C to 35 °C. Seeds do not germinate well at temperatures below 15.6 °C. Cucumber plants are very susceptible to chilling injury in the field; prolonged temperatures below 12.8 °C cause chilling injury to plants (pitting, water-soaked spots, and decay). Cucumber seed is relatively vigorous, and stand establishment is not generally a problem if appropriate soil preparation, temperature, and soil moisture conditions are met (Schrader 2002).

Soils: cucumbers are planted on a wide variety of soils. Lighter soils are usually selected for earlier maturing fields. Cucumbers are a deep-rooted crop that grows best on deep, fertile, well-drained soils. Very light soils that have excessive drainage and poor moisture-holding potential should be avoided. Cucumbers are fairly salt tolerant. Research has shown yield reduction of 10 percent starting at 3 dS/m (Schrader 2002).

Irrigation: cucumbers require frequent irrigation during the growing period. Too little soil moisture, particularly when fruit is filling, can cause poorly shaped and curved cucumbers. Fields should be maintained at or near field capacity to avoid plant stress and to keep plants growing at a constant rate. The use of tensiometers to monitor soil moisture and leaching is recommended.

Banana and Plantain - Musa spp.

Bananas and plantains belong to the family Musaceae, genus Musa. This family is important not only for fruit production, but its other useful plants. Musa spp. have provide man with food, clothing, tools, and shelter prior to recorded history.

Banana cultivars (Rieger 1990)**:**

Gros Michel, (AAA genome) - Formerly the most widely cultivated banana in the western hemisphere, it has now been phased out due to susceptibility to Panama disease (*Fusarium* wilt). It has produced several clones and has been used as the parent for newer cultivars. Male sterile.

Giant Cavendish, (AAA genome; syn.s "Mons Mari", "Williams", "Williams Hybrid", "Grand Naine") Similar to "Gros Michel", this is a medium-sized (3–5 m) plant producing fairly large fruits with thicker skin to withstand bruising. Grown in Columbia, Australia, Martinique, Hawaii, and Ecuador. Triploid; male and female sterile.

Dwarf Cavendish, (AAA genome) - A small (4–7 ft) plant bearing medium sized fruit with thin skin. Grown in East Africa, South Africa, and the Canary Islands. Red bananas are found in both Cavendish groups.

Lady finger, from the "Sucrier" group (AA genome), produces small (4–5 inch), very sweet fruits with thin skin. Common in Latin America and Australia.

Plantain cultivars: “Maricongo”, “Common Dwarf”, “Pelipita”, “Saba” (generally AAB, ABB, and BBB genomes) are the leading cultivars. In Florida, 'Macho' is grown as a dooryard cultivar.

Figure E-2. Plantain in the Santa Elena Peninsula

Soils: Deep, well drained alluvial soils are best, but bananas can tolerate a wide variety of soil conditions. Bananas require heavy fertilization for adequate yield 90–140 kg N/acre and up to 220-270 kg K/acre are used.

Climate: The banana is adapted to hot, wet, tropical lowlands. However, in South and East Africa, banana cultivation may extend to 1500 m above sea level. Mean temperature should be 25 °C, and about 100 mm rain/month are required, with dry seasons no longer than 3 months. Frost kills plants to the ground, although the corm usually survives (Rieger 1990).

Citrus fruits - Citrus spp.

The genus Citrus belongs to the Rutaceae family, sub-family Aurantoideae. This family contains many edible species, some distantly related such as White Sapote (Casimiroa edulis Llave & Lex.) and Wampee (Clausena lansium Skeels.).

The literature on citrus usually recognizes each economically important type as a pecies, yielding the following (Rieger 1990):

C. aurantifolia (limes). The two main cultivars include the “Key” (syn. “Mexican”), and “Tahiti” (syn. “Persian”). The latter is sometimes given species status as C. latifolia (Tanaka) or Citrus x tahiti (C. Campbell). C. macrophylla is a lime-like fruit used as a rootstock for lemons in California.

C. sinensis (the sweet oranges). This is a widely accepted name for this group, containing many cultivars:

Navel oranges are unique in that cultivars have a secondary ovary embedded within the usual ovary, giving a small fruitlet at the stylar end of the fruit at maturity; a fruit-within-a-fruit. ‘Washington' is a major cultivar, but there are dozens.

C. reticulata (mandarin, satsuma, or tangerine). This is probably a "real" species. Due to the success of breeding with these types, many cultivars and hybrids have been produced or formed naturally, some erroneously given species status. Common cultivars include: “Dancy”, “Clementine” or “Algerian”, “Owari” (a satsuma), “Cleopatra” (common mandarin rootstock).

C. paradisi (the grapefruit). This is a relatively recent species (since 1700's) of unknown origin. It probably derives from Caribbean “Forbidden Fruit”, and was introduced to other places from there. Cultivars include: “Duncan”, “Marsh”, “Red-blush”, and “Thompson” (syn. “Pink Marsh”). Hybrids include the tangelos and citrumelos; the latter are used as rootstocks.

Soils: Citrus is adapted to a wide variety of soil types and conditions. Trees are grown from almost pure sand, to organic muck, to loamy, heavy soils.

Climate: Citrus fruit obtains highest internal quality in subtropical humid climates. However, with irrigation, it also grows well in Mediterranean climates, like California, achieving the best external quality. In the tropics, citrus accumulates less sugar and acid, and the peel usually remains green; also, bloom is not synchronized, so several stages of maturity are present on the tree at any given time, causing some immature fruit to be harvested (Rieger 1990).

Cold hardiness is the major limiting factor for citrus production in subtropical areas. Fruit are killed by 30 minutes at –1 to –2 °C; larger fruit are more cold tolerant due to greater thermal mass. Fruit freeze from the stem end to the button, and mildly frozen fruit can be salvaged for juice. Leaves and stems are killed by a few minutes at –4 ° C to –2° C, depending on stage of acclimation, species, and age of tissue. Citrus has no chilling requirement, and does not attain a truly dormant state, but becomes quiescent at temperatures below 13 °C (Rieger 1990).

Grapes - Vitis spp.

Grapes belong to the Vitaceae family. The genus Vitis is broadly distributed, largely between 25 ° and 50 ° N latitude in eastern Asia, Europe, the Middle East, and North America. Additionally, a few species of Vitis are found in the tropics: Mexico, Guatemala, the Caribbean, and northern South America (Rieger 1990).

V. vinifera L., "Old world grape", "European grape". This is the major species of grape, accounting for >90 % of world production. It was probably domesticated more than 5000 years ago in the Middle East.

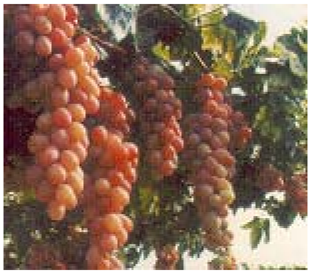

Figure E-3. Grapes

Soils: Grapes are adapted to a wide variety of soil conditions, from high pH and salt, to acidic and clayey. Rootstocks allow adaptation to various soil situations. However, deep, well-drained, light textured soils are best for wine grapes. Highly fertile soils are unsuited to high quality wine production, since vigor and yield must be controlled. Irrigation is detrimental to grape internal quality, and sometimes *illegal* for wine grapes, but is beneficial for table and raisin grapes where high yields are desired.

Climate: Vinifera grapes can be generally characterized as requiring a long growing season, relatively high summer temperatures, low humidity, a ripening season free of rainfall, and mild winter temperatures.

Cold hardiness is a major limiting factor for vinifera grapes. Damage to primary buds occurs at –18 to –23 °C, and trunks may be injured or killed below –23 °C.

Internal quality and hence wine quality is affected by summer temperature.

Humidity is another limiting factor for vinifera grape culture, due to disease susceptibility. Grapes cannot tolerate high RH or rain during harvest (Rieger 1990).

Mango - Mangifera indica L.

The Mango, Mangifera indica L., is the most economically important fruit in the Anacardiaceae (poison ivy family). Other important members of this family include cashew and pistachio.

Figure E-4. Mangos

Cultivars: Hundreds of mango cultivars exist throughout the world. However, in the western hemisphere, a few cultivars derived from a breeding program in Florida are the most popular for international trade. Locally, many cultivars are used, and often seedling trees are grown as a backyard food source.

Tommy Atkins, the most common mango in the US; medium sized (0.5 kg), beautiful exterior but firm, finely fibrous, and low in flavor compared to others. This one sells on eye-appeal.

Keitt, among the largest of major cultivars, about 0.75 kg (up to 1.2 kg). Yellow/green skin color makes it less popular in the US, but the yellow-gold flesh is fiberless and full-flavored.

Kent, red blush to skin, medium sized (0.55 kg), and relatively round. Fiberless, rich-flavored flesh may have a turpentiny aftertaste.

Haden, the old, anthracnose-prone mainstay of Florida market; now replaced by others, but 90 % of Hawaiian production, and grown in Ecuador (Guayaquil area) and western Mexico. Small (< 0.5 kg) and relatively round, the red skin color is excellent when grown in hot, sunny, dry climates. Firm flesh, almost fiberless.

Soils: Mango is adapted to many soil types, but it requires adequate drainage. Excess fertility delays and reduces fruiting. Can be grown on soil with high pH. In Florida, trees are grown on limestone gravel, and still do not develop iron deficiency.

Climate: Adapted to hot, tropical lowlands, to 1,000 m best quality in monsoon climates, i.e., those with a distinct wet and dry season. Leaves and fruit are injured by mild frost (–2 to –1°C), but wood is not killed unless temperatures drop to below –5' °C.

Onion - Allium cepa

Varieties: Onions are often grouped according to taste. The two main types of onions are strong flavored (American) and mild or sweet (sometimes called European). Each has three distinct colors yellow, white, and red. Generally, the American onion produces bulbs of smaller size, denser texture, stronger flavor, and better keeping quality than European types. Globe varieties tend to keep longer in storage (Riofrio & Wittmeyer 2000).

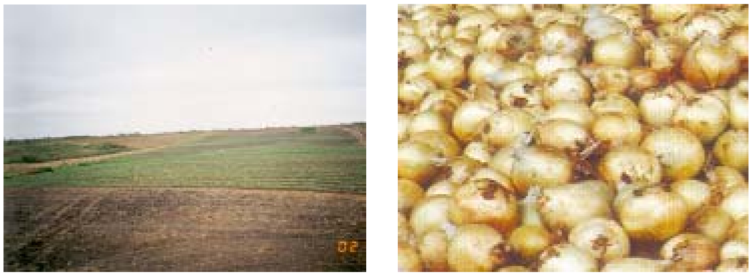

Figure E-5. Onion plantation and onions, Santa Elena Peninsula

Soils: Onions grow best in a loose, well-drained soil with high fertility and plenty of organic matter. Avoid heavier soils such as clay and silt loams, unless they are modified with organic matter to improve aeration and drainage. Onions are sensitive to highly acid soils and grow best when the pH is between 6.2 and 6.8 (Riofrio & Wittmeyer 2000).

Climate: The onion is adapted to a wide range of temperatures and is frost-tolerant. Best production is obtained when cool temperatures prevail over an extended period of time, permitting considerable foliage and root development before bulbing starts. After bulbing begins, high temperature and low relative humidity extending into the harvest and curing period are desirable. A constant supply of adequate moisture is necessary for best results. For onions started from plants, light mulch will help conserve moisture for uniform growth (Riofrio & Wittmeyer 2000).

Papaya - Carica papaya L.

Papaya belongs to a small family of only two genera, the Caricaceae. This family is often lumped into the Passifloraceae or passion fruit family by some. Carica papaya L., the papaya of commerce, is called "Paw-Paw" in some English-speaking countries; however, this is not to be confused with the North American Annonaceous species Asimina triloba Dunal. Carica pentagona Heilborn, the Babaco, is similar to papaya but smaller (<3 m), producing 5-angled fruits reaching 0.3 m in length with few or no seeds (Fruit Facts 2001).

Cultivars: “Solo” or “Sunrise solo”, Introduced to Hawaii from Barbados in 1911, was the first major commercial cultivar. The name derives from the relatively small size of the fruit, it can be eaten by one person, as opposed to the more common family-sized fruits. Very high quality, smaller fruit; female plants produce, rounder, shallowly furrowed fruits, hermaphrodites produce pear-shaped fruits. It has been used as a parent in breeding programs, and produced newer cultivars such as “Kapoho solo”, “Waimanalo”, “Higgins”, and “Wilder”. As of 1999, all of the “Solo” papaya grown in Hawaii is transgenic; it has a gene inserted to confer resistance to papaya ringspot virus (Rieger 1990).

Figure E-6. Papaya plantation in the Santa Elena Peninsula

Soils: Papaya growth is best in soils with pH 5.5–6.7, rich in organic matter. However, fruits may be poor quality on highly fertile soils when vegetative growth is excessive.

Climate: Papaya requires a tropical climate with high rainfall and temperature for proper fruit maturation. Plants are damaged by frost, and completely killed by temperatures close to –5 °C. High wind also causes damage by fruit loss or uprooting (Fruit Facts 2001).

Pineapple - Ananas comosus Merr.

The pineapple, Ananas comosus Merr., is a member of the Bromeliaceae family, a large, diverse family of 2000 species. The bromeliad family contains hundreds of taxa used as ornamentals in greenhouses or sub-tropical areas: Billbergia, Vresia, Nidularium, Pitcairnia, Tillandsia, Tillandsia usneoides is "spanish moss" native to the Gulf States. Formerly, the pineapple was named *A. sativus,* Bromelia ananas, *or B.* comosus (Fruit Facts 2001).

Cultivars: “Smooth Cayenne”, selected and cultivated by Venezuelan indians for its large, juicy fruit and lack of spines on leaves. Subject to diseases, and having poor shipping quality, it has been suplanted by superior sports in many areas. “Hilo” was selected in Hawaii, and “St. Michael” in Azores. Used for canned slices and fresh market. Fruit weight 2–5 kg.

“Red Spanish”, The major fresh cultivar in the Caribbean, the plants are spiny, but disease resistant and fruits ship well. Roundish in shape, orange-red, 1.5–3 kg/fruit, and fewer eyes than “Smooth” (Rieger 1990).

Soils: Well-drained sandy loams, with pH 4.5–6.5 are best. Fumigation is practiced routinely, since nematodes are serious problems in most growing areas.

Climate: Pineapples are resticted to tropical lowlands, with temperatures of 18-35 °C and precipitation of 1,100 mm distributed in spring and fall. Humidity is usually high.

Pineapple is relatively drought-tolerant, and can be grown in areas receiving as little as 600 mm/yr. Alternatively, 3,800 mm/yr are tolerated if drainage is adequate.

If climate during ripening is too cool, fruit are too acid, and if climate is too warm, fruit may be insipidly sweet.

Cherimoya - Annona cherimola

The cherimoya is regarded by many as being among the best of tropical fruits. The cherimoya has a texture of a soft, non-gritty pear and a delicate, highly appealing fruit flavor with little acidity. Cherimoyas usually are eaten fresh; however they are excellent in ice cream and sherbets (Fruit Facts 2001).

Soils: The most critical soil requirement is that of good drainage. Sandy loam or decomposed granite is preferred, but cherimoyas will succeed on many soil types with pH 5 to 8 (Fruit Facts 2001).

Climate: All of the species grown for fruit require a tropical or semitropical climate except for the pawpaw which is native to temperate North America. Moreover, all but the cherimoya are better adapted to wet tropical conditions. The cherimoya's home is the highland tropics which are often characterized as areas of eternal spring with temperatures seldom straying from the 15's ° (C). There are wet and dry seasons with typical annual rainfalls being about 1,200 mm (Fruit Facts 2001).

The cherimoya is adaptable to Mediterranean climates. In addition to San Diego and Santa Barbara and Ventura counties in the United States, significant commercial plantings have been made in Chile, Spain, Peru, Israel, New Zealand, Australia and Italy.

The cherimoya requires a relatively frost-free environment similar to lemons (short periods of –2 °C for mature trees of hardy varieties). Some chilling seems beneficial (50 to 100 hours between 1 °C and 5 °C). However, a sunny location is needed since sufficient heat is required to develop a good flavor (inland, protection from extremely hot temperatures and dry winds is more important). In California most varieties do well extending 2 to 8 km inland from the ocean. Further inland, care must be exercised in selecting a variety that will do well. The cherimoya will not tolerate prolonged high humidity, such as is encountered in Florida (Fruit Facts 2001).

Avocado - Persea spp.

Species: Guatemalan (Persea nubigena var. guatamalensis L. Wms.), Mexican (P. americana var. drymifolia Blake), West Indian (P. americana Mill. var. americana). Hybrid forms exist between all three types (National Department of Agriculture 2000).

Soil: Avocado trees like loose, decomposed granite or sandy loam best. They will not survive in locations with poor drainage. The trees grow well on hillsides and should never be planted in stream beds. They are tolerant of acid or alkaline soil (National Department of Agriculture 2000).

Climate: The 3 best-known avocado races each has specific climatic requirements as a result of adapting to their original environment.

West Indian cultivars originated in the humid, tropical lowlands of Central America and are best adapted to continuous hot, humid conditions with a high summer rainfall. Like all avocado cultivars they are, however, extremely sensitive to drought and do not tolerate frost well (minimum temperature of 1.5 °C). The optimum temperature for growth is 25 to 28 °C. The humidity should preferably be above 60 % (National Department of Agriculture 2000).

The Mexican races originated in the cool, subtropical highland forests of Mexico and mature trees can withstand temperatures of –4 to –5 °C. They should not be planted in areas prone to frost in August and September, because flowers are damaged easily by frost. A humidity range of 45 to 60 % should suffice. The optimum temperature for growth is 20 to 24 °C (National Department of Agriculture 2000).

Guatemalan cultivars originated from the tropical highlands of Guatemala and require a cool, tropical climate without any extremes of temperature or humidity. The trees can withstand light frost, down to –2 °C, but the flowers are very sensitive to frost. High temperatures of about 38 °C, especially if combined with low humidity, could cause flower and fruit drop. A humidity level of 65 % or higher is required (National Department of Agriculture 2000).

Tomato - Lycopersicon esculentum

Soils: A wide variety of soil textures are used for fresh-market tomato production. Sandy soils are preferred for early plantings (Hochmuth 2001). This is because planting can be done in sandy soils more easily during wet weather. Sand also warms more rapidly in the spring, promoting early growth. Loam and clay loam soils, however, are generally more productive than sand. Clay soil may be used, provided it is well drained and irrigated with care (Tomato Production Guide for Florida 2002).

Climate: The tomato is a warm-season vegetable crop that is sensitive to frost at any stage of growth. The optimum soil temperature for seed germination is 20 °C or above; seed germination below 16 °C is very slow. Optimal production temperatures are between 21 °C and 27 °C. These temperatures are ideal for vegetative growth, fruit set, and development. With adequate soil moisture, tomato plants can tolerate temperatures in excess of 38 °C, although fruit set is adversely affected. Tomato fruit development and quality are reduced when day temperatures fall below 20 °C, and plants undergo chilling injury when night temperatures fall below 10 °C (Tomato Production Guide for Florida 2002).

Melon (Cantaloupe) - Cucumis melo L

Soils: Melons prefer well-drained soils. Sandy or silt loams are sometimes selected for the earliest crop. Heavier soils are preferred because of their greater water holding capacity, which slows the onset of vine collapse. Beds should be left cloddy to allow maturing melons to develop with minimal soil contact and good aeration (Mayberry 1996).

Cantaloupes grow best on soils that hold water well and have good air and water infiltration rates. Soil should have a pH of 5.8 to 6.6. Cantaloupes are sensitive to cold temperatures, and even a mild frost can injure the crop (Mayberry 1996).

Climate: The best average temperature range for cantaloupe production during the growing season is between 20 °C and 30 °C; temperatures above 30 °C or below 15 °C will slow the growth and maturation of the crop (Orzolek 2002).

Irrigation: Cantaloupes require a constant supply of moisture during the growing season. However, excess water at any time during crop growth, especially as fruit reaches maturity, can cause the fruit to crack, which will reduce crop yields and fruit quality (Orzolek 2002).

Guava - Psidium guajava L

The place of origin of the guava is uncertain, but it is believed to be an area extending from southern Mexico into or through Central America. It has been spread by man, birds and other animals to all warm areas of tropical America and in the West Indies (since 1526).

The guava is an evergreen tree reaching a height of 3–10 m. The trunk is slender with a greenish-brown scaly bark which peels off in thin flakes. The white flowers are either solitary or in groups of two or three, arising from the leaf axils of younger branches. The fruit is round, ovoid or pear- shaped berry, 5 cm or more in diameter and 4–12 cm long. It has a thin greenish-yellow skin and a flesh of varying thickness which may be white, yellow-pink or red. The outer layer of flesh is a finely granular pulp; the inside is softer pulp with many small hard seeds. Some varieties are seedless. The flavor is variable and is distinguished by a characteristic and penetrating musky aroma of varying intensity.

Guava, a native of tropical America is well distributed throughout the tropics and subtropics.

Soils: the guava is a hardy plant which grows in most soil types. Loam and alluvial types of soil is most ideal. The guava will tolerate many soil conditions, but will produce better in rich soils high in organic matter. They also prefer a well-drained soil in the pH range of 5 to 7. The tree will take temporary water logging but will not tolerate salty soils.

Although the guava can tolerate low moisture condition, availability of water constantly will promote fast growth and leaf flushes. A warm, humid condition is most optimum for guavas. Guavas have survived dry summers with no water, although they do best with regular deep watering. The ground should be allowed to dry to a depth of several inches before watering again. Lack of moisture will delay bloom and cause the fruit to drop.

Fig - Ficus carica L.

Climate: the fig grows best and produces the best quality fruit in Mediterranean and dryer warm-temperate climates. Rains during fruit development and ripening can cause the fruits to split. With extra care figs will also grow in wetter, cooler areas. Diseases limit utility in tropical climates. Fully dormant trees are hardy to –4 °C to –5 °C, but plants in active growth can be damaged at 0 °C. Figs require full sun all day to ripen palatable fruits. Trees become enormous, and will shade out anything growing beneath. The succulent trunk and branches are unusually sensitive to heat and sun damage, and should be whitewashed if particularly exposed. Roots are greedy, traveling far beyond the tree canopy. In areas with short (less than 120 days between frosts), cool summers, espalier trees against a south-facing, light-colored wall to take advantage of the reflected heat. In coastal climates, grow in the warmest location, against a sunny wall or in a heat trap (Rieger 1990).

Irrigation: young fig tees should be watered regularly until fully established. Is recommended to water mature trees deeply at least every one or two weeks. Desert gardeners may have to water more frequently. Mulch the soil around the trees to conserve moisture. Also, drought-stressed trees will not produce fruit and are more susceptible to nematode damage. Recently planted trees are particularly susceptible to water deficits, often runt out, and die (Rieger 1990).

Watermelon - Citrullus lanatus

Watermelon is a warm-season crop related to cantaloupe, squash, cucumber and pumpkin.

Soils: most well drained soil, whether clayey or sandy, can be managed to produce a good crop of watermelon. The best soils, however, are sandy loams that have not been in cucurbit (cantaloupe, cucumber, squash, etc.) production for a minimum of five years (Boyham 2001).

Irrigation: 250 mm of timely rains or irrigations on a deep, sandy soil produce a good crop of watermelons. Growers with limited irrigation capabilities can often increase yields with only one or two irrigations. Inadequate moisture at planting results in poor and uneven emergence. Moisture shortage at bloom results in poor fruit set and misshapen fruit. Moisture stress close to harvest greatly reduces melon size and results in rapid vine decline. When irrigating, apply one to two inches of water (Roberts 2002).

APPENDIX F
IRRIGATION REQUIREMENTS

Table F-1. Chongón-San Isidro, 50% efficiency

	Irrigation Requirement (mm) Chongón-San Isidro, 50% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	94.8	111.0	126.4	117.9	112.3	106.1	112.8	109.4				
Asparagus							95.2	119.3	136.5	91.7		
Plantain	76.3	76.2	74.4	85.9	151.1	139.5	146.0	145.8	23.6			
Citrus	106.8	106.7	104.1	99.8	126.5	90.5	88.8	89.6	93.2	97.3	100.1	87.2
Grapes-T	61.0	60.9	59.5	57.0	74.5	83.0	111.1	116.5	121.9	127.3	123.4	68.6
Mango	136.8	136.9	133.9	133.2	183.0	143.2	146.0	150.8	155.6	156.6	149.3	118.2
Onion					111.3	116.9	139.4	138.4	58.1			
Pineapple	73.7	60.5	44.6	42.8	28.7							
Potato	86.2	133.9	171.1	150.8	37.4							
Melon								83.2	134.4	157.5	137.3	
Watermelon								82.4	103.0	150.0	133.6	
S-Pepper								112.1	127.8	157.5	153.1	
B-Pepper	93.9	115.6	153.6	147.8	111.3	116.9	139.4	136.6				

Table F-2. San Isidro-Playas, 50% efficiency

	Irrigation Requirement (mm) San Isidro-Playas, 50% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	116.6	137.3	157.1	146.0	117.2	127.7	134.1	129.1				
Asparagus							113.3	140.8	160.8	108.4		
Plantain	93.8	94.2	92.4	106.3	184.7	167.8	173.6	172.0	27.8			
Citrus	131.3	131.9	129.4	123.5	154.7	108.8	105.6	105.7	88.3	115.0	118.8	103.8
Grapes-T	75.0	75.3	73.9	70.6	91.1	99.8	132.0	137.5	143.7	150.3	146.5	81.7
Mango	168.2	169.3	166.3	164.9	223.8	172.3	173.6	177.9	185.3	185.0	179.0	140.7
Onion					136.0	140.7	165.7	163.3	68.4			
Pineapple	90.5	74.8	55.4	53.0	31.9							
Potato	106.1	165.3	212.5	186.7	46.0							
Melon								98.2	158.4	186.2	163.0	
Watermelon								97.3	151.4	177.3	158.6	
S-Pepper								132.4	150.6	186.2	181.7	
B-Pepper	115.4	143.0	190.8	182.9	136.0	140.7	165.7	161.3				

Table F-3. Chongón-El Azúcar, 50% efficiency

	Irrigation Requirement (mm) Chongón-El Azúcar, 70% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	96.1	113.7	131.2	122.9	116.7	108.9	114.1	108.9				
Asparagus							96.4	119.0	134.5	92.3		
Plantain	77.3	78.0	77.2	89.6	157.0	143.2	147.6	145.2	23.3			
Citrus	108.2	109.2	108.0	104.1	131.4	92.9	89.8	89.2	91.9	95.5	98.5	86.5
Grapes-T	61.8	62.4	61.7	59.5	77.5	85.2	112.2	116.0	120.2	124.7	121.5	67.8
Mango	139.1	140.3	138.8	138.9	190.2	147.0	147.6	150.4	153.3	153.7	146.9	117.3
Onion					115.6	120.0	140.9	137.8	57.4			
Pineapple	74.6	61.9	46.3	44.6	14.4							
Potato	87.5	137.3	178.2	157.3	38.9							
Melon								82.9	132.3	154.6	135.2	
Watermelon								82.1	101.0	147.2	131.6	
S-Pepper								111.8	125.8	154.6	153.2	
B-Pepper	95.2	118.4	159.4	154.1	115.6	120.0	140.9	136.1				

Table F-4. Chongón - San Isidro, 70% efficiency

	Irrigation Requirement (mm) Chongón-San Isidro, 70% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	82.2	96.2	109.6	102.2	97.4	92.0	97.8	94.8				
Asparagus							82.5	103.4	118.3	79.5		
Plantain	66.1	66.0	64.4	74.5	131.0	120.9	126.5	126.3	20.4			
Citrus	92.6	92.4	90.2	86.5	109.6	78.4	77.0	77.6	80.8	84.3	86.7	75.6
Grapes-T	52.9	52.8	51.6	49.4	64.6	71.9	96.2	101.0	105.7	110.3	107.0	59.5
Mango	118.5	118.7	116.0	115.4	158.6	124.1	126.5	130.7	134.8	135.7	129.4	102.4
Onion					96.4	101.4	120.8	119.9	50.3			
Pineapple	63.8	52.5	38.7	37.1	24.9							
Potato	74.7	116.0	148.3	130.7	32.4							
Melon								72.1	116.5	136.5	119.0	
Watermelon								71.4	89.2	130.0	115.8	
S-Pepper								97.2	110.8	136.5	132.7	
B-Pepper	81.4	100.2	133.1	128.1	96.4	101.4	120.8	118.4				

Table F-5. San Isidro-Playas, 70% efficiency

	Irrigation Requirement (mm) San Isidro-Playas, 70% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	101.0	119.0	136.1	126.5	101.6	110.7	116.2	111.9				
Asparagus							98.2	122.0	139.4	93.9		
Plantain	81.3	81.6	80.1	92.1	160.1	145.5	150.4	149.1	24.1			
Citrus	113.8	114.3	112.1	107.1	134.0	94.3	91.5	91.6	76.5	99.6	103.0	90.0
Grapes-T	65.0	65.3	64.1	61.2	79.0	86.5	114.4	119.2	124.5	130.3	127.0	70.8
Mango	145.8	146.8	144.1	142.9	193.9	149.4	150.4	154.2	160.6	160.3	155.1	121.9
Onion					117.9	121.9	143.6	141.5	59.3			
Pineapple	78.5	64.8	48.0	45.9	27.6							
Potato	91.9	143.3	184.2	161.8	39.8							
Melon								85.1	137.3	161.4	141.3	
Watermelon								84.3	131.2	153.7	137.5	
S-Pepper								114.8	130.5	161.4	157.5	
B-Pepper	100.1	123.9	165.4	158.5	117.9	121.9	143.6	139.8				

Table F-6. Chongón-El Azúcar, 70% efficiency

	Irrigation Requirement (mm) Chongón-El Azúcar, 70% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	83.3	98.5	113.7	106.5	101.2	94.4	98.8	94.4				
Asparagus							83.6	103.1	116.5	80.0		
Plantain	67.0	67.6	66.9	77.6	136.1	124.1	127.9	125.8	20.2			
Citrus	93.8	94.6	93.6	90.2	113.9	80.5	77.8	77.3	79.6	82.7	85.4	75.0
Grapes-T	53.6	54.1	53.5	51.5	67.1	73.8	97.3	100.6	104.1	108.0	105.3	58.8
Mango	120.6	121.6	120.3	120.4	164.8	127.4	127.9	130.3	132.8	133.2	127.3	101.6
Onion					100.2	104.0	122.1	119.4	49.7			
Pineapple	64.7	53.6	40.1	38.6	12.5							
Potato	75.8	119.0	154.4	136.3	33.7							
Melon								71.9	114.7	134.0	117.2	
Watermelon								71.2	87.5	127.6	114.0	
S-Pepper								96.9	109.1	134.0	132.7	
B-Pepper	82.5	102.6	138.1	133.5	100.2	104.0	122.1	117.9				

Table F-7. Chongón-San Isidro, 90% efficiency

	Irrigation Requirement (mm) Chongón-San Isidro, 90% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	69.5	81.4	92.7	86.5	82.4	77.8	82.7	80.2				
Asparagus							69.8	87.5	100.1	67.3		
Plantain	56.0	55.9	54.5	63.0	110.8	102.3	107.1	106.9	17.3			
Citrus	78.3	78.2	76.4	73.2	92.8	66.3	65.1	65.7	68.4	71.3	73.4	63.9
Grapes-T	44.8	44.7	43.6	41.8	54.7	60.9	81.4	85.4	89.4	93.4	90.5	50.3
Mango	100.3	100.4	98.2	97.7	134.2	105.0	107.1	110.6	114.1	114.8	109.5	86.6
Onion					81.6	85.8	102.2	101.5	42.6			
Pineapple	54.0	44.4	32.7	31.4	21.1							
Potato	63.2	98.2	125.4	110.6	27.4							
Melon								61.0	98.5	115.5	100.7	
Watermelon								60.4	75.5	110.0	98.0	
S-Pepper								82.2	93.7	115.5	112.2	
B-Pepper	68.9	84.8	112.7	108.4	81.6	85.8	102.2	100.2				

Table F-8. San Isidro-Playas, 90% efficiency

	Irrigation Requirement (mm) San Isidro-Playas, 90% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	85.5	100.7	115.2	107.0	86.0	93.6	98.4	94.7				
Asparagus							83.1	103.3	118.0	79.5		
Plantain	68.8	69.1	67.7	78.0	135.5	123.1	127.3	126.2	20.4			
Citrus	96.3	96.7	94.9	90.6	113.4	79.8	77.4	77.5	64.7	84.3	87.1	76.1
Grapes-T	55.0	55.3	54.2	51.8	66.8	73.2	96.8	100.8	105.4	110.3	107.4	59.9
Mango	123.4	124.2	122.0	120.9	164.1	126.4	127.3	130.5	135.9	135.7	131.2	103.2
Onion					99.8	103.1	121.5	119.7	50.2			
Pineapple	66.4	54.8	40.6	38.8	23.4							
Potato	77.8	121.2	155.8	136.9	33.7							
Melon								72.0	116.1	136.5	119.5	
Watermelon								71.3	111.0	130.0	116.3	
S-Pepper								97.1	110.5	136.5	133.3	
B-Pepper	84.7	104.9	139.9	134.1	99.8	103.1	121.5	118.3				

Table F-9. Chongón-El Azúcar, 90% efficiency

	Irrigation Requirement (mm) Chongón-El Azúcar, 90% irrigation efficiency											
Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Avocado	70.5	83.4	96.2	90.2	85.6	79.9	83.6	79.9				
Asparagus							70.7	87.2	98.6	67.7		
Plantain	56.7	57.2	56.6	65.7	115.1	105.0	108.2	106.5	17.1			
Citrus	79.4	80.0	79.2	76.3	96.4	68.1	65.8	65.4	67.4	70.0	72.3	63.5
Grapes-T	45.4	45.7	45.3	43.6	56.8	62.4	82.3	85.1	88.1	91.4	89.1	49.7
Mango	102.0	102.9	101.8	101.8	139.5	107.8	108.2	110.3	112.4	112.7	107.8	86.0
Onion					84.8	88.0	103.3	101.1	42.1			
Pineapple	54.7	45.4	33.9	32.7	10.6							
Potato	64.1	100.7	130.7	115.3	28.5							
Melon								60.8	97.0	113.4	99.2	
Watermelon								60.2	74.1	108.0	96.5	
S-Pepper								82.0	92.3	113.4	112.3	
B-Pepper	69.8	86.9	116.9	113.0	84.8	88.0	103.3	99.8				

APPENDIX G
PROGRAM TO CALCULATE CROP IRRIGATION REQUIREMENT

This Excel program uses the crop water requirements calculated using CROPWAT (FAO/UN) plus an application (irrigation) efficiency factor, to determine crop irrigation requirement.

The program can calculate values for three zones: El Azúcar-Chongón, Chongón-San Isidro, and San Isidro-Playas.

In Figure G-1, the inputs for the program are entered into Table 1. The user inputs 1 (one) for crops that are considered in the calculations, and 0 (zero) for crops that are not planted. In this scenario asparagus, citrus, onion, melon, and watermelon. In the example presented here 70 % application efficiency was entered.

The outputs for the Chongón-San Isidro zone are presented in the graph (Figure G-1) and in Table 2 (Figure G-2). These values are expressed in mm of water per month, and represent supplementary irrigation that has to be applied to the crop in each month.

Table 1

Chongón - San Isidro		
Enter estimated in-field efficiency (percentage):		**70**
	Select Crops	
Avocado	0	
Asparagus	1	
Plantain	0	
Citrus	1	
Grapes Table	0	
Mango	0	
Onion	1	
Pineapple	0	
Potato	0	
Melon	1	
Watermelon	1	
Sweet Pepper	0	
Black Pepper	0	

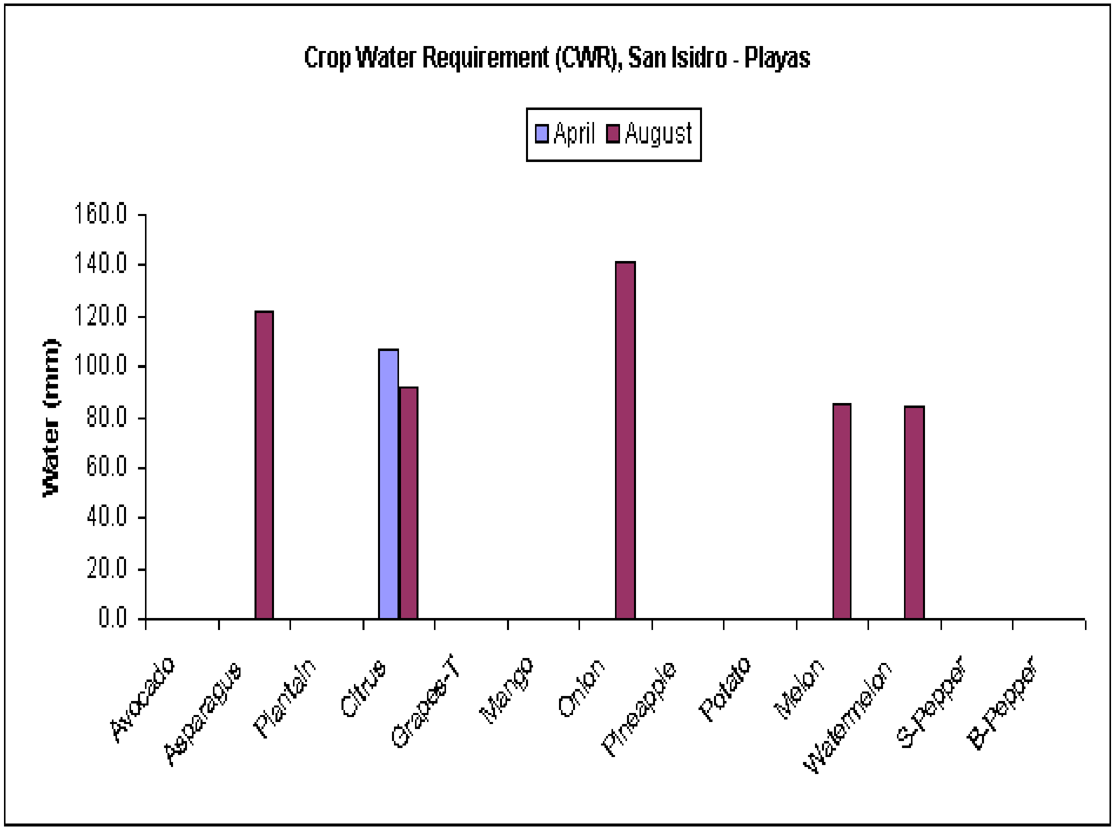

Figure G-1. Program to calculate crop irrigation requirement, input table and graph

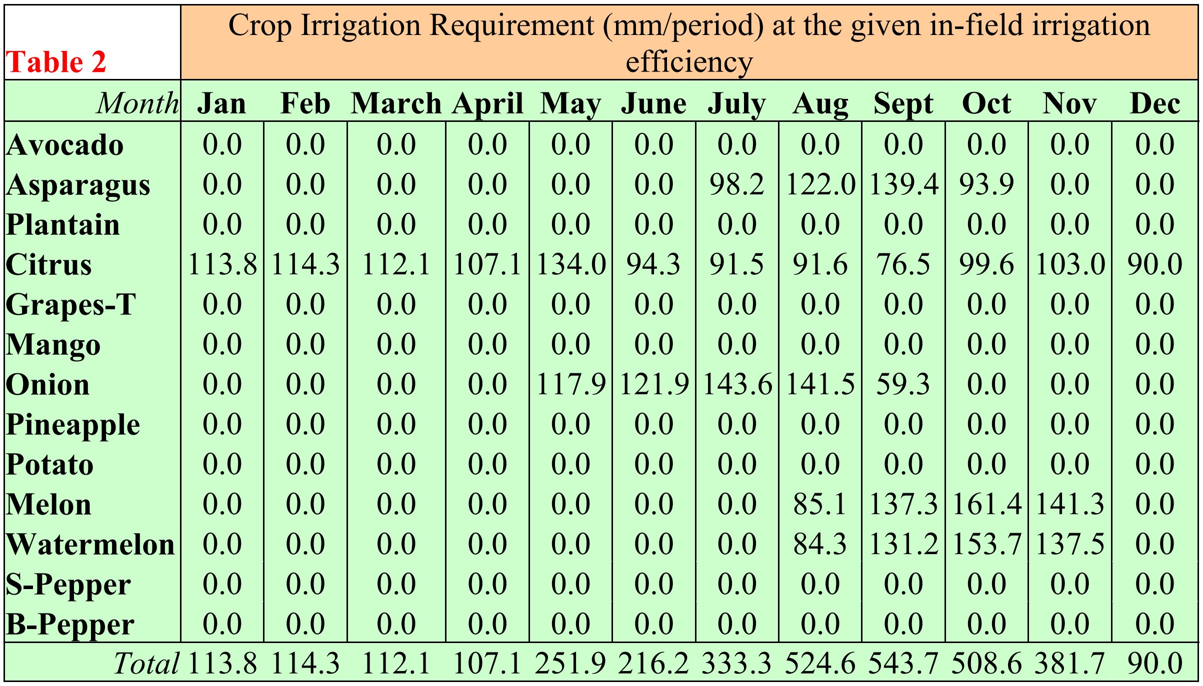

Table 2	Crop Irrigation Requirement (mm/period) at the given in-field irrigation efficiency											
Month	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Avocado	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asparagus	0.0	0.0	0.0	0.0	0.0	0.0	98.2	122.0	139.4	93.9	0.0	0.0
Plantain	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Citrus	113.8	114.3	112.1	107.1	134.0	94.3	91.5	91.6	76.5	99.6	103.0	90.0
Grapes-T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mango	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Onion	0.0	0.0	0.0	0.0	117.9	121.9	143.6	141.5	59.3	0.0	0.0	0.0
Pineapple	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potato	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Melon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.1	137.3	161.4	141.3	0.0
Watermelon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.3	131.2	153.7	137.5	0.0
S-Pepper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-Pepper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	113.8	114.3	112.1	107.1	251.9	216.2	333.3	524.6	543.7	508.6	381.7	90.0

Figure G-2. Program to calculate crop irrigation requirement, results table

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BIOGRAPHICAL SKETCH

Camilo Cornejo Dávila born in July 11, 1978, in Quito, Ecuador. He attended high school at “Colegio Salesiano Sanchéz y Cifuentes” in Ibarra, Ecuador, graduating in 1996. He attended the Escuela Agricola Panamericana “El Zamorano” in Honduras, and later received his “Agronomo” degree in December 1999. He continued further studies at the University of Florida, College of Agriculture and Life Sciences, obtaining the Bachelor of Science degree in May 2001; and the Master of Science degree in agricultural and biological engineering in May 2003.