

IWREDSS, A User-Friendly Water Allocation Software Package

Ali Fares

College of Agriculture and Human Sciences, Prairie View A&M University, Prairie View, TX 77449

Abstract

User friendly water management software packages have proven to be helpful tools in managing water resources. They have been successfully used to perform complex analyses and to make informed predictions concerning consequences of proposed actions. In this paper, we describe a User-Friendly Computer Based Water Management Software Package, IWREDSS. This package was developed using two object oriented high level programming languages, Java and Visual Basics, and a spatial geo-spatial analysis software, ArcGIS.9.x version 1.0 and 10.x version.2.0. The model estimates irrigation requirements (IRR) perennial and annual crops based on site specific soil and weather information for different irrigation systems. IWREDSS has been successfully calibrated and validated using different data sets. A special version of IWREDSS has been used to calculate crop water allocation in Hawaii. A second version of the model developed for Texas will be presented. Results of the model compared favorably with those reported in the literature.

Introduction

Accurate measurement and estimation of water requirements for different uses (agricultural, domestic, or industrial) is a vital component of any water management program. Site specific investigations have been conducted to quantify water uses across all these areas; however, most of these results are commonly site specific, dependent on climatological and edaphic conditions, and costly in time and resources. Numerical water management models based on sound physical theories are practical management tools that have been proven to be useful in quantifying past, current and future water uses for different users. These numerical water management tools combine the subtlety of human judgment combined with the power of personal computers to allow more effective use of available data and account for more complexity.

In addition, these numerical models increase the accuracy of estimates to a level beyond human best judgment. Recent developments in Object oriented programming languages, i.e., Java, Visual Basics, and spatial analysis software, i.e., geographical information systems (GIS), and enhanced computational capabilities present the opportunity to apply hydrological and simulation models to enhance and optimize water supply and river basin managements, and to study impact of management intervention.

IWREDSS version 1.0 (Fares, 2007) and 2.0 (Fares, 2013) are two irrigation water management tools that have been used to calculate irrigation water use for different land uses in Hawaii. IWREDSS 1.0 and 2.0 are the GIS enhanced IManSys (Fares and Fares 2012). IManSys is based on the agricultural field scale irrigation requirements simulation (AFSIRS) model (Smajstrla and Zazueta, 1988). Irrigation requirements calculated using IManSys are more realistic because IManSys accounts for two important components of the water cycle, i.e., surface runoff, and rainfall canopy interception. It also includes others features for evapotranspiration potential calculation using different models (e.g., Panman Monteith Equation, ETM (Fares, 1996)) either daily complete weather data or daily minimum and maximum temperatures.

Rainfall canopy interception is the portion of gross rain that is intercepted by vegetation and evaporated without reaching the ground (Gash, 1979); it approximately represents 20% of net evaporation from the earth land surface (Choudhury et al., 1998), and 25-40% from temperate forests (Linacre and Geerts, 1997). Consequently, It is one of the major components of water cycle. Rainfall canopy interception varies as a function of rainfall amount and intensity, and land cover; for instance, Leuning et al. (1994) reported a wheat rainfall canopy interception of 30%. However, Safeeq and Fares (2012), reported observed canopy interception varying between 23 and 45% for a Hawaiian forest with a native and a non-native plant species mixture. The canopy can retain only a certain amount of rainfall, the so-called The maximum storage capacity, S_{max} , is calculated as a function of the leaf area index (LAI) using the following equation of Dickinson (1984): $S_{max} = 0.2 * LAI$.

Runoff is a major component of the water cycle at the plot, field, or watershed scales. For instance, under semi-arid condition, the average annual runoff is about 10% of the annual rainfall; however, it can be as high as 70% of a given rainfall event. Runoff widely varies according to the seasonal distribution of rainfall, catchment characteristics (shape, size, steepness), and vegetation type and density (Edwards et al., 1983). IManSys calculates surface runoff using SCS curve number method (SCS, 1985 and 1993).

Site specific irrigation water requirements, determined by IManSys, are calculated based on plant growth parameters, soil properties, irrigation systems, and long-term daily weather data (rain, and potential evapotranspiration). In case daily potential evapotranspiration data are missing, IManSys can calculate them based on daily temperature data using different models, e.g. ETM (Fares et al. 1996). IManSys requires several databases of soil physical properties, and plant growth parameters, irrigation systems, and canopy interception. IManSys was implemented in JAVA object oriented language. IManSys output includes detailed net and gross IWRs, and all water budget components at different time scales (daily, weekly, biweekly, monthly, and annually) based on non-exceedance drought probability which is calculated from a

conditional probability model that uses the type I extreme value distribution for positive non-zero irrigation values. More details about IManSys can be found in Fares and Fares (2012).

Accurate estimation of IWRs should use site specific input data; thus, the spatial distribution of major input parameters (e.g., rainfall, potential evapotranspiration, soil water holding capacity) should be used. Thus, there is a need for an irrigation water management calculation model that accounts for spatial variation of major water cycle components and the soil physical properties (water holding capacity of each layer, and the depths of all soil layers). Thus, the objectives of this work are to i) give an overview of a site and crop specific, variable scale, GIS-based water allocation decision support system, and ii) evaluate the performance of this model in determining (gross irrigation requirements, GIRs) for different crops under high spatio-temporal variations.

Model

The water management model IWREDSS version 1.0 (Fares, 2007) and version 2.0 (Fares, 2013) are based on IManSys which was developed to account for the spatial variation of the input databases used by IManSys, e.g., soil physical properties, rainfall, and evapotranspiration.

A daily water balance model

Based on a daily mass balance approaches (equation 1), IManSys, uses long-term historical daily rainfall, evapotranspiration, irrigation systems specification, soil physical properties, and crop parameters to calculate daily, weekly, biweekly, monthly and yearly gross irrigation requirement (G_IRR), which is also called irrigation water allocation. In addition, IManSys calculates all the other water budget components at the same frequencies of those of irrigation requirements cited above.

IManSys calculates the crop irrigation water demand as follows:

$$G_IRR = \frac{ET_{crop} + Dr + RO + CI - R - Ge}{(1-LR).fs} \quad (1)$$

where ET_{crop} is the crop evapotranspiration, R is gross rainfall, CI is canopy interception, Dr is excess drainage below the rootzone, RO is surface runoff, Ge is groundwater contribution, fs is efficiency of irrigation method (e.g., 85% and 50% for drip and flood, respectively) and LR is the leaching requirement to avoid salt built up in rootzone. All terms are in mm.

How to use the software

This is a step by step procedure on how to use IWREDSS. Users need to follow these steps to use the software:

Step 1: Starts of the Software

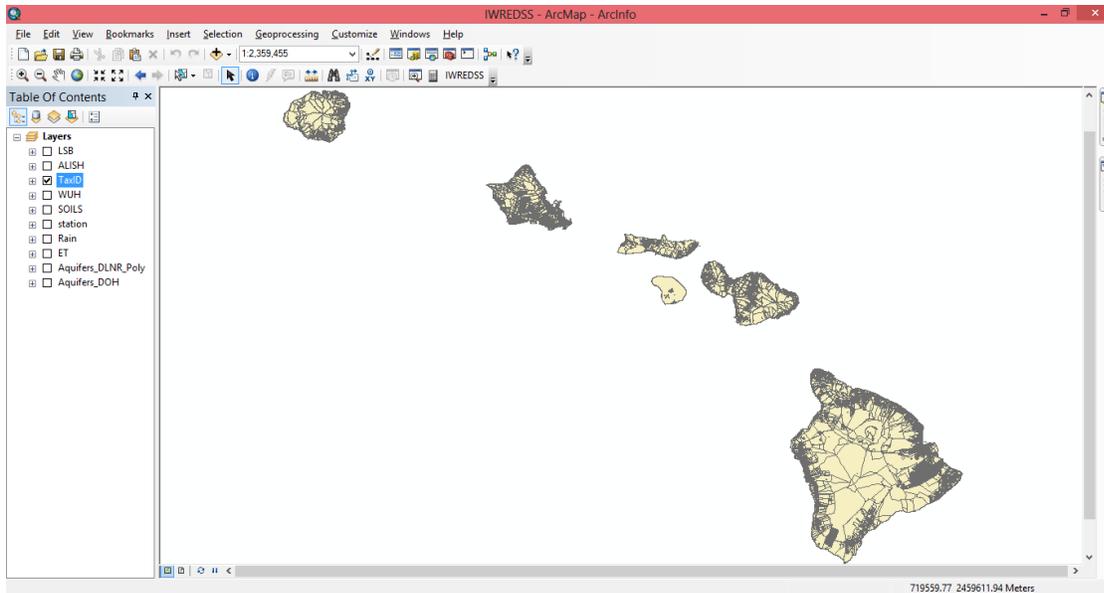


Figure 1. Through this Interface the user selects the location of interest for which irrigation water requirements will be calculated.

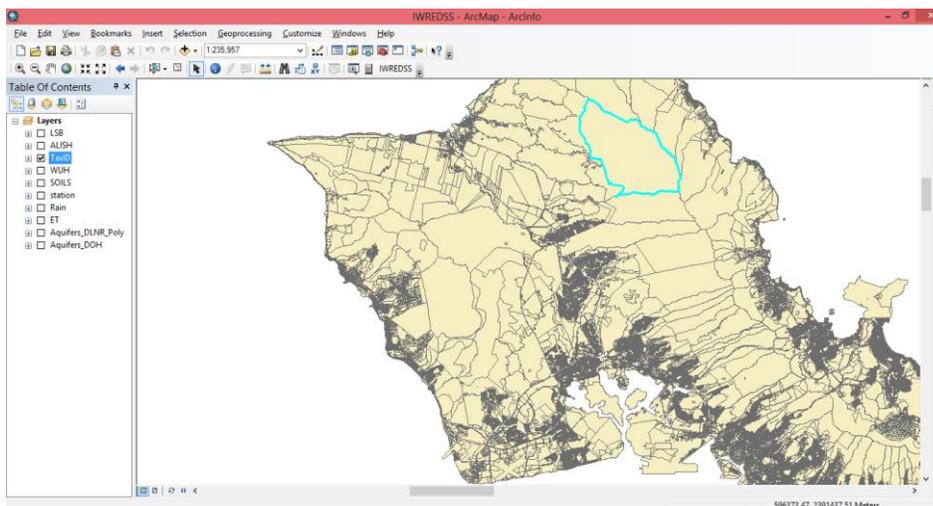
Step 2: Selecting the area of interest

Locate the area of interest from one of the Hawaiian Islands. It is suggested to zoom in the island of interest and click on TaxID of the area of interest. There are two ways to select a TaxID area as follows:

Direct selection on the map.

First, Zoom in using the Zoom-in tool ; then, find the area of interest.

irrigated/simulated. Second, use the feature-selection tool  and select the area of interest as shown in Figure 2. Note that you can choose 1 area (TaxID) for simulation at a time.



Select by area from the attribute table. This method is detailed in Fares (2007).

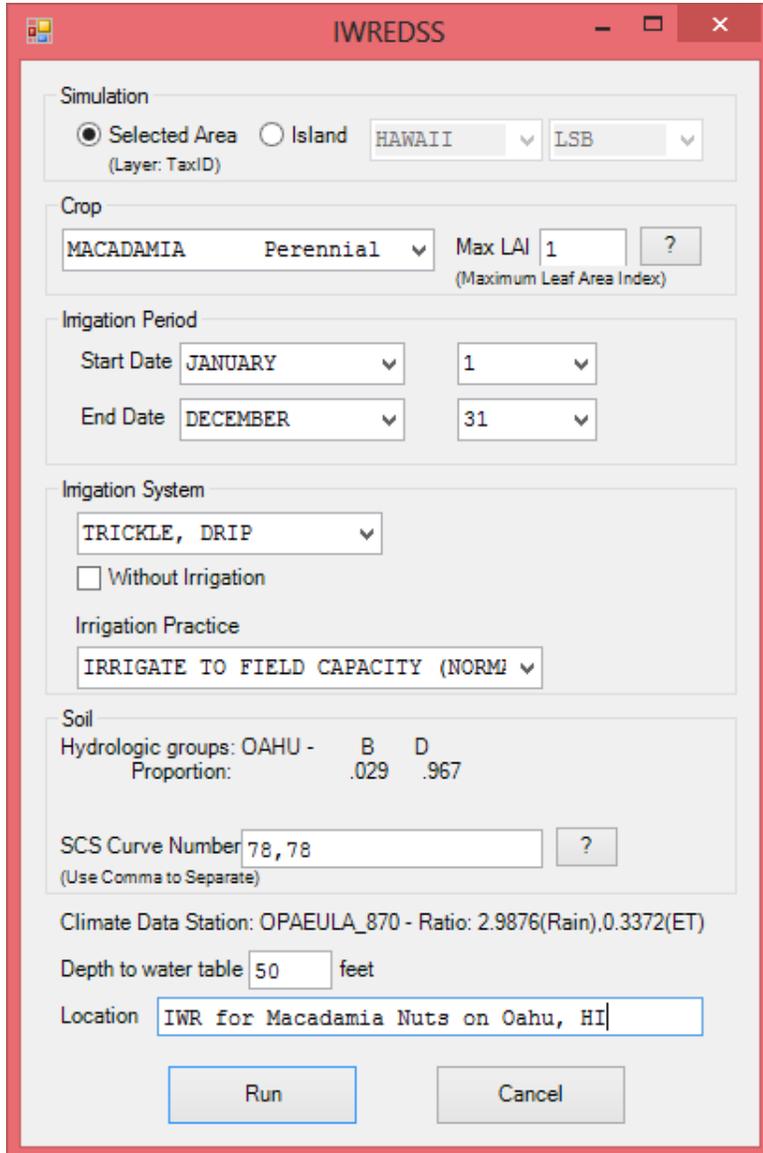
Figure 2. Direct selection of the area for which irrigation requirements will be calculated.

Step 3: Set other input parameters

During this step, the user selects

additional input parameters most of which are done using a drop down menu. First, click on the tool button , this opens the window shown in Figure (3). Second, the user needs to input/select the following parameters:

Crop: User can select from the predefined list of crops given below:



Perennial crops

Figure 3. The main input parameters (crop type, irrigation period, LAI, irrigation system, and hydrological soil group) selection.

The following crops are included in the database of IWREDSS: Generic Crop, Avocado, Bermuda Grass, Breadfruit, Citrus, Coconut, Palms, Coffee, Dendrob. in Pot, Dillis Grass, Domest. Garden, Draceane Pot, Eucalypt., Old, Eucalyptus Young, Garden Herbs, Guava, Heliconia, Kikuyu Grass, Koa, Lychee, Macadamia, Mango, Papaya, St. Augustina, Ti, Turf, Golf, Turf, Landscape, and Zoysia Grass.

Annual crops

Generic Crop, Alfalfa Init, Alfalfa, Ratn, Banana Init, Banana Ratn, Cabbage, Cantaloup, Dry Onion, Egg Plant, Ginger, Lettuce, Melon, Peanuts, Peppers, Pineapp. Yearr-1, Pineapp. Yearr-2, Pumpkin,

Seed Corn, Soybean, Sugar C. Ratn, Sugar C. Yr-1, Sugar C. Yr-2, Sunflowers, Sweet Potato, Taro (Dry), Taro (Wet), Tomato, and Water Melon.

For each crop type, different root zone depths and water use coefficient data are defined: for perennial crops, the parameters include irrigate crop zone depth, total zone depth, monthly crop water use coefficient (K_C), and monthly allowable water depletion (AWD). For annual crops, the parameters include initial crop zone depth, maximum crop

zone depth, fraction of growth of 4 stages, crop water use coefficient (K_C) of 4 stages, and AWD of 4 stages.

Maximum leaf area index: The user should select the appropriate value of LAI, from the drop down list, this parameter is used to calculate canopy rainfall interception.

Irrigation period: User should specify the irrigation period that can be up to 1 year long; it can start at any month of the year and go around to the next year, i.e. starting date October of year one and ending date November of the following year.

Irrigation system: The users can select from a predefined list of irrigation systems given as follows: User-Specified System, Trickle Drip, Trickle Spray, Multiple Sprinklers, Container Nursery, Sprinkler Large Guns, Seepage/Sub-irrigation, Crown Flood, and Flood Irrigation for Taro.

Option for no irrigation: A provision is given to simulate the different water budget for rainfed agriculture. This option could be used for research purpose as to consider a natural hydrologic cycle where only rainfall is the input parameter and calculations are needed regarding effective rainfall, evapotranspiration, canopy interception, runoff, and drainage for range/conservation lands or other natural areas.

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. The system bed height is needed for crown flood irrigation; the depth to water table is needed for seepage irrigation system; and the flood storage depth must be included for the flood irrigation system.

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

Soil hydrological groups and SCS curve numbers: All soil types in the selected TaxID area are grouped into four hydrologic groups (A, B, C, and D). The portion of each group of the soils in the selected area is given (for example, a selected area may have 11.3% of group B, 22.8% of group C, and 64.8% of group D). For each group, user has to specify the corresponding SCS curve number (CN). The curve number is used in the calculation of runoff. For details on determining CN values refer to IWREDSS User Guide (Fares, 2007).

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. A list of CN values for different cover and soil types is provided in Figure 4. User can refer to this list by clicking the “?” button next to the CN input box.

FormCN

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

Table 2-2a
Runoff curve numbers for urban areas (1)
Curve numbers for:

Cover description	Average percent	hydrologic soil group			
		A	B	C	D
impervious area (2)					
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) (3):					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) (4)		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85

Figure 4. Lists of CN values for different land cover under the four main soil types.

Depth to water table: This site-specific information is optional. 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; the user can type additional information to identify each simulation. The name appears in the beginning of the IWREDSS text output file.

Step 4: Execute IWREDSS

After completing the required inputs, the user can run IWREDSS by clicking the “Run” button to start simulation. A text box message will be prompted to the user about the state of simulation (fails or succeeds).

Step 5: Reading the result

After successful execution, a message (Figure 5) pops up giving user an option to view the results. A notepad text file opens after 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 by using File>Save as option in notepad.

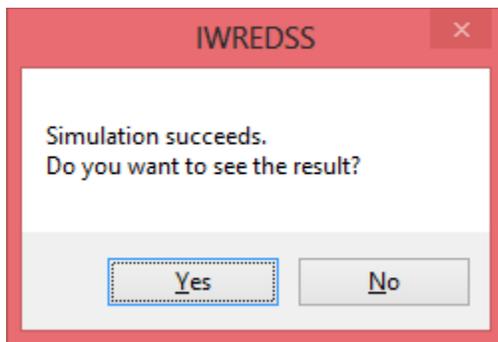


Figure 5. User’s Choice to Display Text Results.

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, e.g., crop type, irrigation system, soil type. The simulation results for yearly, monthly, bi-weekly, and weekly periods (Figure 6).

```

*****
*                               SUMMARY                               *
*****
TMK : 88001001
SOILS: Ewa(0.078), Lualualei, extremely stony(0.198), Lualualei(0.029), Lualualei, stony(0.075), Lualualei, stony

-----
ANNUAL IRRIGATION REQUIREMENT (INCHES)
-----

          WATER BUDGET COMPONENTS
NIR  GIR  GAL_A  G_RAIN  N_RAIN  ER  ER21  RO  INT  ETo  ET  DR
29.2 29.2  791.6   33.3   26.7 19.9 19.1  5.4  1.3 48.9 49.0  6.9

          GIR STATISTICS
ACRES  UNIT  MEAN  MED.  XMAX  XMIN  50%  80%  90%  95%
inch/acre  29.153 29.804 40.524 19.106 29.390 34.159 36.429 38.198
Thou. gpd/acre  2.169 2.217 3.015 1.421 2.187 2.541 2.710 2.842
7104.00 Total thou. gpd 15407.553 15751.391 21417.200 10097.666 15532.916 18053.401 19252.839 20187.618

          NIR STATISTICS
ACRES  UNIT  MEAN  MED.  XMAX  XMIN  50%  80%  90%  95%
inch/acre  29.153 29.804 40.524 19.106 29.390 34.159 36.429 38.198
Thou. gpd/acre  2.169 2.217 3.015 1.421 2.187 2.541 2.710 2.842
7104.00 Total thou. gpd 15407.553 15751.391 21417.200 10097.666 15532.916 18053.401 19252.839 20187.618

Note:- Irrigated area for the selected USER-SPECIFIED SYSTEM irrigation system is 1.0 of the total area

-----
MONTHLY IRRIGATION REQUIREMENT (INCHES)
-----

          WATER BUDGET COMPONENTS
MO  NIR  GIR  GAL_A  G_RAIN  N_RAIN  ER  ER21  RO  INT  ETo  ET  DR
1   1.0  1.0  26.3   4.1   3.3  1.9  2.2  0.6  0.1  3.0  3.0  1.4

```

Figure 6. Detailed Summary of IWREDSS Text Results.

At the end of the output file, there is a summary of the results. Actually, the simulation of IWREDSS is based on one soil type. Thus, if there is more than one soil type for a particular area (or TaxID), IWREDSS calculates irrigation requirements for each of these soils independently. The total irrigation requirement for the area of interest is a weighted average of all the soils available in that area using the following formula:

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

where IRR_i , A_i are the calculated irrigation requirements and the area occupied by i -th soil, respectively; A_T is the total area of the different soils available in the total area of the TaxID of interest. Note that IWREDSS does not simulate irrigation requirements for the non-arable parts of the area of the TaxID. 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.

IWREDSS uses calculated daily irrigation water requirements to calculate statistical parameters and probabilities of occurrence of IRRs for various time periods (i.e., weekly, bi-weekly, monthly and yearly). Summary of IWREDSS results provides IRRs for different probability levels, e.g. 50% (2 year return period), 80% (5 year return period), 90% (10 year return period) and 95% (20 year return period) probability of

GIRs. The 80% probability level (1 in 5 year return period) is recommended by USDA-NRCS and is also used by the irrigation industry when designing irrigation systems; thus, it was adopted for the recommended crop water allocation. The summary table also provides information on irrigation season, irrigation system, climate database, TMK, soil data, and other parameters used.

Step 6: Plotting the result

Switching from the text output file to ArcMap .The user is prompted to plot the results (Figure 7). The results are plotted on the map based on the yearly irrigation requirements for different soil type in the TaxID area.

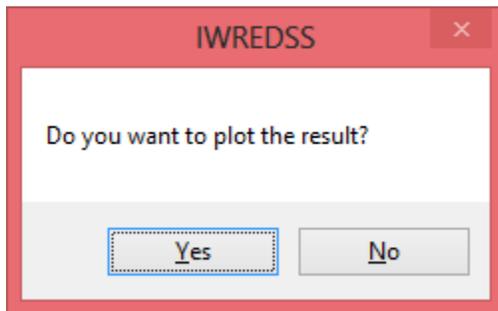


Figure 7. User's Choice for a Graphic Display of Results.

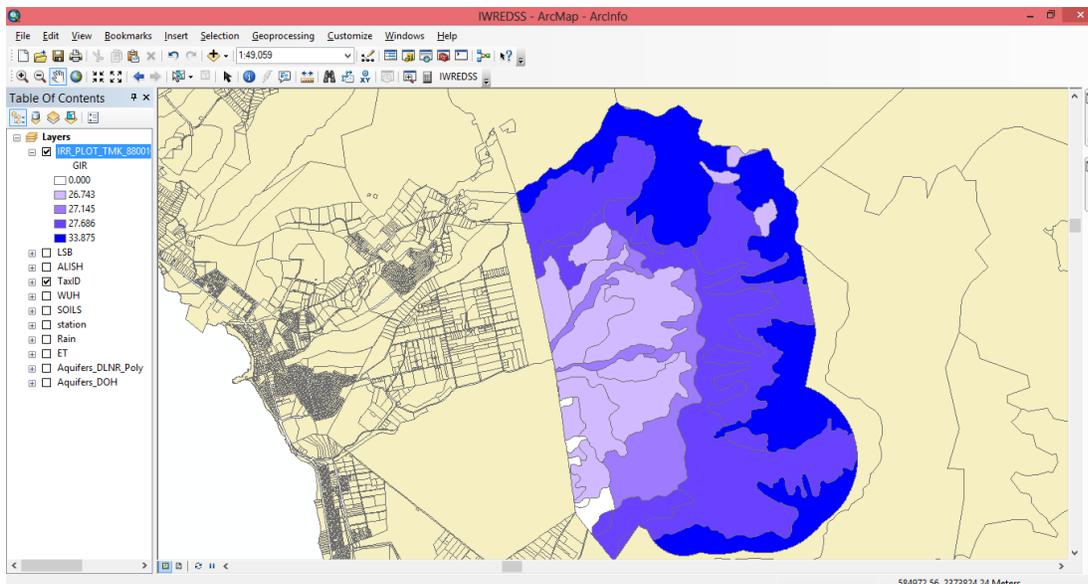


Figure 8. Graphic Display of IRRs Results and the Surrounding Properties.

An example of a color map plotting the results is given in Figure 8. The user can visualize the results on an enhanced option (Figure 9) by clicking the  button to zoom to the whole TaxID Area.

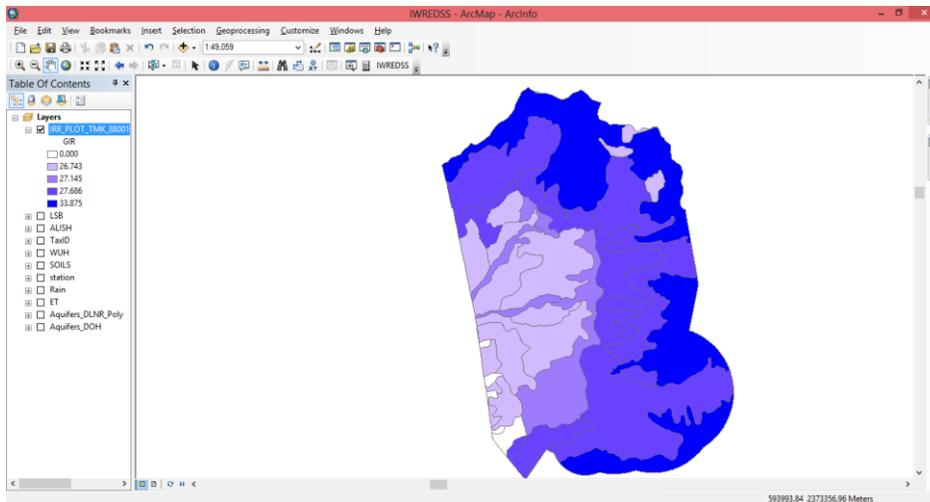


Figure 9. Irrigation Requirement Results of the Area of Interest Only.

IWRDESS was calibrated and validated with irrigation data estimates from Hawaii USDA-NRCS Handbook 38 (USDA-NRCS, 1996). These data include irrigation requirements maps for some crops on the major Hawaiian Islands. Irrigation requirements calculated with IWREDESS for different crops grown under specific to Hawaiian Islands are in close agreement with those estimated by USDA-NRCS Handbook 38. The relative small differences between the two datasets could be due to several factors including spatial and temporal variability of rainfall, evapotranspiration, and soil physical properties, and interpolation methods used to estimate rainfall and evapotranspiration.

References

1. Dickinson, R. E. 1984. Modeling Evapotranspiration For Three-Dimensional Global Climate Models. In *Climate Processes and Climate Sensitivity*, Geophys. Monogr. 29, American Geophys. Union, Washington, DC, pp. 58–72.
2. Edwards, K.A., G.A. Classen and E.H.J. Schroten. 1983. The water resource in tropical Africa and its exploitation. ILCA Research Report No. 6 International Livestock Centre for Africa, December 1983.
3. Fares A. 1996. Environmental impact of unharvested forest buffer zones upon cypress-pond systems in coastal plains regions. Doctoral Dissertation; University of Florida. 1996.
4. Fares, A. 2007. Water Management Software to Estimate Crop Irrigation Requirements for Consumptive Use Permitting In Hawaii. Report for Commission on Water Resources Management. Pp 58.
5. Fares, A. 2013. Water Management Software to Estimate Crop Irrigation Requirements for Consumptive Use Permitting In Hawaii Version 2.0. Report for Commission on Water Resources Management. Pp 58.
6. Fares, A. and Fares, S. 2012. Irrigation Management System, IMANSYS, a User-Friendly Computer Based Water Management Software Package. Proceedings of the Irrigation Show and Education Conference, Orlando FL, Nov. 2 – 6 2012.
7. Hargreaves, G.H., and Samani, Z.A., 1982. Estimating potential evapotranspiration. Tech. Note, *J. Irrig. and drain. Engrg.*, ASCE, 108(3):225-230.
8. Leuning R., A.G. Condon, F.X. Dunin, S. Zegelin, O.T. Denmead. 1994. Rainfall interception and evaporation from soil below a wheat canopy. *Agricultural and Forest Meteorology*, Volume 67, Issue 3, Pages 221-238.
9. Safeeq, M. and Fares, A. (2012), Interception losses in three non-native Hawaiian forest stands. *Hydrol. Process.* doi: 10.1002/hyp.9557.
10. SCS, 1985. National engineering handbook, section 4: Hydrology. Soil Conservation Service, USDA, Washington, D.C.
11. SCS, 1993. National engineering handbook, section 4: Hydrology. Soil Conservation Service, USDA, Washington, D.C.
12. Samani, Z. 2000. Estimating solar radiation and evapotranspiration using minimum climatological data. *J Irrig Drain Engin.* 126(4):265–267.
13. SCS. 1970. Irrigation Water Requirements. Technical Release No. 21. USDA Soil Conservation Service. Washington, DC.
14. Shah, S.B., Edling, R.J. 2000. Daily evapotranspiration prediction from Louisiana flooded rice field. *J. Irrig. Drain. Eng.* ASCE 126 (1), 8–13.
15. Smajstrla, A.G. 1990. Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) Model Version 5.5. Technical Manual. Department of Agriculture Engineering- University of Florida. 197pp.
16. USDA-NRCS. 1996. Handbook Notice # 38. Irrigation estimation maps for Hawaii.