**The University of Hawai'i at Mānoa**
Department of Natural Resources and Environmental Management
College of Tropical Agriculture and Human Resources, University of Hawaii-Manoa

# Water Management Software to Estimate Crop Irrigation Requirements for Consumptive Use Permitting In Hawaii

## Final Report

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**Prepared for:**
STATE OF HAWAII
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**COMMISSION OF WATER RESOURCES MANAGEMENT**
P.O. BOX 621
Honolulu, HI 96809

**Submitted by:**
Ali Fares, PhD
Associate Professor of Watershed Hydrology and Tropical Soils,
Department of Natural Resources and Environmental Management,
College of Tropical Agriculture and Human Resources,
University of Hawai`i at Mānoa,
1910 East-West Road, Honolulu, HI 96822

# EXECUTIVE SUMMARY

Irrigation Water Requirement Estimation Decision Support System (IWREDSS) is an ArcGIS-based numerical simulation model developed as part of the Water Management Software to Estimate Crop Irrigation Requirements for Consumptive Use Permitting in Hawaii project. The model calculates irrigation requirements (IRR) for different crops grown under Hawaiian conditions. In addition to IRR, IWREDSS calculates other water budget components including net irrigation water requirements (*NIR*), gross irrigation water requirements (*GIR*), water duty in 1000 gallons per acre (GAL_A), gross rain (G_RAIN), net rain (N_RAIN), effective rain (*ER*), runoff (*RO*), canopy interception (*INT*), potential evapotranspiration ($ET_O$), reference evapotranspiration ($ET_C$), and drainage (*DR*). IWREDSS calculates GIR for different irrigation application systems; trickle-drip, trickle-spray, multi sprinkler, nursery/container sprinkler, large gun sprinkler, seepage/sub irrigation, crown flood, and flood (Taro), growing seasons and irrigation practices; irrigate to field capacity (usual practice), apply a fixed water rate per irrigation, deficit or rainfed. IWREDSS takes in account the effect of water table on IRR calculations through the depth to water table option; its default value was set to 50 ft.

IWREDSS uses long-term weather, crop parameters, and soil physical properties databases. These databases and other input parameters used by IWREDSS are summarized in this report and include 1) pan evaporation/potential evapotranspiration, total and effective rainfall from National Oceanographic and Atmospheric Administration (NOAA) cooperative observer stations, 2) NOAA climate stations, 3) aquifer system maps, 4) soil water holding capacities based on USDA-NRCS soil survey, and 5) crop water management parameters including (a) length of growing season, (b) crop coefficient, (c) evapotranspiration, and (d) effective rooting depth of various crops.

IWREDSS runs as an extension of the ESRI ArcGIS 9.2 software. The user's manual of IWREDSS provides step by step instructions on how to use IWREDSS for various scenarios which include 1) Island-wide simulation using Agricultural Lands of Importance to the State of Hawaii (ALISH), 2) Island-wide simulation using Land Study Bureau Classification (LSB), 3) particular area simulation using Tax_ID from a TMK, and 4) simulation of a user's provided GIS layer (digitized information). IWREDSS outputs can be retrieved in form of text (ASCII) files and visualized in ArcMap.

IWRDESS was calibrated and validated based on crop water requirement for different crops using the Hawaii USDA-NRCS Handbook 38 (USDA-NRCS, 1996). A sensitivity analysis was also carried out to test the effect of the timing of the growing seasons on IRR for Seed Corn. During this analysis, we used twelve different growing seasons that were rotated between January and December, i.e., the first growing season was January 1 to April 30 and the twelfths growing season was between December 1 of the year one and March 30 of the year 2. Estimations of IRR were also calculated for different bioenergy crops for windward and leeward conditions on the islands of Maui, Kauai, Oahu and Hawaii. Results of the analysis showed that IWREDSS is a practical tool that can be used to assess irrigation requirements for a variety of potential and specific crops of Hawaiian Islands. IWREDSS model estimates were in close agreement with those estimated by USDA-NRCS Handbook 38.

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**GLOSSARY**:

- ALISH: Agricultural Lands of Importance to the State of Hawaii.
- AWD (Allowable Water Depletion): Fraction of the available soil water storage capacity that can be allowed to deplete without significant reduction in crop yield.
- DR (Drainage): Portion of incoming water that drains below plant root zone.
- ER (Effective Rain): Portion of water that is stored in the root zone and used by the plants.
- $ET_C$ (Reference Evapotranspiration): Portion of water that vaporizes back to the atmosphere via plants. The $ET_C$ is the amount of $ET_O$ occurring from a specific crop.
- $ET_O$ (Potential Evapotranspiration): Evapotranspiration to the given atmospheric conditions.
- G_RAIN (Gross Rain): The rain that falls from the clouds and reaches the crown of plants.
- GAL_A: Water duty in inches of 1000 gallons per acre.
- GIR (Gross Irrigation Requirements): NIR divided by the application efficiency of irrigation application system.
- GIS: Geographic information system.
- INT (Canopy Interception): Portion of G_RAIN intercepted by the plant canopy or crown.
- IWREDSS: Irrigation Water Requirement Estimation Decision Support System.
- IRR: Irrigation requirements
- $K_C$: Crop coefficient.
- LAI (Leaf Area Index): Ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows.
- LSB: Island-wide simulation using Land Study Bureau Classification.
- N_RAIN (Net Rain): The volume of rainfall that reaches the soil and comprises throughfall and stemflow.
- NIR (Net Irrigation Requirements): Irrigation requirements estimated by model without accounting for irrigation losses.
- PE: Open pan evaporation
- RO (Runoff): Portion of incoming water that runs off to the low level areas.
- SCS CN (Soil Conservation Services Curve Number): It is related to the imperviousness of a surface; for impervious and water surfaces CN=100, for natural surfaces CN < 100.

## 1. INTRODUCTION

<u>I</u>rrigation <u>W</u>ater <u>R</u>equirement <u>E</u>stimation <u>D</u>ecision <u>S</u>upport <u>S</u>ystem, IWREDSS, was developed as part of the Water Management Software to Estimate Crop Irrigation Requirements for Consumptive Use Permitting in Hawaii project. IWREDSS allows users to estimate irrigation requirements for different crops, soils, irrigation systems, growing seasons, and climate conditions. The irrigation requirement of a crop is the amount of water required by the crop, in addition to precipitation, to meet its water demand resulting from evapotranspiration (ET). The irrigation requirements do not account for excess water losses due to poor irrigation

management, leaching, and water applied for freeze protection, or crop cooling requirements, even though water for these purposes may be applied through an irrigation system.

IWREDSS is an ArcGIS based software with a user-friendly interface. There are two ways that the user can follow to select the area for which irrigation requirements, IRR, are calculated. First, the user can use the Tax-ID GIS layer. The second option would be to use a georeferenced map of the area. In this document, we have details on how to digitize a hard copy of the area of interest. After choosing the area of interest, the user continues entering the input parameters. This includes crop to be grown/irrigated, crop leaf area index (LAI), the growing season, irrigation system to be used, appropriate curve number, and water table depth. In addition to these user selected data, IWREDSS uses the corresponding weather and soil data from its Geodatabases. Based on the coordinates of the location and the closest climate station, IWREDSS interpolates the appropriate rainfall and evapotranspiration for the area of interest that is used for IRR calculations. On successful execution, the users are given the option to retrieve and visualize the results in the form of a text (ASCII) file and a GIS map.

Recent developments in geographical information systems (GIS) present the opportunity to apply physically based soil water balance and simulation models at a regional scale (Satti et al, 2004). Satti and Jacobs (2004) developed GWRAPPS (GIS-based Water Resources and Agricultural Permitting and Planning System) model by coupling the AFSIRS model with GIS. Several models including CropSyst (Stockle et al., 1994), AEGIS/WIN (Engel et al., 1997), and GWRAPPS are able to simulate the soil water budget components (WBC) by coupling crop and soil parameters with long-term climate databases.

This report covers the following deliverables.

- Databases of the IWREDSS elements and parameters
- GIS island maps showing climate stations used to develop the rainfall and ET databases.
- A DVD containing tested version of IWREDSS
- Results of IWREDSS calibration and validation
- Results of IWREDSS sensitivity analysis
- Testing of IWREDSS using energy crops
- IWREDSS user manual
- IWREDSS technical guide

The user's manual and the technical guide for IWREDSS are two separate documentations and are attached with this report as appendices 1 and 2, respectively.

## 2. REVIEW OF LITERATURE

Technical Release 21 method developed by the Soil Conservation Service (SCS, 1970), estimates monthly IRR based on monthly average rainfall and ET, and on soil water-holding capacity. However, IWREDSS model integrates the effects of day-to-day distributions of rainfall, ET, and soil water-holding capacity to calculate IRR.

Since the 1980's, the regional water management districts of Florida have been using this daily water budget approach. Melaika and Bottcher (1988) applied this approach to model nutrient movement from a South Florida watershed in the Everglades Agricultural Area. Villalobos and Fereres (1989) developed a water budget model based on long-term average potential ET and actual rainfall data. In their model, potential ET was assumed to be constant each year because long-term data were not available. Water budget approach is used to develop a crop yield model, and weather data are simulated if long-term climate data were not available. Smajstrla and Zazueta (1987) demonstrated the data requirements and sensitivity of the water budget approach to determine irrigation requirements of Florida nursery and agronomic crops.

Water budget models have been developed for different crops. Brown et al. (1978), Odhiambo and Murty (1996), and Mishra (1999) studied the water balance of rice. Pereira (1989) developed the rice water balance model IRRICEP and tested its performance against field data. Smith (1991) developed a simulation model, CROPWAT, that also uses water balance approach. Paulo et al. (1995) validated IRRICEP using historical data on water use for selected sectors of Sorraia irrigation system in Brazil. Shah and Edling (2000) used the water balance approach to determine daily evapotranspiration from a flooded rice field based on measured values of water level, precipitation, irrigation, seepage, and tail water runoff. Khepar et al. (2000) developed a water balance model applicable to intermittent irrigation practice in rice fields by incorporating saturated and unsaturated water flow concepts to predict deep percolation losses during wet and dry periods.

Many water budget models lack user-friendly interface and offer limited flexibility in selecting a suitable method for estimating potential evapotranspiration. There had been some efforts to couple user-friendly interfaces with GIS for efficient and quick data handling. Knox et al. (1996, 1997) developed a procedure for mapping the spatial distribution of irrigation water requirements for a main crop (potato) by taking into account crop, climate and soil factors in England and Wales. George et al. (2000) developed a user-friendly irrigation scheduling model, ISM, for field crops. Weatherhead and Knox (2000) developed a methodology for predicting the future growth in irrigation demand in countries with supplemental irrigation such as England and Wales using GIS. The GIS based water- and salt-balance studies at irrigation district level have also been attempted (Young and Wallender, 2002). George et al. (2004) used GIS as a helping tool to handle spatial and extensive input information for their irrigation scheduling model.

IWREDSS calculates IRR on a weekly, bi-weekly and monthly basis giving the user different options for periodical irrigation requirements. IWREDSS uses different databases to calculate IRR.

## 3. DATABASES

IWREDSS database includes historical daily potential evapotranspiration and rainfall for different locations across the major five Hawaiian Islands. The range of these two databases is variable across the different locations. In addition, there is the crop database that includes all crop coefficients and root development parameters.

### 3.1 Crop Parameters

The crop parameters including effective rooting depths, crop coefficients (Kc), duration of crop cycle, allowable water depletion for the listed annual (Table 1) and perennial (Table 2) crops.

### 3.2 Irrigation System Efficiency

Irrigation efficiencies of the preferred irrigation systems including sprinkler, micro-spray, and drip irrigation systems are listed in Tables 1 and 2.

### 3.3 Climate Stations and Soils

There are two full climate stations operating in Hawaii.

(1) At HI Mauna Loa 5 NNE Mauna Loa Observation, NOAA Earth Systems Research Lab.,Global Monitoring Division, location: 19.5N 155.6W 11092’ (Fig. 1).

(2) At University of Hawaii Waiakea Experiment Station which is named HI Hilo 5 S, location: 19.6N 155.1W 730’ (Fig. 2).

Rainfall and ET were measured (Appendix 3) at different stations across the major Hawaiian Islands. The stations include Mana, Kekaha, Wahiawa, McBryde Station (ET), Bydswood Station (rain), Lihue Variety Station, Kunia Substation, Waimanalo Experiment Station, Kualapuu Reservoir (ET), Kualapuu (rain), Pohakea Bridge (Rain), Field 906 (ET), Kula Branch, Lalaumilo , Hamakua Makai Field Office, and Paauilo (Appendices 4a to 4d). Rain isohyets demonstrate high spatial variation in rainfall (dark contours) to a certain extent with elevation (light contours). Station information is provided in Table 3. Characteristics of Climate stations are given in Table 3. Texture and water holding capacity of the major soil types in Hawaii are presented in Table 4.

**3.4 Rainfall and Evapotranspiration**

The rainfall and ET data cover different periods i.e., period of 25 years (1980-2005) and accompany IWREDSS in shape of GIS layers and excel spreadsheets.

Table 1. Annual crop effective root depth, Kc values and stage lengths as a fraction of growing period

| Crop | Root depth (in) | | $Kc_{initial}$ | $Kc_{mid}$ | $Kc_{late}$ | Duration (fraction of crop cycle) | | | | Allowable water depletion (fraction of total) | | | | Irrigation type | Irrigation efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | Final | | | | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 1 | Stage 2 | Stage 3 | Stage 4 | | |
| Alfalfa, initial | 8 | 24 | 0.4 | 0.95 | 0.9 | 0.14 | 0.38 | 0.31 | 0.17 | 0.5 | 0.5 | 0.5 | 0.5 | Sprinkler | 70 |
| Alfalfa, ratoon | 24 | 24 | 0.4 | 0.95 | 0.9 | 0.14 | 0.38 | 0.31 | 0.17 | 0.5 | 0.5 | 0.5 | 0.5 | Sprinkler | 70 |
| Bana Grass (Sudan), 1st cut | 18 | 36 | 0.5 | 0.9 | 0.85 | 0.33 | 0.33 | 0.2 | 0.14 | 0.5 | 0.5 | 0.5 | 0.5 | Sprinkler | 70 |
| Bana Grass (Sudan), 2nd cut | 36 | 36 | 0.5 | 1.15 | 1.1 | 0.08 | 0.4 | 0.32 | 0.19 | 0.5 | 0.5 | 0.5 | 0.5 | Sprinkler | 70 |
| Banana, initial | 24 | 48 | 0.5 | 1.1 | 1 | 0.31 | 0.23 | 0.31 | 0.15 | 0.35 | 0.35 | 0.35 | 0.35 | Micro-spray | 80 |
| Banana, ratoon | 48 | 48 | 1 | 1.05 | 1.05 | 0.33 | 0.16 | 0.49 | 0.01 | 0.35 | 0.35 | 0.35 | 0.35 | Micro-spray | 80 |
| Cabbage | 8 | 12 | 0.7 | 1.05 | 0.95 | 0.24 | 0.36 | 0.3 | 0.09 | 0.45 | 0.45 | 0.45 | 0.45 | Drip | 85 |
| Cantaloupe | 8 | 12 | 0.5 | 0.85 | 0.6 | 0.08 | 0.5 | 0.21 | 0.21 | 0.35 | 0.35 | 0.35 | 0.35 | Drip | 85 |
| Dry Onion | 8 | 12 | 0.7 | 1.05 | 0.75 | 0.1 | 0.17 | 0.5 | 0.23 | 0.25 | 0.25 | 0.25 | 0.9 | Drip | 85 |
| Eggplant | 8 | 12 | 0.7 | 1.05 | 0.9 | 0.21 | 0.32 | 0.29 | 0.18 | 0.4 | 0.4 | 0.4 | 0.4 | Drip | 85 |
| Ginger (AWD potatoes) | 8 | 12 | 0.7 | 1.05 | 0.75 | 0.1 | 0.17 | 0.5 | 0.23 | 0.25 | 0.25 | 0.25 | 0.25 | Drip | 85 |
| Lettuce | 8 | 12 | 0.7 | 1 | 0.95 | 0.2.7 | 0.4 | 0.2 | 0.13 | 0.3 | 0.3 | 0.3 | 0.3 | Sprinkler | 70 |
| Other melon | 8 | 12 | 0.5 | 1.05 | 0.75 | 0.21 | 0.29 | 0.33 | 0.17 | 0.35 | 0.35 | 0.35 | 0.35 | Drip | 85 |
| Pineapple, year 1 | 12 | 12 | 0.5 | 0.3 | 0.3 | 0.16 | 0.33 | 0.26 | 0.25 | 0.6 | 0.6 | 0.6 | 0.6 | Drip | 85 |
| Pineapple, year 2 | 24 | 24 | 0.3 | 0.3 | 0.3 | 0.38 | 0.32 | 0.27 | 0.03 | 0.6 | 0.6 | 0.6 | 0.6 | Drip | 85 |
| Pumpkin | 8 | 12 | 0.5 | 1 | 0.8 | 0.2 | 0.3 | 0.3 | 0.2 | 0.35 | 0.35 | 0.35 | 0.5 | Drip | 85 |
| Seed Corn | 12 | 18 | 0.4 | 1.2 | 0.5 | 0.16 | 0.28 | 0.32 | 0.24 | 0.6 | 0.6 | 0.6 | 0.8 | Drip | 85 |
| Sugarcane, New-year 1 | 18 | 36 | 0.4 | 1.25 | 1.25 | 0.21 | 0.29 | 0.25 | 0.25 | 0.65 | 0.65 | 0.65 | 0.65 | Drip | 85 |
| Sugarcane, New- year 2 | 36 | 36 | 1.25 | 1.25 | 0.75 | 0.14 | 0.14 | 0.14 | 0.59 | 0.65 | 0.65 | 0.65 | 0.65 | Drip | 85 |
| Sugarcane, ratoon | 36 | 36 | 0.4 | 1.25 | 0.75 | 0.1 | 0.15 | 0.46 | 0.29 | 0.65 | 0.65 | 0.65 | 0.65 | Drip | 85 |
| Sweet potato | 8 | 12 | 0.5 | 1.15 | 0.65 | 0.12 | 0.24 | 0.4 | 0.24 | 0.65 | 0.65 | 0.65 | 0.65 | Drip | 85 |
| Taro | 8 | 12 | 1.05 | 1.15 | 1.1 | 0.2 | 0.13 | 0.4 | 0.27 | 0 | 0 | 0 | 0 | Flood | 50 |
| Tomato | 8 | 12 | 0.6 | 1.15 | 0.8 | 0.2 | 0.27 | 0.34 | 0.19 | 0.4 | 0.4 | 0.4 | 0.65 | Drip | 85 |
| Watermelon | 8 | 12 | 0.4 | 1 | 0.75 | 0.15 | 0.26 | 0.26 | 0.32 | 0.26 | 0.32 | 0.26 | 0.32 | Drip | 85 |

Table 2. Perennial crop effective root depth and KC values by month of the year

| Crop | Root depth (in) | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Irrigation type | Irrigation efficiency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | Final | | | | | | | | | | | | | | |
| Coffee | 24 | 48 | 0.85 | 0.85 | 0.85 | 0.9 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.9 | 0.9 | Micro spray (MS) | 0.8 |
| Dendrobium, pot | 8 | 8 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | MS; nursery sprinkler | 0.80, 0.20 |
| Draceana, pot | 8 | 8 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | MS; nursery sprinkler | 0.80, 0.20 |
| Eucalyptus closed canopy (old) | 72 | 72 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Micro spray | 0.8 |
| Eucalyptus young | 48 | 72 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | Micro spray | 0.8 |
| Guava | 30 | 60 | 8.0 | 0.9 | 1.0 | 1.0 | 9.0 | 0.8 | 0.8 | 0.9 | 1.0 | 1.0 | 9.0 | 8.5 | Micro spray | 0.8 |
| Heliconia | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Micro spray | 0.8 |
| Kikuyu grass | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Sprinkler | 0.75 |
| Leuceana (Old) | 72 | 72 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Micro spray | 0.8 |
| Leuceana (Young | 48 | 72 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | Micro spray | 0.8 |
| Lychee | 30 | 60 | 0.95 | 1.0 | 1.0 | 1.0 | 0.95 | 0.9 | 0.9 | 0.85 | 0.8 | 0.8 | 0.9 | 0.9 | Micro spray | 0.8 |
| Macadamia nut | 30 | 60 | 0.85 | 0.85 | 0.85 | 0.9 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.9 | 0.9 | Micro spray | 0.8 |
| Ti | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Micro spray | 0.8 |
| Dillisgrass | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Sprinkler | 0.75 |
| Bermudagrass | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Sprinkler | 0.75 |
| St. Augustina | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Sprinkler | 0.75 |
| Zoysiagrass | 24 | 48 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | Sprinkler | 0.75 |

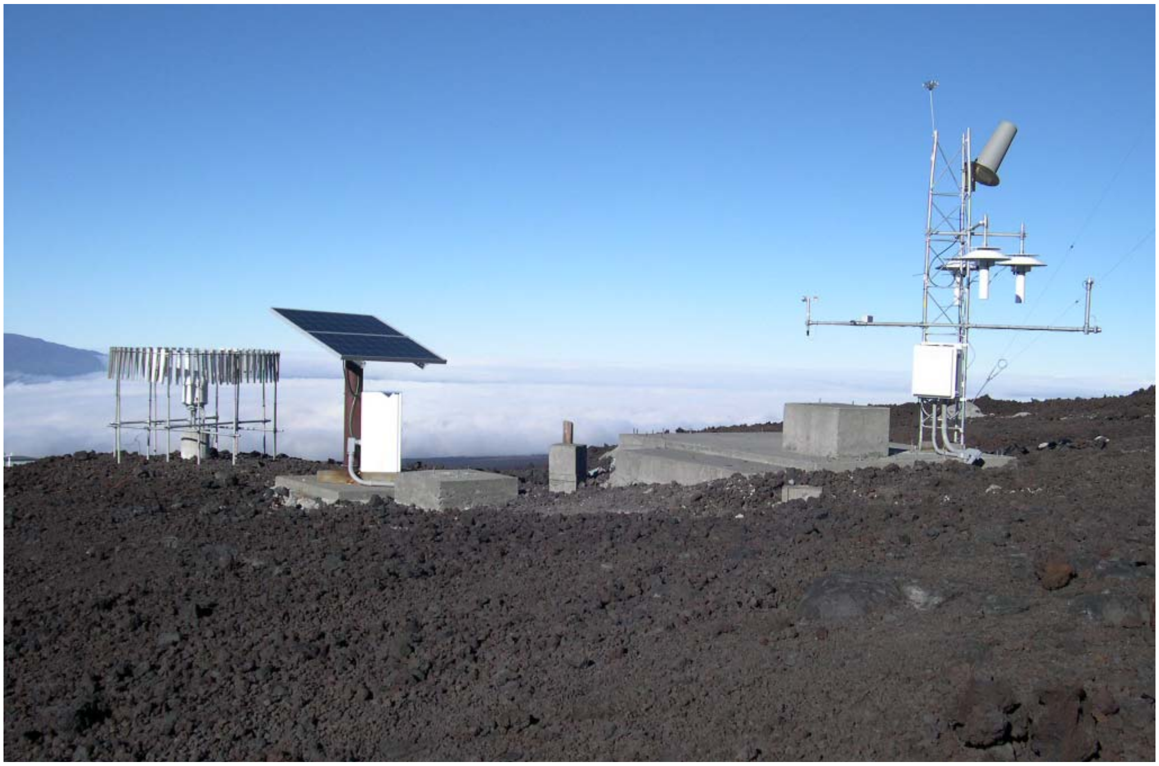

Fig. 1. HI Mauna Loa 5 NNE Mauna Loa Observation, NOAA Earth Systems Research Lab.,Global Monitoring Division (Source: NCDC-NOAA).

Fig. 2. University of Hawaii Waiakea Experiment Station is named as HI Hilo 5 S (Source: NCDC-NOAA).

Table 3. Climate stations and characteristics of the ten target systems.

| System | STATION | Map ID Number (Appendices 4a-4d) | State Key Number | Island | Elevation (ft) | Latitude | Longitude | --------------Rain--------- | | | --------------ET----------- | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Years of record | Period[a] | Annual mean (in) | Years of record | period | Annual mean (in) |
| Kekaha | Mana | 1 | 1026.0 | Kauai | 10 | 22.04 | -159.77 | 45 | 1950-1995 | 28.4 | 4 | 1962-83 | 60.3 |
| Kekaha | Kekaha | 2 | 944.0 | Kauai | 10 | 21.97 | -159.71 | 48 | 1950-1999 | 21.3 | 9 | 1960-83 | 58.9 |
| Kauai Coffee | Wahiawa | 3 | 930.0 | Kauai | 215 | 21.90 | -159.56 | 54 | 1950-2004 | 35.3 | 15 | 1960-83 | 67.2 |
| Kauai Coffee | McBryde Station (ET) | 4 | 986.1 | Kauai | 630 | 21.92 | -159.54 | 0 | -- | -- | 16 | 1960-83 | 62.5 |
| Kauai Coffee | Bydswood Station (rain) | 5 | 985 | Kauai | 720 | 21.93 | -159.54 | 50 | 1952-2004 | 59.2 | 0 | -- | -- |
| East Kauai | Lihue Variety Station | 6 | 1062.1 | Kauai | 340 | 22.03 | -159.39 | 36 | 1964-1999 | 73.5 | 11 | 1965-83 | 54.8 |
| Waiahole | Kunia Substation | 7 | 740.5 | Oahu | 285 | 21.39 | -158.03 | 10 | 1994-2005 | 20.8 | 9 | 1994-2005 | 57 |
| Waimanalo | Waimanalo Experiment Station | 8 | 795.1 | Oahu | 60 | 21.34 | -157.71 | 29 | 1970-2000 | 42.5 | 31 | 1970-2000 | 47.5 |
| Molokai | Kualapuu Reservoir. (ET) | 9 | 531.1 | Molokai | 800 | 21.16 | -157.04 | 0 | -- | -- | 11 | 1970-1984 | 94.2 |
| Molokai | Kualapuu (rain) | 10 | 534.0 | Molokai | 870 | 21.16 | -157.04 | 26 | 1950-1977 | 33.8 | 0 | -- | -- |
| West Maui | Pohakea Bridge (Rain) | 11 | 307.2 | Maui | 165 | 20.82 | -156.51 | 40 | 1950-2004 | 19.4 | 0 | -- | -- |
| West Maui | Field 906 (ET) | 12 | 310.1 | Maui | 160 | 20.83 | -156.50 | 0 | -- | -- | 19 | 1962-83 | 77.7 |
| Upcountry | Kula Branch | 13 | 324.5 | Maui | 933 | 20.76 | -156.33 | 24 | 1979-2005 | 23.8 | 23 | 1979-2005 | 49.5 |
| Waimea | Lalaumilo Field Office | 14 | 191.1 | Hawaii | 2620 | 20.01 | -155.69 | 23 | 1981-2004 | 16.9 | 4 | 1976-84 | 51.4 |
| Lower Hamakua | Hamakua Makai | 15 | 221.3 | Hawaii | 750 | 20.05 | -155.38 | 0 | -- | -- | 15 | 1964-1982 | 63.7 |
| Lower Hamakua | Paauilo | 16 | 221.0 | Hawaii | 800 | 20.04 | -155.37 | 55 | 1950-2005 | 94.9 | 0 | -- | -- |

[a]Time period includes missing or incomplete years not used in the study and not included in the “years of record” column.

Table 4. Representative soils for each of the ten target systems.

| System | Station | soil series | Texture | Water holding capacity (in/in) |
|---|---|---|---|---|
| East Kauai | Lihue Variety | Kapaa | Silty clay | 0.14 |
| Kauai Coffee | Wahiawa | Makaweli | Stony silty clay loam | 0.15 |
| Kauai Coffee | Brydswood | Koloa | Stony silty clay | 0.11 |
| Kekaha | Kekaha | Kekaha | Silty clay | 0.105 |
| Kekaha | Mana | Lualualei | Clay | 0.115 |
| Waiahole | Kunia.Sub | Kunia | Silty clay | 0.13 |
| Waimanalo | Wai.Exp.Sta | Waialua | Silty clay | 0.14 |
| Molokai | Kaunakakai | Molokai | Silty clay loam | 0.12 |
| West Maui | Pohakea | Pelehu | Clay loam | 0.13 |
| Upcountry | Kula | Kula | Loam | 0.14 |
| Waimea | Lalaumilo | Waimea | V. fine sandy loam | 0.14 at 0-50 in<br>0.02 at 50-90in |
| Lower Hamakua | Paauilo | Paauhau | Slty clay loam | 0.14 at 0-50 in<br>0.06 at 50-90 in |

## 4. CALIBRATION AND VALIDATION

IWREDSS was calibrated for various scenarios and validated with data from the USDA-NRCS Handbook Notice 38 that comprises net annual water requirement maps for various crops grown on the major islands of Hawaii. A range of truck crops were selected (Egg Plant, Tomato, Cabbage, Ginger, Dry Onion, Sweet Potato, Lettuce, Watermelon, Taro). Irrigation requirements were calculated for truck crops and banana at two locations on each island. The trickle / drip irrigation system was selected since it is commonly used in Hawaii. Table 5 presents a summary of IWREDSS calculated irrigation requirements and their corresponding estimates from the USDA-NRCS Handbook 38 (USDA-NRCS, 1996).

Table 5 also shows the percent differences between the two calculations. Net irrigation requirements (NIR) reported by the USDA-NRCS Handbook 38 were 12.8 and 25.6% higher than those calculated with IWREDSS for egg plant and lettuce in Waimea and north Kohala, respectively. Handbook 38 NIR calculations were also, 10.6 and 11.0% for cabbage and egg plant in Hoolehua, respectively. The difference in the estimates was expected since the NRCS technique is more general and was not used for a specific crop such as the calculation of the IWREDSS.

Regression analysis between the calculations of IWREDSS and those of the NRCS Handbook 38 was conducted (Figure 3). Results of this regression show that there was a good agreement between the two techniques ($R^2 = 0.97$). However, NIR calculations of Handbook 38 were constantly higher than those of IWREDSS by almost 8%.

Table 5. Table Calibration and validation

| Scenario | Annual NIR (in) | | Variation |
|---|---|---|---|
| Location, Crop, Irrigation System | IWREDSS | USDA-NRCS maps | % |
| Waimanalo (OA), Banana (init)-Drip | 37.5 | 38.0 | 1.32 |
| Waimanalo (OA), Banana (rtn), Drip | 36.9 | 38.0 | 2.89 |
| Waimanalo (OA), Banana, Trickle-Spray | 37.5 | 38.0 | 1.32 |
| Waimanalo (OA), Egg Plant, Trickle-Drip | 36.3 | 38.0 | 4.47 |
| Waianae (OA), Tomato, Trickle-Drip | 61.8 | 59.0 | 4.53 |
| Waianae (OA), Ginger, Trickle-Drip | 58.5 | 59.0 | 0.85 |
| Waianae (OA), Cabbage, Trickle-Drip | 56.0 | 59.0 | 5.08 |
| Waianae (OA), Egg Plant, Trickle-Drip | 51.4 | 56.0 | 8.21 |
| Waianae (OA), Dry Onion, Trickle-Drip | 55.1 | 56.0 | 1.61 |
| Waianae (OA), S. Potato, Trickle-Drip | 57.1 | 56.0 | 1.93 |
| N. Kohala(HA), Alfalfa (init), Trickle-Drip | 44.1 | 43.0 | 2.49 |
| N. Kohala(HA), Alfalfa (rtn), Trickle-Drip | 44.1 | 43.0 | 2.49 |
| Waimea (HA), Tomato, Trickle-Drip | 34.7 | 38.0 | 8.68 |
| Waimea (HA), Dry Onion, Trickle-Drip | 35.4 | 38.0 | 6.84 |
| Waimea (HA), Ginger, Trickle-Drip | 35.6 | 38.0 | 6.32 |
| Waimea (HA), Cabbage, Trickle-Drip | 16.6 | 15.0 | 9.64 |
| Waimea (HA), Egg Plant, Trickle-Drip | 15.7 | 18.0 | 12.8 |
| N. Kohala (HA), Lettuce, Trickle-Drip | 13.4 | 18.0 | 25.6 |
| Kula (MA), Watermelon, Trickle-Drip | 35.7 | 37.0 | 3.51 |
| Kula (MA), Ginger, Trickle-Drip | 40.3 | 37.0 | 8.19 |
| Kula (MA), Tomato, Trickle-Drip | 40.0 | 37.0 | 7.50 |

| | | | |
|---|---|---|---|
| Kula (MA), Egg Plant, Trickle-Drip | 36.1 | 37.0 | 2.43 |
| Kula (MA), Cabbage, Trickle-Drip | 35.0 | 37.0 | 5.41 |
| Kula (MA), Lettuce, Trickle-Drip | 36.5 | 37.0 | 1.35 |
| Haiku (MA), Banana (init), Trickle-Drip | 41.1 | 42.5 | 3.29 |
| Haiku (MA), Banana (init), Trickle-Drip | 29.9 | 32.0 | 6.56 |
| Haiku (MA), Banana (init), Trickle-Drip | 28.4 | 30.0 | 5.33 |
| Hoolehua (ML), Banana, Trickle-Drip | 65.9 | 65.0 | 1.37 |
| Hoolehua (ML), Banana, Trickle-Spray | 62.4 | 65.0 | 4.00 |
| Hoolehua (ML), Cabbage, Trickle-Drip | 67.1 | 60.0 | 10.6 |
| Hoolehua (ML), Egg Plant, Trickle-Drip | 67.4 | 60.0 | 11.0 |
| Hoolehua (ML), Lettuce, Trickle-Drip | 61.6 | 60.0 | 2.60 |
| Kaunakakai (ML), Banana, Trickle-Drip | 56.2 | 60.0 | 6.33 |
| Kaunakakai (ML), Taro, Trickle-Drip | 74.4 | 75.0 | 0.80 |

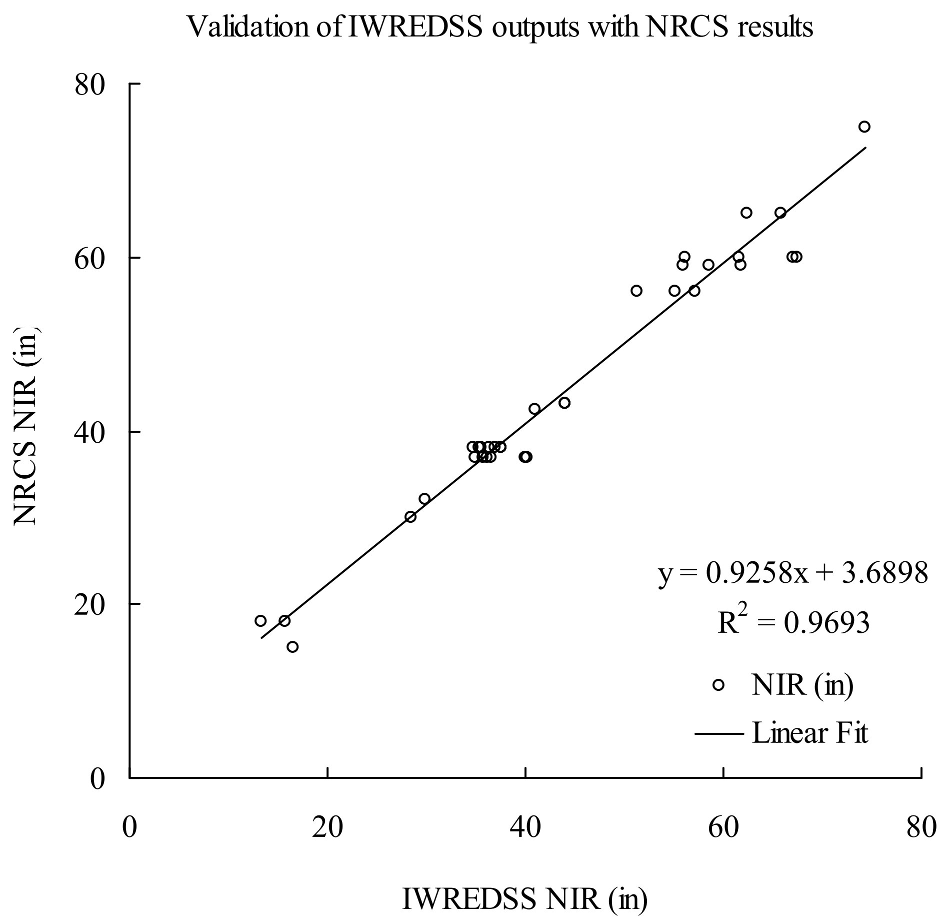


Figure 3: Validation of IWREDSS with USDA-NRCS results

## 5. MAPPING THE MODEL RESULTS

The simulation results for all water budget components can be visualized in ArcMap. For further analyses, all ArcGIS functions can be used on these output layers i.e., labeling, classifying the parameters into various categories, merging or clipping more than one layer, and/or application of field calculator to generate further data from the attribute tables of the layers.

## 6. SENSITIVITY ANALYSIS

Sensitivity analysis is used to quantify the impact of input parameters on the model results/output. If a small change in a input parameter results in relatively large changes in the output, the model is considered to be sensitive to that parameter. This mean that the parameter has to be determined very accurately.

Seed corn was selected for the sensitivity analysis because it has become a popular and economically important crop in Hawaii. Table 6 shows some information about seed corn, the acreage of which in Hawaii is expected to increase over 57 % (NASS, 2006). The Trickle/drip irrigation system was used in these calculations due to its common use in Hawaii irrigated agriculture. The water requirements/allocations were simulated for a four-month-growing season with twelve different planting dates (from January until December). An average LAI value of 2 was used for the entire growing season. Water table depth was selected at 50 ft to consider deep water table conditions with no effect on IRR calculations. The values of these parameters were kept the same for all the simulations; there were 12 simulations for windward (Waimanalo) and 12 simulations for leeward (Kunia) sides of Oahu. Efforts were made to conduct simulations for the same soil type.

Table 6: Sweet corn: Acreage, yield, production, price, and value, in Hawaii, 1999-2003.

| Year | Acres | Yield per acre | Production | Farm price |
|---|---|---|---|---|
| | | *1,000 pounds* | | *Cents per pound* |
| 1999 | 450 | 3.8 | 1,700 | 58.0 |
| 2000 | 440 | 5.5 | 2,400 | 55.0 |
| 2001 | 440 | 4.3 | 1,900 | 64.0 |
| 2002 | 610 | 3.9 | 2,400 | 54.0 |
| 2003 | 830 | 3.0 | 2,500 | 51.0 |

The results of the sensitivity analysis are shown in Appendices 5a and 5b. The net irrigation requirements for the 12 different growing periods are plotted in Figure 4. There is a significant difference in NIR for windward and leeward sides of the island. The NIR were the least during the rainy season of the year (November to April) and the highest during the dry season of the year (May to October) regardless of the location on the island. On average, it requires almost twice as much water to grow Seed Corn in the leeward side of the island as it does in the windward

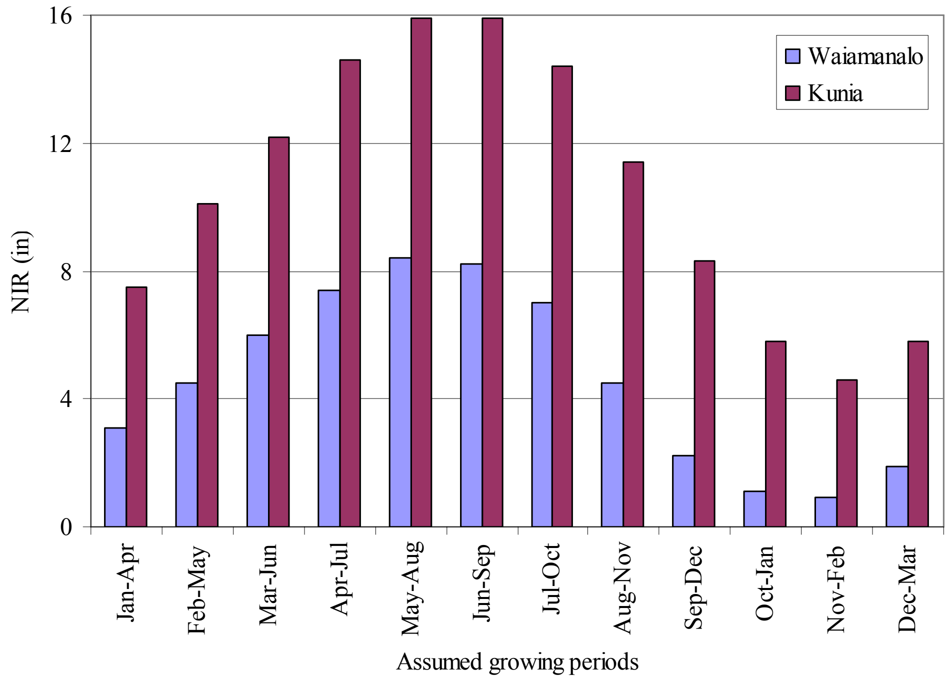


Figure 4. Changes in NIR based on changes in growing periods for seed corn grown on windward (Waiamanalo) and leeward (Kunia) sides of Oahu.

### 6.1 Effect of Crop Leaf Area Index on Irrigation Allocations

For seed corn (growing season: April 15 to August 15), the NIR correlated negatively with effective rain (ER) and correlated positively with leaf area index (Figure 5). NIR increased and ER decreased by almost 5% and 3%, respectively for every unit increase in the average LAI (Figure 6).

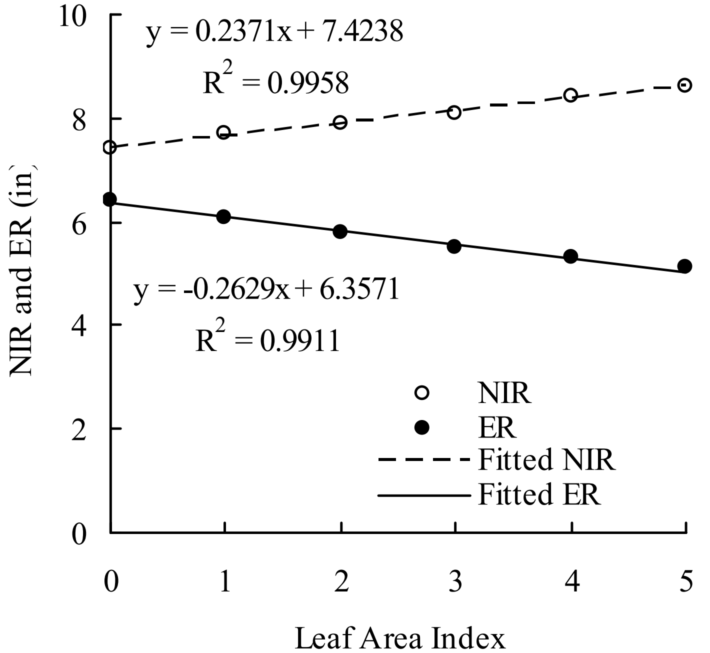


Figure 5: Effect of changes in leaf area index on net irrigation requirements and effective rain for Seed Corn grown in Waimanalo Oahu, Hawaii.

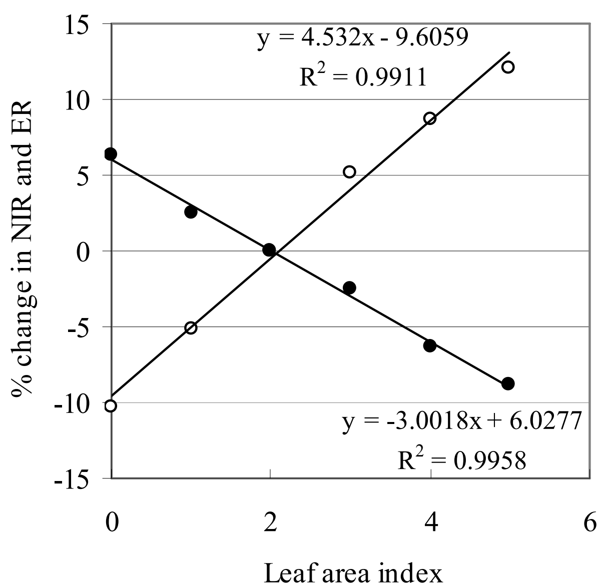


Figure 6. Percent change in net irrigation requirements (open symbol) and effective rain (closed symbol) as a result of changes in leaf area index for Seed Corn grown in Waimanalo Oahu, Hawaii.

## 7. SIMULATION FOR ENERGY CROPS

Energy crops are the crops that could be used to produce energy in forms of heat or liquid fuel. Bioenergy crops often include food crops such as corn (starch for ethanol production) and sugarcane (sugar for ethanol production). The water budget components for these two energy crops (Sugarcane and Corn) were simulated for the dry and rainy growing seasons for wind- and leeward sides of the islands of Hawaii, Oahu, Maui and Kauai.

Growing seasons and their lengths for the selected energy crops are given in Table 7. Sugar cane has one year length irrigation seasons starting in May and October referred to as dry and wet seasons, respectively. For corn, the dry and wet seasons start in April and October, respectively.

Table 7. Energy crops and growing seasons selected for simulating irrigation requirements.

| Crop | Season | Sowing | Harvesting | Length of season |
|---|---|---|---|---|
| Corn | Dry | April 15 | August 15 | 123 |
| Corn | Wet | October 15 | February 15 | 124 |
| Sugar cane Y-2 | Dry | May 1 | April 1 | 365 |
| Sugar cane Y-2 | Wet | October 1 | November 30 | 365 |

The results of the simulations are given in Table 8 and plotted in Figure 7. There is between 0.2 and 22% difference (Table 9) in NIR calculations for Sugarcane; during the rainy and dry seasons across the major Hawaiian Islands. However, the difference between rainy and dry season for Corn ranges between 63 and 88%. These variations are attributed to the temporal variability of rain and ET throughout the different growing seasons for these crops.

Table 8: Net irrigation requirements (in) for energy crops grown on windward and leeward sides of the islands in dry and wet seasons

| Crop | Irrigation season | Waiamanalo Oahu windward | Kunia Oahu leeward | Kula Maui windward | W. Maui Maui leeward | Waimea Hawaii windward | Kekaha Hawaii leeward | Lihue Kauai windward | Kekaha Kauai leeward |
|---|---|---|---|---|---|---|---|---|---|
| Corn | Dry | 8.1 | 14.4 | 12.0 | 23.2 | 10.8 | 11.5 | 5.3 | 16.0 |
| Corn | Wet | 1.0 | 4.6 | 2.8 | 9.3 | 3.2 | 4.3 | 1.3 | 4.3 |
| Sugar C. Y-2 | Dry | 13.8 | 32.4 | 26.4 | 50.4 | 26.3 | 33.7 | 8.2 | 34.7 |
| Sugar C. Y-2 | Wet | 15.2 | 32.9 | 26.7 | 50.5 | 25.0 | 33.0 | 10.6 | 36.2 |

Table 9: Percent difference in the NIR calculated for energy crops during dry and wet seasons

| Crops | Waiamanalo<br>Oahu<br>windward | Kunia<br>Oahu<br>leeward | Kula<br>Maui<br>windward | W. Maui<br>Maui<br>leeward | Waimea<br>Hawaii<br>windward | Kekaha<br>Hawaii<br>leeward | Lihue<br>Kauai<br>windward | Kekaha<br>Kauai<br>leeward |
|---|---|---|---|---|---|---|---|---|
| Corn | 88 | 68 | 77 | 60 | 70 | 63 | 75 | 73 |
| Sugarcane | 9.2 | 1.5 | 1.1 | 0.2 | 4.9 | 2.1 | 22.6 | 4.1 |

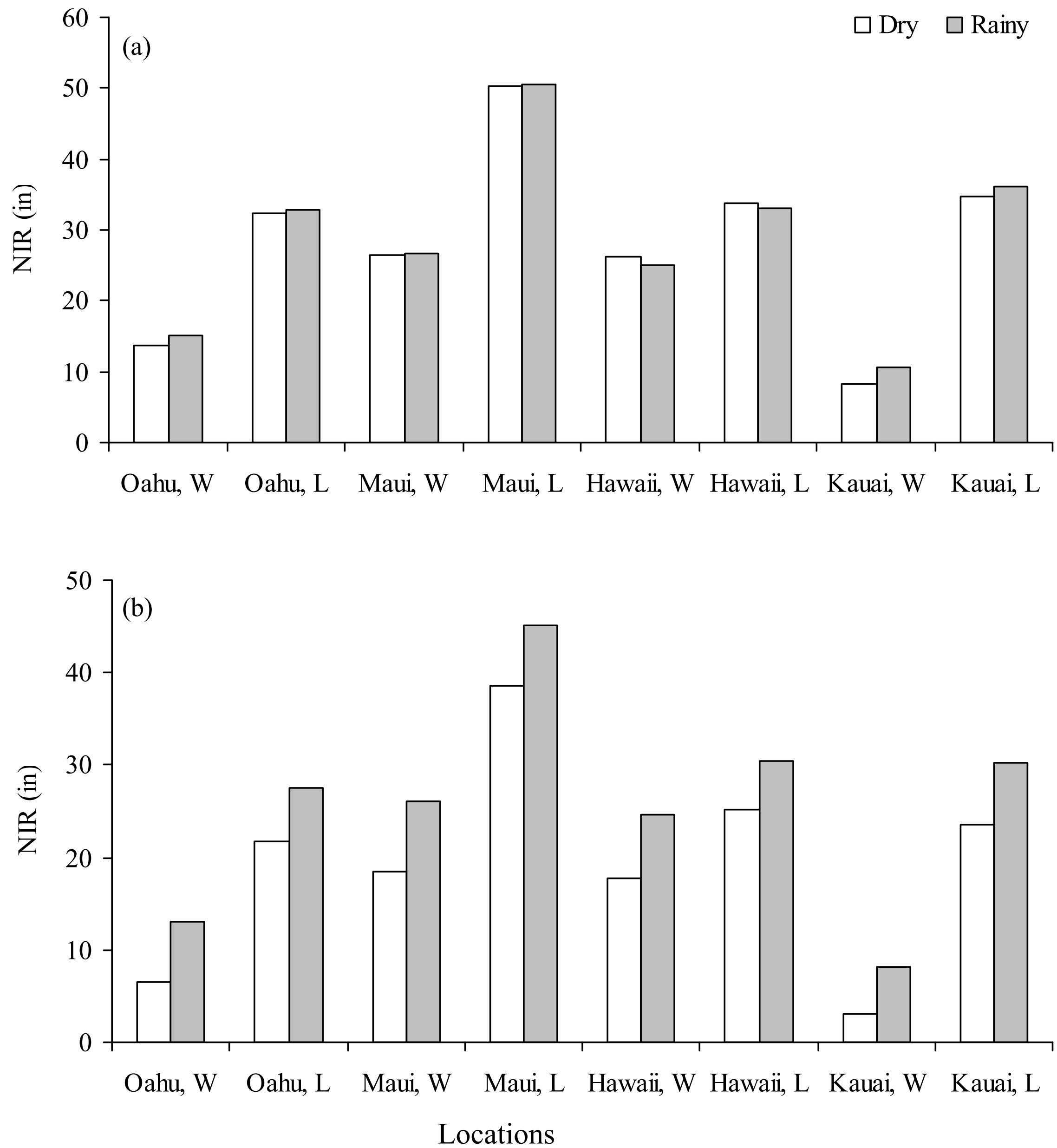


Figure 7: Net irrigation requirements for the energy crops (a) Corn and (b) Sugarcane grown on various locations across the five major Hawaiian Islands.

## 8. SUMMARY AND CONCLUSION

This is a final report on the project "Water Management Software to Estimate Crop Irrigation Requirements for Consumptive Use Permitting inn Hawaii". ArcGIS based IWREDSS model was developed, calibrated, validated, and tested through a sensitivity analysis. The report presents and discusses results of the calibration, validation and sensitivity analysis. Hardware and software requirements are given in the IWREDSS user manual (Appendix 1). Details of the governing equations and methodologies are given in the technical guide (Appendix 2).

IWREDSS was calibrated and validated for truck and energy crops based on data of the USDA-NRCS Handbook 38. A close agreement was observed between the estimates of the two techniques. A sensitivity analysis was also carried out to test the sensitivity of IWREDSS to input parameters. IWREDSS was sensitive to the timing of the growing season due to the temporal variations of rainfall and ET. The LAI had positive effect on NIR. IWREDSS is capable of calculating and visualizing water budget components. It comes with the following features:

- It estimates irrigation requirements for multiple crops/land uses, i.e., vegetable and fruit crops, lawn and golf courses for different time intervals: daily, weekly, bi-weekly, monthly, seasonally, and annually.
- It uses long-term historical climate databases of daily ET and rain, from different locations within Hawaii, to calculate daily water budgets of the crop root zone.
- It estimates IRR based on extreme event probabilities calculated from daily irrigation requirements simulated. The year-to-year distributions are used to calculate extreme values by fitting a theoretical function to the actual annual data. A coefficient is calculated which indicates how well the data fit the theoretical distribution so the user can determine whether the data base is sufficiently long to accurately estimate the desired extreme values.
- It estimates IRR for common Hawaii irrigation application systems, including sprinkler, surface, micro and seepage systems. All four types of systems are included in the model by simulating the effects of periodic irrigations of the entire soil surface with sprinkler and surface irrigation systems, high water tables in seepage irrigation systems, and partial root zone irrigation in microirrigation

systems.

- It uses inputs which describe crop, soil, irrigation system, and management parameters. Default values are included for each input, based on typical Hawaii conditions; however, the user can change them based on a specific condition.
- The model is flexible enough to allow the users to include more input data about crops as it become available for a specific application or based on the most recent research results.
- Data output of the model is used to develop GIS maps of IRR and other water budget components.

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## 10. APPENDICES

### Appendix 1.

# USER MANUAL

ArcGIS based graphical user interface of the Irrigation Water Requirement Estimation Decision Support System (IWREDSS) enables user to calculate irrigation requirements for the area of interest. Irrigation requirements can be calculated by either using a Tax-ID GIS layer or by using a georeferenced map of the area. This manual includes the details on how to digitize a hard copy of the area of interest. The user inputs include crop to be grown/irrigated, crop leaf area index (LAI), the growing season, irrigation system to be used, appropriate curve number, and water table depth. In addition to these inputs, IWREDSS uses the corresponding weather and soil data from its Geodatabases. IWREDSS results can be retrieved and visualized in the form of a text (ASCII) file and a GIS map upon successful execution.

### System Requirement

**Hardware**
The system should have minimum specifications of Pentium III, 256MB memory, and 800MB hard drive space.

**Software**
IWREDSS was developed and tested on Windows XP with installed applications of ArcGIS 9.2 (ESRI product) and JRE (Java Runtime Environment) 5.0. JRE can be downloaded at http://java.sun.com. The following steps need to be completed to successfully operate the program.

**Installation of IWREDSS**

1. Copy the project files (IWREDSS.mxd) and data folder (data) to any location on the hard drive of the machine. The IWREDSS.mxd initiates ArcMap application of ArcGIS and the data folder contains geodatabases of soil, climate, taxID, ALISH, LSB and an executable file of IWREDSS.

2. Set system variable "IWREDSS_HOME" to be the location of IWREDSS (Figure 1). Note that you need to include a "/" at the end the name of system variable. This can usually be don via Control Panel -> System -> Advanced -> Environment Variables -> System variable- >New >OK.

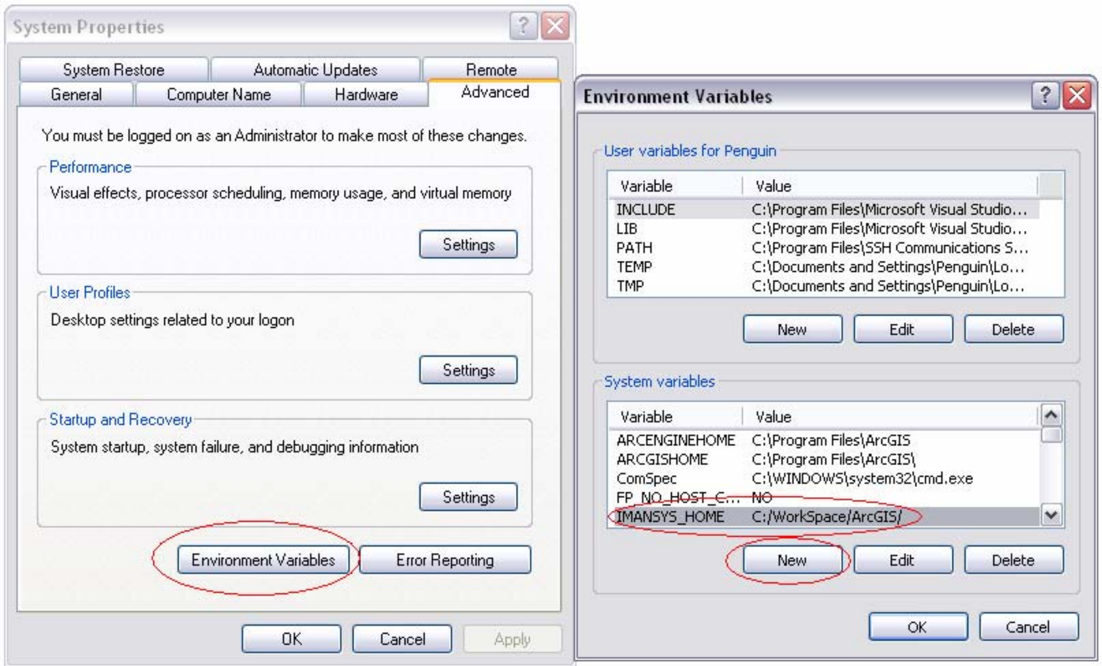



Figure 1

**Simulation using IWREDSS**

The user needs to select a TaxID area on any of the major Hawaiian Islands or provide a GIS georeferenced layer.

**Area simulation using TaxID**

**Step 1: Open the ArcMap document**

Open the file "IWREDSS.mxd" by double- or by right-clicking. An alternative way is to launch ArcMap first, then open the document "IWREDSS.mxd" using the File->Open menu or from ArcMap dialog, click the option to start using ArcMap with An existing map, then click OK to browse for IWREDSS.mxd file. The document opens displaying a map of Hawaii with polygons of different Tax ID areas (Figure 2).

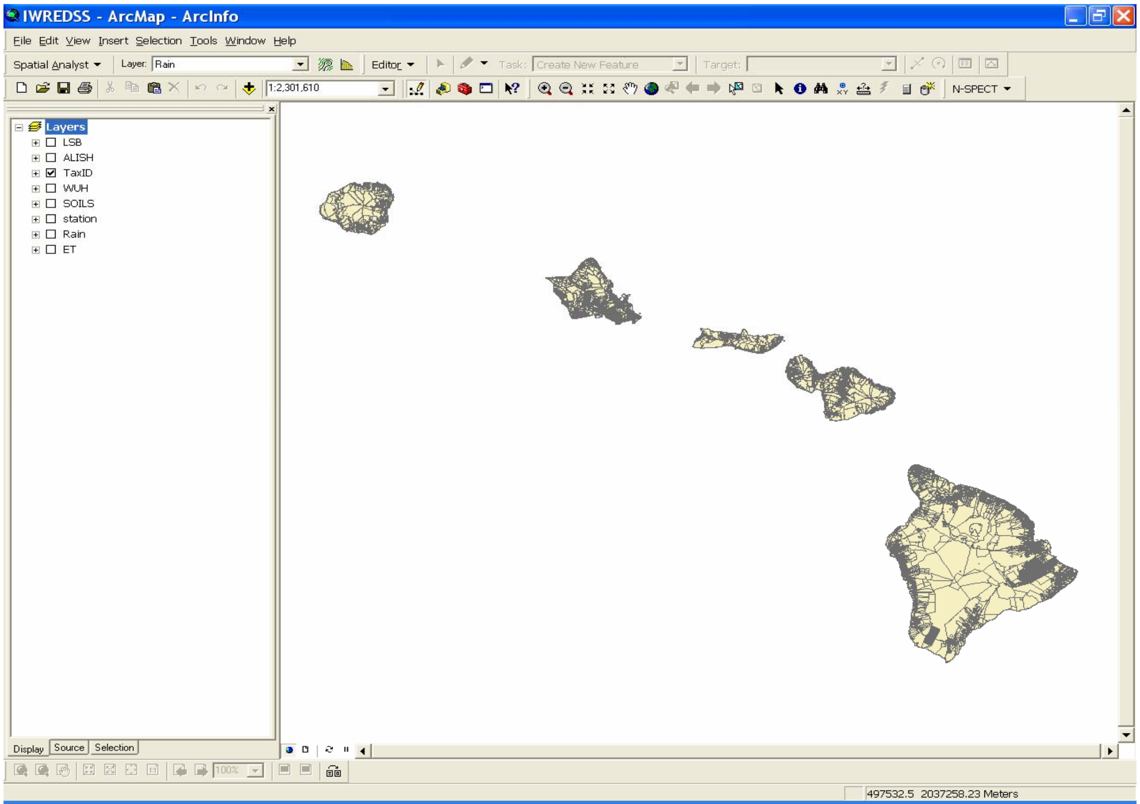



Figure 2

The table of content (TOC) of ArcMap (a list on the left side of the window) includes the following visible layers:

**LSB**: Land Study Bureau.

**ALISH**: Agricultural Lands of Importance to the State of Hawaii.

**TaxID**:The TaxID areas of all the islands

**station**: The climate stations whose historical daily rainfall and ET data are used by IWREDSS.

**Rain**: Raster layer of rainfall. It contains annual average precipitation of every pixel on the map. The values are calculated from the rainfall isohyets (Giambelluca, et al., 1986). This layer is unselected by default.

**ET**: Raster layer of evapotranspiration which contains annual average Pan ET of every pixel on the map. The values are calculated from the pan ET contours (Ekern and Cheng, 1985). This layer is unselected by default.

**SOILS**: This soil layer presents the soils of Hawaii used in simulation.

The above layers may be at different order in TOC.

**Step 2: Select a TaxID area**

Locate the area of interest on one of the Hawaiian islands. It is suggested to zoom in the the island of interest and click on the Tax-ID (irregular shaped polygons, sections on the map) specific to the area of interest. There are two ways to select a Tax-ID area as follows:

1. Directly select on the map.

a) Using Zoom-in tool  find the area to be irrigated/simulated.

b) Using Feature-selection tool  select the area as shown in Figure 3. Note that with this option you can only choose 1 area (Tax-ID) per simulation.

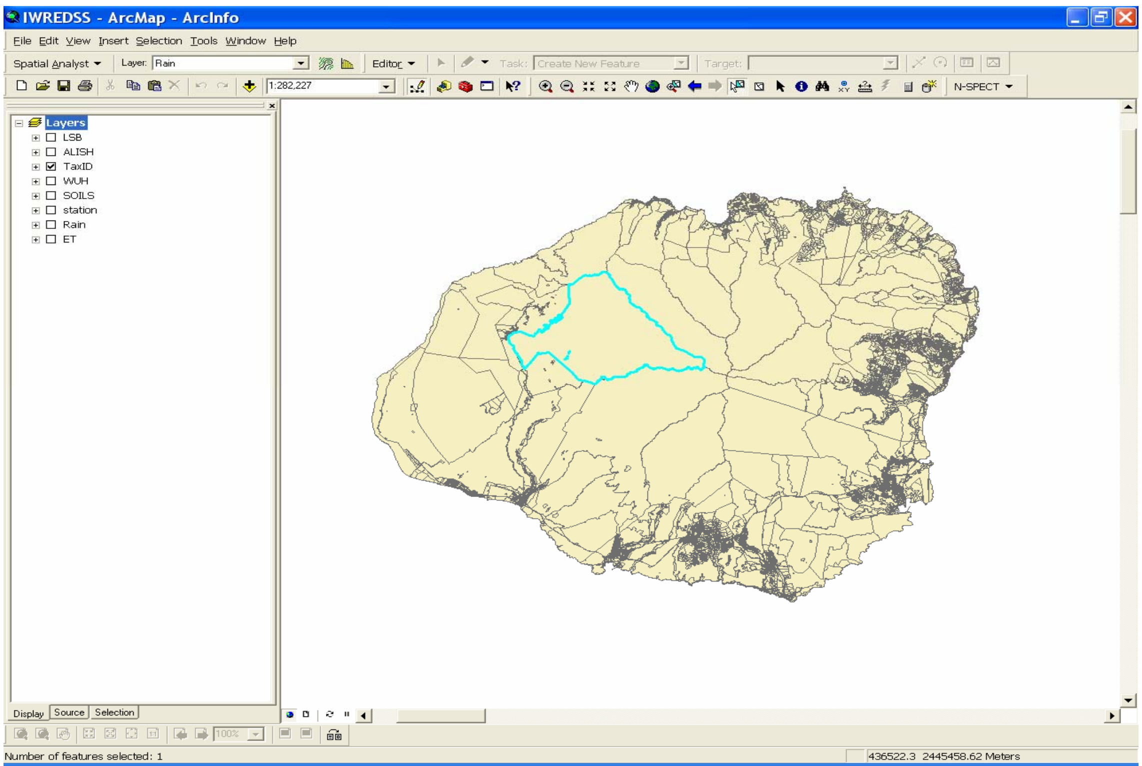



Figure 3

2. Area selection using the attribute table of the Tax-ID Layer (Figure 4).

a) In TOC, right click on TaxID and choose "Open Attribute Table" from the pop-up menu.

b) In the attribute table, select Options->Select by Attribute, and then you can search by TMK or other features (like all areas larger than 300,000 acres)

c) After clicking "apply", the matched record(s) and their corresponding area(s) will be highlighted. If there are more than one matched records, you need to select one.

d) Select TMK number chosen for simulation.

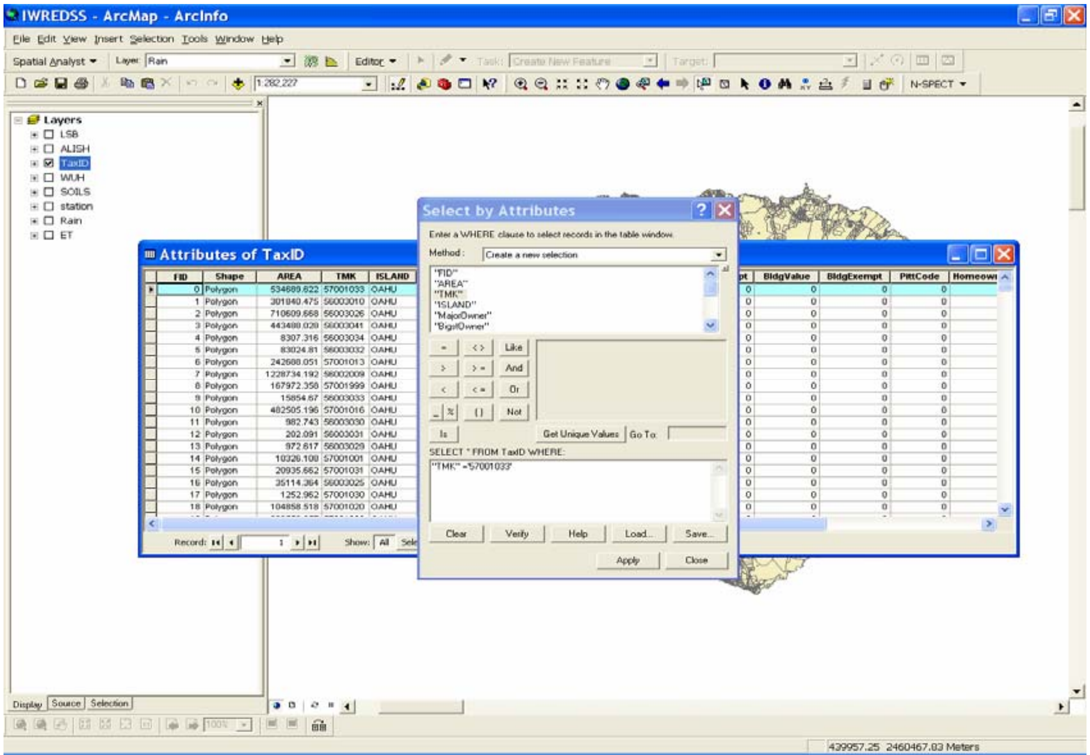



Figure 4

**Step 3: Selection of the other Input Parameters**

After selecting an area, the user will need to input other required parameters by clicking the IWREDSS tool button . The following window (Figure 5) will pop up.

User will need to input/select the following parameters:
**Crop**: User can select from the predefined list of crops given below:

16 PERENNIAL CROPS
GENERIC CROP
COFFE
DENDROB.,POT
DRACEANE,POT
EUCALYP.,OLD
EUCALYP.,YNG
GUAVA
HELICONIA
KIKUYU GRASS
LYCHEE
MACADAMIA
TI
DILLIS GRASS
BERMUDA GRASS
ST.AUGUSTINA
ZOYSIA GRASS

23 ANNUAL CROPS
GENERIC CROP
ALFALFA,INIT
ALFALFA,RATN
BANANA,INIT
BANANA,RATN
CABBAGE
CANTALOUPE
DRY ONION
EGG PLANT
GINGER,(AWD)
LETTUCE
OTHER MELON
PINEAPP.YR-1
PINEAPP.YR-2
PUMPKIN
SEED CORN
SUGAR C.YR-1
SUGAR C.YR-2
SUGAR C.RATN
SWEET POTATO
TARO
TOMATO
WATER MELON

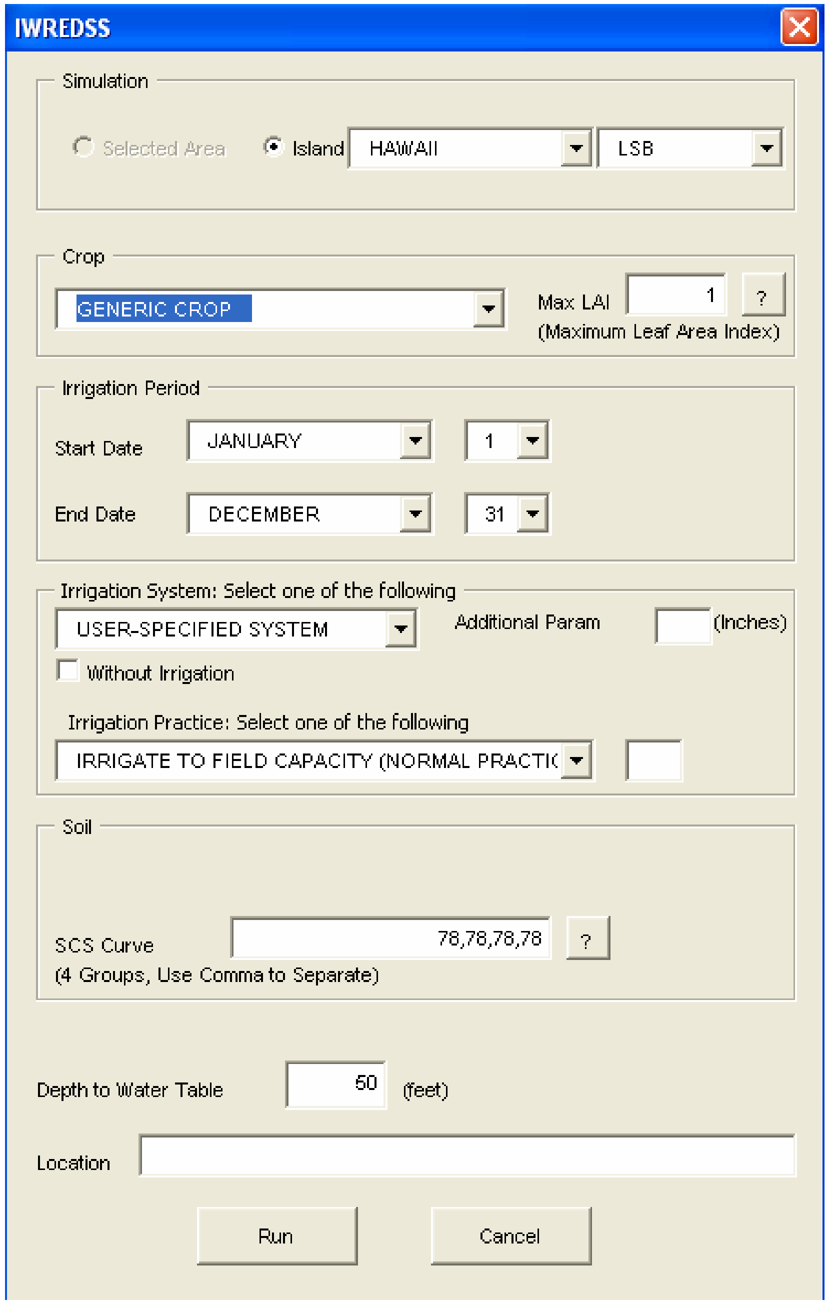



Figure 5: Interface of IWREDSS

Each crop has its own parameters included in the crop database of IWREDSS. For perennial crops, the parameters include irrigate crop zone depth, total zone depth, monthly crop water use coefficient (KC), and monthly allowable water depletion (AWD). For annual crops, the crop parameters include initial crop zone depth, maximum crop zone depth, fraction of growth of 4 stages, crop water use coefficient (KC) of 4 stages, and allowable water depletion (AWD) of 4 stages.

Additional crops can be added to the list as needed.

**Max LAI**: Maximum Leaf Area Index is used to calculate rainfall canopy interception. For details of the calculation of interception, please refer to IWREDSS User Guide.

**Irrigation period**: User needs to specify the start and end of the growing season that can be up to 1 year long; it can start at any month of the year and can go around to the next year, i.e. starting date October of year one and ending date September of the following year. Note that if the irrigation period is too short (less than 45 days) for some annual crops, the simulation results would not be accurate.

**Irrigation system**: The users can select from the predefined list of irrigation systems given below:

USER-SPECIFIED SYSTEM
TRICKLE, DRIP
TRICKLE, SPRAY
MULTIPLE SPRINKLER
SPRINKLER, CONTAINER NURSERY
SPRINKLER, LARGE GUNS
SEEPAGE, SUBIRRIGATION
CROWN FLOOD
FLOOD (TARO)

For different irrigation systems mentioned above, the following parameters should be defined; system application efficiency, fraction of soil surface irrigated, and fraction of evapotranspiration.

**Option for no irrigation:** A provision is given to calculate water budget components without supplying additional irrigation. This option could be used for research purpose as to simulate natural rainfed cropping system.

**Irrigation practice**: The users are given options to select irrigation practice. A dropdown menu provides options for irrigation practices including a) Irrigate to field capacity (normal practice), b) Apply a fixed depth per irrigation, and c) Deficit irrigation. In case option "b" is selected, the users are asked to enter the depth of irrigation in inches. Percentage of deficit irrigation is required to enter in case option "c" is selected.

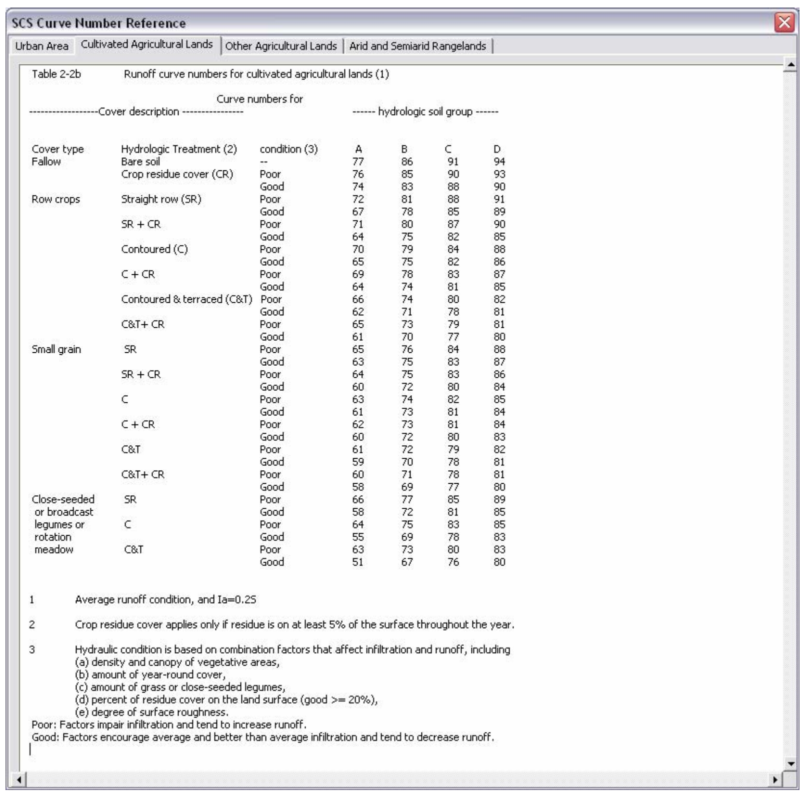
**Additional Parameters**: For the following list of the irrigation systems, additional parameters are needed.

| IR System | Extra parameters |
|---|---|
| Crown Flood System | Crown flood System bed height |
| Seepage System | Depth to water table |
| Flood System | Rice flood storage depth |

The additional parameters (in inches) can be entered in a box provided next to the Irrigation System box. When extra parameters are not needed, this box is grayed out.

**Soil Hydrological Groups and SCS Curve Numbers**: Based on the SCS curve number method, all soils are grouped into 4 hydrologic groups (A, B, C, and D). Based on the composition of the selected area, IWREDSS calculates the % of each soil group with respect to the total superficie of the selected area (for example, a selected area may have 11.3% of group B, 22.8% of group C, and 64.8% of group D). Based on the land use, the user should specify the corresponding SCS curve number for all the soil hydrologic groups present in the area of interest. The curve number is used in the calculation of runoff. For details of the calculation, please refer to IWREDSS User Guide.

By default, a CN value of 78 is given for each hydrologic group to remind users that they need to change these values to their correct values. To see a list of CN values for different cover and soil types the user needs to click "?" button next to the CN input box (Figure 6).



SCS Curve Number Reference

Urban Area | Cultivated Agricultural Lands | Other Agricultural Lands | Arid and Semiarid Rangelands

Table 2-2b Runoff curve numbers for cultivated agricultural lands (1)

| ------------------Cover description ---------------- | | | Curve numbers for ------ hydrologic soil group ------ | | | |
|---|---|---|---|---|---|---|
| Cover type | Hydrologic Treatment (2) | condition (3) | A | B | C | D |
| Fallow | Bare soil | -- | 77 | 86 | 91 | 94 |
| | Crop residue cover (CR) | Poor | 76 | 85 | 90 | 93 |
| | | Good | 74 | 83 | 88 | 90 |
| Row crops | Straight row (SR) | Poor | 72 | 81 | 88 | 91 |
| | | Good | 67 | 78 | 85 | 89 |
| | SR + CR | Poor | 71 | 80 | 87 | 90 |
| | | Good | 64 | 75 | 82 | 85 |
| | Contoured (C) | Poor | 70 | 79 | 84 | 88 |
| | | Good | 65 | 75 | 82 | 86 |
| | C + CR | Poor | 69 | 78 | 83 | 87 |
| | | Good | 64 | 74 | 81 | 85 |
| | Contoured & terraced (C&T) | Poor | 66 | 74 | 80 | 82 |
| | | Good | 62 | 71 | 78 | 81 |
| | C&T+ CR | Poor | 65 | 73 | 79 | 81 |
| | | Good | 61 | 70 | 77 | 80 |
| Small grain | SR | Poor | 65 | 76 | 84 | 88 |
| | | Good | 63 | 75 | 83 | 87 |
| | SR + CR | Poor | 64 | 75 | 83 | 86 |
| | | Good | 60 | 72 | 80 | 84 |
| | C | Poor | 63 | 74 | 82 | 85 |
| | | Good | 61 | 73 | 81 | 84 |
| | C + CR | Poor | 62 | 73 | 81 | 84 |
| | | Good | 60 | 72 | 80 | 83 |
| | C&T | Poor | 61 | 72 | 79 | 82 |
| | | Good | 59 | 70 | 78 | 81 |
| | C&T+ CR | Poor | 60 | 71 | 78 | 81 |
| | | Good | 58 | 69 | 77 | 80 |
| Close-seeded | SR | Poor | 66 | 77 | 85 | 89 |
| or broadcast | | Good | 58 | 72 | 81 | 85 |
| legumes or | C | Poor | 64 | 75 | 83 | 85 |
| rotation | | Good | 55 | 69 | 78 | 83 |
| meadow | C&T | Poor | 63 | 73 | 80 | 83 |
| | | Good | 51 | 67 | 76 | 80 |

1 Average runoff condition, and Ia=0.2S

2 Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

3 Hydraulic condition is based on combination factors that affect infiltration and runoff, including
(a) density and canopy of vegetative areas,
(b) amount of year-round cover,
(c) amount of grass or close-seeded legumes,
(d) percent of residue cover on the land surface (good >= 20%),
(e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Figure 6: CN numbers

**Depth to water table**: This site-specific information is optional as the model considers 50 ft of water table depth. It is recommended to use the default depth unless the precise value of water table depth is known. Note that the unit of water table depth is in feet.

**Location**: This is the name of location or area of interest and any additional information the user wants to add to the title. The name appears in the beginning of the IWREDSS text output file.

**Step 4: Execute IWREDSS**
After completing the required inputs, the user should click the "Run" button to start simulation. A text box message will be prompted to the user about the state of simulation (fails or succeeds) (Figure 7).

**Step 5: Reading the result**
After successful execution, a message (Figure 7) pops up giving user an option to view the results. A text file opens by clicking the "Yes" button on the option message box. By default, the output file is saved in the subfolder "data" of the installation folder of IWREDSS with the default name as "IWREDSS_out.txt" and is automatically overwritten by successive execution. Therefore, the user is advised to save the results after every simulation with a different name using the File>Save as option in notepad.

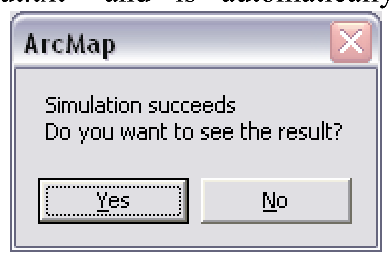


Figure 7:

The output text file contains three major sections: a legend table, simulation parameters and simulation results. The legend table defines the abbreviations of parameters used in the output and their corresponding units. These parameters include the inputs parameters described in step 3 and the predefined parameters for crop type, irrigation system and soil type. The simulation results are presented for different time periods; yearly average, monthly average, bi-weekly average and weekly average. These results are presented for each soil series that has over 1% of the total area.

At the end of the output file, there is a summary of the results. IWREDSS would calculate irrigation requirements for each of these soils independently. The total irrigation requirements for the area of interest will be the weighted average of all the soils available in that area using the following formula:

$IRR = IRR_1 * A_1 / A_T + IRR_2 A_2 / A_T + \ldots + IRR_n * A_n / A_T$

where $IRR_i$ , $A_i$ are the calculated irrigation requirements, and the area occupied by i-th soil type, respectively; $A_T$ is the total superficie of the different soils of the Tax-ID area of interest. Note that IWREDSS will not simulate irrigation requirements for the non-arable parts of the area of the TaxID; thus, the sum of the sums of all A's will not be equal if there are non-arable part of the area of interest. In these cases, the proportion will be normalized so as to add up to 1. The list of all the simulated soil types and corresponding proportion of each of them are given in the beginning of the summary section of the report.

**Step 6: Ploting the result**

After the text output, the user is prompted to select to plot the results (Figure 8). The results are plotted on the map based on the yearly irrigation requirements for the different soil types in the TaxID area.


Figure 8

An example of color plotting is given in Figure 9. The user can visualize the results on an enhanced option (Figure 10) by clicking the button to zoom to the whole TaxID Area.

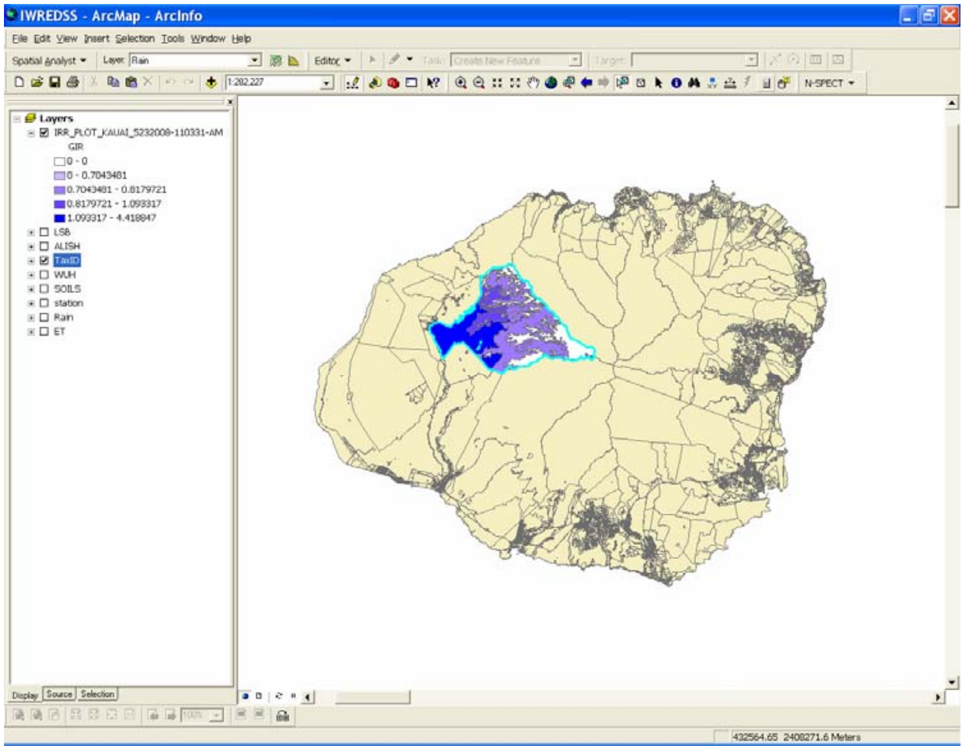



Figure 9

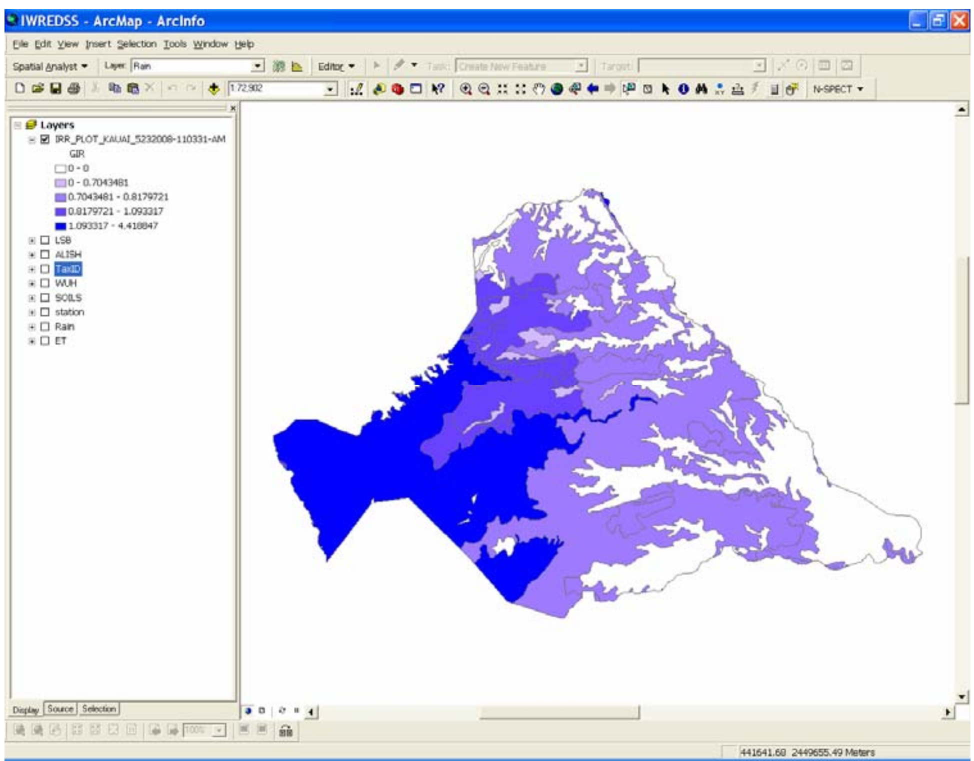



Figure 10

**Simulation of user's provided layer.**

Simulation of an actual location and net acres on a parcel can be conducted by using a layer provided by the user. Ideally user's layer need to be a georeferenced GIS layer. In case user's layer is in the shape of a parcel or a farm map, it needs to be digitized, georeferenced, saved as a polygon shapefile and have attribute table containing fields including FID, SHAPE, ID, ISLAND. Stepwise procedure on how to digitize from a parcel map is referred in the Technical Guide of IWREDSS.

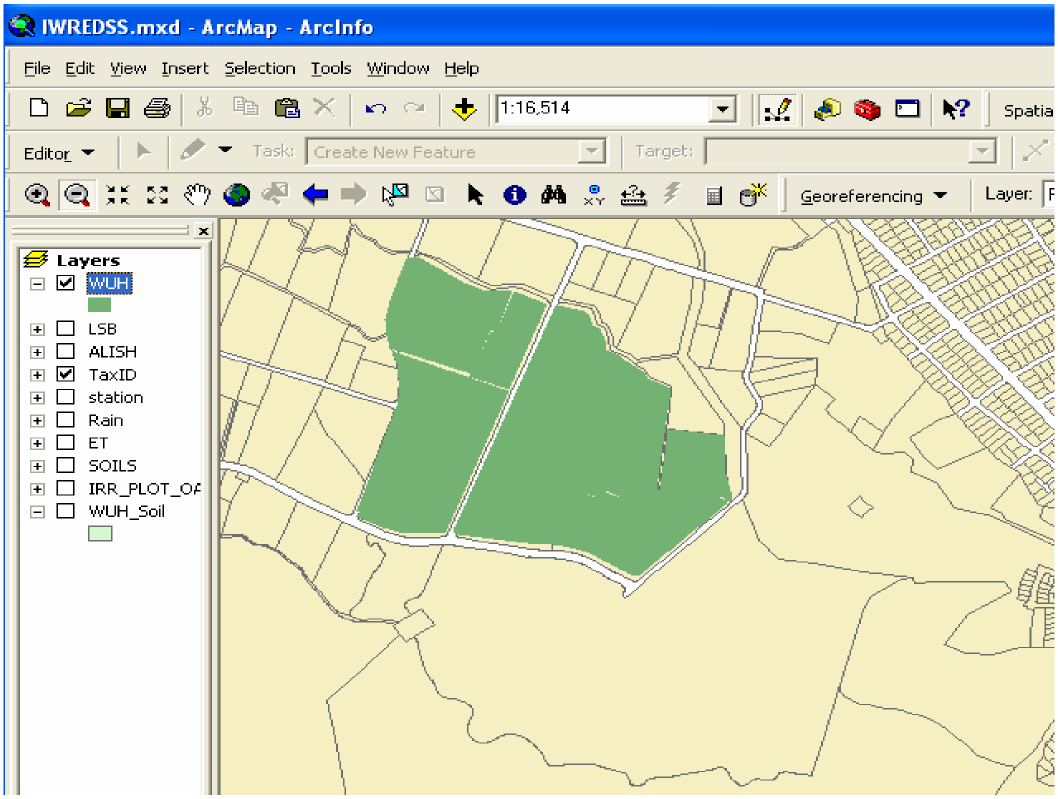
The irrigation requirements for a user's specified GIS layer can be simulated using two methods. The user needs to provide a Georeferenced GIS boundary layer of the area of interest e.g. an agricultural field or a golf course. Method 1 gives a detailed text output including information about soil and other statistics. Method 2 gives a summarized table of the simulated water budget components and therefore is quicker. Both methods gave the same estimates of water budget components.

**Method 1.**

1. Add the Georeferenced GIS layer of which irrigation requirements need to be calculated to the TOC of ArcMap (IWREDSS program).

2. If you have a paper copy of an agricultural field, a lawn or a golf course, scan the image and save it with extension .img or .jpeg. Digitize the layer following the steps explained in section "How to digitize in ArcGIS" in IWREDSS Technical Guide.

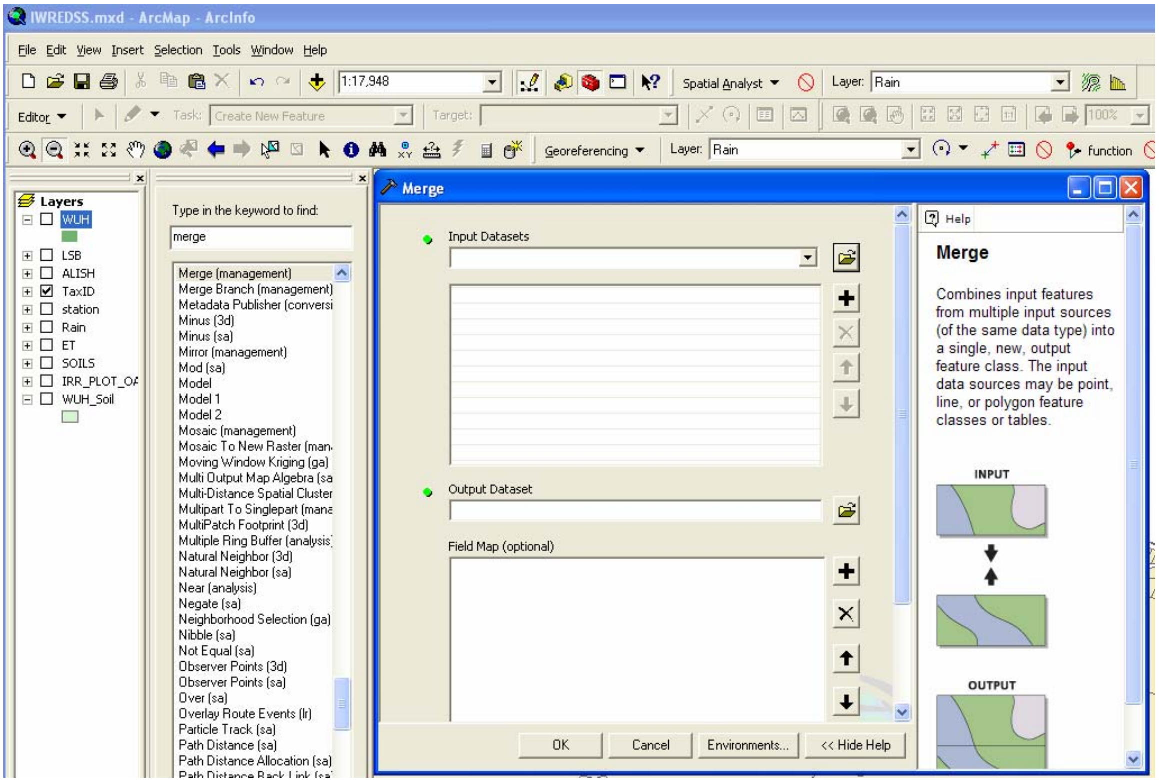
2. Overlay the layer on existing TMK layer (TaxID). Your layer may occupy more than one TMK. In the following figure, a layer "WUH" (Waimanalo experimental research station of the University of Hawaii-Manoa) has been overlaid on the TMK layer of Oahu.



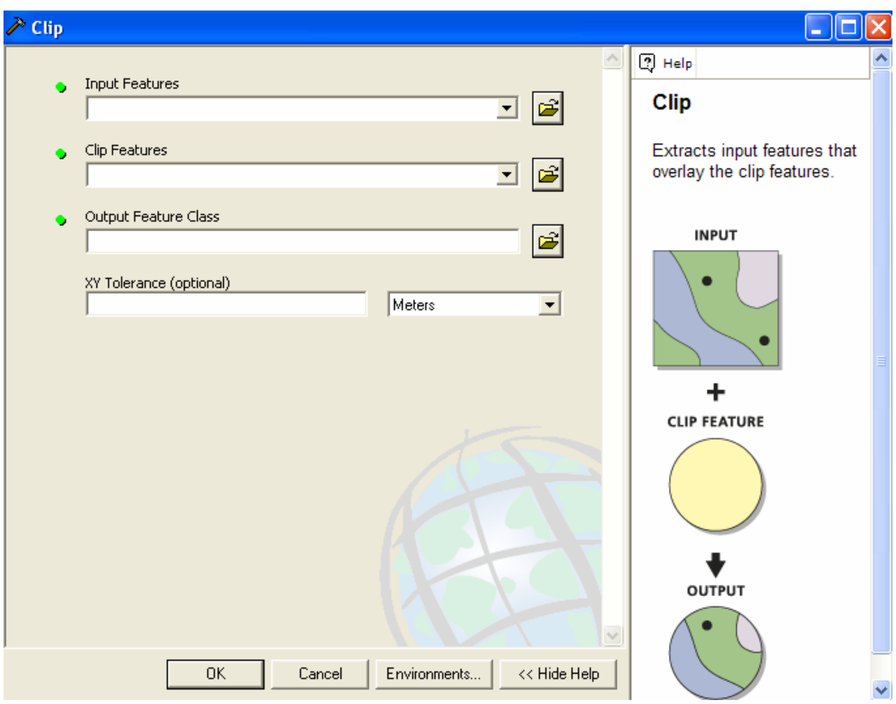

3. Run simulation for the TMK on which the layer falls

4. Run multiple simulations in case the layer falls on more than one TMK (as is the case of "WUH" layer.

5. Plot the simulation results (merge TaxID simulations results in case of multiple simulations). The output layers can be merged using "Merge (management)" tool as shown in following figure. The tool can be accessed by typing in the keyword "merge" in the "Index" table of ArcToolbox.




6. Clip the simulated result (individual or merged) with the user's layer following ArcToolbox > Analysis Tools > Extract > Clip as shown in the following figure.




7. The clipped layer contains all the simulation results for the user specified layer. The text results can be obtained from the text output files.

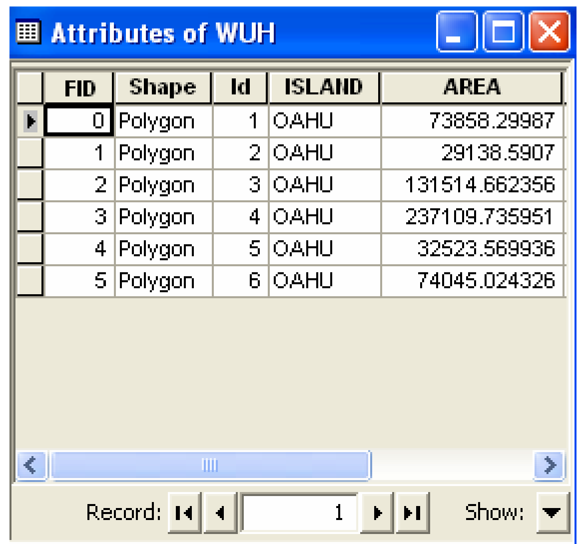
**Method 2.**

1. Add the folder containing supporting files of Georeferenced GIS user's layer in "IWREDSS\data\GIS"

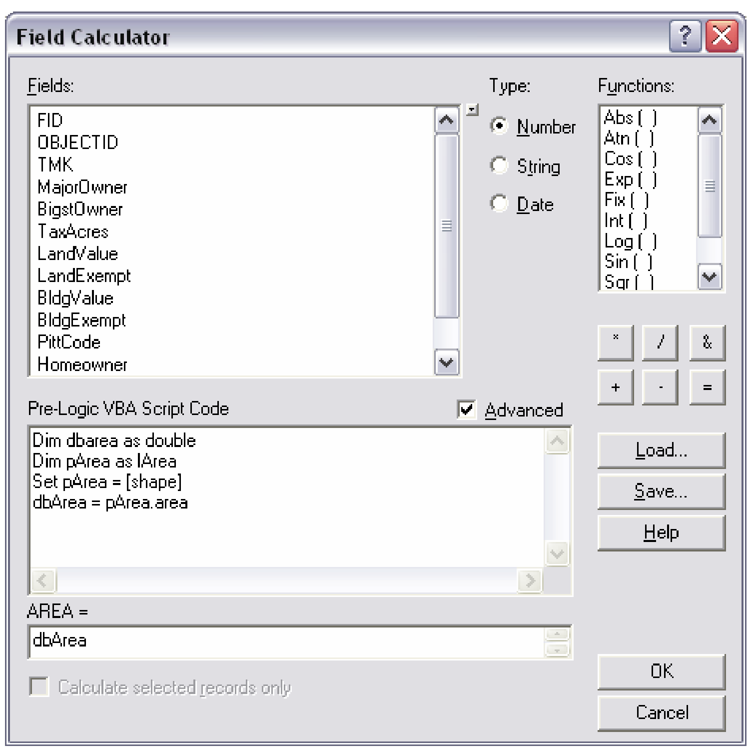
2. Create a folder "XXX_Soil" in IWREDSS\data\GIS, where XXX is the name of user's layer. The name of the folder is case sensitive.

3. Add user's layer in ArcMap TOC from "IWREDSS\data\GIS\folder containing layer" (Step 2 of Method 1).

4. The attribute table of the layer must contain fields including FID, Shape, Id, ISLAND, and AREA. The AREA field should have data "Type" as "double". The ISLAND filed should have data "Type" as "Text" and "Length" equivalent to 10.

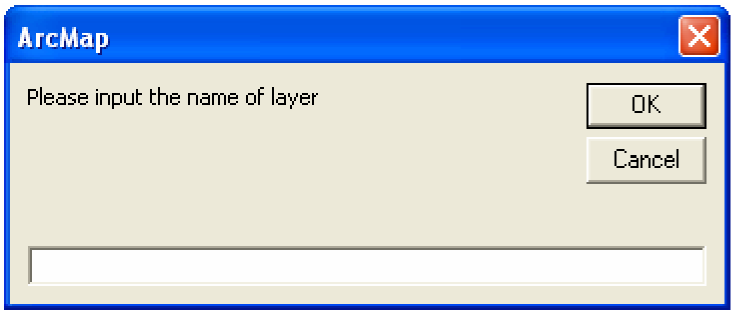



5. Values for the AREA field can be calculated using Pre-Logic VBA script code as follows.



6. Input file for IWREDSS can be prepared by clicking the database button besides IWREDSS button . (Buttons for IWREDSS execution and input file preparation are both located in the Tools toolbar).

7. Clicking prompts a message box asking user to type in the name of user's layer (CASE SENSITIVE). Enter the layer name and click OK button. This executes a code to prepare input files (database).




8. After a successful execution, a layer with the name "XXX_Soil" will be automatically added to the TOC of ArcMap.
9. Clicking IWREDSS button brings an interface that requires input parameter selections.
10. From dropdown menus select the name of Island and the name of the user's layer (case sensitive). (Complete Steps 3 through 6 i.e., complete the other input parameter selections. Hit "Run" to start simulation, "Yes" to continue, "Yes" to see text simulation results, and "Yes" to plot the simulation results.

**Appendix 2.**

# TECHNICAL GUIDE

## GeoDatabases, datasets and layers

Beside the visible layers in the table of contents of ArcMAP, the following datasets are also part of the IWREDSS package:

**TaxID_Soil_Statistics**: is the dBase dataset of the intersection between Tax-ID layer and Soil Layer. To ensure efficient calculations by IWREDSS, the original intersection is summed by Tax-ID polygon and soil type so that there will be only one record for each soil type in one Tax-ID area. .

**Alish_Soil_Statistics**: is the dBase dataset of the intersection between Alish layer and Soil Layer. Note in order to calculate efficiently, the original intersection is summed by Alish polygon and soil type so that there will be only one record for each soil type in one Alish area. .

**LSB_Soil_Statistics**: is the dBase dataset of the intersection between LSB layer and Soil Layer. Only the soil categories A, B, C, and D in LSB areas are included in the simulation as the category E is conservation lands. In order to improve the calculation efficiency, the original intersection is summed by LSB polygon and soil type so that there will be only one record for each soil type in one LSB area. .

**User's provided layer**: There could be other layers for simulation and their corresponding intersection layer (with soil) and statistic dataset should also be named as XXX_Soil and XXX_Soil_Statistics. (XXX is the layer name).

## IWREDSS Mechanism

### Area simulation

Upon user's clicking on the IWREDSS tools button, the following data collection process is launched:

1) Get the user's selection; make sure there is only one selected area (of all layers); get the name of the layer the selection belongs to.
2) Query the statistic dataset described above (the datasets of the layer the selected area belongs to) to get all the soil types and corresponding proportions and hydrologic

groups inside the selected area; note that non-arable soil types such as water, quarry will be filtered out before sending them to IWREDSS for simulation, and soil types that are of less than 1% of the whole area will not be simulated; get the summation of each hydrologic group for user's reference of CN specification later.

3) Find the geographically closest climate station (from the station layer) to the centroid of the selected area; use the raster layers Rain and ET to get the annual average rainfall and ET of the closest station and those of the centroid of the selected area so as to get the approximate ratios of rain and ET between the station and the area of interest. The historic daily climate records (rain and ET) of the climate station will be multiplied by these ratios to calculate their site specific values during the simulation:

   Rain_of_the_area = Rain_Ratio * Rain_of_Station

   ET_of_the_area = ET_Ratio * ET_of_Station

   The ratios are also shown on the parameter window.

4) Open the dialog to accept user's input; assign the CN of each hydrologic soil group to all the soil types of that group; launch IWREDSS; get results summary from IWREDSS log; prompt error if fails, or confirmation if succeeds.

## Data Plotting

After a successful execution, plotting is done upon request. The followings explain how it is done by the VBA code.

**1. Area simulation (XXX is the name of layer the selected area belongs to)**

1) Add the intersection layer of the simulated area to the map, i.e. data/GIS/XXX_Soil/XXX _Soil;
2) Select all the features (polygons) within the simulated area (the records with FID_XXX = FID of the simulated area).
3) Output the selected features to IRR_PLOT_NNN_TT, where NNN is the island name and TT is the current time of the plotting;
4) Add fields to the attribute table of the output layer, one for each of the water components, and set the values to the IWREDSS results
5) Plot based on GIR field using natural breaks.
6) Remove the added and unused intersection layer.

**2. Island simulation (XXX is the name of layer for the simulation)**

Similar to area simulation, with the following differences:

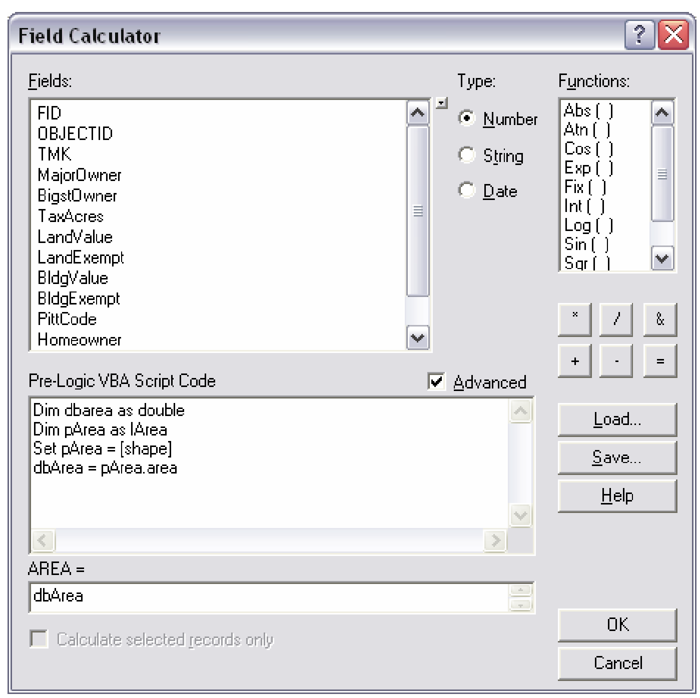
1) The plotting is for the whole island, and the unit is area instead of soil polygons within each area
2) The plotting is based on the summarized GIR values of each area and the user can manually plot on any other water component.
3) The exported layer includes all areas of the selected island, while some of the areas are not simulated because of non-arability. These un-simulated areas will have value 0 for all water component fields (displayed as white in the plotting).

## Procedure for preparing Statistics dataset

This procedure works behind the input files preparation button provided besides IWREDSS simulation button. The following description is for TaxID-related simulations. The procedure for the other layers (ALISH, LSB, etc.) is mostly the same.

The TaxID layers are obtained from Hawaii State GIS Program (http://www.hawaii.gov/dbedt/gis) and the soil layers are provided by the USDA. In case there are changes in the TaxID area division or soil type coverage, the statistics dataset may need to be reproduced. The following procedure can be followed:

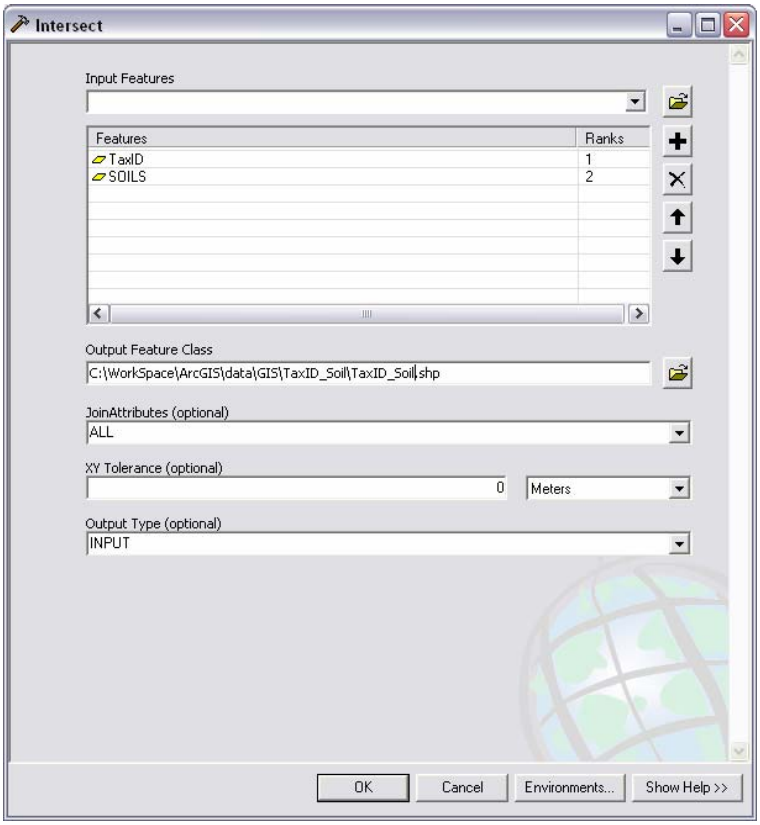
1) Merge the layers to be one big layer: TaxID. The *Merge* tool in ArcToolBox provided by ArcMap is suitable for this task.
2) Rename the TaxID layer as *TaxID*. Put it in the data/GIS/TaxID folder. Add ISLAND field and set values. Add area field in the TaxID layer and use the following pre-VBA code to set the value:




3) Use the ArcTool Intersect to intersect the TaxID layer and

the soil layer; add field *NewArea* (Double, length 19) to be the area of the intersected polygon and field *Portion* (Double, length 19) to be the proportion of *NewArea* to *Area* (the field from TaxID layer): NewArea/Area. Output the intersection layer as data/GIS/TaxID_Soil/TaxID_Soil.

4) Add to the TaxID layer field *FID_TaxID* and set its value to be same as field *FID*.



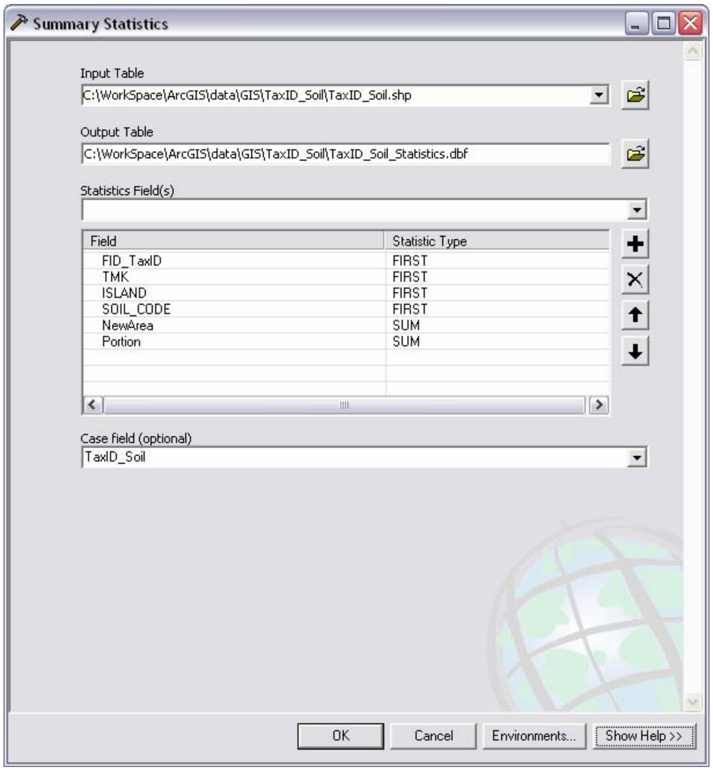

5) Add the field *TAX_SOIL* (Text, length 20) in the intersect layer. Calculate the field value as:

"" & [FID_TaxID] & "_" & [SOIL_CODE]

The field *FID_TaxID* is the *FID* field from TaxID layer which is automatically renamed so during the intersection..

6) Use the ArcTool Summary Statistics to generate the statistic dataset. The summary should be based on *TAX_SOIL* and output *FID_TaxID*, *TMK*, *ISLAND*, *SOIL_CODE*, *NewArea*, and *Portion*. The first three fields can be summarized by first or last while the last two fields must be summed. Output the statistic layer as

data/GIS/TaxID_Soil/ TaxID_Soil_Statistics. Note if for layer of other names, not only the layer name should be changed to XXX_Soil_Statistics, but also the path should be changed: data/GIS/**XXX**_Soil/ XXX_Soil_Statistics




7) Rename the field names of the summary dataset:

first_fid_tax -> FID_TaxID (Double)

first_tmk -> TMK (Double)

first_island -> ISLAND (Text, 10)

first_soil_code -> SOIL_CODE (Text, 20)

sum_newarea -> AREA (Double)

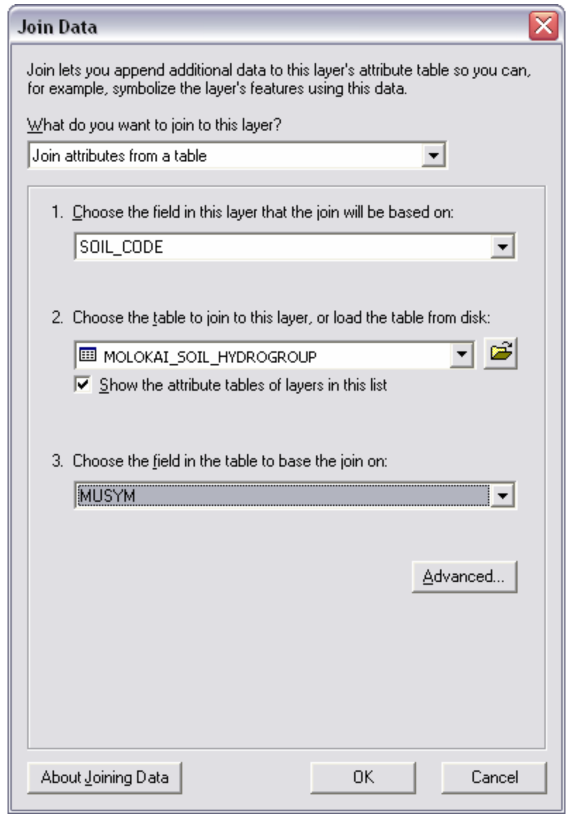
sum_portion -> PORTION (Double)

The renaming process can be done by first add a new field with the desired name and then calculate that field value by assigning it with the old field, and finally delete the old field.

8) Add a field *IL_Soil* (Text, length 20) in the statistic dataset with the following value:

[ISLAND] & "_" & [SOIL_CODE]

9) Add the data/GIS/Soil/SOIL_HYDROGROUP.dbf; join it to the statistic dataset using IL_Soil <-> IL_Soil. Add a new field *GROUP* (Text, length 1) in the statistic dataset, assign the field value to be the field HYDROLIC of SOIL_HYDROGROUP, then delete the join and remove SOIL_HYDROGROUP as SOIL_HYDROGROUP.HYDROLIC.




9) Recalculate field *PORTION* to make all portions that are larger than 1 to be 1.as:

- Open the attribute table
- "Search by Attribute": "Portion" > 1
- Switch from all records to selected records
- Right click on the portion field and choose "field calculator"
- In the input box, type in 1 and click ok.

10) Check and make sure the records with empty value of field *GROUP* are fine.

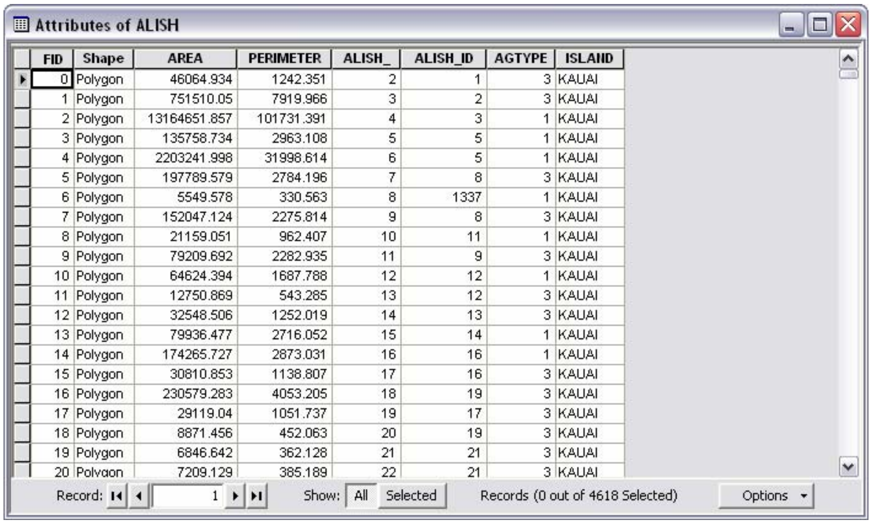
11) Remove the intersection layer (XXX_SOIL) because it will be added and removed automatically to the ArcMap document by code.

## Procedure for preparing Statistics dataset (for ALISH and LSB)

The Alish and LSB layers are obtained from Hawaii State GIS Program (http://www.hawaii.gov/dbedt/gis). In case there are changes in the ALISH/LSB area division or soil type coverage, the corresponding statistics dataset may need to be reproduced. The procedure is similar to that for TaxID case, with the following differences:

1) The original layers of Alish and LSB provided by Hawaii Statewide GIS Program are state-wide and don't have island information. Before intersection, a field in the

attribute table indicating the island should be added as shown below.



Attributes of ALISH

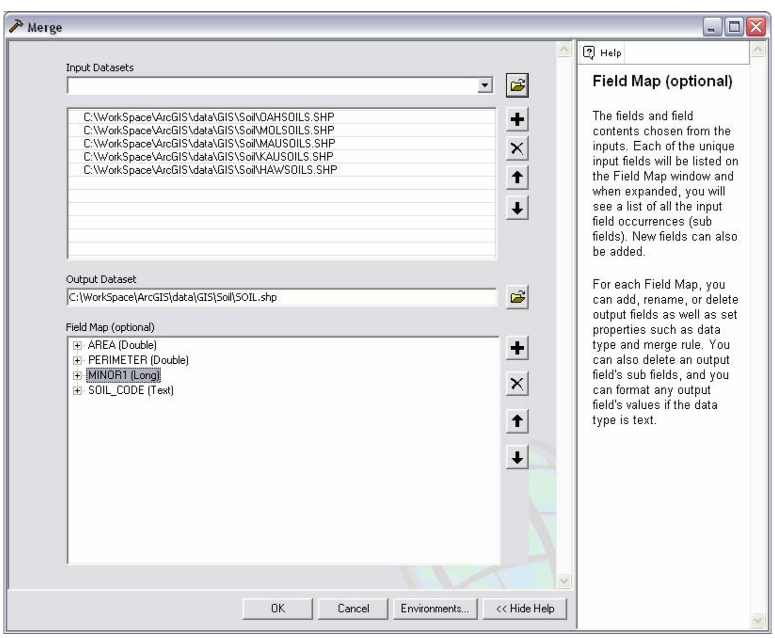
| FID | Shape | AREA | PERIMETER | ALISH_ | ALISH_ID | AGTYPE | ISLAND |
|---|---|---|---|---|---|---|---|
| 0 | Polygon | 46064.934 | 1242.351 | 2 | 1 | 3 | KAUAI |
| 1 | Polygon | 751510.05 | 7919.966 | 3 | 2 | 3 | KAUAI |
| 2 | Polygon | 13164651.857 | 101731.391 | 4 | 3 | 1 | KAUAI |
| 3 | Polygon | 135758.734 | 2963.108 | 5 | 5 | 1 | KAUAI |
| 4 | Polygon | 2203241.998 | 31998.614 | 6 | 5 | 1 | KAUAI |
| 5 | Polygon | 197789.579 | 2784.196 | 7 | 8 | 3 | KAUAI |
| 6 | Polygon | 5549.578 | 330.563 | 8 | 1337 | 1 | KAUAI |
| 7 | Polygon | 152047.124 | 2275.814 | 9 | 8 | 3 | KAUAI |
| 8 | Polygon | 21159.051 | 962.407 | 10 | 11 | 1 | KAUAI |
| 9 | Polygon | 79209.692 | 2282.935 | 11 | 9 | 3 | KAUAI |
| 10 | Polygon | 64624.394 | 1687.788 | 12 | 12 | 1 | KAUAI |
| 11 | Polygon | 12750.869 | 543.285 | 13 | 12 | 3 | KAUAI |
| 12 | Polygon | 32548.506 | 1252.019 | 14 | 13 | 3 | KAUAI |
| 13 | Polygon | 79936.477 | 2716.052 | 15 | 14 | 1 | KAUAI |
| 14 | Polygon | 174265.727 | 2873.031 | 16 | 16 | 1 | KAUAI |
| 15 | Polygon | 30810.853 | 1138.807 | 17 | 16 | 3 | KAUAI |
| 16 | Polygon | 230579.283 | 4053.205 | 18 | 19 | 3 | KAUAI |
| 17 | Polygon | 29119.04 | 1051.737 | 19 | 17 | 3 | KAUAI |
| 18 | Polygon | 8871.456 | 452.063 | 20 | 19 | 3 | KAUAI |
| 19 | Polygon | 6846.642 | 362.128 | 21 | 21 | 3 | KAUAI |
| 20 | Polygon | 7209.129 | 385.189 | 22 | 21 | 3 | KAUAI |

Record: 1 Show: All Selected Records (0 out of 4618 Selected) Options

2) Because the layers are state-wide, the corresponding soil and hydrologic group layer need to be merged from island-wide to state-wide. The merge tool in ArcToolBox provided by ArcMap is suitable for this task. Note that only some of the fields are needed, so you can delete the fields that are not commonly existing in the process of merge:

SOILS: SOIL_CODE

HYDROGROUP: MUSYM, HYDROLOGIC, ISLAND



## Procedure for preparing Statistics dataset (for user's layers)

This program is designed to be able to handle new layers for simulation. To do that, the corresponding layer and dataset need to be prepared as described above. The most important things to be careful about are: field names, path and layer names. After all datasets are prepared with the correct name in the correct path, the user will be able to do exactly the same simulating job as when using the existing three layers. Area simulation is also doable by choosing the desired area and run. Currently, the database button performs this task for a user's layer.

## IWREDSS CommandLine Parameters

This is the command line version of the graphic version of IWREDSS. User is required to enter the input parameters in the following orders:

1) Path
2) Crop Index (starting from 0)
3) Irrigation Starting Day (0~364)
4) Irrigation Ending Day (0~364)
5) Climate Station File Name (without the extension portion of the file name)
6) Rainfall ratio as defined before
7) ET ratio as defined before
8) Irrigation System Index (starting from 0)
9) Irrigation System Capacity Method Index (starting from 0)
10) Irrigation System Capacity Method Parameter (0 for Normal Practice)
11) Soil file name (usually the name of the island, without the extension portion of the file name)
12) Soil types within the simulated area concatenated by comma
13) Soil proportions corresponding to the soil types parameter (also concatenated by comma)
14) Depth to water depth (in feet)
15) Max LAI (see table for values)
16) Curve Numbers corresponding to the soil types parameter (also concatenated by comma)

17) Name of simulated location and additional comments that will be in the title
18) Extra Irrigation system parameter

This is a commandline example:

""C:\WorkSpace\ArcGIS\data/ImansysCLS" "C:\WorkSpace\ArcGIS\data/" " 17 0 364 kuala 0.4168 1.0105 1 0 0 MOLOKAI GL,HzC,KKTC,KcC3,LaC3,LaD3,LuA,MmA,PID,PID2,PJD2,rRK,rRR,rVS,rVT2 .071,.035,.012,.010,.011,.015,.019,.024,.026,.040,.042,.209,.027,.248,.061 50 1 78,78,78,78,78,78,78,78,78,78,78,78,78,78,78 "test" "

- ✓ The crop is the 22nd crop in the list (cabbage)
- ✓ Irrigation period is from 1/1 to 12/31
- ✓ Climate station file is "kuala" (kuala.csv)
- ✓ The irrigation system is the 2nd in the list (Trickle, Drip)
- ✓ The irrigation capacity method is the 1st in the list (Normal practice)
- ✓ The irrigation capacity method parameter is 0 (not used in this example as Normal practice is selected)
- ✓ The soil data file is MOLOKAI.csv
- ✓ The soil types (MUSYM code) in the simulated area are "GL, HzC, KKTC, KcC3, LaC3, LaD3, LuA, MmA, PID, PID2, PJD2, rRK, rRR, rVS, rVT2"
- ✓ The corresponding ratios of the soil types to the area are (omitting the leading zeros) ".071, .035, .012, .010, .011, .015, .019, .024, .026, .040, .042, .209, .027, .248, .061"
- ✓ The corresponding curve numbers of the soil types are "78, 78,78, 78,78,78, 78,78,78,78, 78, 78, 78, 78, 78"
- ✓ The depth to water table is 50 feet
- ✓ The location name of this simulation is "test……"
- ✓ There is no additional irrigation system parameter based on the irrigation system chosen.

**IWREDSS-related data**

All the other data files that haven't been described are of IWREDSS' use. For more details, please refer to IWREDSS User Manual.

**How to Digitize in ArcGIS**

1. Scan the image of a field and save it as an image file in ".img" or ".jpeg" format.

2. Open ArcCatalog, right click on your project folder (where your files are located) and click , go to "New", click on "Shapefile". In "Create New Shapefile" window name the new shapefile and select "polyline" as feature type. Select a projection through the "Edit" button under "Description box". You are in Spatial Reference Properties dialog box. Click "Select" button, double click "Geographic coordinate systems", double click "North America", double click "North American Datum 1983.prj, click "Add" button, and Click "Ok" at the end.

3. Open a new ArcMap session and add the scanned image (.img or .jpeg extensions) and the newly created polyline shape file, (You will find this file in the folder you created from ArcCatalog. You can also drag it from ArcCatalog and drop it in TOC of ArcMap). Add an already coordinated/georeferenced layer (It could be the coast line layer of the islands or any other layer which have at least three bench marks or proper boundary resembling the scanned image). This layer will be named "reference layer" in the rest of the document.

4. Select Toolbars from the "View" menu in ArcMap and click "Editor" to turn on the Editor toolbar if it is not already opened.

5. From the "View" menu go to "Toolbars" and click "Georeferencing" if it is not already opened.

6. Click the image layer to initiate it. Click the dropdown button of "Georeferencing" and click "Fit to Display". You will see the scanned image on screen.

7. Right click the reference layer (e.g. island coast layer) and select "Zome to Layer". You should see both the layers (the scanned image and the reference layer) on screen.

8. From "Georeferencing" toolbar click on 'Add Control Points", the line with red and green x as endpoints.

9. Click a bench mark (any corner of a park, building or boundary) on the image first followed by another click on the reference layer.

10. Repeat step 9 at least three or preferably four times to obtain different bench marks or until you see the two layers overlaid.

11. Right click the new shape file and add a new “Field” from the “Options” button on the bottom right corner. While creating a new field, select proper features of the filed i.e. string for “text” data and integer or double (depending on the size of the data) “number” data. Text may be the name of Island and number may be the amount of rainfall or PE.

12. Click the new shapefile to initiate it, and from the “Editor” toolbar select “Start Editing”

13. From the dropdown menu of “Georeference” button, select the new shapefile as the target “Layer”.

14. Zoom to the feature to be digitized, and from the Editor toolbar, select the “Sketch Tool” (the pencil icon).

15. Choose from the following options to create and modify the new feature:

- To create a polygon feature, left-click once in the Data Frame to start a new polygon. Successive single left-clicks will create vertices. Double-click at the last vertex to create a closed polygon.
- If you are editing a point feature class, left-click to add a single point location.
- If you are editing a line feature, left-click to start a new line and add vertices with successive single left-clicks. End the line with a double left-click.
- If you are in the middle of editing a line and realize that you want to make a correction to a part of that line you have already completed, double-click to finish the line segment. Then select the “Edit Tool” (the black arrow just to the left of the pencil icon in the Editor toolbar). Use this tool to select a feature by double-clicking it, and move the vertices individually.
- Use the “Esc” key to get out of a particular step.
- The Undo option can be quite helpful. To use it, press Ctrl-z; alternatively, from the Edit menu, select Undo. If your polygon gets too complicated to fix, you can use the Edit Tool to select it, and then delete it by pressing the Del key.

Note: You can pan and zoom while in the middle of digitizing a feature. Another handy feature is the magnifier window. To open this, from the main ArcMap menu bar, from the “Window” menu, select “Magnifier”. This allows you to have a separate window zoomed into a portion of the main Data Frame. You can pan and zoom this window around your Data Frame, which is a convenient way to follow the path of a long feature.

16. After the digitizing is complete, enter the information to the attribute table of the shapefile. Right click shapefile, click “Open Attribute Table”

17. Once you have digitized all the features, to save your edits, from the Editor toolbar, select “Save Edits” from Editor.

18. To stop editing, from the Editor toolbar, select “Stop Editing’ from Editor.

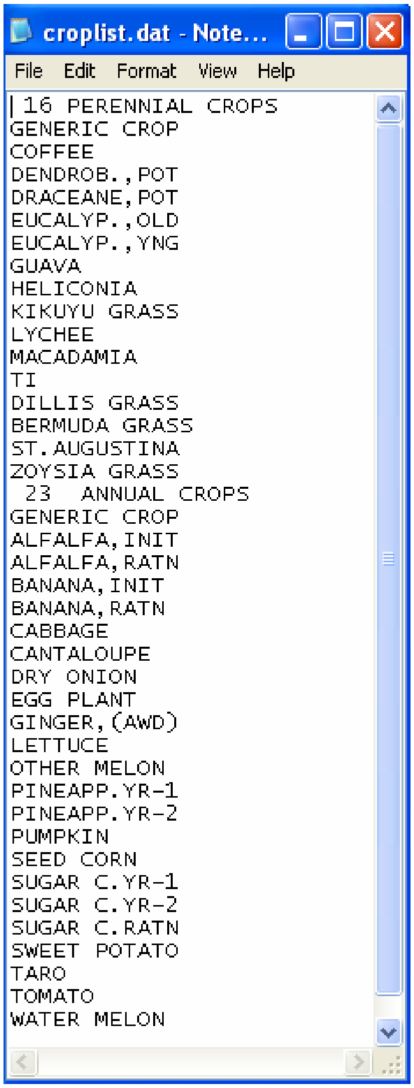
19. Save the shapefile and use it with its supporting files.

**How to add new crops in the existing crop list**

IWREDSS gives the option to add a new crop in the existing list of crops. Users need to figure out if the crop to be added is annual or perennial. There are two sets of crops in the existing list of 16 perennial and 23 annual crops. Detail on crop parameters including effective rooting depths, crop coefficients (KC), duration of crop cycle and their fractions, and allowable water depletion (AWD) for major annual and perennial crops are given in Tables 1 and 2 of the project report.

To update the existing list of crops:

- Open **croplist.dat** with Notepad from IWREDSS\data. The first line in the text gives the number of perennial crops followed by the names of the crops in the sequence these appear in the interface of the IWREDSS model as demonstrated in the following figure.




```
16 PERENNIAL CROPS
GENERIC CROP
COFFEE
DENDROB.,POT
DRACEANE,POT
EUCALYP.,OLD
EUCALYP.,YNG
GUAVA
HELICONIA
KIKUYU GRASS
LYCHEE
MACADAMIA
TI
DILLIS GRASS
BERMUDA GRASS
ST.AUGUSTINA
ZOYSIA GRASS
 23  ANNUAL CROPS
GENERIC CROP
ALFALFA,INIT
ALFALFA,RATN
BANANA,INIT
BANANA,RATN
CABBAGE
CANTALOUPE
DRY ONION
EGG PLANT
GINGER,(AWD)
LETTUCE
OTHER MELON
PINEAPP.YR-1
PINEAPP.YR-2
PUMPKIN
SEED CORN
SUGAR C.YR-1
SUGAR C.YR-2
SUGAR C.RATN
SWEET POTATO
TARO
TOMATO
WATER MELON
```

- Update the crop list with the exact number and the names of the crops to be added.
- Save the file **croplist.dat** before closing it.
- Open **crop.dat** with Notepad from IWREDSS\data. The first two lines in the text give the number of perennial crops and root zone and water use coefficient data i.e., crop name, crop depth (inches), KC, Fraction, and AWD. The list of crops and the related coefficients should be updated following the example of the existing information as shown in the following figure.

crop.dat - Notepad

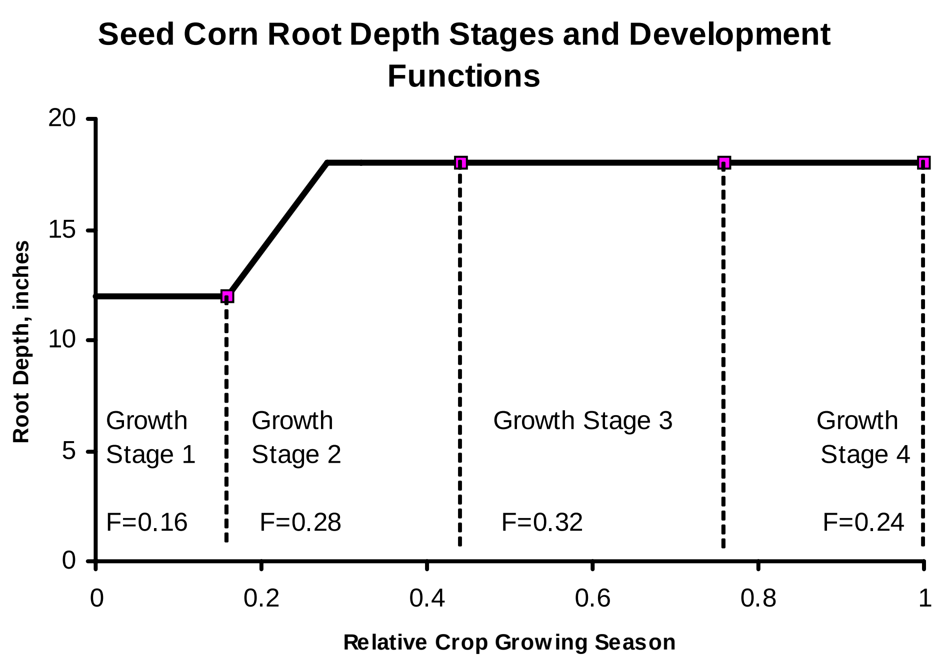
File Edit Format View Help

```
16 PERENNIAL CROPS : ROOT ZONE AND WATER USE COEFFICIENT DATA
  CROP   DEPTH(IN) ............   KC   / AWD  ..........................
GENERIC CROP ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
COFFEE       ;0.85;0.85;0.85;0.90;0.95;0.95;0.95;0.95;0.95;0.95;0.90;0.90
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
DENDROB.,POT ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
         8; 8;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
DRACEANE,POT ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
         8; 8;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
EUCALYP.,OLD ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        72;72;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
EUCALYP.,YNG ;0.60;0.60;0.60;0.60;0.60;0.60;0.60;0.60;0.60;0.60;0.60;0.60
        48;72;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
GUAVA        ;0.80;0.90;1.00;1.00;0.90;0.80;0.80;0.90;1.00;1.00;0.90;0.85
        30;60;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
HELICONIA    ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
KIKUYU GRASS ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
LYCHEE       ;0.95;1.00;1.00;1.00;0.95;0.90;0.90;0.85;0.80;0.80;0.90;0.90
        30;60;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
MACADAMIA    ;0.85;0.85;0.85;0.90;0.95;0.95;0.95;0.95;0.95;0.95;0.90;0.90
        30;60;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
TI           ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
DILLIS GRASS ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
BERMUDA GRASS;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
ST.AUGUSTINA ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50
ZOYSIA GRASS ;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00;1.00
        24;48;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50;0.50

 23  ANNUAL CROPS  : ROOT ZONE AND WATER USE COEFFICIENT DATA
   CROP   DEPTH(IN) .....KC.....  .....FRACTION ..... ALLOWABLE DEPLETION
GENERIC CROP; 8;12;0.40;1.00;0.90;0.25;0.33;0.25;0.17;0.50;0.50;0.50;0.50
ALFALFA,INIT; 8;24;0.40;0.95;0.90;0.14;0.38;0.31;0.17;0.50;0.50;0.50;0.50
ALFALFA,RATN;24;24;0.40;0.95;0.90;0.14;0.38;0.31;0.17;0.50;0.50;0.50;0.50
BANANA,INIT ;24;48;0.50;1.10;1.00;0.31;0.23;0.31;0.15;0.35;0.35;0.35;0.35
BANANA,RATN ;48;48;1.00;1.05;1.05;0.33;0.16;0.49;0.01;0.35;0.35;0.35;0.35
CABBAGE     ; 8;12;0.70;1.05;0.95;0.24;0.36;0.30;0.09;0.45;0.45;0.45;0.45
CANTALOUPE  ; 8;12;0.50;0.85;0.60;0.08;0.50;0.21;0.21;0.35;0.35;0.35;0.35
DRY ONION   ; 8;12;0.70;1.05;0.75;0.10;0.17;0.50;0.23;0.25;0.25;0.25;0.90
EGG PLANT   ; 8;12;0.70;1.05;0.90;0.21;0.32;0.29;0.18;0.40;0.40;0.40;0.40
GINGER,(AWD); 8;12;0.70;1.05;0.75;0.10;0.17;0.50;0.23;0.25;0.25;0.25;0.25
LETTUCE     ; 8;12;0.70;1.00;0.95;0.27;0.40;0.20;0.13;0.30;0.30;0.30;0.30
OTHER MELON ; 8;12;0.50;1.05;0.75;0.21;0.29;0.33;0.17;0.35;0.35;0.35;0.35
PINEAPP.YR-1;12;24;0.40;0.30;0.30;0.16;0.33;0.26;0.25;0.60;0.60;0.60;0.60
PINEAPP.YR-2;24;24;0.30;0.30;0.30;0.38;0.32;0.27;0.03;0.60;0.60;0.60;0.60
PUMPKIN     ; 8;12;0.50;1.00;0.80;0.20;0.30;0.30;0.20;0.35;0.35;0.35;0.50
SEED CORN   ;12;18;0.40;1.20;0.50;0.16;0.28;0.32;0.24;0.60;0.60;0.60;0.80
```

- For perennial crops, the crop data occupy the two rows for the two root zone depths of Hawaiian crops, minimum and maximum i.e., 0-24 and 24-48 inches, respectively. The values of KC and AWD are given in the first and second lines, respectively. The root depth data are considered as average data for Hawaii conditions.
- Leave one line space between perennial and the annual crop information.
- Details on the data for annual crops can be found in Table 1 of the project report. The entries in Table 1 and in the above screen shot are explained in the following table:

| Column entries | Description |
|---|---|
| 1st | Minimum annual crop irrigated root zone depth. This depth is usually irrigated in the beginning of crop season |
| 2nd | Maximum crop irrigated root zone depth. Crops obtain and maintain this maximum depth during their growth stages. Patterns of crop root zone development are shown in the following figure (Case of Seed Corn). |
| 3rd through 6th | The values of KC at initial, mid, and late stages of crop. |
| 7th through 10th | These are fraction of crop growing season under the heading of FRACTION. The data represent duration of crop growth stage that varies for various crops. |
| 11th through 14th | The fraction of total AWD during the four stages of crop. |



**Appendix 3**. Calculation of daily $ET_o$ using temperature data.

STEP 1: Extraterrestrial radiation (Ra) is calculated for each day using the following equations from Duffie and Beckman (1980) (reproduced from Snyder and Eching, 2002).

$G_{SC}$ = solar constant in MJ $m^{-2}$ $min^{-1}$

$$G_{SC} = 0.082$$

$\sigma$ = Steffan-Boltzman constant in MJ $m^{-2}$ $d^{-1}$ $K^{-4}$

$$\sigma = 4.90 \times 10^{-9}$$

$\phi$ = latitude in radians converted from latitude ($L$) in degrees

$$\phi = \frac{\pi L}{180}$$

$d_r$ = correction for eccentricity of Earth's orbit around the sun on day $i$ of the year

$$d_r = 1 + 0.033 cos\left(\frac{2\pi}{365} i\right)$$

$\delta$ = declination of the sun above the celestial equator in radians on day $i$ of the year

$$\delta = 0.409 sin\left(\frac{2\pi}{365} i - 1.39\right)$$

$\omega_s$ = sunrise hour angle in radians

$$\omega_s = cos^{-1}\left[-tan \phi \, tan \delta\right]$$

$R_a$ = extraterrestrial radiation (MJ $m^{-2}$ $d^{-1}$)

$$R_a = \left(\frac{24 \cdot 60}{\pi}\right) G_{SC} d_r \left[\omega_s \sin\delta \sin\phi + \cos\phi \cos\delta \sin\omega_s\right]$$

STEP 2: Calculate ET using 1995 Hargreaves equation (Hargreaves and Samani, 1985) (reproduced from Snyder and Eching, 2002).

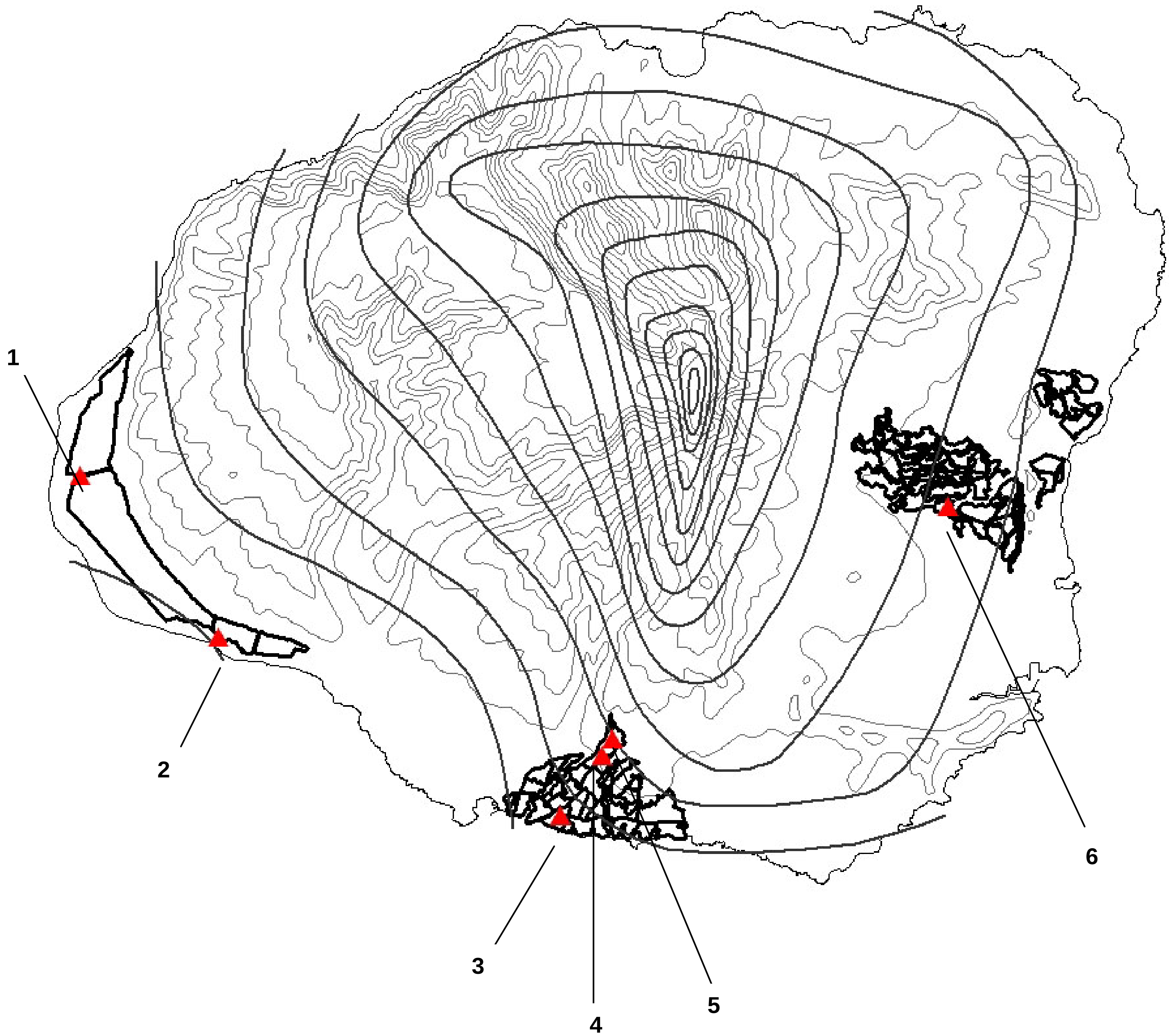
Hargreaves-Samani equation for ET of a short, 0.12 m tall reference surface

$$ET_h = 0.408\left(0.0023 R_a [T_m + 17.8]\sqrt{T_x - T_n}\right)$$

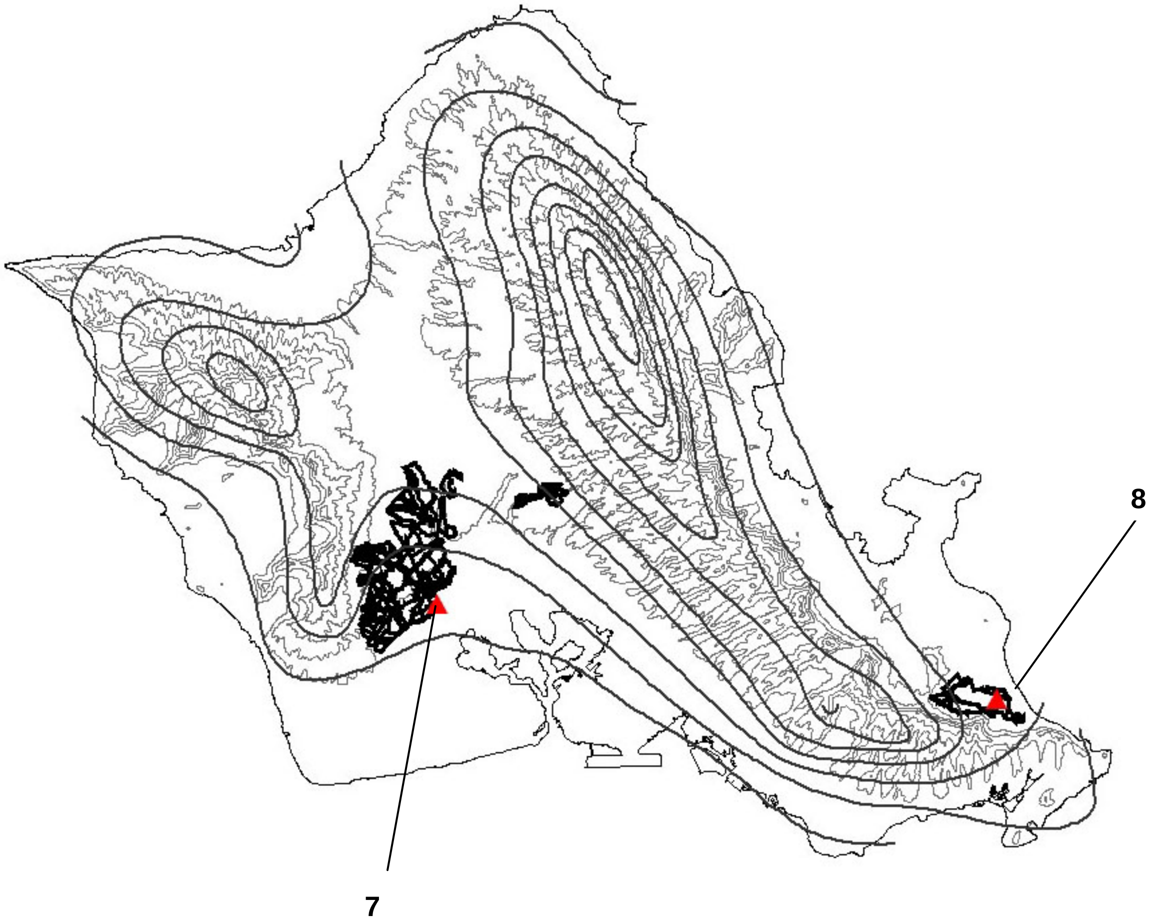
where the 0.408 = $1/\lambda$ factor converts from MJ $m^{-2}d^{-1}$ to mm $d^{-1}$.

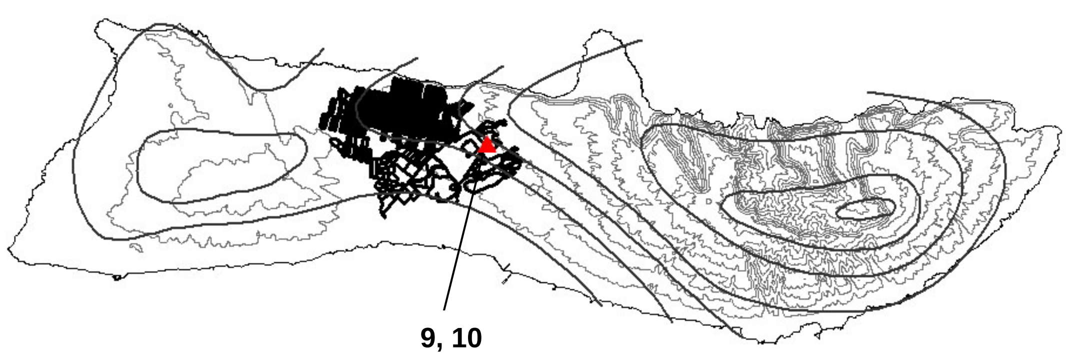
Where: $T_m$ = mean daily temperature in $^{o}$C, $T_X$ = the maximum daily air temperature in $^{o}$C, and $T_n$ = the minimum daily air temperature in $^{o}$C.

**Appendix 4a.** System boundaries and climate data stations for the Kekaha, Kauai and East Kauai systems. Stations information is in Table 3. The isohyets (dark contours) indicate gradients in rainfall, while the contours (light lines) indicate the elevation.

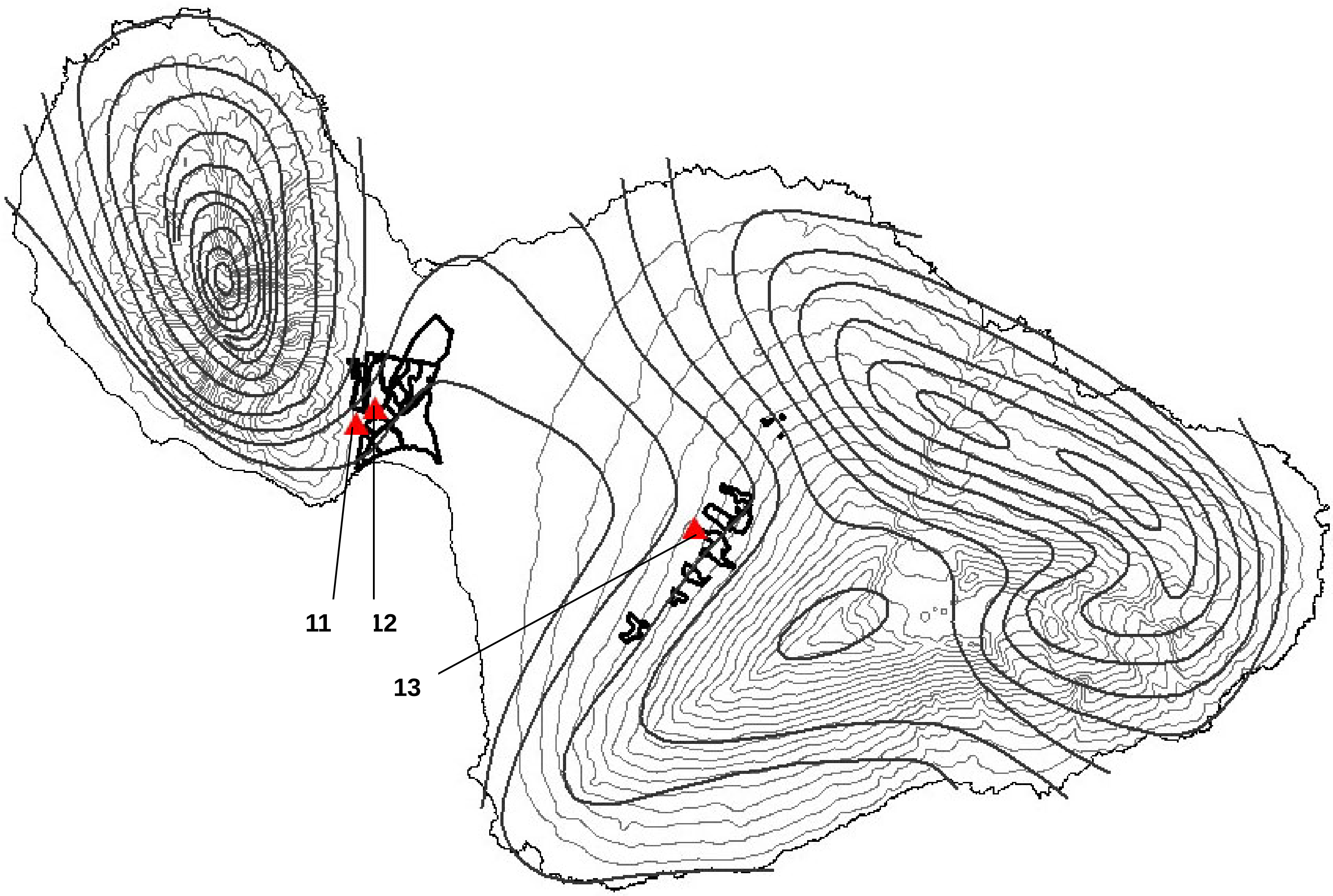


**Appendix 4b.** System boundaries and climate data stations for the Waiahole, Waimanalo and Molokai systems. Stations information is in Table 3. Isohyets (dark) indicate gradients in rainfall (dark). The contours (light) indicate the elevation.

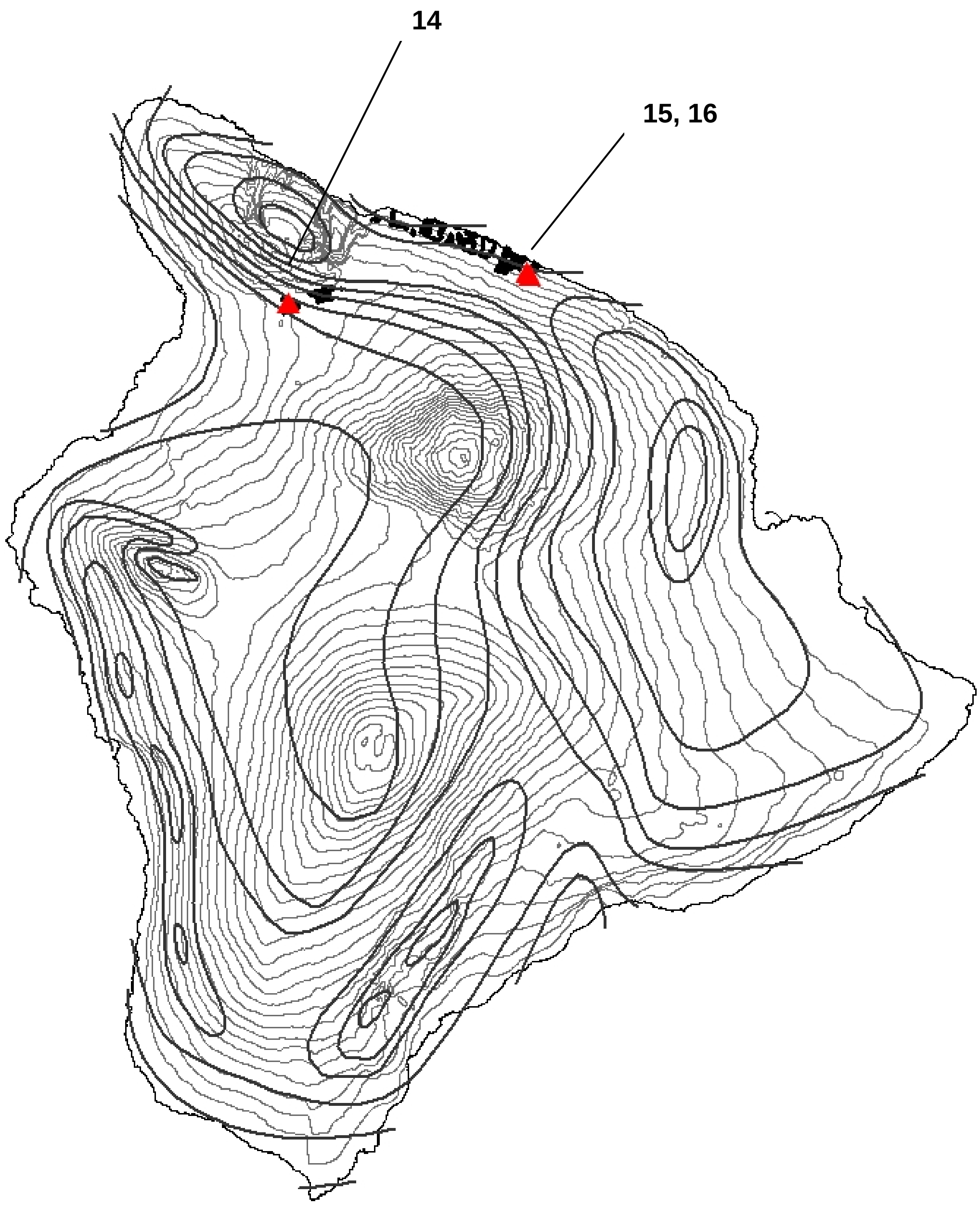


**Appendix 4c.** System boundaries and climate data stations for the West Maui and Kula systems. Station information is in Table 3. Isohyets (dark) indicate gradients in rainfall. Elevation is indicated by the contours (light).



**Appendix 4d.** System boundaries and climate data stations for the Kamuela and Lower Hamakua systems. Stations information is in Table 3. Isohyets (dark) indicate gradients in rainfall. Elevation is indicated by the contours (light).



**Appendix: 5a**: Annual water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 | 0.0 | 0.0 | 6.9 | 5.2 | 2.2 | 3.2 | 1.7 | 0.0 | 3.2 | 2.0 | 2.9 |
| 2 | 0.0 | 0.0 | 1.1 | 4.3 | 3.6 | 1.7 | 2.0 | 0.7 | 0.0 | 3.3 | 2.0 | 1.8 |
| 3 | 0.4 | 0.4 | 11.3 | 3.8 | 3.1 | 1.8 | 2.0 | 0.7 | 0.0 | 4.0 | 2.7 | 1.3 |
| 4 | 0.8 | 0.9 | 25.3 | 3.2 | 2.7 | 2.2 | 2.0 | 0.4 | 0.1 | 4.2 | 3.5 | 0.5 |
| 5 | 1.9 | 2.3 | 61.6 | 3.0 | 2.3 | 1.9 | 1.9 | 0.5 | 0.2 | 4.7 | 4.8 | 0.4 |
| 6 | 3.3 | 3.8 | 104.0 | 1.4 | 1.1 | 1.1 | 1.1 | 0.1 | 0.2 | 4.6 | 5.4 | 0.0 |
| 7 | 4.1 | 4.8 | 130.7 | 1.7 | 1.4 | 1.4 | 1.3 | 0.0 | 0.2 | 4.7 | 5.7 | 0.0 |
| 8 | 4.3 | 5.1 | 138.8 | 1.5 | 1.2 | 1.2 | 1.1 | 0.1 | 0.2 | 4.7 | 5.6 | 0.0 |
| 9 | 3.5 | 4.1 | 112.6 | 2.1 | 1.8 | 1.8 | 1.5 | 0.1 | 0.2 | 4.4 | 5.2 | 0.0 |
| 10 | 2.5 | 2.9 | 79.0 | 3.6 | 2.8 | 2.7 | 2.3 | 0.6 | 0.2 | 3.9 | 4.3 | 0.1 |
| 11 | 0.7 | 0.8 | 21.9 | 6.1 | 4.5 | 3.4 | 3.2 | 1.3 | 0.3 | 3.1 | 2.8 | 1.1 |
| 12 | 0.1 | 0.2 | 4.5 | 5.0 | 3.9 | 2.6 | 2.6 | 0.9 | 0.2 | 2.9 | 2.1 | 1.3 |
| Total | 21.6 | 25.4 | 690.7 | 42.5 | 33.5 | 24.0 | 24.1 | 7.2 | 1.8 | 47.5 | 46.2 | 9.5 |

Seasonal (Jan-Apr) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 | 0.0 | 0.0 | 6.9 | 5.2 | 2.3 | 3.2 | 1.7 | 0.0 | 3.2 | 2.2 | 2.9 |
| 2 | 0.3 | 0.4 | 9.9 | 4.3 | 3.4 | 2.1 | 2.4 | 0.7 | 0.1 | 3.3 | 3.4 | 1.3 |
| 3 | 1.6 | 1.9 | 52.4 | 3.8 | 2.9 | 2.2 | 2.4 | 0.7 | 0.2 | 4.0 | 4.8 | 0.7 |
| 4 | 1.1 | 1.3 | 35.5 | 3.2 | 2.6 | 2.4 | 2.1 | 0.4 | 0.2 | 4.2 | 3.6 | 0.2 |
| NIR | 3.1 | 3.6 | 97.8 | 18.2 | 14.0 | 9.0 | 10.1 | 3.5 | 0.6 | 14.6 | 14.0 | 5.1 |

Seasonal (Feb-May) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.1 | 0.1 | 1.9 | 4.3 | 3.5 | 1.9 | 2.0 | 0.7 | 0.0 | 3.3 | 2.1 | 1.7 |
| 3 | 0.9 | 1.0 | 27.3 | 3.8 | 2.9 | 2.0 | 2.3 | 0.7 | 0.2 | 4.0 | 4.0 | 1.0 |
| 4 | 1.8 | 2.1 | 57.9 | 3.2 | 2.6 | 2.3 | 2.2 | 0.4 | 0.2 | 4.2 | 5.0 | 0.3 |
| 5 | 1.7 | 2.0 | 55.4 | 3.0 | 2.2 | 2.0 | 1.8 | 0.5 | 0.2 | 4.7 | 4.1 | 0.2 |
| NIR | 4.5 | 5.2 | 142.5 | 14.3 | 11.3 | 8.2 | 8.3 | 2.4 | 0.6 | 16.1 | 15.2 | 3.1 |

Seasonal (Mar-Jun) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 0.1 | 0.1 | 3.1 | 3.8 | 3.1 | 1.9 | 1.9 | 0.7 | 0.0 | 4.0 | 2.4 | 1.2 |
| 4 | 1.0 | 1.2 | 32.4 | 3.2 | 2.6 | 2.1 | 2.1 | 0.4 | 0.2 | 4.2 | 4.3 | 0.5 |
| 5 | 2.6 | 3.0 | 81.9 | 3.0 | 2.2 | 2.0 | 2.0 | 0.5 | 0.2 | 4.7 | 5.6 | 0.2 |
| 6 | 2.4 | 2.8 | 75.7 | 1.4 | 1.1 | 1.1 | 1.0 | 0.1 | 0.2 | 4.6 | 3.9 | 0.0 |
| NIR | 6.0 | 7.1 | 193.1 | 11.4 | 9.1 | 7.1 | 7.0 | 1.8 | 0.6 | 17.4 | 16.2 | 2.0 |

Seasonal (Apr-Jul) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 0.1 | 0.1 | 3.7 | 3.2 | 2.8 | 2.0 | 1.8 | 0.4 | 0.0 | 4.2 | 2.6 | 0.8 |
| 5 | 1.5 | 1.7 | 47.1 | 3.0 | 2.3 | 1.8 | 1.9 | 0.5 | 0.2 | 4.7 | 4.8 | 0.5 |
| 6 | 3.2 | 3.8 | 102.1 | 1.4 | 1.1 | 1.1 | 1.1 | 0.1 | 0.2 | 4.6 | 5.5 | 0.0 |
| 7 | 2.6 | 3.0 | 82.6 | 1.7 | 1.4 | 1.4 | 1.2 | 0.0 | 0.2 | 4.7 | 4.1 | 0.0 |
| NIR | 7.4 | 8.7 | 235.5 | 9.3 | 7.6 | 6.3 | 5.9 | 1.1 | 0.6 | 18.1 | 17.0 | 1.3 |

Seasonal (May-Aug) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 0.2 | 0.3 | 8.0 | 3.0 | 2.4 | 1.7 | 1.5 | 0.5 | 0.0 | 4.7 | 2.8 | 0.7 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 2.1 | 2.5 | 67.6 | 1.4 | 1.1 | 1.1 | 1.0 | 0.1 | 0.1 | 4.6 | 4.7 | 0.0 |
| 7 | 3.4 | 4.0 | 109.5 | 1.7 | 1.4 | 1.4 | 1.3 | 0.0 | 0.2 | 4.7 | 5.7 | 0.0 |
| 8 | 2.6 | 3.0 | 82.8 | 1.5 | 1.2 | 1.2 | 1.0 | 0.1 | 0.2 | 4.7 | 4.1 | 0.0 |
| NIR | 8.4 | 9.9 | 267.8 | 7.6 | 6.2 | 5.4 | 4.8 | 0.8 | 0.6 | 18.7 | 17.2 | 0.8 |

Seasonal (Jun-Sep) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 0.4 | 0.4 | 11.4 | 1.4 | 1.3 | 1.1 | 0.8 | 0.1 | 0.0 | 4.6 | 2.5 | 0.1 |
| 7 | 2.1 | 2.4 | 65.9 | 1.7 | 1.5 | 1.5 | 1.2 | 0.0 | 0.2 | 4.7 | 4.8 | 0.0 |
| 8 | 3.6 | 4.2 | 113.5 | 1.5 | 1.2 | 1.2 | 1.1 | 0.1 | 0.2 | 4.7 | 5.6 | 0.0 |
| 9 | 2.3 | 2.7 | 72.0 | 2.1 | 1.8 | 1.8 | 1.4 | 0.1 | 0.2 | 4.4 | 3.8 | 0.0 |
| NIR | 8.2 | 9.7 | 262.9 | 6.7 | 5.8 | 5.6 | 4.5 | 0.4 | 0.6 | 18.4 | 16.8 | 0.1 |

Seasonal (Jul-Oct) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 0.3 | 0.3 | 9.3 | 1.7 | 1.6 | 1.6 | 1.0 | 0.0 | 0.0 | 4.7 | 2.8 | 0.1 |
| 8 | 2.2 | 2.6 | 70.6 | 1.5 | 1.3 | 1.3 | 1.0 | 0.1 | 0.1 | 4.7 | 4.8 | 0.0 |
| 9 | 2.9 | 3.4 | 93.3 | 2.1 | 1.8 | 1.8 | 1.5 | 0.1 | 0.2 | 4.4 | 5.2 | 0.0 |
| 10 | 1.5 | 1.8 | 49.0 | 3.6 | 2.8 | 2.6 | 2.2 | 0.6 | 0.2 | 3.9 | 3.5 | 0.2 |
| NIR | 7.0 | 8.2 | 222.1 | 8.9 | 7.5 | 7.2 | 5.7 | 0.8 | 0.6 | 17.6 | 16.4 | 0.3 |

Seasonal (Aug-Nov) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 0.4 | 0.5 | 13.6 | 1.5 | 1.4 | 1.3 | 0.9 | 0.1 | 0.0 | 4.7 | 2.7 | 0.1 |
| 9 | 1.6 | 1.9 | 52.4 | 2.1 | 1.8 | 1.8 | 1.4 | 0.1 | 0.1 | 4.4 | 4.5 | 0.0 |
| 10 | 2.0 | 2.3 | 63.0 | 3.6 | 2.8 | 2.5 | 2.3 | 0.6 | 0.2 | 3.9 | 4.6 | 0.3 |
| 11 | 0.5 | 0.6 | 16.0 | 6.1 | 4.5 | 3.3 | 3.2 | 1.3 | 0.3 | 3.1 | 2.8 | 1.2 |
| NIR | 4.5 | 5.3 | 144.9 | 13.2 | 10.5 | 9.0 | 7.8 | 2.1 | 0.6 | 16.0 | 14.5 | 1.6 |

Seasonal (Sep-Dec) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 0.2 | 0.2 | 5.5 | 2.1 | 2.0 | 1.8 | 1.2 | 0.1 | 0.0 | 4.4 | 2.6 | 0.2 |
| 10 | 1.0 | 1.2 | 32.2 | 3.6 | 2.8 | 2.2 | 2.2 | 0.6 | 0.2 | 3.9 | 3.9 | 0.6 |
| 11 | 0.7 | 0.8 | 23.0 | 6.1 | 4.5 | 3.2 | 3.4 | 1.3 | 0.3 | 3.1 | 3.7 | 1.3 |
| 12 | 0.3 | 0.4 | 11.1 | 5.0 | 3.9 | 2.8 | 2.7 | 0.9 | 0.2 | 2.9 | 2.6 | 1.2 |
| NIR | 2.2 | 2.6 | 71.7 | 16.8 | 13.2 | 10.0 | 9.5 | 2.8 | 0.7 | 14.2 | 12.8 | 3.3 |

Seasonal (Oct-Jan) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.1 | 0.1 | 2.5 | 3.6 | 3.0 | 2.0 | 1.0 | 0.6 | 0.0 | 3.9 | 2.4 | 1.0 |
| 11 | 0.3 | 0.3 | 8.2 | 6.1 | 4.6 | 2.6 | 1.5 | 1.3 | 0.2 | 3.1 | 3.2 | 2.0 |
| 12 | 0.6 | 0.7 | 19.7 | 5.1 | 4.0 | 2.9 | 1.2 | 0.9 | 0.2 | 2.9 | 3.5 | 1.1 |
| 1 | 0.1 | 0.2 | 4.8 | 6.6 | 4.7 | 2.7 | 3.0 | 1.7 | 0.2 | 3.0 | 2.7 | 2.0 |
| NIR | 1.1 | 1.3 | 35.3 | 21.7 | 16.5 | 10.3 | 6.7 | 4.5 | 0.7 | 13.0 | 11.8 | 6.2 |

Seasonal (Nov-Feb) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 0.0 | 0.0 | 0.0 | 6.1 | 4.8 | 2.1 | 1.5 | 1.3 | 0.0 | 3.1 | 2.1 | 2.7 |
| 12 | 0.2 | 0.2 | 6.5 | 5.1 | 4.1 | 2.4 | 1.2 | 0.9 | 0.2 | 2.9 | 3.0 | 1.7 |
| 1 | 0.4 | 0.4 | 11.7 | 6.8 | 4.9 | 3.1 | 3.0 | 1.7 | 0.3 | 3.1 | 3.8 | 1.8 |
| 2 | 0.3 | 0.4 | 10.8 | 4.0 | 3.2 | 2.2 | 2.0 | 0.6 | 0.2 | 3.2 | 2.8 | 1.0 |
| NIR | 0.9 | 1.1 | 29.1 | 22.4 | 17.1 | 9.9 | 7.7 | 4.7 | 0.7 | 12.4 | 11.7 | 7.2 |

Seasonal (Dec-Mar) water budget components

| MO | NIR | GIR | GAL_A | G_RAIN | N_RAIN | ER | ER21 | RO | INT | ETo | ET | DR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 0.0 | 0.0 | 0.7 | 5.1 | 4.2 | 2.0 | 1.2 | 0.9 | 0.0 | 2.9 | 1.9 | 2.3 |
| 1 | 0.2 | 0.2 | 5.9 | 6.8 | 4.9 | 2.6 | 3.0 | 1.7 | 0.2 | 3.1 | 3.3 | 2.3 |
| 2 | 0.7 | 0.8 | 22.8 | 4.4 | 3.4 | 2.5 | 2.0 | 0.7 | 0.2 | 3.3 | 4.0 | 0.9 |
| 3 | 1.0 | 1.2 | 31.3 | 3.8 | 2.8 | 2.0 | 1.9 | 0.7 | 0.2 | 3.9 | 3.5 | 0.8 |
| NIR | 1.9 | 2.2 | 60.6 | 20.2 | 15.5 | 9.3 | 8.1 | 4.0 | 0.6 | 13.3 | 12.8 | 6.3 |

**Appendix 5b**: Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Feb | 0.0 | 0.0 | 3.7 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mar | 0.4 | 0.0 | 1.3 | 2.0 | 0.0 | 0.0 | 0.8 | 0.4 | 0.9 | 1.2 | 1.5 |
| Apr | 0.9 | 0.7 | 1.0 | 2.5 | 0.0 | 0.0 | 0.8 | 0.8 | 1.8 | 2.4 | 3.1 |
| May | 2.3 | 2.6 | 0.5 | 3.6 | 0.0 | 0.0 | 0.9 | 2.1 | 3.4 | 4.1 | 4.7 |
| Jun | 3.8 | 3.9 | 0.3 | 5.9 | 0.9 | 0.0 | 1.0 | 3.8 | 5.0 | 5.5 | 6.0 |
| Jul | 4.8 | 4.9 | 0.2 | 6.3 | 2.8 | 0.0 | 0.9 | 4.9 | 5.7 | 6.2 | 6.5 |
| Aug | 5.1 | 5.2 | 0.2 | 7.1 | 2.9 | 0.0 | 0.9 | 5.2 | 6.1 | 6.6 | 6.6 |
| Sep | 4.1 | 3.9 | 0.3 | 6.1 | 1.9 | 0.0 | 0.9 | 4.2 | 5.0 | 5.4 | 5.7 |
| Oct | 2.9 | 2.6 | 0.5 | 4.9 | 0.9 | 0.0 | 0.9 | 2.7 | 4.2 | 5.0 | 5.0 |
| Nov | 0.8 | 0.0 | 1.2 | 2.5 | 0.0 | 0.0 | 0.8 | 0.9 | 1.7 | 2.2 | 2.6 |
| Dec | 0.2 | 0.0 | 2.5 | 1.2 | 0.0 | 0.0 | 0.8 | 1.1 | 1.2 | 1.2 | 1.2 |
| Total | 25.4 | 25.6 | 0.2 | 35.4 | 16.2 | 0.0 | 1.0 | 25.6 | 30.2 | 32.5 | 34.2 |
| NIR | 21.6 | 21.8 | 0.2 | 30.1 | 13.8 | 0.0 | 1.0 | 21.8 | 25.7 | 27.6 | 29.1 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Feb | 0.4 | 0.0 | 1.4 | 1.7 | 0.0 | 0.0 | 0.5 | 0.6 | 0.9 | 1.1 | 1.2 |
| Mar | 1.9 | 1.9 | 0.7 | 5.0 | 0.0 | 0.0 | 0.9 | 1.7 | 3.2 | 4.1 | 5.0 |
| Apr | 1.3 | 1.2 | 0.8 | 2.6 | 0.0 | 0.0 | 0.7 | 1.5 | 2.3 | 2.7 | 3.1 |
| Total | 3.6 | 3.5 | 0.7 | 9.2 | 0.0 | 0.0 | 0.9 | 3.1 | 6.0 | 8.0 | 9.9 |
| NIR | 3.1 | 2.9 | 0.7 | 7.8 | 0.0 | 0.0 | 0.9 | 2.6 | 5.1 | 6.8 | 8.4 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb | 0.1 | 0.0 | 3.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mar | 1.0 | 0.9 | 0.9 | 2.7 | 0.0 | 0.0 | 0.8 | 0.9 | 1.7 | 2.1 | 2.6 |
| Apr | 2.1 | 1.9 | 0.6 | 4.0 | 0.0 | 0.0 | 0.9 | 1.9 | 3.3 | 4.1 | 4.8 |
| May | 2.0 | 2.4 | 0.6 | 3.8 | 0.0 | 0.0 | 0.9 | 2.0 | 3.0 | 3.6 | 4.1 |
| Total | 5.2 | 5.2 | 0.5 | 10.8 | 0.9 | 0.0 | 1.0 | 5.0 | 7.6 | 9.2 | 10.5 |
| NIR | 4.5 | 4.4 | 0.5 | 9.1 | 0.8 | 0.0 | 1.0 | 4.2 | 6.5 | 7.8 | 8.9 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar | 0.1 | 0.0 | 2.2 | 0.7 | 0.0 | 0.0 | 0.8 | 0.5 | 0.6 | 0.7 | 0.7 |
| Apr | 1.2 | 0.9 | 0.8 | 2.8 | 0.0 | 0.0 | 0.8 | 1.1 | 2.0 | 2.5 | 3.1 |
| May | 3.0 | 2.9 | 0.5 | 4.9 | 0.0 | 0.0 | 0.9 | 2.9 | 4.3 | 5.2 | 5.8 |
| Jun | 2.8 | 2.5 | 0.4 | 3.9 | 0.0 | 0.0 | 0.8 | 2.9 | 3.7 | 4.0 | 4.4 |
| Total | 7.1 | 6.5 | 0.4 | 11.0 | 2.9 | 0.0 | 1.0 | 7.0 | 9.5 | 10.7 | 11.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NIR | 6.0 | 5.5 | 0.4 | 9.4 | 2.5 | 0.0 | 1.0 | 6.0 | 8.0 | 9.1 | 10.0 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Apr | 0.1 | 0.0 | 2.0 | 0.7 | 0.0 | 0.0 | 1.0 | 0.6 | 0.6 | 0.7 | 0.7 |
| May | 1.7 | 1.8 | 0.5 | 3.4 | 0.0 | 0.0 | 0.9 | 1.6 | 2.5 | 3.0 | 3.4 |
| Jun | 3.8 | 3.9 | 0.3 | 5.8 | 0.9 | 0.0 | 0.9 | 3.8 | 4.9 | 5.5 | 5.9 |
| Jul | 3.0 | 2.6 | 0.3 | 4.8 | 1.2 | 0.0 | 0.8 | 3.1 | 3.7 | 3.9 | 4.2 |
| Total | 8.7 | 9.1 | 0.3 | 12.2 | 4.3 | 0.0 | 1.0 | 8.7 | 10.8 | 11.8 | 12.6 |
| NIR | 7.4 | 7.7 | 0.3 | 10.4 | 3.6 | 0.0 | 1.0 | 7.4 | 9.2 | 10.0 | 10.7 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| May | 0.3 | 0.0 | 1.1 | 0.7 | 0.0 | 0.0 | 0.9 | 0.6 | 0.7 | 0.7 | 0.7 |
| Jun | 2.5 | 2.6 | 0.4 | 4.4 | 0.9 | 0.0 | 0.9 | 2.4 | 3.4 | 3.9 | 4.3 |
| Jul | 4.0 | 3.9 | 0.2 | 5.8 | 1.9 | 0.0 | 0.9 | 4.1 | 4.8 | 5.2 | 5.5 |
| Aug | 3.0 | 2.6 | 0.3 | 5.1 | 1.2 | 0.0 | 0.9 | 3.0 | 3.9 | 4.4 | 4.8 |
| Total | 9.9 | 9.9 | 0.2 | 14.8 | 5.0 | 0.0 | 1.0 | 10.0 | 12.0 | 12.9 | 13.7 |
| NIR | 8.4 | 8.5 | 0.2 | 12.6 | 4.3 | 0.0 | 1.0 | 8.5 | 10.2 | 11.0 | 11.6 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jun | 0.4 | 0.6 | 0.7 | 0.7 | 0.0 | 0.0 | 1.0 | 0.6 | 0.7 | 0.7 | 0.7 |
| Jul | 2.4 | 2.7 | 0.4 | 3.6 | 0.9 | 0.0 | 0.9 | 2.4 | 3.3 | 3.8 | 4.2 |
| Aug | 4.2 | 3.9 | 0.3 | 5.9 | 1.9 | 0.0 | 0.9 | 4.2 | 5.1 | 5.6 | 5.9 |
| Sep | 2.7 | 2.5 | 0.3 | 4.9 | 1.2 | 0.0 | 0.8 | 2.6 | 3.4 | 3.7 | 4.0 |
| Total | 9.7 | 9.8 | 0.2 | 14.8 | 4.9 | 0.0 | 1.0 | 9.8 | 11.8 | 12.7 | 13.5 |
| NIR | 8.2 | 8.3 | 0.2 | 12.6 | 4.2 | 0.0 | 1.0 | 8.3 | 10.0 | 10.8 | 11.5 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul | 0.3 | 0.0 | 1.1 | 1.3 | 0.0 | 0.0 | 0.6 | 0.5 | 0.7 | 0.8 | 0.9 |
| Aug | 2.6 | 2.7 | 0.4 | 4.5 | 0.9 | 0.0 | 0.9 | 2.5 | 3.7 | 4.4 | 5.0 |
| Sep | 3.4 | 3.0 | 0.3 | 5.0 | 1.9 | 0.0 | 0.9 | 3.4 | 4.4 | 4.8 | 5.2 |
| Oct | 1.8 | 1.3 | 0.6 | 3.6 | 0.0 | 0.0 | 0.9 | 1.8 | 2.7 | 3.2 | 3.7 |
| Total | 8.2 | 8.0 | 0.3 | 13.7 | 3.9 | 0.0 | 1.0 | 8.2 | 10.5 | 11.6 | 12.6 |
| NIR | 7.0 | 6.8 | 0.3 | 11.6 | 3.3 | 0.0 | 1.0 | 6.9 | 8.9 | 9.9 | 10.7 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug | 0.5 | 0.6 | 0.8 | 1.3 | 0.0 | 0.0 | 0.6 | 0.6 | 0.8 | 0.9 | 1.0 |
| Sep | 1.9 | 1.8 | 0.5 | 3.6 | 0.0 | 0.0 | 0.9 | 1.9 | 2.8 | 3.3 | 3.8 |
| Oct | 2.3 | 2.8 | 0.5 | 4.0 | 0.0 | 0.0 | 0.9 | 2.3 | 3.3 | 3.9 | 4.4 |
| Nov | 0.6 | 0.0 | 1.2 | 2.5 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total | 5.3 | 5.5 | 0.4 | 9.2 | 1.8 | 0.0 | 1.0 | 5.2 | 7.4 | 8.5 | 9.5 |
| NIR | 4.5 | 4.6 | 0.4 | 7.8 | 1.6 | 0.0 | 1.0 | 4.4 | 6.3 | 7.2 | 8.1 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sep | 0.2 | 0.0 | 1.5 | 0.7 | 0.0 | 0.0 | 1.0 | 0.5 | 0.6 | 0.7 | 0.7 |
| Oct | 1.2 | 0.9 | 0.9 | 3.4 | 0.0 | 0.0 | 0.9 | 1.1 | 2.1 | 2.7 | 3.3 |
| Nov | 0.8 | 0.0 | 1.3 | 2.9 | 0.0 | 0.0 | 0.8 | 0.8 | 1.8 | 2.6 | 3.3 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec | 0.4 | 0.0 | 1.4 | 1.3 | 0.0 | 0.0 | 0.9 | 1.1 | 1.2 | 1.2 | 1.2 |
| Total | 2.6 | 2.5 | 0.7 | 5.8 | 0.0 | 0.0 | 1.0 | 2.3 | 4.4 | 5.7 | 7.0 |
| NIR | 2.2 | 2.1 | 0.7 | 4.9 | 0.0 | 0.0 | 1.0 | 1.9 | 3.7 | 4.9 | 6.0 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct | 0.1 | 0.0 | 2.5 | 0.7 | 0.0 | 0.0 | 0.9 | 0.5 | 0.6 | 0.6 | 0.7 |
| Nov | 0.3 | 0.0 | 1.8 | 1.7 | 0.0 | 0.0 | 0.8 | 0.3 | 0.8 | 1.2 | 1.5 |
| Dec | 0.7 | 0.9 | 1.1 | 2.8 | 0.0 | 0.0 | 0.8 | 0.7 | 1.4 | 1.8 | 2.1 |
| Jan | 0.2 | 0.0 | 2.5 | 1.3 | 0.0 | 0.0 | 1.0 | 1.1 | 1.2 | 1.2 | 1.3 |
| Total | 1.3 | 0.9 | 1.0 | 4.9 | 0.0 | 0.0 | 0.9 | 1.1 | 2.2 | 3.0 | 3.7 |
| NIR | 1.1 | 0.8 | 1.0 | 4.1 | 0.0 | 0.0 | 0.9 | 0.9 | 1.8 | 2.5 | 3.1 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nov | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dec | 0.2 | 0.0 | 1.6 | 0.9 | 0.0 | 0.0 | 0.7 | 0.7 | 0.8 | 0.9 | 0.9 |
| Jan | 0.4 | 0.0 | 1.4 | 1.9 | 0.0 | 0.0 | 0.7 | 0.6 | 1.0 | 1.3 | 1.5 |
| Feb | 0.4 | 0.0 | 1.9 | 2.5 | 0.0 | 0.0 | 0.8 | 0.4 | 1.1 | 1.7 | 2.2 |
| Total | 1.1 | 0.9 | 1.1 | 4.3 | 0.0 | 0.0 | 1.0 | 0.9 | 2.1 | 3.0 | 3.8 |
| NIR | 0.9 | 0.8 | 1.1 | 3.6 | 0.0 | 0.0 | 1.0 | 0.8 | 1.8 | 2.5 | 3.3 |

Statistics for annual and seasonal net irrigation requirements

| MO | MEAN | MED. | CV | XMAX | XMIN | ZERO | RSQ | 50% | 80% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec | 0.0 | 0.0 | 5.3 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jan | 0.2 | 0.0 | 1.8 | 0.9 | 0.0 | 0.0 | 0.8 | 0.7 | 0.8 | 0.9 | 0.9 |
| Feb | 0.8 | 0.9 | 1.1 | 3.0 | 0.0 | 0.0 | 0.8 | 0.8 | 1.5 | 2.0 | 2.5 |
| Mar | 1.2 | 1.1 | 1.1 | 3.7 | 0.0 | 0.0 | 0.8 | 1.3 | 2.3 | 3.0 | 3.5 |
| Total | 2.2 | 2.0 | 0.9 | 7.6 | 0.0 | 0.0 | 0.9 | 1.7 | 4.0 | 5.8 | 7.7 |
| NIR | 1.9 | 1.7 | 0.9 | 6.4 | 0.0 | 0.0 | 0.9 | 1.4 | 3.4 | 4.9 | 6.5 |