

1. Abstract

The Jobos Bay National Estuarine Research Reserve (JBNERR) is located in the south coast of Puerto Rico. Rapid changes in land use represent a problem of point and nonpoint source pollution. JBNERR needs a tool to assess and manage these problems. One of the approaches that deal with data storage and manipulation when working with point and nonpoint pollution is the Better Assessment Science Integrating Point and Nonpoint Source (BASINS) package developed by the U.S. Environmental Protection Agency (USEPA). BASINS incorporates geographic information system (GIS) technology and includes the model Soil and Water Assessment Tool (SWAT). A drawback in the local application of BASINS is that USEPA has not developed the database for Puerto Rico. The objectives of this research were to identify the sources of data, obtain the data from these sources, and translate them in to the required format of BASINS database for JBNERR. Most of the data were collected from the Internet and other from JBNERR facilities. The data available in GIS format were converted into State Plane NAD 27 and the digital tables were converted into dBase format. This effort makes possible the application of BASINS to JBNERR's watershed, and represents the first step for the creation of the database for Puerto Rico.

(Key Words: Simulation, watershed and water quality modeling, BASINS, GIS, SWAT, Point and Nonpoint Pollution, data collection)

2. Introduction

The Jobos Bay National Estuarine Research Reserve (JBNERR) is one of 22 Estuarine Research Reserves under National Oceanic and Atmospheric Administration (NOAA) Sanctuaries and Reserves Division. It is located in the south coast of Puerto Rico as shown in Figure 1. Most of the land north to the reserve is devoted to the agriculture, although there is a high demand for urban and industrial development. Surface runoff and groundwater flow is toward the seashore, where the reserve is located. Changes in the land use, irrigation methods, and the increase in groundwater extraction, due to industrial and urban development, represent a serious threat to the overall water supply and water quality of the area. For this reason, JBNERR need a tool to assess and manage these types of problems within its watershed.

The U.S. Environmental Protection Agency (USEPA) developed a computer software package to perform watershed water quality based studies. The Better Assessment Science Integrating Point and Nonpoint Sources, BASINS (USEPA, 1998), is a multipurpose environmental analysis system that deals with data storage and data manipulation when working with point and nonpoint source pollution.

The use of BASINS in JBNERR will provide a good tool for assessing and evaluating the impact of changes (land use, agricultural practices, etc.) within the watershed. One drawback of using BASINS is that the required database is only available for the contiguous United States as a database in GIS form. BASINS's data are not currently available for Puerto Rico in the required format. For Puerto Rico, most of the data are available from different sources such as the USEPA, US

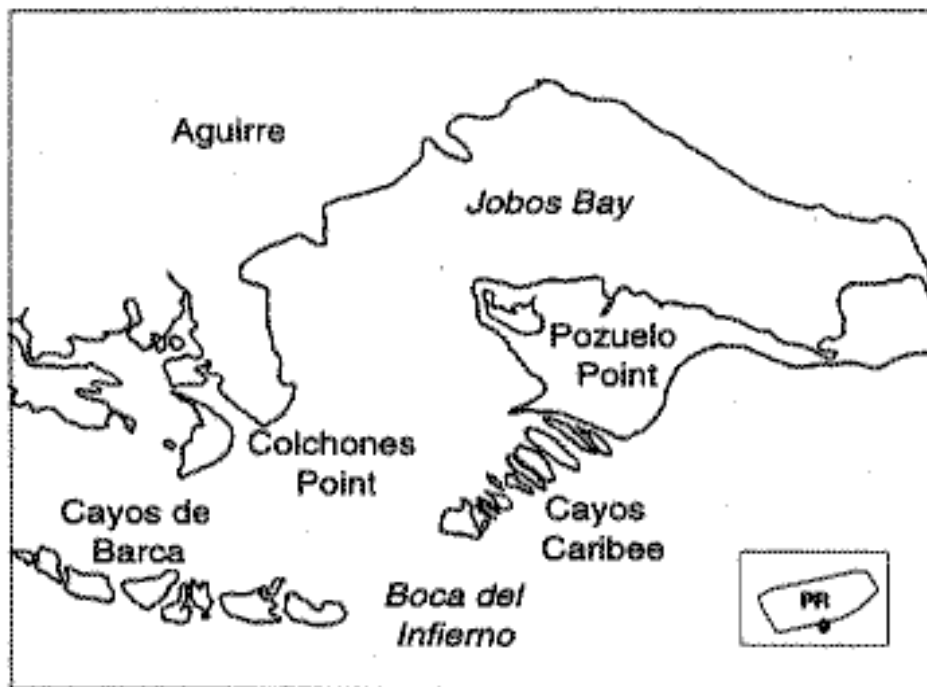
Geological Survey (USGS), USDA Natural Resources Conservation Services (NRCS), NOAA, and others. These data need to be collected from those sources and converted into the BASINS format so the model can use it.

The use of BASINS at JBNERR will allow the determination of the impacts of the continuous development in the area and the implementation of management practices to reduce these impacts. It is also, a first step for the creation of the BASINS's database for Puerto Rico.

This effort started using BASINS 2.0. The database required by this version included Reach File 1 (RF1), Reach File 3 (RF3), Digital Elevation Model (DEM), land use and land cover, State Soil and Geographic (STATSGO) Database, among other data files. Of these files, RF1 required the most effort and time due to its complexity and the great amount of data needed.

On June 2001, the new version of BASINS, BASINS 3.0, was released. This version includes the program Soil and Water Assessment Tool, SWAT. SWAT reduces the data collection and manipulation time by several folds. Since this version was released before the project was completed and does not require the RF1, it was decided to create the database for this version.

Figure 1. JBNERR location map



3. Objectives

There are three main objectives in this project. The achievement of the objectives will allow JBNERR's technical staff to use BASINS as a watershed management tool to assess specific agricultural practices and proposed urban developments effects over the quality of the waters reaching the Reserve area.

These objectives are:

1. Develop the database required by BASINS.
 - a. Identify the sources of data
 - b. Obtain the data from these sources
 - c. Convert the data into the required format
2. Document its development so other users can benefit from this effort.
3. Adapt the BASINS program package to JBNERR's watershed.

4. Literature Review

4.1 Jobos Bay National Estuarine Research Reserve

JBNERR is located in the south coast of Puerto Rico. Groundwater is the main source of freshwater to the Jobos Bay estuary and the communities in the area. This freshwater comes from an alluvial shallow aquifer, which is recharged by water infiltration from rainfall and runoff.

Most of the land north to the Reserve is devoted to agriculture. Agriculture is a major contributor of Nonpoint source (NPS) pollutants that cause the degradation of surface and groundwater systems. NPS pollutant, account for 73 percent of the Biochemical Oxygen Demand (BOD), 83 percent of the bacterial loads, and 92 percent of the suspended sediments in waterways (Brenner and Mondok, 1995).

Crops planted in this area are corn, tomatoes, peppers, plantains, and bananas. The area contiguous to the Reserve belongs to the Puerto Rico Land Authority and it is currently leased to the Lippy Brothers, Inc. This area is mostly dedicated to corn and fruit crops. The fruit crops are mostly irrigated by a drip system, and the corn is irrigated by a pivot sprinkler system.

Into the development and management of agriculture it is necessary the use of pesticides and fertilizers, to improve the quality of the crops. Various types of the pesticides and chemical fertilizers used in the JBNERR area crops are presented on Table 1 (Fuentes and Sastre, 1995).

Table 1. Some of the pesticides applied to the agricultural areas surrounding the JBNERR

Herbicides	Insecticides	Fungicides
Alachlor	Chloropyrifos	Chlorothalonil
Cyanazide	Thiodicard	
Glyphosate	Ferverate	
Paraquat	Espenvalerate	
Trifluralin	Endosulfon	
	Acephate	

The pesticides and fertilizers are good for the agriculture, but due to infiltration and runoff, they contaminate the soil and water of the watershed. An example of that is the 1993 great flood along the Mississippi River, where concentrations of two of these herbicides, Alachor and Cyanazide, were found in soil samples of flooded and no flooded soils (Chong, et al., 1998).

Also, the watershed land has a high demand for urban and industrial development. Some of these developments include residential complexes, and the recently finished poultry-processing plant. Recently, a lateral expansion was made to the existing solid waste sanitary landfill.

JBNERR is located at the lowest portion of the watershed, receiving practically all runoff discharge from the watershed and a great deal of groundwater. The pollution generated by the NPS within the watershed is a potential source of pollution to the aquifer and to the Reserve, affecting the ecosystem of the area.

4.2 BASINS

The water programs of the U.S. Environmental Protection Agency and their counterparts in states and pollution control agencies are increasingly emphasizing watershed and water quality-based assessment and integrated analysis of point and nonpoint sources. They are using existing computer programs and models and developed their own software for this purpose. Some of these programs and technology are Hydrological Simulation Program-FORTRAN (HSPF), Geographical Information System (GIS), Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), and Soil and Water Assessment Tool (SWAT).

The HSPF is frequently used to simulate surface runoff, groundwater recharge, and transport of sediments, nutrients, and pesticides, as a basis to quantify impacts and evaluate alternatives. It was used in the West Wellfield Interim Protection Area in West Day County in South Florida as a planning tool to evaluate pollutants entering surface and groundwater based on current agricultural practices as well as to test preventive actions to reduce pollution levels (Tsihrintzis, et al., 1996).

The Geographic Information System (GIS) is based on spatial analysis. It has been playing an important role in natural resources modeling and has proved to be an effective tool for NPS pollution models (Srinivasan, et al., 1998). Inputs can be accumulated from hydrographic and geographic databases and mapped using a raster-based GIS. This is the case of Richland and Chambers Creeks watershed in upper Trinity River basin in Texas (Srinivasan, et al., 1998). Also, GIS can be use used to analyze topographic slope, channel length, land use, and soil characteristic of the watershed. This was done for an area in the East of Massif Central in France, with excellent results (Laurent, et al., 1998).

BASINS is a system developed to meet the needs of such agencies as U.S. Environmental Protection Agency. It is a multipurpose environmental analysis system for use by regional, states, and local agencies in performing watershed and water quality based studies. It integrates GIS, national watershed data, and environmental assessment and modeling tools into one convenient package.

Originally released in September 1996, BASINS addresses three objectives (USEPA, 2000):

1. Facilitate examination of environmental information

2. Provide an integrated watershed and modeling framework
3. Support analysis of point and nonpoint source management alternatives

BASINS supports the development of total maximum daily loads (TMDLs), which require a watershed-based approach that integrates both point and nonpoint sources. It can support the analysis of a variety of pollutants at multiple scales, using tools that range from simple to sophisticated.

Many components are interrelated in BASINS to perform watershed and water quality analysis. These components are grouped into five categories:

1. National database
2. Assessment tools for evaluating water quality and point source loadings at a variety of scales. These tools are:
 - a. TARGET: Allows environmental managers to make broad-base evaluations of watershed's water quality and point source loading.
 - b. ASSESS: Focused on the status of specific water quality stations, or discharge facilities, and their proximity to water bodies.
 - c. Data Mining: Links different data elements using a combination of tables and maps.
3. Utilities including local data import, land-use and Digital Elevation Model (DEM) reclassification, watershed delineation, and management of water quality observation data
4. Watershed and water quality models including WINHSPF, QUAL2E and SWAT
5. Post processing output tools for interpreting model results, like GenScn.

The BASINS databases and the assessment tools are directly integrated within an ArcView GIS environment. By using GIS, a user can fully visualize, explore, and query to bring a watershed to life. The simulation models are Windows based and use data input files generated in ArcView.

4.3 SWAT

Soil and Water Assessment Tool (SWAT) is a watershed and water quality model (Neitsch, et al, 1999) that operates on a daily time step. The objective of the model development was to predict the impact of land management practices on water, sediment and agricultural chemical yields in watersheds with varying soils, land use and management conditions over long periods of time. The model is physically based and computationally efficient, uses readily available inputs and enables users to study long-term impacts. Benefits of this approach are:

1. Watersheds with no monitoring data (e.g. stream gage data) can be modeled.
2. The relative impact of alternative input data (e.g. changes in management practices, climate, vegetation, etc.) on water quality or other variables of interest can be quantified.

The model is currently used to estimate the off-site impacts of climate and management on water use, NPS loadings, and pesticide contamination. It was used in Richland and Chambers Creeks watershed in upper Trinity River basin in Texas to reduce the data collection and manipulation time by several folds, and allowed modify and analyze various alternative management practices rather easily (Arnold, et al., 1998).

The reasons to apply SWAT to the JBNERR watershed are:

1. Since BASINS only uses and accepts data generated by USEPA, which does not include data for Puerto Rico, it was necessary a computer program which allows the creation and modification of databases. The new version of BASINS has these features.
2. BASINS requires the management of a great amount of data such as designation of land use, soil, weather, groundwater, water use, management, soil chemistry, pond, and stream water quality data, as well as the simulation period. SWAT have an Input menu that, using the Land Use and Soil themes, allows to build the watershed database file containing the information needed to auto generate the default input for the model. Once, the databases are generated, using the Database Editors, the user can verify and change the default data with the Jobos Bay Watershed data.

5. Methodology

Since BASINS 3.0 was released before the project was completed, and it was decided to work with the new version of the program, this section applies only to the work performed with BASINS 3.0.

To meet the objectives it was necessary to understand how BASINS operates. For this reason a training course was taken in the Center of Lifelong Engineering Education in Austin, Texas on June 2000. This was useful to identify the benefits and limitations of the program, and learn how to use it. Although BASINS 3.0 was not released at that time, it was introduced to the students and it was possible to do some practice sessions with SWAT.

To identify the required data for BASINS, a search was done in the Internet at the BASINS homepage (USEPA, 2000), <http://www.epa.gov/OST/BASINS/>, and in the BASINS Manual.

After the required data and format was identified, a search was done for the data available. This was done through the Internet and the data was downloaded and stored locally. For the data not available online, potential sources of data, including key government agencies personnel, were contacted.

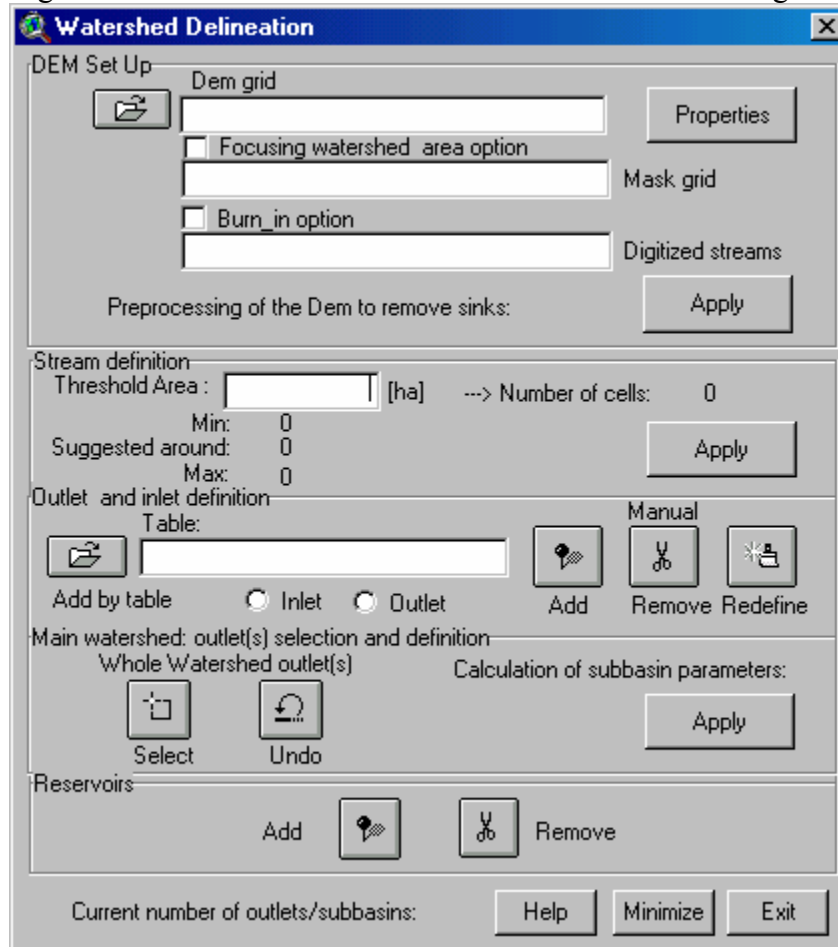
Most of the data available on-line are in ARC coverage or ARC shape GIS file format and projected in State Plane NAD 83. It was converted to a common map projection, State Plane NAD 27, to be consistent with most of the data that were previously generated at JBNERR. The changes in coordinates were done using ERDAS IMAGINE 8.4 and the ArcView projection utility.

5.1 Watershed and Subwatershed Delineation

The JBNERR watershed was delineated using the BASINS Automatic Delineation Tool. This tool allows the user to delineate watersheds and subwatersheds based on an automatic procedure using Digital Elevation Model (DEM) data. The tool requires Spatial Analyst (ver.1.1 or later) and Dialog Designer (ver.3.1 or later) ArcView extensions installed on the PC. The delineation process requires a Digital Elevation Model (DEM) in ArcInfo grid format, and optionally a pre-digitized stream network (user provided blue lines, Reach File Version 1 (RF1), Reach File Version 3 (RF3) or National Hydrographic Datasets (NHD)) in ArcView shape (PolyLine) format.

The first step of the automatic delineation is to load the Automatic Delineation extension. This extension is located in the BASINS Extension Manager (Watershed Delineation category), and activates the Automatic choice in the Delineate menu. When the Automatic choice is selected, the Watershed Delineation dialog is opened. The dialog is divided into five sections and is presented on Figure 2.

Figure 2. BASINS Automatic Watershed Delineation Dialog Box



1. DEM Setup

To activate this section, it was necessary to click the button beside the text box labeled DEM Grid. Once it was active the DEM grid named JBDEM.grd was selected. This DEM was previously projected in State Plane NAD 27. To continue, the properties button beside the DEM grid text box was clicked and the DEM vertical and horizontal measures were set to meters.

To reduce the processing time, a focused area was defined. The focused area was established drawing a polygon mask around the Jobos Bay watershed region.

2. Stream Definition

The next step was to load the stream network used in the delineation. A typical user has four options for the stream network, Digitized Stream Network, RF1, RF3, and NHD. For Puerto Rico the RF1 and the NHD are not available. The available RF3 is not a final release and do not has all the information required. The only option was to select the Digitized Stream Network option. This option uses the RF3 to create a stream network with the required flow directions.

The DEM map grid has non-draining zones (sinks), which need to be removed. BASINS has an option that allows the removal of non-draining zone by clicking the Apply button next to the label Preprocessing of the DEM.

The stream definition section lets the user decide how many subwatersheds, based on the area, will be used during the simulation. After preprocessing the DEM, the program calculates a minimum and maximum value for the subwatershed area, and suggests the average value between them to be the subwatershed area. If the user wants a more detailed study, a smaller area can be chose, to produce more subwatersheds or fewer subwatersheds as necessary. In our case, the suggested subwatershed was selected. This procedure adds to the BASINS view the streams and outlets themes.

3. Outlet and Inlet Definition

Outlets are defined as the most downstream location of the respective delineation subbasin. Inlets are defined as either the outlet of draining watersheds (part of the overall watershed that is not intended to be simulated) or point sources of discharge. All the outlets and inlets that are not part of the watershed region were deleted.

4. Main Watershed Outlet(s) Selection and Definition

The Jobos Bay watershed has seven principal outlets. They were selected and after clicking the Apply button, the watershed and subwatersheds themes were added to the BASINS view.

5. Reservoirs

Once the delineation is completed, the user may optionally add or remove reservoir locations to complete or refine the hydraulic framework.

In this study, the Melanía Lake was not included since the runoff it collects drains to the Patillas irrigated channel.

Once the watershed and subwatersheds were created, they were compared with a previously manually delineated watershed to verify that both were consistent. After comparing, it was noticed that the Automatic Delineation Tool did not include the Mar Negro area which is in the southwest of the Reserve. To include it, it was necessary to edit the watershed and sub watersheds themes.

5.2 Land Use Theme

The most recent available Land Use data for JBNERR was created in 1999 by surveying Professor Linda Vélez of the University of Puerto Rico at Mayagüez.

5.2.1 Jobos Bay Land Use and Land Cover 1999 (by Prof. Linda Vélez)

The process of monitoring the land use in and around Jobos Bay National Estuarine Reserve involved the use of Geographical Informational Systems (GIS) and Remote Sensing Technologies. A digital database was created from aerial photographs - color prints taken by the National Ocean Service (NOS) Mission in February, 1999, and by the NASA Mission flight 94-019-HR-732. The later included Color prints and Color Infrared (CIR) transparencies for December, 1993.

Building the database followed three major distinct phases. The first phase involved the use of photograph interpretation as the primary source of information. The photographs were used to study the current land use and land cover within the Jobos Bay watershed region. The data were classified using the Anderson classification system used by the USGS. Ten land use classifications were made and

summarized as Urban, Agriculture, Grass, Forest Land Closed, Forest Land Open, Forested Wetlands, Non Forested Wetlands, Barren land, Dry Forest, and Water. The second phase included the use of a computer and a digitizer to build the database. The PC ARC/INFO computer software version 3.4.2 made by ESRI was used in the process. The third phase involved generation of the statistical summaries with the use of tables, charts and graphs for all the land use and land cover in the region. This was done using both PC ARC/INFO and ArcView.

5.2.2 Land Use Reclassification

The SWAT Land Use database is more detailed than the Anderson land use classification. The properties of both classifications were studied, and the land use classifications created by Prof. Linda Vélez was reclassified with the name of other land use classifications with the same characteristics of the previous.

5.3 Soil Theme

The soil themes and tables used in BASINS were originally obtained from the US Department of Agriculture (USDA) Natural Resources Conservation Services (NRCS) State Soil and Geographic Database (STATSGO). Fortunately, this database is available for Puerto Rico. It was downloaded from the Internet and projected in State Plane NAD 27, with the ArcView Projection Utility Wizard.

STATSGO breaks down the area coverage into smaller georeferenced units, called map units, and identified each one with a Muid number. The Muid numbers are required in the Definition of Land Use and Soil Theme dialog box as Stmuid. The Stmuid has five digits; the first two digits represent the state numeric code and the

last three digits the State STATSGO polygon (Muid) number. SWAT only accepts the contiguous 48 states Stmuids. SWAT does not recognize Stmuid for Puerto Rico. To overcome this shorthand, instead of use the Stmuid to classify the soils, new soils and their properties were added to the BASINS database. That was done with the soil Database Editor. The soil characteristics were entered manually since a dbase table couldn't be loaded. To facilitate their manipulation they were rearranged in an EXCEL table.

5.4 Weather Data

SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, and relative humidity and wind speed. A typical user may choose to read these inputs from a file or generate the values using monthly average data summarized over a number of years. To generate the values, SWAT includes the WXGEN weather generator model (Neitsch, et al, 2001) that generates the climatic data and fill in gaps in measured records. This weather generator was developed only for the contiguous US and cannot be use for Puerto Rico. Therefore, the only option was to collect the weather data available for the weather stations in the Reserve and analyzed them to make the required calculations. The stations selected were Aguirre station and JBNERR station.

The data had to be daily for a minimum period of one year. Once collected, the daily values were rearranged, using EXCEL, and converted to dBase (.dbf) format. The daily values are used in the Weather Station dialog box, located into the SWAT Input menu.

Using the daily values, the monthly values were calculated. They are used to modify, with the Database Editor, the subbasins default parameters. These values are entered manually and cannot be loaded as a dBase table. To facilitate its manipulation they were rearranged in an EXCEL table.

6. Results and Discussion

6.1 Identification of the key procedures to apply BASINS

Before identified the required data for BASINS, it was necessary to identify the procedures that should be done before BASINS can be apply to JBNERR successfully. The key procedures are divided in 7 steps:

1. Watershed and Sub-watershed Delineation
 - a. Load the Automatic Delineation extension by checking the relative box in the BASINS Extension Manager (Watershed Delineators category).
 - b. Select the Automatic choice from the Delineate menu in BASINS View.
 - c. Load the DEM
 - d. Define the working area (Focused Area)
 - e. Load the stream network to be used for the delineation (RF3)
 - f. Run the preprocessing
 - g. Specify the minimum sub-watershed area (critical source area)
 - h. Review and edit the stream network points
 - i. Run the calculation of the sub basin parameters
2. Land Use and Soil Definition – SWAT requires land use and soil data to determine the area and the hydrologic parameters of each land-soil category simulated within each sub-watershed. The land use and soil

definition is done using the Land Use, Soil Classification and Overlay tool. The steps to make the Land Use and Soil Definition are:

- a. Select the model to be used (SWAT)
 - b. Define the land use theme
 - c. Reclassify the land use theme
 - d. Define the soil theme
 - e. Reclassify the soil theme
 - f. Overlay the land use and soil theme
3. HRUs Distribution – Before the set up of the SWAT model, the distribution of hydrologic response units (HRUs) within the watershed must be determined based on the land use and soil data layers specified in the previous step. The HRUs Distribution choice in the Utilities menu allows the user to specify criteria to be used in determining the HRU distribution. One or more unique land use/soil combinations (hydrologic response units or HRUs) can be created for each sub basin. The HRUs can be used to assess the varying hydrologic conditions between sub-watersheds. Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for various crops and soils. With SWAT model, runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance. The HRU's Distribution can be done using the following steps:

- a. Select single or multiple HRUs per sub watershed
 - b. For multiple HRUs, define land use and soil threshold levels
 - c. Click the OK button to determine the HRU distribution
4. Weather Data Definition – The Weather Data Definition dialog is divided in five sections listed below and is presented on Figure 3. In each section is necessary to load the specific data.
 - a. Weather Simulation data
 - b. Rainfall data
 - c. Temperature data
 - d. Solar Radiation data
 - e. Wind Speed data
 - f. Relative Humidity data
5. Application of the default input files writer – To run the SWAT model is necessary to build the initial watershed input values. These values are set automatically based on the previously watershed delineation and land use-soil characterization.
6. Edition of the default input files and SWAT databases – The Edit Input menu allows the user to edit the SWAT model databases and the watershed database files containing the current inputs for the SWAT model.
7. Set up and run SWAT – The items contained in the Simulation menu allow the user to finalize the set up of the inputs and run the SWAT model.

Figure 3. Weather Data Definition Dialog Box

The dialog box is titled "Weather data definition" and contains the following sections:

- Rainfall data:** Radio buttons for "Simulation" and "Raingages". A "Locations table:" field with a browse button.
- Solar Radiation data:** Radio buttons for "Simulation" and "Solargages". A "Locations table:" field with a browse button.
- Temperature data:** Radio buttons for "Simulation" and "Climate stations". A "Locations table:" field with a browse button.
- Wind Speed data:** Radio buttons for "Simulation" and "Windgages". A "Locations table:" field with a browse button.
- Weather simulation data:** Radio buttons for "US database" and "Custom database". A "Locations table:" field with a browse button.
- Relative Humidity data:** Radio buttons for "Simulation" and "Rel. Humidity gages". A "Locations table:" field with a browse button.

At the bottom right, there are three buttons: "Help", "Close", and "OK".

6.2 Identification of the required data and their sources

After determine the key procedures to run SWAT into BASINS environment, and with the help of BASINS homepage and the BASINS manual, the required data were determined. The required data to run SWAT and their sources are listed in Table 2.

Table 2. Identification of the required data and their sources

Required Data	Source	Description
Digital Elevation Model (DEM)	US Geological Survey	Topographic relief mapping; supports watershed delineations and modeling
Reach File Version 3 (RF3) Alpha	USEPA	Provides a detailed stream network and supports development of stream routing for modeling purposes
Land Use and Land Cover	Prof. Linda Vélez – University of Puerto Rico at Mayagüez	Boundaries associated with land use classifications
State Soil and Geographic (STATSGO) Database	USDA Natural Resources Conservation Services (NRCS)	Soils information including soil component data and soils
Weather Stations Data	JBNER http://water.dnr.state.sc.us	Location of selected meteorological stations and associated monitoring information used to support modeling

6.3 Watershed and Sub watersheds Delineation

To delineate the watershed and subwatersheds, it was used the Automatic Delineation tool. This tool required the DEM and a pre-digitized stream network, which was a modified version of RF3 (Figure 4). The modified version did not include the Guamaní and Patillas irrigation channels because they flow across the watershed without making any contribution to the runoff that affect the reserve. Also the Melania Lake was not considered since the runoff it collects drains to the Patillas irrigation channel. Another change was to join all the segments of each stream using the ArcView Union Tool, since the RF3 has many divisions for each stream and BASINS does not recognize this format.

After preprocessing the DEM, the streams and outlets themes were added to the BASINS View (Figure 5). Finally the watershed and sub watersheds themes were added to the BASINS View, but it was not consistent with the previously manually delineated watershed. Using the Edit Shapefile option and with the help of a digitized quadrangle, the west side of the automatic delineation shapefile was modified to include the community of Las Mareas and the area of Mar Negro. The final watershed and sub watersheds themes can be observed on Figure 6 and Figure 7, respectively. This process produced 78 sub watersheds.

6.4 Land Use Theme

The most recent available Land Use data for JBNERR was created in 1999 by surveying Professor Linda Vélez of the University of Puerto Rico at Mayagüez. This land use was categorized using the Anderson classification system used by the USGS. The SWAT Land Use database is more detailed than the Anderson land use classification. The properties of both classifications were studied, and the land use classifications created by Prof. Linda Vélez was reclassified with the name of other land use with the same characteristics of the Anderson classification. The new classification of Linda Vélez land use can be observed in Table 3. The options provided by SWAT to categorize the land use are presented on Table 4 and Table 5. Figure 8 presents the Land Use theme for the Jobos Bay watershed.

Table 3. Anderson and SWAT land use classification

Anderson Classification	SWAT Classification	Code
AGRICULTURAL LAND	Agricultural Land Generic	AGRL
URBAN OR BUILT-UP LAND	Residential-High Density	URHD
GRASS	Pasture	PAST
BARREN LAND	Southwestern US (Arid) Range	SWRN
DRY FOREST	Forest-Deciduous	FRSD
FOREST LAND CLOSED	Forest-Evergreen	FRSE
FOREST LAND OPEN	Forest-Mixed	FRST
FORESTED WETLAND	Wetland-Forested	WETF
NON-FORESTED WETLAND	Wetland-Non-Forested	WETN
WATER	Water	WATR

Table 4. SWAT land use classification for urban areas

Urban	Code
Commercial	UCOM
Industrial	UIDU
Institutional	UINS
Residential-High Density	URHD
Residential-Medium Density	URMD
Residential-Low/Med Density	URML
Residential-Low Density	URLD
Transportation	UTRN

Table 5. SWAT land use classification for agricultural areas

Land Cover/Plant	Code	Land Cover/Plant	Code
Agricultural Land Close-grown	AGRC	Onion	ONIO
Agricultural Land Generic	AGRL	Orchard	ORCD
Agricultural Land-Row Crops	AGRR	Pasture	PAST
Alamo Switch grass	SWCH	Peanut	PNUT
Alfalfa	ALFA	Pearl Millet	PMIL
Alsike Clover	CLVA	Pine	PINE
Altai Wild rye	RYEA	Poplar	POPL
Apple	APPL	Potato	POTA
Asparagus	ASPR	Range-Brush	RNGB
Bell Pepper	PEPR	Range-Grasses	RNGE
Bermuda grass	BERM	Red Clover	CLVR
Big Bluestem	BBLS	Rice	RICE
Broccoli	BROC	Russian Wild rye	RYER
Cabbage	CABG	Rye	RYE
Cantaloupe	CANT	Sebasnia	SESB
Carrot	CRRT	Sideoats Grama	SIDE
Cauliflower	CAUF	Slender Wheatgrass	SWGR
Celery	CELR	Smooth Bromegrass	BROS
Corn	CORN	Sorghum Hay	SGHY
Corn Silage	CSIL	Southwestern US(Arid) Range	SWRN
Cowpeas	CWPS	Soybean	SOYB
Crested Wheatgrass	CWGR	Spinach	SPIN
Cucumber	CUCM	Spring Barley	BARL
Durum Wheat	DWHT	Spring Canola-Argentine	CANA
Eastern Gamagrass	EGAM	Spring Canola-Polish	CANP
Eggplant	EGGP	Spring Wheat	SWHT
Field Peas	FPEA	Strawberry	STRW
Flax	FLAX	Sugarbeet	SGBT
Forest-Deciduous	FRSD	Sugarcane	SUGC
Forest-Evergreen	FRSE	Summer Pasture	SPAS
Forest-Mixed	FRST	Sunflower	SUNF
Garden or Canning Peas	PEAS	Sweet Corn	SCRN
Grain Sorghum	GRSG	Sweetclover	CLVS
Green Beans	GRBN	Sweetpotato	SPOT
Hay	HAY	Tall Fescue	FESC
Head Lettuce	LETT	Timothy	TIMO
Honey Mesquite	MESQ	Tobacco	TOBC
Honeydew Melon	HMEL	Tomato	TOMA
Indiangrass	INDN	Upland Cotton-harvested with...	COTP
Italian (Annual) Ryegrass	RYEG	Upland Cotton-harvested with...	COTS
Johnson Grass	JHGR	Water	WATR
Kentucky Bluegrass	BLUG	Watermelon	WMEL
Lentils	LENT	Western Wheatgrass	WWGR
Lima Beans	LIMA	Wetland-Forested	WETF
Little Bluestem	LBLS	Wetland-Mixed	WETL
Meadow Bromegrass	BROM	Wetland-Non-Forested	WETN
Mung Beans	MUNG	Winter Pasture	WPAS
Oak	OAK	Winter Wheat	WWHT
Oats	OATS		

6.5 Soil Theme

The STATSGO of Puerto Rico is not linked to the STATSGO soil database included in BASINS. To make BASINS recognize the soil theme and its properties is necessary to first modify the BASINS database and then load the soil theme. The BASINS Soil database is presented in Figure 9. It can be found in the Edit Input menu, into the database option. With the Soil Database Editor the user can add new soils with their properties to the BASINS database. Table 6 shows a brief description of the variables that need to be filling in the soil database. They are listed in the order they appear within the file. Most of those variables are in the STATSGO database of Puerto Rico and others were calculated. Since these values are manually entered they were rearranged in an EXCEL spreadsheet, presented in Table7, to facilitate its manipulation. The name of this table is JobosSoils.xls, and it is located in the CD included with this report.

After the database was edited, the user can load the soil theme and manually assign the soil codes in the Definition of Land Use and Soil Theme Dialog Box. For user provided soil data is necessary to choose the radio button labeled Name. A new dialog box will show the name of the soils previously entered in the soil database. Using the dlg number and the table JobosSoils.xls the user can assign the properties of the soils.

Figure 9. Soils Database Editor

User Soils

By Soil

SNAM

NLAYERS [1 to 10]

HYDGRP [A, B, C or D]

SOL_ZMX [mm]

ANION_EXCL [fraction]

SOL_CRK [m3/m3]

TEXTURE

By Layer

SOL_Z [mm]

SOL_BD [g/cm3]

SOL_AWC [mm/mm]

SOL_K [mm/hr]

SOL_CBN [% soil weight]

CLAY [% soil weight]

SILT [% soil weight]

SAND [% soil weight]

ROCK [% vol]

SOL_ALB [fraction]

USLE_K [0.013 t m² hr/(m³ t cm)]

SOL_EC [dS/m]

Up Down
Layer

Save Cancel Help

Table 6. Identification of the data required for the soil input file and their sources

Required Data	Source	Description
SNAM		Soil name
NLAYERS	STATSGO Database Table: layer Element: layernum	Number of layers into the soil
HYDGRP	STATSGO Database Table: comp Element: hydgrp	Soil hydrologic group (A, B, C, or D)
SOL_ZMX	Blank	Maximum rooting depth of soil profile (mm). If no depth is specified, the model assumes the roots can develop throughout the entire depth of the soil profile.
ANION_EXCL	Default Value = 0.5	Fraction of porosity (void space) from which anions are excluded. This parameter is currently used only in nitrate transport. If no value for ANION_EXCL is entered, the model will set ANION_EXCL = 0.50
SOL_CRK	Optional	Crack volume potential of soil (optional).
TEXTURE	Optional	Texture of soil layer (optional). The model does not use this data.
SOL_Z (layer #)	STATSGO Database Table: layer Element: laydepth	Depth from soil surface to bottom of layer (mm).
SOL_BD (layer #)	STATSGO Database Table: layer Elements: bdh, bdl	Moist bulk density (Mg/m ³ or g/cm ³). The soil bulk density expresses the ratio of the mass of solid particles to the total volume of the soil, $\rho_b = MS/VT$. In moist bulk density determinations, the mass of the soil is the oven dry weight and the total volume of the soil is determined when the soil is at or near field capacity. Bulk density values should fall between 1.1 and 1.9 Mg/m ³ .
SOL_AWC (layer #)	STATSGO Database Table: layer Elements: awch, awcl	Available water capacity of the soil layer (mm H ₂ O/mm soil). This is the volume of water that should be available to plants if the soil, inclusive of rock fragments, was at field capacity. Available water capacity is estimated by determining the amount of water released between in situ field capacity (the soil water content at soil matrix Potential of -0.033 MPa) and the permanent wilting point (the soil water content at soil matrix potential of -1.5 MPa).

Required Data	Source	Description
SOL_K (layer #)	STATSGO Database Table: layer Elements: permh, perml	Saturated hydraulic conductivity (mm/hr). The saturated hydraulic conductivity, Ksat, relates soil water flow rate (flux density) to the hydraulic gradient and is a measure of the ease of water movement through the soil. Ksat is the reciprocal of the resistance of the soil matrix to water flow.
SOL_CBN (layer #)	STATSGO Database Table: layer Elements: omh, oml	Organic carbon content (% soil weight). When defining by soil weight, the soil is the portion of the sample that passes through a 2 mm sieve
CLAY (layer #)	STATSGO Database Table: layer Elements: clayh, clayl	Clay content (% soil weight). The percent of soil particles, which are < 0.002 mm in equivalent diameter.
SILT (layer #)	STATSGO Database Formula: 100%-%sand-%clay	Silt content (% soil weight). The percentage of soil particles which have an equivalent diameter between 0.05 and 0.002 mm.
SAND (layer #)	STATSGO Database Table: layer Elements: n10h, n10l, n200h, n200l Formula: ((n10h+n10l)/2)- ((n200h+n200l)/2)	Sand content (% soil weight). The percentage of soil particles which have a diameter between 2.0 and 0.05 mm.
ROCK (layer #)	STATSGO Database Table: layer Elements: n10h, n10l Formula: 100%-((n10h+n10l)/2)	Rock fragment content (% total weight). The percent of the sample which has a particle diameter > 2 mm, i.e. the percent of the sample which does not pass through a 2 mm sieve.
SOL_ALB (layer #)	Formula: (Appendix A) SOL_ALB = 0.6/ exp (0.4*SOL_CBN)	Moist soil albedo. The ratio of the amount of solar radiation reflected by a body to the amount incident upon it, expressed as a fraction. The value for albedo should be reported when the soil is at or near field capacity.
USLE_K (layer #)	STATSGO Database Table: layer Elements: kffact	USLE equation soil erodibility (K) factor (units: 0.013 (metric ton m ² hr)/(m ³ - metric ton cm)). The units given are numerically equivalent to the traditional English units (0.01 (ton acre hr)/(acre ft-ton inch)). The values for the metric units will be exactly the same as those for the English units.
SOL_EC (layer #)	Not currently active	Not currently active. Electrical conductivity (dS/m).

6.6 Weather data

SWAT requires daily precipitation, maximum/minimum air temperature, solar radiation, wind speed, and relative humidity. The daily precipitation and air temperature were collected from the JBNERR weather station and the nearby Aguirre weather stations. The solar radiation, wind speed, and relative humidity were collected only from JBNERR weather station, because no other station in/or near to the area collected that kind of data.

The Input Menu, on the SWAT View, presented on figure 11, allows the user to load the weather data. After selecting Weather Stations, the Weather Data Definition dialog, presented on Figure 12, pops up. The Weather Data Definition dialog is divided in five sections: Weather Simulation data, Rainfall data, Temperature data, Solar Radiation data, Wind Speed data, and Relative Humidity data. The first one listed must be set prior to proceed with the next input data.

Figure 11. Input Menu

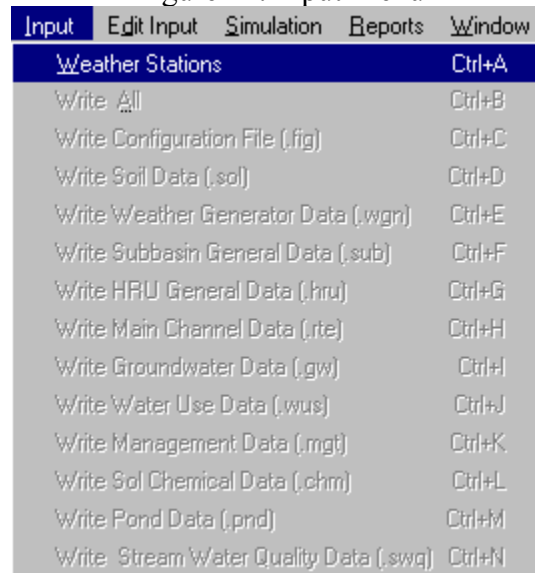








Figure 12. Weather Data Definition Dialog Box

Weather data definition

<p>Rainfall data</p> <p><input type="radio"/> Simulation</p> <p><input checked="" type="radio"/> Raingages</p> <p>Locations table: <input type="text"/> </p>	<p>Solar Radiation data</p> <p><input type="radio"/> Simulation</p> <p><input checked="" type="radio"/> Solargages</p> <p>Locations table: <input type="text"/> </p>
<p>Temperature data</p> <p><input type="radio"/> Simulation</p> <p><input checked="" type="radio"/> Climate stations</p> <p>Locations table: <input type="text"/> </p>	<p>Wind Speed data</p> <p><input type="radio"/> Simulation</p> <p><input checked="" type="radio"/> Windgages</p> <p>Locations table: <input type="text"/> </p>
<p>Weather simulation data</p> <p><input type="radio"/> US database</p> <p><input checked="" type="radio"/> Custom database</p> <p>Locations table: <input type="text"/> </p>	<p>Relative Humidity data</p> <p><input type="radio"/> Simulation</p> <p><input checked="" type="radio"/> Rel. Humidity gages</p> <p>Locations table: <input type="text"/> </p>

Help Close

6.6.1 Weather Simulation Data

In this section the user must set what kind of data the SWAT model will use to generate all the weather data. A typical user can provide the weather station locations and the respective Weather Input file in two ways: using the built-in US database or providing custom stations data. The US database provides the weather information of 1,041 stations around the United States, but Puerto Rico is not included. For the purpose of this study, it was necessary to select the custom database option. This option allows the user to use the data of specific weather stations, in this case, Aguirre and JBNERR stations. A location table is required to locate the custom weather generator stations, while the relative parameters, that contain the properties of those stations, must be entered in the User Weather Stations Database. The name of the location table is WEATHERSTA.dbf and the format used and suggested by BASINS is presented on Table 8.

The NAME field in the location table is used to name the linked weather station data. The weather station data need to be previously entered with the User Weather Stations Database Editor, which is presented in Figure 13. The User Weather Stations Dialog is displayed to start the editing session (Figure 14).

The user has three options: edit an existing station dataset, add a new station data set, or delete a station dataset. For this study, two new stations were added, as mentioned before, Aguirre station and JBNERR station. In Table 9 presents a brief description of the parameters that need to be entered in the User Weather Station Dialog Box. These parameters were calculated, using the daily values collected from both stations. They were entered manually since they could not be loaded as a dBase

table. To facilitate its manipulation they were rearranged in EXCEL spreadsheets named WGN_Aguirre.xls and WGN_JBNERR.xls, and presented in Tables 10 and 11.

Figure13. Weather Station Database Editor

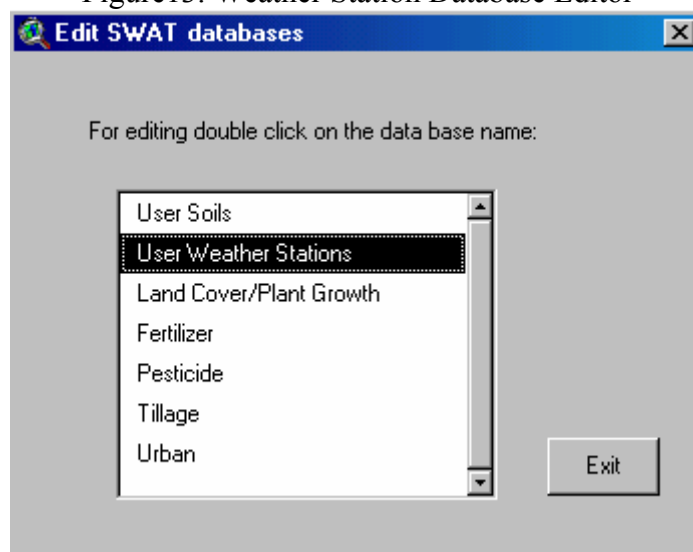


Figure14. User Weather Stations Dialog Box

User Weather Stations

User Defined Weather Station

Sample

Weather Station Name

RAIN_YRS 5.00 [Years] WELEV 0.00 [m]

WLATITUDE -90.00 [Degrees] XPR

WLONGITUDE [Degrees] YPR

Monthly parameters

TMPMX PR_W1
 TMPMN PR_W2
 TMPSTDMX PCPD
 TMPSTDMN RAINHHMX
 PCPMM SOLARAV
 PCPSTD DEWPT
 PCPSKW WNDV

Jan.	-30.00	Jul.	-30.00
Feb.	-30.00	Aug.	-30.00
Mar.	-30.00	Sep.	-30.00
Apr.	-30.00	Oct.	-30.00
May	-30.00	Nov.	-30.00
Jun.	-30.00	Dec.	-30.00

[°C]

Save Cancel Help

Table 8. dBase table format for Custom Database location table

Field Name	Field Format	Definition
ID	Integer	Gage identification number (not used)
NAME	String max 8 chars	Corresponding table name string
LAT	Floating point	Latitude in decimal degrees
LONG	Floating point	Longitude in decimal degrees

Table 9. Data required for the weather generator input file

Required Data	Description
WLATITUDE	Latitude of weather station used to create statistical parameters (degrees). The latitude is expressed as a real number with minutes and seconds converted to fractions of a degree. Optional.
WLONGITUDE	Longitude of weather station (degrees). The model does not use this variable. Optional.
WELEV	Elevation of weather station (m). Optional.
RAIN_YRS	The number of years of maximum monthly 0.5 h rainfall data used to define values for RAIN_HHMX (1,:) - RAIN_HHMX (12,:).
TMPMX(mon)	Average daily maximum air temperature for month (°C).
TMPMN(mon)	Average daily minimum air temperature for month (°C).
TMPSTDMX(mon)	Standard deviation for daily maximum air temperature in month (°C).
TMPSTDMN(mon)	Standard deviation for daily minimum air temperature in month (°C).
PCPMM(mon)	Average amount of precipitation falling in month (mm H ₂ O).
PCPSTD(mon)	Standard deviation for daily precipitation in month (mm H ₂ O/day).
PCPSKW(mon)	Skew coefficient for daily precipitation in month.
PR_W(1,mon)	Probability of a wet day following a dry day in the month.
PR_W(2,mon)	Probability of a wet day following a wet day in the month.
PCPD(mon)	Average number of days of precipitation in month.
RAINHHMX(mon)	Maximum 0.5 hour rainfall in entire period of record for month (mm).
SOLARAV(mon)	Average daily solar radiation for month (MJ/m ² /day).
DEWPT(mon)	Average daily dew point temperature in month (°C).
WNDVAV(mon)	Average daily wind speed in month (m/s).

6.6.2 Rainfall data

This section provides two options to select from: Simulation or Raingages. The Simulation option is used when the user does not have the precipitation data and wants to use the data provided by the US database. Raingages is selected when the user wants to use the precipitation data of a specific weather station or the US database do not provide a weather station in or near the study area. Because Puerto Rico is not included in US database, the daily precipitation data was collected and rearranged in an input file that BASINS can recognize. Daily precipitation data is used when the surface runoff will be model with the SCS curve number method.

When measured precipitation data are to be used and not generated by BASINS, a location table is required to locate the rainfall stations. The location table created was called PRECIP.dbf. The format used to this location table can be observed in Table 12.

The NAME field contains the string used to name the linked precipitation data table. The precipitation data table is used to store the daily precipitation for each rain gage: there will be one precipitation data table for each location listed in the rain gage location table. The input file must contain data for the entire period of simulation; the record does not have to begin with the first day of simulation. SWAT is able to search for the beginning date in the file, saving editing time on the user's part. Once SWAT locates the record for the beginning day of simulation, it no longer processes the year and date. Because it does not check the subsequent dates, it was very important that the data for the remaining days in the simulation were listed sequentially. (If no year

and date are entered for any of the records, the model assumes the first line data corresponds to the first day of simulation.).

The names of the precipitation files created for the watershed are JBPRECIP.dbf and AGPRECIP.dbf. The format and variables used are listed on Table 13.

Table 12. dBase table format of location table for Rainfall data

Field Name	Field Format	Definition
ID	Integer	Gage identification number (not used)
NAME	String max 8 chars	Corresponding table name string
LAT	Floating point	Latitude in decimal degrees
LONG	Floating point	Longitude in decimal degrees
ELEVATION	Floating point	Elevation of the rain gage location (m)

Table 13. dBase table format for Rainfall data

Field Name	Field Format	Definition
DATE	Date (yyyyMMdd)	Day of precipitation
PCP	Floating point	Amount of daily precipitation (mm)

6.6.3 Temperature data

Like the rainfall data, the user can choose between Simulation and Climate Stations. Selecting Climate Stations, the user can load his own data. This is the option selected to use the data collected from JBNERR and Aguirre stations. Using the browser the user has to load the location table named TEMP.dbf. The format used to create this table is presented in Table 14.

The NAME field contains the string used to name the linked temperature data table. The temperature data table was used to store the daily maximum and minimum temperature, in Celsius, for a temperature gage: there was one temperature data table for each location listed in the temperature gage location table. The names of the temperature tables created for the Jobos Bay watershed are JBNERRTEMP.dbf and AGUIRRETEMP.dbf. They were created using the format presented in Table 15.

Table 14. dBase table format of location table for temperature data

Field Name	Field Format	Definition
ID	Integer	Gage identification number (not used)
NAME	String max 8 chars	Corresponding table name string
LAT	Floating point	Latitude in decimal degrees
LONG	Floating point	Longitude in decimal degrees
ELEVATION	Floating point	Elevation of the rain gage location (m)

Table 15. dBase table format for temperature data

Field Name	Field Format	Definition
DATE	Date (yyyyMMdd)	Day of measure
Max	Floating point	Daily maximum temperature (°C)
Min	Floating point	Daily minimum temperature (°C)

6.6.4 Wind Speed data and Relative Humidity data

The wind speed and relative humidity data were collected only from the JBNERR weather station. A typical user has the option of use his own data or to use the simulation option. To use the JBNERR data, location tables were created. The names of these tables are WND.dbf and HMD.dbf and include the location of the station where the wind and relative humidity were measured. The format of both tables is the same as shown on Table 16.

The NAME field contains the string used to name the linked wind and relative humidity data table. Since only one station was used, only one table was created for each one. The table that contains the wind speed data measured in m/s was named JBNERRWND.dbf. The table that contains the relative humidity data expressed in percent was named JBHMD.dbf. To create those tables it was necessary to use the format shown on Table 17.

Table 16. dBase table format of location table for wind and relative humidity data

Field Name	Field Format	Definition
ID	Integer	Gage identification number (not used)
NAME	String max 8 chars	Corresponding table name string
LAT	Floating point	Latitude in decimal degrees
LONG	Floating point	Longitude in decimal degrees

Table 17. dBase table format for wind speed and relative humidity data

Field Name	Field Format	Definition
DATE	Date (yyyyMMdd)	Day of measure
WND/HMD	Floating point	Data Value (m/s) or (%)

6.6.5 Solar Radiation

The solar radiation is used to calculate evapotranspiration. The JBNERR station is the only station in the watershed that collects the solar radiation. Data available are from January 2000 to August 2001. From January 2000 to September 2000, the data have many missing values and this makes it not reliable. From November 2000 the data is more consistent. This can be observed in Figure 15.

Efforts were made to obtain the solar radiation data from another station near the watershed. The nearest weather station was the Fortuna station in Juana Díaz. This station has data from June 2001 to October 2001. This short record is not enough, since BASINS requires at least one year of continuous data from the same station. A comparison between the data for both stations, did not add further information because JBNER and Fortuna station data are not concurrent, except for three months.

BASINS accept the solar radiation to calculate evapotranspiration, through the Set Up and Run SWAT menu, presented in Figure 16. The options to calculate evapotranspiration are Priestley-Taylor method (Neitsch, et al, 2001), Penman-Monteith method (Neitsch, et al, 2001), Hargreaves method (Neitsch, et al, 2001), and the Read in option that allows the user to enter his own evapotranspiration data. Priestley-Taylor and Penman-Monteith methods use the solar radiation data to calculate the evapotranspiration. Hargreaves method uses only the minimum, maximum, and average temperatures. This method is explained in details on Appendix F. Since the solar radiation data found was not reliable and the last method did not uses solar radiation, it was selected to calculate evapotranspiration.

Figure 16. Set Up and Run SWAT model simulation menu

Set Up and Run SWAT model simulation

Period of simulation:

Starting date: Month: Day: Year:

Ending date: Month: Day: Year:

Rainfall/Runoff/Routing:

Rainfall distribution:

Skewed normal

Mixed exponential

Potential ET method:

Priestley-Taylor method

Penman-Monteith method

Hargreaves method

Read in

Crack flow: Not active Active

Channel water routing method: Variable Storage Muskingum

Channel degradation: Not Active Active

Stream Water Quality Processes: Not Active Active

Lake Water Quality Processes: Not Active Active

Printout frequency: Daily Monthly Yearly

Routing Pesticide:

Watershed parameters:

Basin Input File:

General Water Quality Input File:

7. Summary and Conclusions

In this project the BASINS's database for the JBNERR watershed was created. The database was created for last version of BASINS, that is BASINS 3.0. This version includes the watershed and water quality model called SWAT. Since the database for Puerto Rico was not included in the original BASINS's database, Puerto riko's data was introduced using SWAT, which allows the editing of BASINS's database.

The database created for BASINS can be found in the CD labeled "BASINS's Database for JBNERR", included with this report. A list and a description of the data available in the CD are shown in Table 18. A total of 23 files, containing all the sort of climatic, geographic, and hydrologic data, make up the database. In Appendix G is a brief description of how the database created can be incorporate into BASINS and how to run SWAT.

The creation of this database and the future application of BASINS to the JBNERR watershed will provide a good tool for assessing and evaluating the actual condition of the watershed. Also, could help to visualize the impacts of future changes in the land use and the agricultural practices within the watershed. The expansion of this study to other areas in Puerto Rico will facilitate the process of making decisions and the land use management to government and private agencies.

Table 18. Files available in the Jobs Bay database CD

Type of Data	Name	Description
Digital Elevation Model (DEM)	Bj.shp	Topographic relief mapping; supports watershed delineations and modeling
Reach File Version 3 (RF3) Alpha	RF3.shp	Provides a detailed stream network and supports development of stream routing for modeling purposes
Watershed Delineation	watershed.shp	Watershed delineation created with the Automatic Delineation Tool.
Subwatershed Delineation	subwater.shp	Subwatershed delineation created with the Automatic Delineation Tool.
Digitized Stream Network	streams.shp	Digitized Stream Network created with the Automatic Delineation Tool.
Streams Outlets	outlet.shp	Oulets shapefile created with the Automatic Delineation Tool.
Land Use and Land Cover	landuse.shp	Boundaries associated with land use classifications
Land Use Look Up Table	luc.dbf	Land use table created to automatic load the land use classification
State Soil and Geographic (STATSGO) Database	soils.shp	Soils information including soil component data and soils
Soil Database	JobosSoils.xls	Contains the parameters to be fill in the Soil Database Editor
Weather Stations Data (location table)	weasta.dbf	Location of selected meteorological stations and associated monitoring information used to support modeling
Weather Station data (JBNERR)	WGN_JBNERR.xls	Contains the parameters to be manually fill in the Weather Stations Database Editor
Weather Station data (Aguirre)	WGN_Aguirre.xls	Contains the parameters to be manually fill in the Weather Stations Database Editor
Precipitation data (location table)	PRECIP.dbf	Contains the coordinates of the weather station from which the values were collected.

Type of Data	Name	Description
Precipitation data (JBNERR)	JBPRECIP.dbf	Contains the precipitation data of JBNERR station from 1/1/2000 to 8/31/2001
Precipitation data (Aguirre)	AGPRECIP.dbf	Contains the precipitation data of Aguirre station from 1/1/1998 to 7/31/2001
Temperature data (location table)	TEMP.dbf	Contains the coordinates of the weather station from which the values were collected.
Temperature data (JBNERR)	JBTEMP.dbf	Contains the precipitation data of JBNERR station from 1/1/2000 to 8/31/2001
Temperature data (Aguirre)	AGTEMP.dbf	Contains the temperature data of Aguirre station from 1/1/1998 to 7/31/2001
Wind speed data (location table)	WND.dbf	Contains the coordinates of the weather station from which the values were collected.
Wind speed data	JBWND.dbf.	Contains the wind speed data of JBNERR station from 1/1/2000 to 8/31/2001
Relative humidity data (location table)	HMD.dbf	Contains the coordinates of the weather station from which the values were collected.
Relative humidity data	JBHMD.dbf	Contains the relative humidity data of JBNERR station from 1/1/2000 to 8/31/2001

8. Literature cited

- Arnold J., R. Muttiah, R. Srinivasan, and J. Williams, 1998. Large Area Hydrologic Modeling and Assessment, Part I: Model Development. Water Resources Bulletin, American Water Resources Association. 34(1):73-88.
- Brenner, F. and J. Mondok, 1995. Nonpoint Source Pollution Potential in an Agricultural Watershed in Northwestern Pennsylvania. Water Resources Bulletin, American Water Resources Association. 31(6):1101-1112.
- Chong, S., B. Klubek, and J. Weber, 1998. Herbicide Contamination by the 1993 Great Flood Along the Mississippi River. Water Resources Bulletin, American Water Resources Association. 34(3):687-693.
- Fuentes, F. and M. Sastre, 1995. A Preliminary Assessment of Pesticides on Nonpoint Source Pollution in JBNERR. Final Report. Puerto Rico Department of Natural and Environmental Resources.
- Laurent F., W. Anker, and D. Graillet, 1998. Spatial Modeling with Geographic Information System for Determination of Water Resources Vulnerability Application to an Area in Massif Central (France). Water Resources Bulletin, American Water Resources Association. 34(1):123-134.
- Neitsch, S., J. Arnold, and J. Williams, 1999. Soil And Water Assessment Tool (SWAT version 99.2): User's Manual. Grassland, Soil and Water Research Laboratory, Agricultural Research Service.
- Neitsch, S., J. Arnold, J. Kiniry, and J. Williams, 2001. Soil And Water Assessment Tool (SWAT version 2000): User's Manual. Grassland, Soil and Water Research Laboratory, Agricultural Research Service.

- Srinivasan, R., J. Arnold, S. Bednarz, and T. Ramanarayanan, 1998. Large Area Hydrologic Modeling and Assessment, Part II: Model Application. Water Resources Bulletin, American Water Resources Association. 34(1):91-101.
- Tsihrintzis, V., H. Fuentes, and R. Gadipudi, 1996. Modeling Prevention Alternatives for Nonpoint Sources Pollution at a Wellfield in Florida. Water Resources Bulletin, American Water Resources Association. 32(2):317-330.
- USEPA, 1998. Better Assessment Science Integrating Point and Nonpoint Sources (BASINS version 2.0): User's Manual. U.S. Environmental Protection Agency. EPA -823-B-98-98-006.
- USEPA, 2000. Better Assessment Science Integrating Point and Nonpoint Sources Homepage. <http://www.epa.gov/OST/BASINS/> . Active December 2001.
- Viessman, W., G. Lewis, 1996. Introduction to Hydrology. Addison-Wesley Educational Publishers, Inc., New York, NY, 682-684 pp.

9. Appendices

A. Soil Albedo (SOL_ALB)

Albedo is the percent of the solar radiation, which is reflected back to the atmosphere. This parameter is used to estimate the net radiation reaching the soil surface. The formula used to estimate the moist soil albedo is the following:

$$\text{SOL_ALB} = 0.6 / \exp(0.4 * \text{SOL_CBN}) \quad (\text{a.1})$$

SOL_ALB = moist soil albedo (%)

SOL_CBN = percent organic matter of the surface soil.

B. Standard Deviation (Viessman, et al.,1996)

To obtain all the weather station parameters, which are entered in the User Weather Stations Database, it was necessary to calculate the standard deviation for the precipitation and maximum/minimum temperature. The formula to calculate the standard deviation is the following:

$$\text{SQRT}(s^2) = (1/(n-1)) * \Sigma (x-x(\text{avg}))^2 \quad (\text{b.1})$$

s = standard deviation

n = number of values

x(avg) = average value of x, measure of central tendency

C. Skew Coefficient (Viessman, et al.,1996)

The skew coefficient is calculated for the precipitation and maximum/minimum temperature values obtained from the weather stations. It is used

to enter the monthly values in the User Weather Stations Database. The equation (c.1) was used to calculate the skew coefficient.

$$C_s = a / s^3 \quad (c.1)$$

$$a = (n/(n-1)(n-2)) * \Sigma (x-x(\text{avg}))^3 \quad (c.2)$$

C_s = skew coefficient

s = standard deviation

n = number of values

$x(\text{avg})$ = average value of x , measure of central tendency

D. Dew point from relative humidity and temperature

The average daily dew point temperature was calculated using the relative humidity (RH) and the air temperature (T_c). With the temperature, in degrees Celcius, the saturation vapor pressure (E_s) was obtained using equation (d.1).

$$E_s = 6.11 * 10.0^{(7.5 * T_c / (237.7 + T_c))} \quad (d.1)$$

E_s = saturation vapor pressure

T_c = air temperature ($^{\circ}\text{C}$)

Next with the saturation vapor pressure and the relative humidity, the actual vapor pressure (E) of the air was computed. This was done with equation (d.2).

$$E = (RH * E_s) / 100 \quad (d.2)$$

E = actual vapor pressure

RH = relative humidity of air expressed as a percent. (i.e. 80%)

Then with the equation (d.3), was calculated the dew point temperature in degrees Celsius.

$$T_{dc} = (-430.22 + 237.7 \cdot \ln(E)) / (-\ln(E) + 19.08) \quad (d.3)$$

T_{dc} = dew point temperature ($^{\circ}\text{C}$)

E. Solar Radiation

The solar radiation values were obtained from the JBNERR station. This station used a LI-COR Radiation Sensor (Quantum Sensor). LI-COR quantum sensors measure photosynthetically active radiation (PAR) in the 400 to 700 nm waveband. The units of measurement are micro einsteins per second per square meter ($\mu\text{E s}^{-1} \text{m}^{-2}$).

$$\mu\text{E s}^{-1} \text{m}^{-2} = \mu\text{mol s}^{-1} \text{m}^{-2} \quad (e.1)$$

BASINS require the daily solar radiation values in mega joules per day per square meter ($\text{MJ day}^{-1} \text{m}^{-2}$). The factors used to convert the micro einsteins to mega joules are presented in formulas (e.2) and (e.3).

$$\mu\text{E s}^{-1} \text{m}^{-2} = (1/0.483) \text{ watt m}^{-2} \quad (e.2)$$

$$1 \text{ watt} = \text{J/s} \quad (e.3)$$

F. Evapotranspiration

After comparing the solar radiation values of the JBNERR station with the values of Fortuna station in Juana Díaz, it was decided to use a solar radiation

independent equation to calculate the evapotranspiration. The equation selected was Hargreaves-Samani method.

Hargreaves-Samani Technique

The Hargreaves method was originally derived from eight years of cool-season Alta fescue grass lysimeter data from Davis, California (Hargreaves, 1975). Several improvements were made to the original equation (Hargreaves and Samani, 1982 and 1985) and the form used in SWAT was published in 1985 (Equation f.1) (Hargreaves et al., 1985):

$$\lambda E_o = 0.0023 * H_o * (T_{mx} - T_{mn})^{0.5} * (T_{av} + 17.8) \quad (f.1)$$

where λ is the latent heat of vaporization (MJ kg⁻¹), E_o is the potential evapotranspiration (mm d⁻¹), H_o is the extraterrestrial radiation (MJ m⁻² d⁻¹), T_{mx} is the maximum air temperature for a given day (C), T_{mn} is the minimum air temperature for a given day (C), and T_{av} is the mean air temperature for a given day (C).

G. Procedure to apply BASINS to JBNERR using the database herein created

G.1. Project Builder

1. Navigate through the Start, Programs, and BASINS menus on your desktop and click the Project Builder icon (Figure 17). This initiates the BASINS Project Builder subsystem.
2. Supply a name for the project file to be created. The file name may be up to eight characters in length. Do not provide a file name extension. The file name will be assigned an .apr extension. Click OK after you enter a project file name.
3. Select the tutorial data directory from the drop-down list (Figure18). Click OK after making the selection.
4. A dialog box indicates the completion of Project Builder.

G.2. Open Project

1. Click the BASINS icon in the BASINS Windows program group (Figure 19). This initiates the “Open BASINS Project” dialog box.
2. Select a project file from the \BASINS\APR directory. Click on OK after selection is complete. This will open the BASINS project.

Figure17. Opening the Project Builder

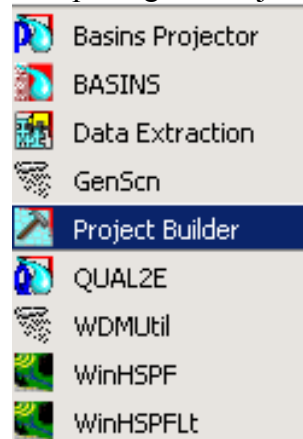


Figure 18. BASINS Project Builder

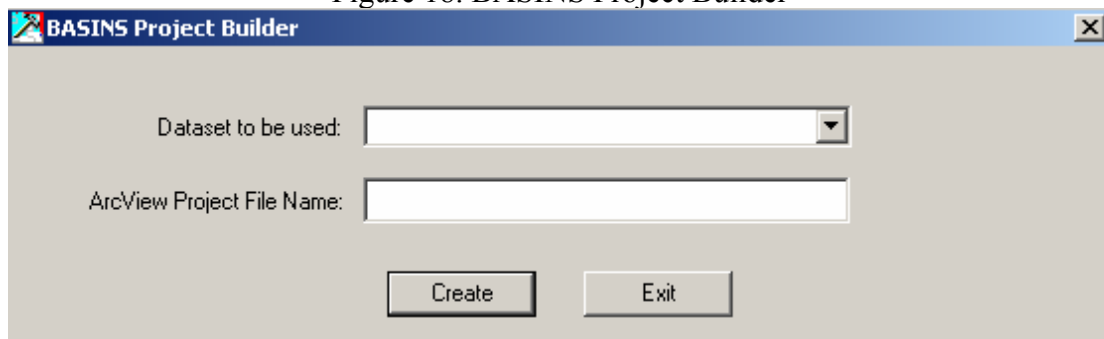
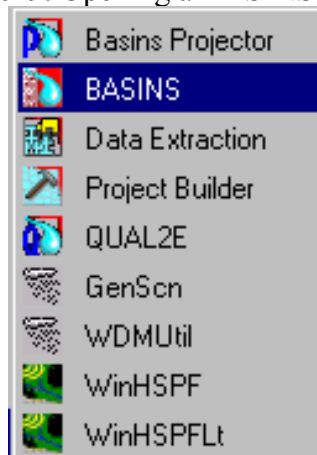


Figure19. Opening a BASINS project



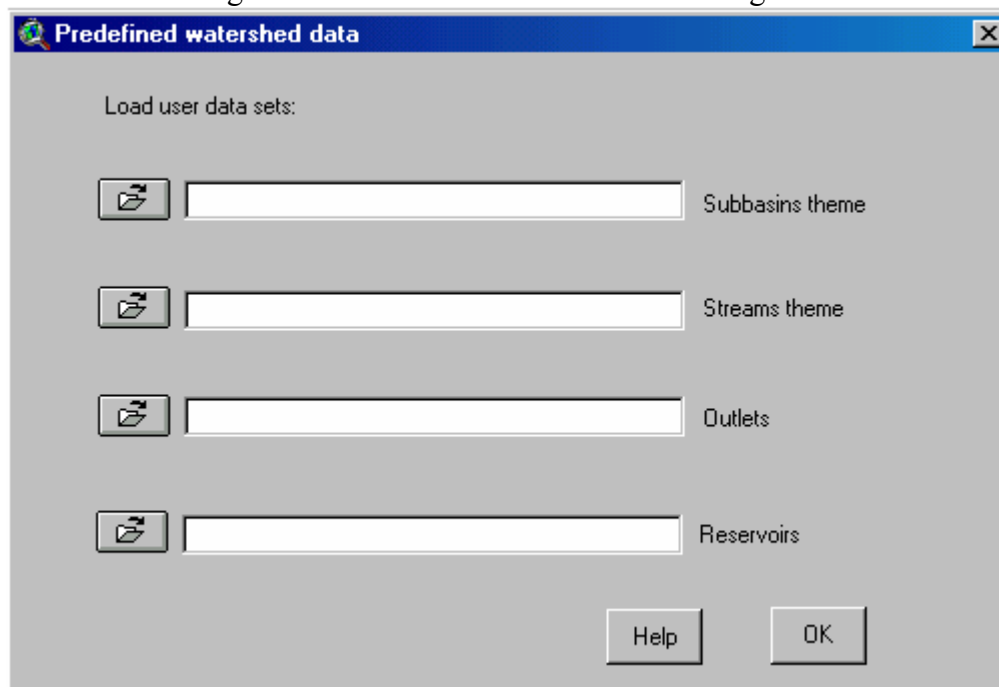
G.3. Loading the predefined delineation

The Predefined Delineation option is available once the BASINS Automatic Delineation extension is loaded.

1. Select the choice Predefined data, from the BASINS View menu Delineate, to begin the set up. The Predefined Watershed Data dialog will open (Figure 20).
2. Load the Sub basins theme by clicking the button beside the text box labeled Sub basins theme.
3. Use the browser to select and load the theme file. The shape file name is subwater.shp.
4. Load the Streams theme by clicking the button beside the text box labeled Streams theme. The loading theme must be a Polyline shape file and its name is streams.shp.
5. Load the Outlets theme by clicking the button beside the text box labeled Outlets theme. The loading theme must be a Point shape file and its name is outlet.shp.
6. Click OK. The dialog will close and you can proceed.

The following resulting themes will be added to the BASINS View: Sub basins, Streams, and Outlets.

Figure 20. Predefined watershed data dialog box



G.4 SWAT databases edition

The databases that will be edited are: User Soils and User Weather Stations. Before getting started make active the SWAT model, by selecting it from the BASINS extensions menu.

G.4.1 User Soils

1. From the Utilities menu select SWAT databases.
2. From the Edit Databases dialog box select the User Soils option (Figure 21). A new dialog box will be displayed (Figure 22).
3. Into the new dialog box select the Add New button to add the JBNERR watershed soils and their properties.
4. The soil name and its properties can be filled using the table named JobosSoils.xls presented in page 40.
5. After filling the blanks for each soil, click Save.

Figure 21. Edit SWAT databases dialog box

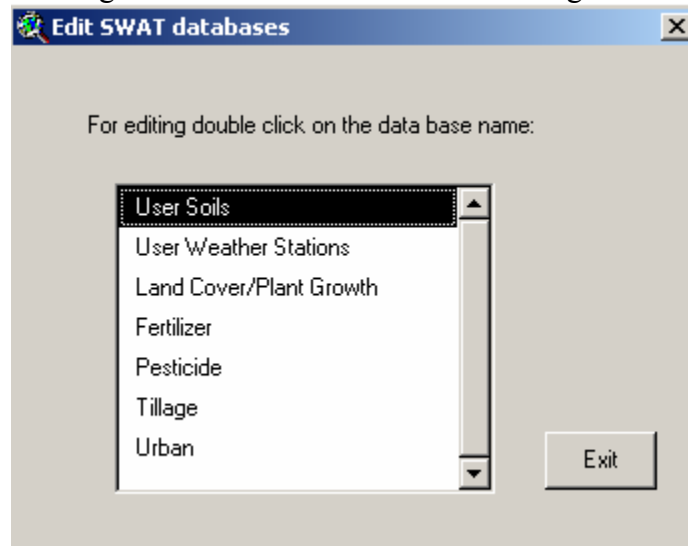
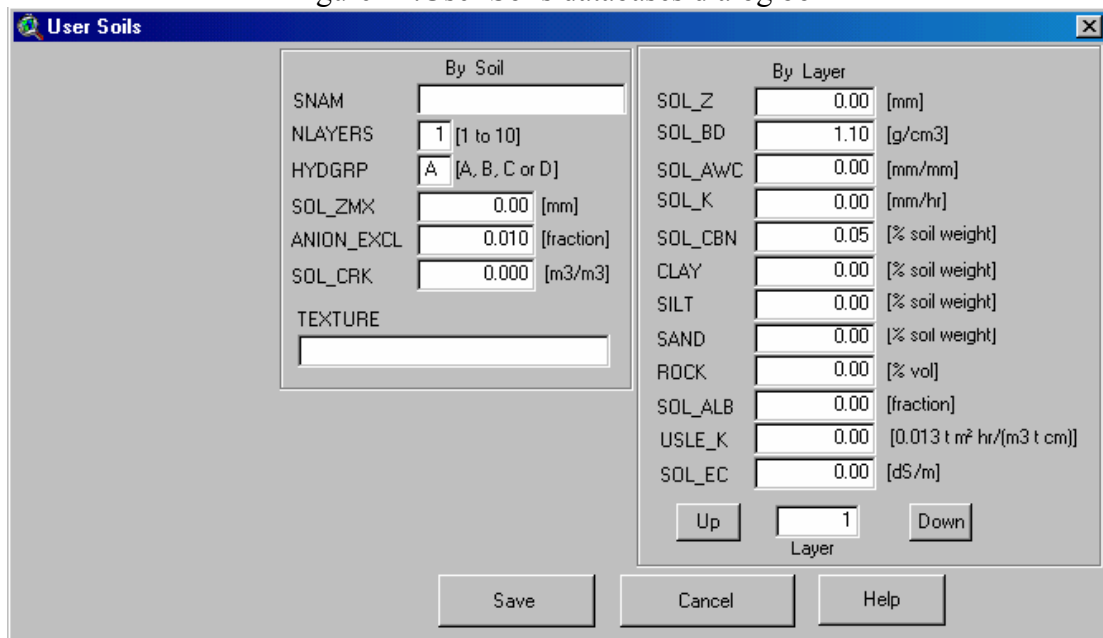


Figure 22. User Soils databases dialog box



G.4.2 User Weather Stations

1. From the Utilities menu select SWAT databases.
2. From the Edit Databases dialog box select the User Weather Stations option (Figure23). A new dialog box will be display (Figure24).
3. Into the new dialog box select the Add New button to add the two weather stations selected and their properties.
4. The weather stations names and it properties can be filled using the tables named WGN_Aguirre.xls and WGN_JBNERR presented in pages 49 and 50, respectively.
5. After filling the blanks for each weather station, click Save.

Once the database are edited, there is not necessary to edit them every time a new project is created. BASINS add them into its database, therefore it is not necessary to input they again, except if the model is uninstalled and installed again.

Figure 23. Edit SWAT databases dialog box

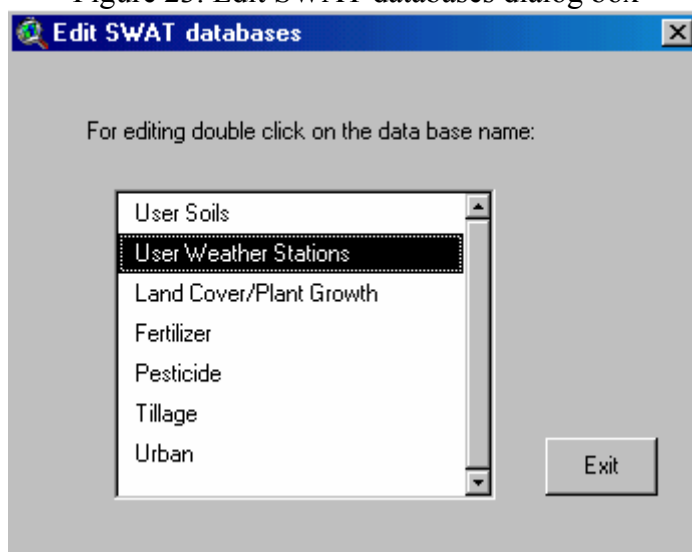
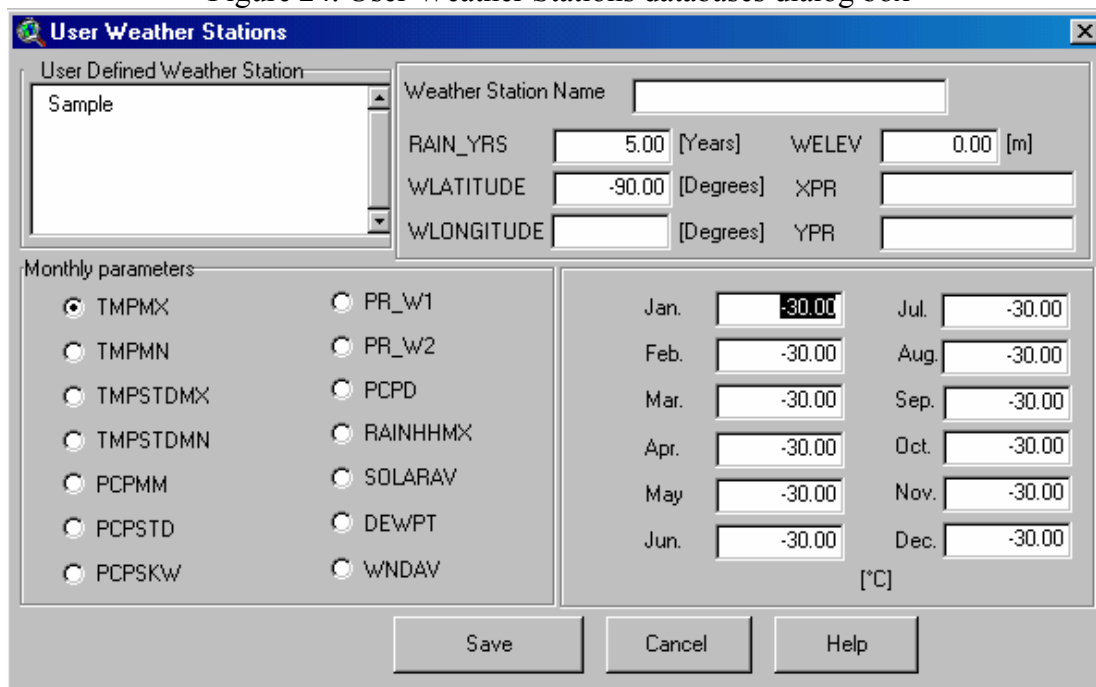


Figure 24. User Weather Stations databases dialog box



G.5. Land Use, Soils and Overlay

Before you get started, active the Land Use and Soil Classification and Overlay extension in your BASINS project by selecting the BASINS Extension menu choice in the File menu.

1. Select LandUse and Soil definition from the BASINS View menu Utilities to start working with the tool. The Definition of Landuse and Soil themes dialog will open. The dialog is divided into two main sections: Land Use data layer and Soil data layer (Figure 25).
2. Select SWAT model by clicking the appropriate radio button.

G.5.1. Define LandUse/LandCover theme

1. Select the land use data layer by clicking the button next to the text box labeled Land Use Grid. The Set the LandUse Grid dialog pops up.
2. Select Load the Land Use Theme from Disk (Figure 26); then click OK (or double click the election). A new dialog pops up. Select Shape from the drop-down menu and click OK (Figure 27), a file browser pops up.
3. Select the theme named landuse.shp and click OK.
4. A prompt box pops up asking if the shape file(s) are already projected. Click Yes.
5. Since the watershed was not delineated using a DEM and the Automatic Delineation tool, a dialog box pops up asking you to provide a base cell size in map units to convert the shape theme(s) to grid and clip them to the study watershed. Type the base cell value and click OK. The default value

is 100. The selected themes are converted in a grid theme with cell size as the base cell size.

6. By default the script will look for the Lucode field (contained in the USGS land use data distributed with BASINS) in the table of attributes of the shape themes and use these values for the conversion to grid. If this field is not included, the script will look for the field type integer and string. Since more than one field is usable, a dialog box will list them. Select land use from the list and click OK.
7. When the previous step is complete, a Load and Clip Land Use message box will appear informing you that the land use data have been clipped to the watershed and reminding you to load a look-up table or manually define the land use classes.
8. To load and join a look-up table created; select the land use look-up table by clicking on the open button in the Look up table section. A dialog box pops up.
9. Select the User Table option and click OK. A dialog allows you to select one of the two available formats, dBase and ASCII. Select dBase format.
10. Load the table named luc.dbf and click OK.
11. Select the Reclassify button. A new theme named SwatLandUseClass will be set within the BASINS view.

Figure 25. Definition of Land Use and Soil Themes Dialog Box

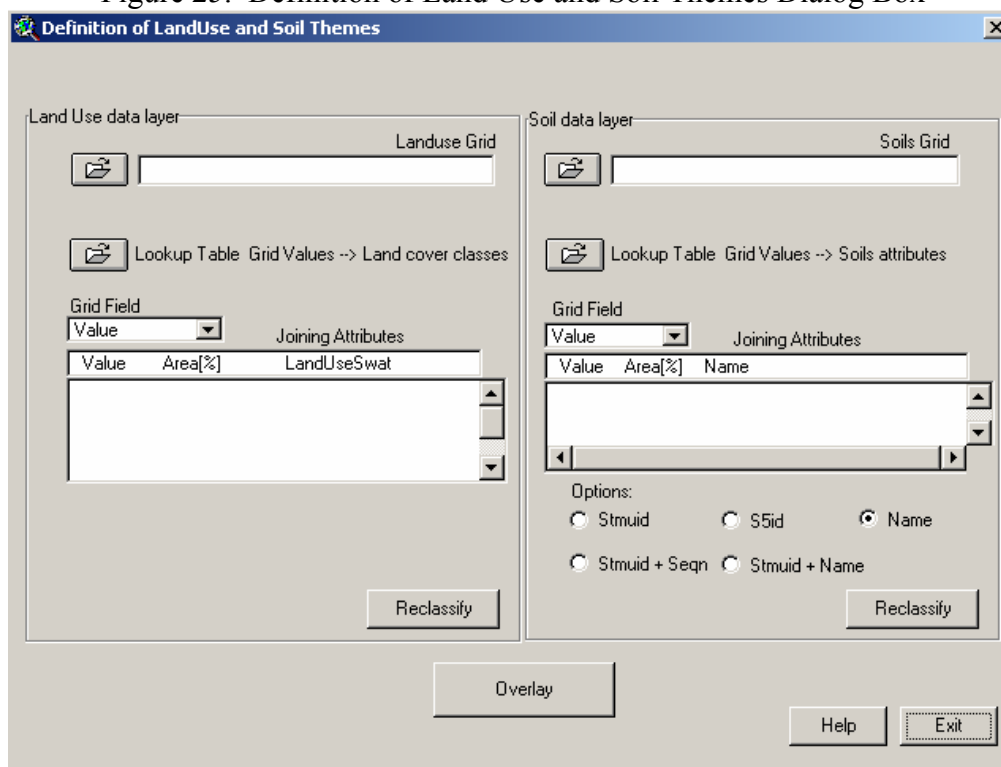


Figure 26. Definition of Land Use Theme

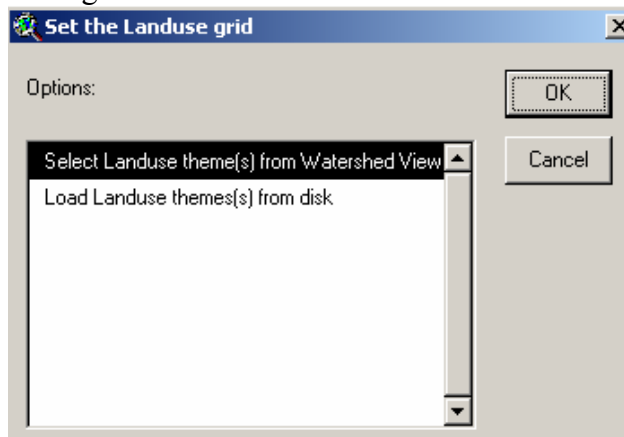
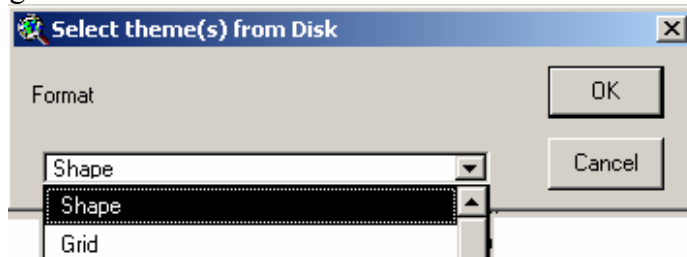


Figure 27. Selection of the format of the Land Use Theme



G.5.2. Define Soil theme

1. To define the soil theme click the button next to the text box labeled Soil Grid (Figure 25). The Set the Soil Grid dialog pops up.
2. Select Load the Soil Theme from Disk; then click OK (or double click the election). A new dialog pops up (Figure 27). Select Shape from the drop-down menu and click **OK**, a file browser pops up.
3. Select the theme named soils.shp and click OK.
4. A prompt box pops up asking if the shape file(s) are already projected. Click Yes.
5. Since the watershed was not delineated using a DEM and the Automatic Delineation tool, a dialog box pops up, asking you to provide a base cell size in map units to convert the shape theme(s) to grid and clip them to the study watershed. Type the base cell value and click OK. The default value is 100. The selected themes are converted in a grid theme with cell size as the base cell size.
6. When the loading, conversion, and clipping are complete, a message box pops up informing you that the soil data have been clipped to the watershed and reminding you to load a look-up table.
7. In this case, instead of loading a look-up table, the soil map grid value will be entered manually, clicking the radio button labeled Name. Since the SWAT databases were previously edited, using the JobosSoils.xls table manually selected the name of the corresponding soils.

8. Select the Reclassify button. A new theme named SoilClass will be set within the BASINS View.

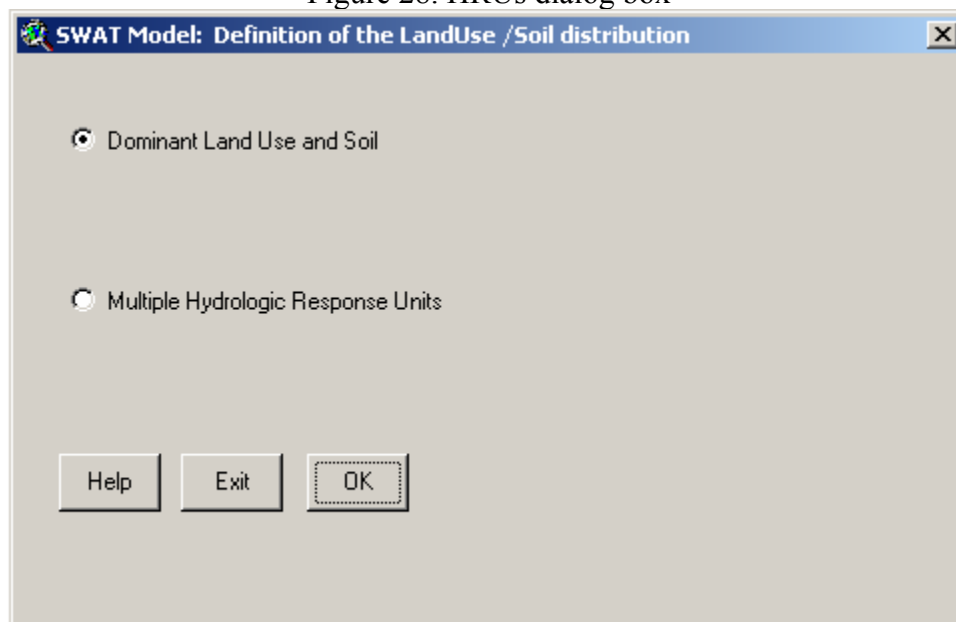
When both the land use and soil grids are reclassified the Overlay button is enabled. Click the Overlay button to start the overlay process.

G.6. Hydrologic Response Units (HRUs) Distribution

1. Select HRU Distribution option from the utilities menu in the BASINS View. A dialog box will open (Figure 28).
2. Select the Dominant Land Use and Soil radio button.
3. Click OK to determine the HRU distribution and then click Exit if the distribution is satisfactory.

After finish the previously process the SWAT model is active automatically and a SWAT View will open.

Figure 28. HRUs dialog box



G.7. Weather Data Definition

1. Select the Weather Stations item from the Input menu on the SWAT View. The Weather Data Definition dialog pops up (Figure 29).
2. The Weather Data Definition dialog is divided in five sections: Weather simulation data, Rainfall data, Temperature data, Solar Radiation data, Wind Speed data and Relative Humidity data.
 - a. Rainfall Data - Select the Raingages radio button. Using the file browser, select the dBase location table named pcp.dbf. Click OK.
 - b. Temperature Data - Select the Climate Stations radio button. Using the file browser, select the dBase location table named temp.dbf. Click OK.
 - c. Weather Simulation Data - Select the Custom Database radio button. Using the file browser, select the dBase location table named weathersta.dbf. Click OK.
 - d. Solar Radiation Data - Select the Simulation radio button.
 - e. Wind Speed Data - Select the Windgages radio button. Using the file browser, select the dBase location table named wnd.dbf. Click OK.
 - f. Relative Humidity Data - Select the Rel. Humidity gages radio button. Using the file browser, select the dBase location table named hmd.dbf. Click OK.

Figure 29. Weather data definition

Weather data definition

Rainfall data

Simulation
 Raingages

Locations table:

Solar Radiation data

Simulation
 Solargages

Locations table:

Temperature data

Simulation
 Climate stations

Locations table:

Wind Speed data

Simulation
 Windgages

Locations table:

Weather simulation data

US database
 Custom database

Locations table:

Relative Humidity data

Simulation
 Rel. Humidity gages

Locations table:

Help Close

G.8. Application of the default input files writer

1. Select the Write All item from the Input menu on the SWAT View (Figure 30).
2. The Write All Inputs dialog box will appear verifying that you want to generate all of the input at once. Click Yes to proceed.
3. Current Status of Input Data message box that lists the different databases being generated appears. As each database is completed, a check mark appears next to the database name and a beep sounds (Figure 31).
4. When the writing of the .mgt (management input) database begins, a prompt box pops up with two options for defining plant growth heat units. Click No, a dialog box will appear asking for a default heat unit value. The default heat unit value will be used for all land cover/plants within the watershed. Click OK to use the current value in the input box.
5. When all databases have been built, a message box will be displayed. Click OK to proceed.

Figure 30. Selection of the Write All option

Input	
Weather Stations	Ctrl+A
Write All	Ctrl+B
Write Configuration File (.fig)	Ctrl+C
Write Soil Data (.sol)	Ctrl+D
Write Weather Generator Data (.wgn)	Ctrl+E
Write Subbasin General Data (.sub)	Ctrl+F
Write HRU General Data (.hru)	Ctrl+G
Write Main Channel Data (.rte)	Ctrl+H
Write Groundwater Data (.gw)	Ctrl+I
Write Water Use Data (.wus)	Ctrl+J
Write Management Data (.mgt)	Ctrl+K
Write Soil Chemical Data (.chm)	Ctrl+L
Write Pond Data (.pnd)	Ctrl+M
Write Stream Water Quality Data (.swq)	Ctrl+N

Figure 31. Current Status of Input Data message box

Current Status of Input Data ...	
Watershed Configuration File (.fig)	<input checked="" type="checkbox"/>
Soil Input (.sol)	<input checked="" type="checkbox"/>
Weather Generator Input (.wgn)	<input checked="" type="checkbox"/>
Subbasin General Input (.sub)	<input checked="" type="checkbox"/>
HRU General Input (.hru)	<input checked="" type="checkbox"/>
Main Channel Input (.rte)	<input checked="" type="checkbox"/>
Groundwater Input (.gw)	<input checked="" type="checkbox"/>
Water Use Input (.wus)	<input checked="" type="checkbox"/>
Management Input (.mgt)	<input checked="" type="checkbox"/>
Soil Chemical Input (.chm)	<input checked="" type="checkbox"/>
Pond Input (.pnd)	<input checked="" type="checkbox"/>
Stream Water Quality Input (.swq)	<input checked="" type="checkbox"/>

G.9. Set up and run SWAT

1. On the Simulation menu, click Run SWAT. A dialog box will be brought up (Figure 32).
2. The initial and final day of simulation are set to the first and last days of the measured weather data.
3. Set the Potential Evapotranspiration method to Hargreaves and the Printout Frequency to Monthly.
4. Click the button labeled Setup SWAT Run to build the climate and watershed level input files.
5. A prompt box will appear asking if any input files need to be written from modified .dbf files. Click No.
6. Click the Run SWAT button.
7. When the SWAT run is finished, a message box will be displayed noting that the simulation was successfully complete. Click OK.

Figure 32. Set Up and Run SWAT model Simulation menu

Set Up and Run SWAT model simulation

Period of simulation:

Starting date:
 Month Day Year

Ending date:
 Month Day Year

Rainfall/Runoff/Routing:

Rainfall distribution:

Skewed normal
 Mixed exponential

Potential ET method:

Priestley-Taylor method
 Penman-Monteith method
 Hargreaves method
 Read in

Crack flow:

Not active
 Active

Channel water routing method:

Variable Storage
 Muskingum

Channel degradation:

Not Active
 Active

Stream Water Quality Processes:

Not Active
 Active

Lake Water Quality Processes:

Not Active
 Active

Printout frequency:

Daily
 Monthly
 Yearly

Routing Pesticide:

Watershed parameters:

Basin Input File:

General Water Quality Input File:

Help Exit Setup SWAT Run