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A Comparative Review of HEC-1, HEC-HMS, WMS, and SMADA Hydrological Modeling Tools for Runoff Simulation and Flood Assessment

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ABSTRACT
Hydrological models are widely used to study the relationship between rainfall and runoff and to understand how watersheds respond to different rainfall events. This study presents an overview of four commonly used hydrological modeling programs: HEC-1, HEC-HMS, WMS, and SMADA. It describes the development and main features of HEC-HMS, including its ability to simulate infiltration, rainfall losses, surface runoff, baseflow, and streamflow routing. The study also discusses the role of WMS in watershed delineation, terrain analysis, and the estimation of hydrological parameters, as well as its integration with HEC-HMS. In addition, the main applications of SMADA in hydrograph generation, storm water management, and hydrological calculations are reviewed. Practical examples are presented to illustrate how the three programs can be used to generate unit hydrographs and simulate runoff from watersheds. The comparison shows that each program offers different but complementary capabilities. HEC-HMS is useful for rainfall–runoff simulation, WMS facilitates watershed analysis and model preparation, while SMADA provides a range of tools for hydrological calculations and result presentation. Together, these programs offer practical support for watershed studies, flood assessment, and drainage planning.
Keywords: HEC-HMS; HEC-1; WMS; SMADA; Rainfall-Runoff Modeling; Watershed Analysis; Unit Hydrograph; Flood Assessment

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I. INTRODUCTION

The (HEC-1) program was developed by the Hydrologic Engineering Center. It is the most commonly-used lumped parameter model available. It is designed to simulate surface runoff from a single precipitation event. The Hydrologic Modeling System HEC-HMS is program designed to simulate surface water hydrology and it is Windows version of HEC-1 with significant advances in computer science and hydrologic engineering which was developed by the U.S. Army Corps of Engineers. Those programs are used in engineering practices to determine the drainage characteristics of both rural and urban watersheds. HEC-HMS is new generation software for precipitation runoff simulation that will supersede the HEC-1 Flood Hydrograph Package also it contains most of the HEC-1 capabilities, such as flow-frequency curve analysis, snow accumulation and melt. HEC-HMS includes several hydrologic components that represent rainfall, evaporation, and snowmelt. There are subroutines for the calculation of infiltration, losses, base flow, and run-off and different methods for the calculation of each one. Furthermore, it offers different analysis tools to better visualize and understand the results obtained. Regarding to the hydraulics features of dam capabilities are underway but have not yet been incorporated. The flood damage analyses is performed by HEC-FDA software and are not included in HEC-HMS.

II. OBJECTIVES

- To present the theory and applications of HEC-1 and HEC-HMS models.
- To describe the structure of the HEC-HMS software.
- To review WMS and SMADA simulation models and its capabilities.
- To run the HEC-HMS, WMS and SMADA models for case studies.
- To present the Model's outputs.

III. HISTORY OF THE MODELS DEVELOPMENT

The computation engine draws on over 30 years experience with hydrologic

simulation software. Many algorithms from HEC-1 (USACE 1998), HEC-1F (USACE 1989), PRECIP (USACE 1989), and HEC-IFH (USACE 1992) have been modernized and combined with new algorithms to form a comprehensive library of simulation routines. HEC model has been begun with separate Programs since 1967 by Leo R. Beard. A major revision and unification have been done in 1973 and the second Major revision has been reviewed in 1981 for (Dam Breach and Kinematic Wave). And finally, PC versions for both partially and fully have been developed in 1988 and 1984 respectively. All future releases, beginning with Version 3.0, have been developed using the Java language. HEC-1/HMS has been the final release in 1998. The first release for HEC-HMS has been in April 1998. HEC-HMS is comprised of a graphical user interface, integrated hydrologic analysis components, data storage and management tools, and graphics and reporting. HEC "Next Generation Software Development Project" has been begun in 1990 for (RAS, HMS, FDA). Algorithms originally developed for the Distributed Snow Process Model (DSPM) has been adapted for use in HEC-HMS. As time allows, many features have been added to HMS. These features may include snowmelt simulation customizable reports, automatic depth-area reduction analysis, additional reservoir capabilities for modeling interior flood zones, energy budget, user scripting to automate simple tasks, frequency curve. The HEC-Geospatial Hydrologic Modeling Extension (GeoHMS) is a public-domain extension to Arc GIS and Spatial Analyst extension (USACE 2000a).

Arc GIS and its Spatial Analyst extension are available from the Environmental Systems Research Institute (ESRI). HEC-GeoHMS has been developed as a geospatial hydrology tool kit for engineers and hydrologists with limited GIS experience. The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate sub basins and streams, construct inputs to hydrologic models, and assist with report preparation. Working with HEC-GeoHMS through its interfaces, menus, tools, in a Windows environment, allows the user to expediently create hydrologic inputs that can be used directly with the HEC-HMS program generation, and internationalization of the software.

IV. APPLICATIONS AND USES OF Models:

4.1 HEC-1 PROGRAM

The model based on the rainfall-runoff process in a watershed depending on watershed physiographic data. It offers a variety of modeling options in order to compute unit hydrograph (UH) for basin areas and also offers a variety of options for flood routing along streams. It is capable of estimating parameters for calibration of each basin based on comparison of computed data to observed data. Ease of use so user can run projects with different parameters instead of creating new projects, in addition, it is capable of handling NEXRAD-rainfall data and girded precipitation, furthermore converting HEC-1 files into HMS files.

4.2 APPLICATIONS OF HEC-HMS

The software includes a variety of model choices for each segment of the hydrologic cycle especially in the methods used for the calculation of run-off and other hydrologic elements, so it is very adaptable. The challenge for the modeler is to use the most appropriate methods for the estimation or calculation of required parameters as shown in figure1.

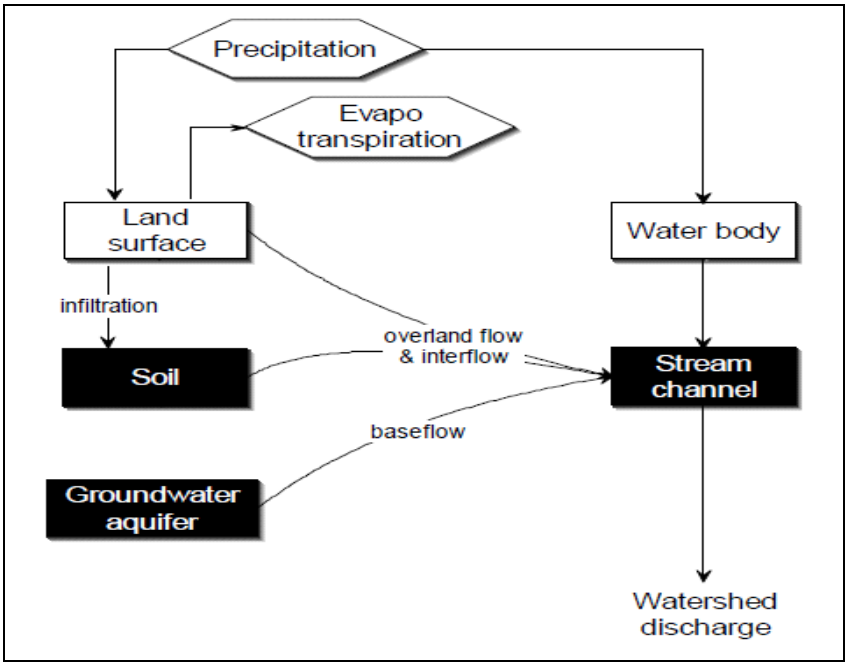


Figure 1: HEC-HMS representation of Watershed Runoff

It has been used in many studies for achieving goals in flood damage reduction, reservoir and system operation, floodplain regulation, environmental restoration, water supply planning, among others.

Several important new capabilities are available in HEC-HMS; mainly, continuous hydrograph simulation over long periods of time, and spatially distributed runoff computation using a grid-cell depiction of the watershed. This initial continuous hydrograph simulation capability (termed 'deficit/constant') is a simple single-reservoir soil-moisture representation; more comprehensive soil moisture accounting is currently under development. HEC-HMS is comprised of a graphical user interface, integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities.

4.3 GENERAL DESCRIPTION OF HEC-HMS SOFTWARE

When developing HMS model the following component models: Basin Model, Metrological Model and Control Specifications need to be defined through the model interface tools as shown in figure 2. The project definition May contain several basin models, meteorologic models, and control specifications and user can select a variety of combinations of the three models in order to see the effects of changing parameters on one sub basin.

Figure 2: HEC HMS interface and main model components

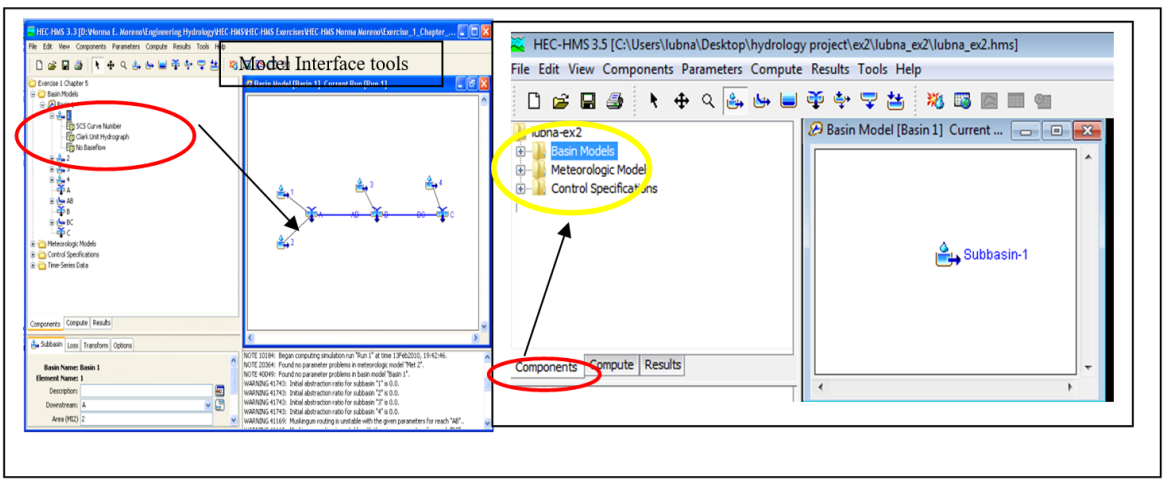


Figure 2: model interface and components

The physical representation of watersheds or basins and rivers is configured in the basin model. Hydrologic elements are connected in a dendrite network to simulate runoff processes. Available elements are: subbasin, reach, junction, reservoir, diversion, source, and sink. Hydrologic elements are the building blocks of the basin model. Table 1 lists and provides a description for each element available in a basin model. An element uses a mathematical model to describe the physical process.

Table 1
Description of Basin Model Element

Element	Description
Subbasin	A subbasin is an element that usually has no inflow and only one outflow. This element is one of only two ways to produce flow in the basin model. Outflow is computed from meteorologic data by subtracting losses, transforming excess precipitation, and adding baseflow. The subbasin can be used to model a wide range of watershed catchment sizes.
Reach	A reach is an element with one or more inflows and only one outflow. Inflow comes from other elements in the basin model. If there is more than one inflow, all inflows are added together before computing the outflow. Outflow is computed using one of the several available methods for simulating open channel flow. The reach can be used to model rivers and streams.
Reservoir	A reservoir is an element with one or more inflows and one computed outflow. Inflow comes from other elements in the basin model. If there is more than one inflow, all inflows are added together before computing the outflow. Assuming that the water surface is level, outflow is either computed using a user-specified monotonically increasing storage-outflow relationship or an outlet structure and an elevation-storage relationship. The element can be used to model reservoirs, lakes, and ponds.
Junction	A junction is an element with one or more inflows and only one outflow. All inflow is added together to produce the outflow by assuming zero storage at the junction. It is usually used to represent a river or stream confluence.
Diversion	A diversion is an element with two outflows, main and diverted, and one or more inflows. Inflow comes from other elements in the basin model. If there is more than one inflow, all inflows are added together before computing the outflows. The amount of diverted outflow is computed from a user-specified monotonically increasing inflow-diversion relationship. Diverted outflow can be connected to an element that is computationally downstream. The diversion can be used to represent weirs that divert flow into canals, flumes, or off-stream storage.
Source	A source is an element with no inflow, one outflow, and is one of only two ways to produce flow in the basin model. The source can be used to represent boundary conditions to the basin model such as measured outflow from reservoirs or unmodeled headwater regions.
Sink	A sink is an element with one or more inflows but no outflow. Multiple inflows are added together to determine the total amount of water entering the element. Sinks can be used to represent the lowest point of an interior drainage area or the outlet of the basin model.

Meteorologic data analysis is performed by the meteorologic model and includes precipitation and evapotranspiration. The time span of a simulation is controlled by control specifications, which include a starting date and time, ending date and time, and computation time step.

As noted above, a mathematical model consists of equations that represent the behavior of various hydrologic system components. Here in the term *method* is used in this context. For example, the Muskingum-Cunge channel routing method encapsulates equations for continuity and momentum to form a mathematical model of open-channel flow for routing. All of the details of the equations, initial conditions, state variables, boundary conditions, and method of solving the equations are contained within the method. To make the program suitable for many different conditions, most elements have more than one method for approximating the physical process. For example, there are seven different methods for calculating the excess precipitation in a subbasin element. Table 2 lists available methods for certain basin model elements and the precipitation model.

Table 2
Summary of Simulation Methods Included in HEC-HMS

Category	Method
Precipitation	User-specified hyetograph
	User-specified gauge weighting
	Inverse-distance-squared gauge weighting
	Gridded precipitation
	Frequency-based hypothetical storms
	Standard project storm (SPS) for eastern U.S.
	Soil conservation service (SCS) hypothetical storm
Evapotranspiration	Monthly average
Loss	Initial and constant rate
	SCS curve number (CN)
	Gridded SCS CN
	Green and Ampt
	Deficit and constant rate
	Soil moisture accounting (SMA)
	Gridded SMA
Direct runoff	User-specified unit hydrograph (UH)
	Clark's UH
	Snyder's UH
	SCS UH
	ModClark
	Kinematic wave
	User-specified s-graph
Baseflow	Constant monthly
	Exponential recession
	Linear reservoir
Routing	Kinematic wave
	Lag
	Modified Puls
	Muskingum
	Muskingum-Cunge standard section
	Muskingum-Cunge 8-point section
	Diversion
	Reservoir

A brief description of the methods provided by the software:

•*Precipitation methods:* describe an observed (historical) precipitation event; a frequency based hypothetical precipitation event, or an event that represents the upper limit of precipitation possible at a given location. Also, a snowmelt method is being added that can partition precipitation into rainfall and snowfall and then account for accumulation and melt of the snow pack. These methods describe the spatial and temporal distribution of precipitation on a watershed.

• *Evapotranspiration methods:* used in continuous simulation for computing the amount of water that is removed back to the atmosphere through evaporation and plant use.

• *Loss methods:* estimate the amount of precipitation that infiltrates from the land surface into the soil. Among the loss methods are a simple one-layer and more complex five-layer soil moisture- accounting model for continuous simulation. They can be used to simulate the long-term response of a watershed to wetting and drying. The loss methods address questions about the volume of precipitation that falls on the watershed: How much infiltrates on pervious surfaces? How much runs off of the impervious surfaces? When does it run off?

• *Direct-runoff methods:* describe overland flow, storage, and energy losses as water runs off a watershed and into the stream channels. These are generally called transform methods because they "transform" excess precipitation into watershed outflow. These methods describe what happens as water that has not infiltrated or been stored on the watershed moves over or just beneath the watershed surface. A quasi-distributed transform model for use with distributed precipitation data, such as the data available from radar, is available.

• *Baseflow methods:* estimate the amount of infiltrated water returning to the channel. Some of the included methods conserve mass through the infiltration process to baseflow; others do not have the same conserving properties. These methods simulate the slow subsurface drainage of water from a hydrologic system into the watershed's channels.

• *Hydrologic routing methods:* account for storage and energy flux as water moves through stream channels and water control structures. These routing

methods simulate one dimensional open channel flow, thus predicting time series of flow, stage, or velocity, given upstream hydrographs.

The program has been designed to be as flexible as possible in defining the hydrologic system. For example, the user could choose to combine the deficit and constant rate loss method with the Clark transform method. The program will do the work of connecting the excess precipitation from the loss method to the transform method for computing surface runoff.

Most methods can be successfully combined with any other method to compute watershed discharge. However, the applicability of any particular method depends on the characteristics of the watershed and some methods may not be appropriate for some hydrologic engineering studies.

The data-entry steps, program execution, and result visualization are easy with the HMS

Program. Each of the subbasin model elements and the precipitation model has an editor for selecting computation methods and entering the required parameter data. The user indicates method choices and specifies initial conditions and parameters using a graphical user interface (GUI). In general, the user enters quantitative parameter values. For example, the Green and Ampt infiltration method requires an initial loss, volume moisture deficit, wetting front suction, hydraulic conductivity, and percent impervious area. The user is responsible for collecting and analyzing the land use and soil data necessary to compute the parameter values. A similar approach is used

for all of the other method choices included in the program. The HEC-HMS Technical Reference Manual (USACE 2000b) includes suggestions for estimating the parameters for each method included in the program.

A computation run is created by combining a basin model, meteorologic model, and control specifications. Run options include a precipitation or flow ratio, capability to save all basin states at a point in time, and ability to begin a simulation from previously saved states.

Computation results are viewed from the basin model schematic. Global and element summary tables include information on peak flow and total volume. Time-series tables and graphs are available for elements. Input data requirements depend on the method choices made by the user. Precipitation data are required for almost all applications and are subsequently processed within the program to produce a precipitation boundary condition for the watershed. Depending on the use, precipitation data may be time-series gauge records, spatial grids from radar rainfall estimates, or statistical data from a NOAA product such as TP-40. Discharge records may be required as an upstream boundary condition when only part of a watershed is modeled.

Comparing computed and actual results: plot observed data on the same hydrograph to by selecting a discharge gage for an element.

4.4 AN OVERVIEW OF EXAMPLE USING HEC-HMS

- Generation of flood Unit Hydrograph (UH) for a watershed through the following modeling process in HEC HMS as shown in figure 3:

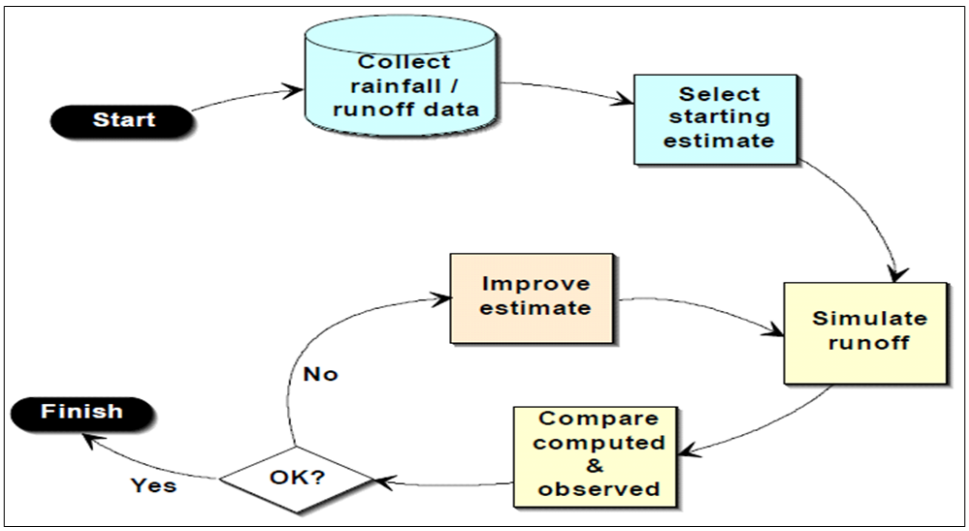


Figure 3: Schematic modeling process in HEC HMS

✓ Identification of the three main components:

1- Basin model: Determination of the (basins no. and subbasins no.), area, loss method (i.e, SCS curve number) and the required parameters as shown in figure 4.

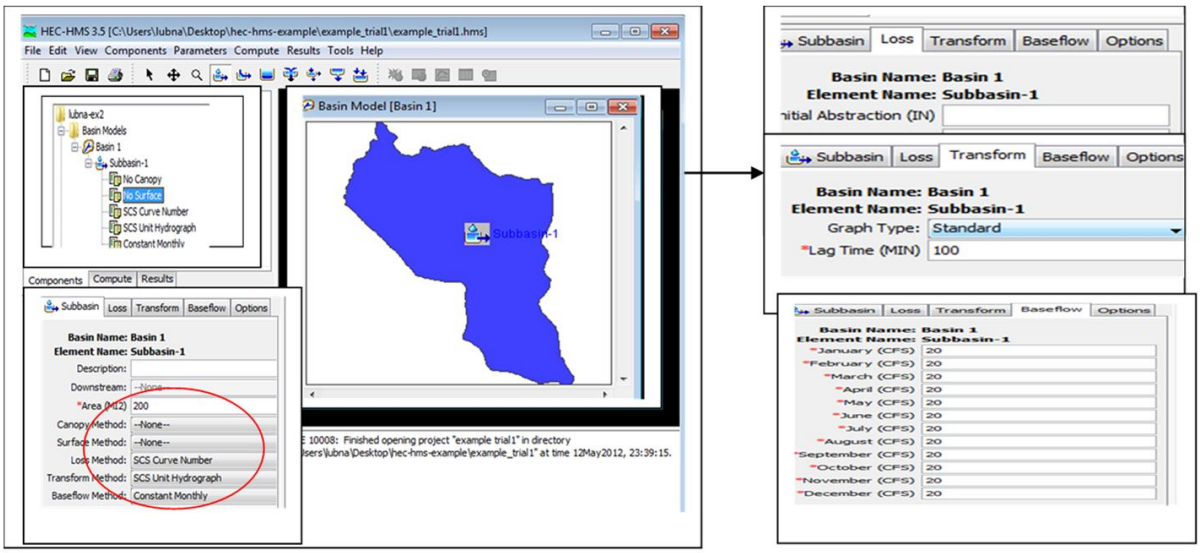


Figure 4: Determination of the parameters required for "basin model" component

2- Meteorologic model: Determination of the precipitation method (i.e. Specified hyetograph) and fill the required information as shown in figure 5

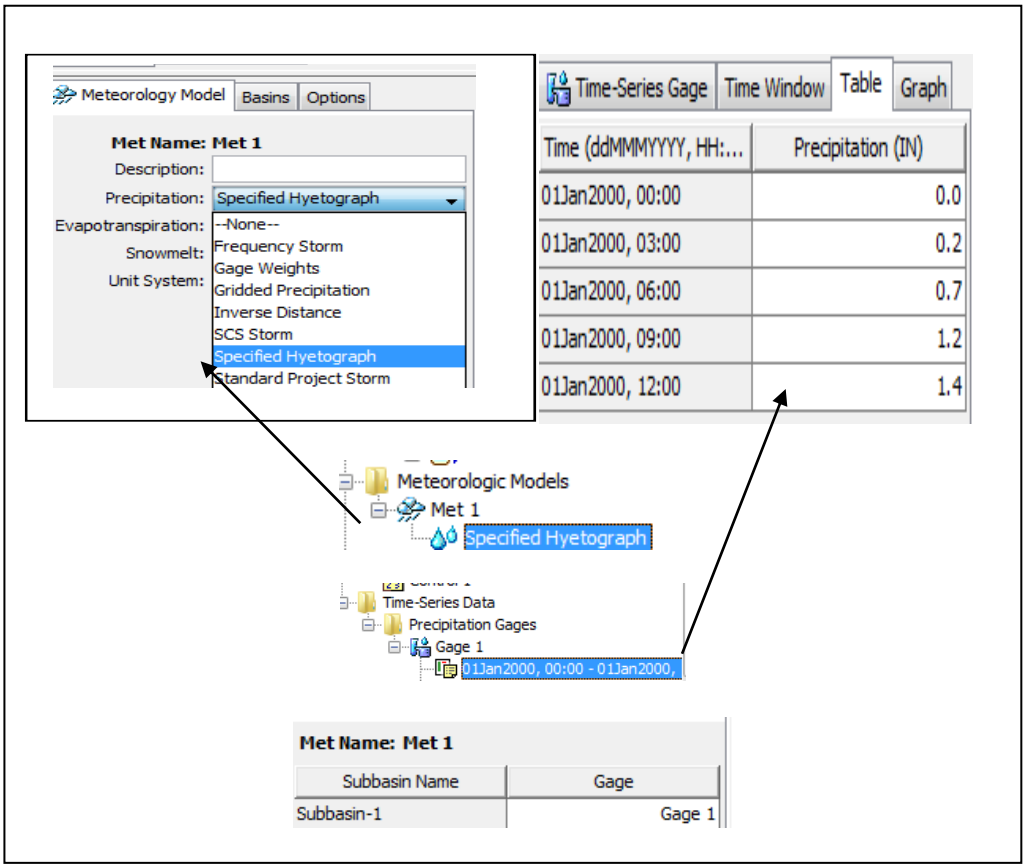


Figure 5: Determination of the parameters required for "Meteorologic model" component

3- Control specifications: Determination of the starting and ending time and dates for specific interval necessary for model's execution process as shown in figure 6.

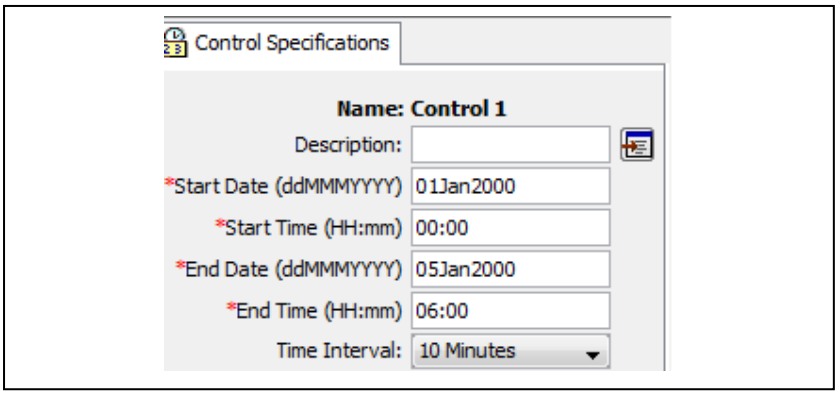
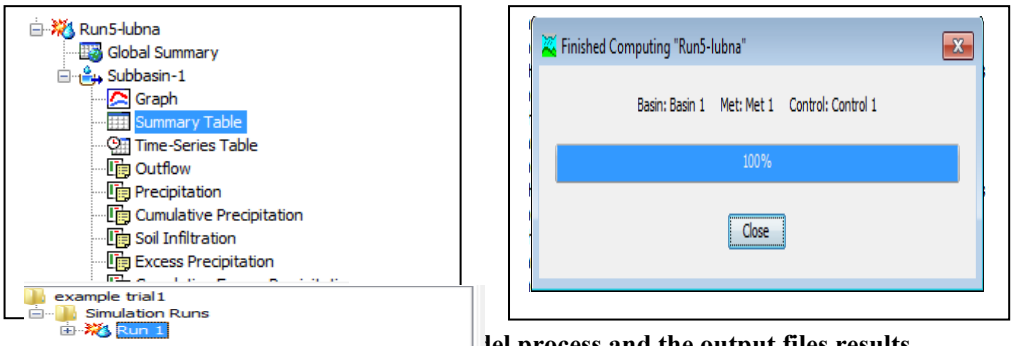


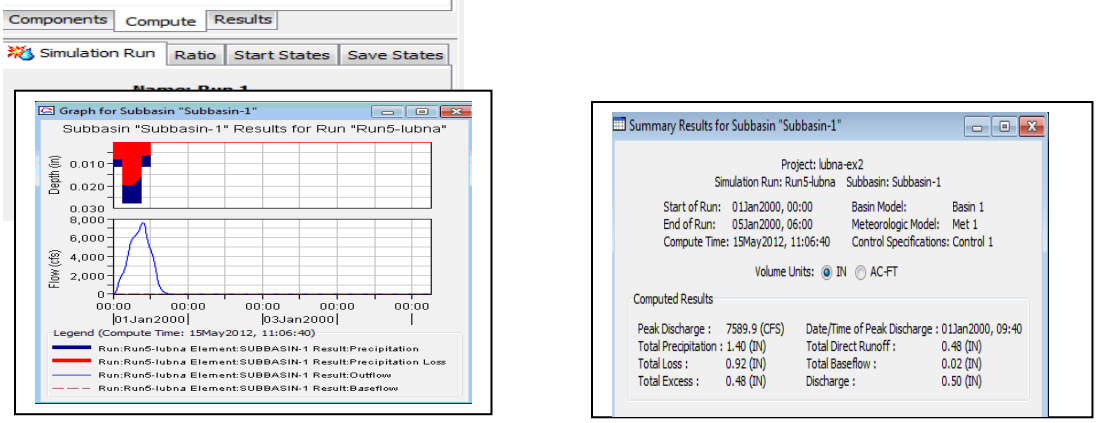
Figure 6: Determination of the parameters required for "Control specifications" component

✓ Run the model as shown in figure 7.



lel process and the output files results

✓ ; (i.e. unit hydrograph (UH), and Tables (i.e. summary tables) as show



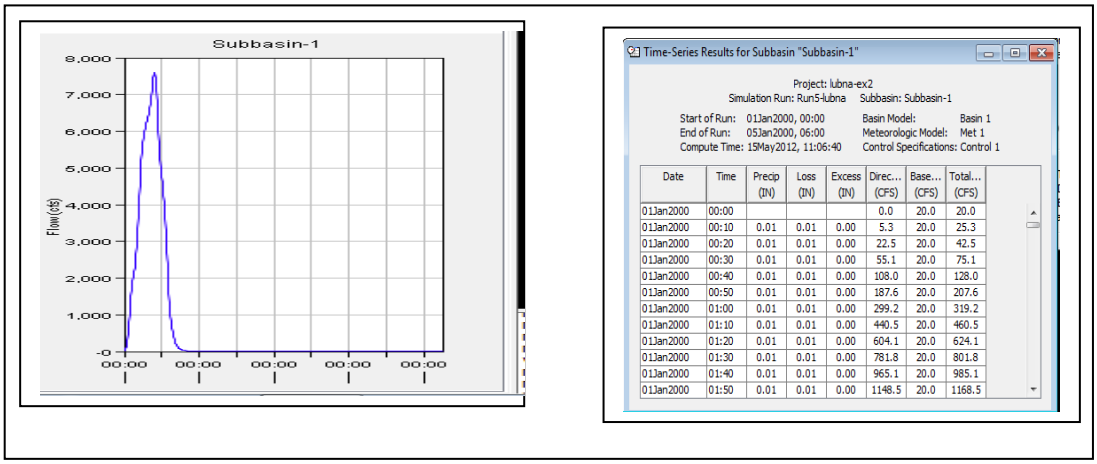


Figure 8: output files: tables an graphs

✓ Calibration

4.5 AN OVERVIEW OF WATERSHED MODELING SYSTEM "WMS" SOFTWARE

WMS the Watershed Modeling System is a comprehensive hydrologic modeling environment that provides tools for all phases of watershed modeling including automated watershed and sub-basin delineation, geometric parameter computation, hydrologic parameter computation (CN, time of concentration, rainfall depth, etc.) and result visualization. WMS is the most powerful tool for analysis and visualization of watersheds. It provides complete support of the industry-standard U.S. Army Corps of Engineers HEC-1 and HEC-HMS, U.S. Soil Conservation Service TR-20 and TR-55, and Rational Method Equation hydrologic routing programs. Also supported the National Flood Frequency (NFF) model, support for the EPA/USGS hydrologic water quality HSPF model is also provided.

4.5.1 WMS MODULES

The WMS interface is separated into several modules; these modules contain tools that allow manipulation and model creation from different data types. The modules are: Map , DEM, TIN ,Hydrologic Modeling ,Scatter point , 2D grid as shown in figure 9.

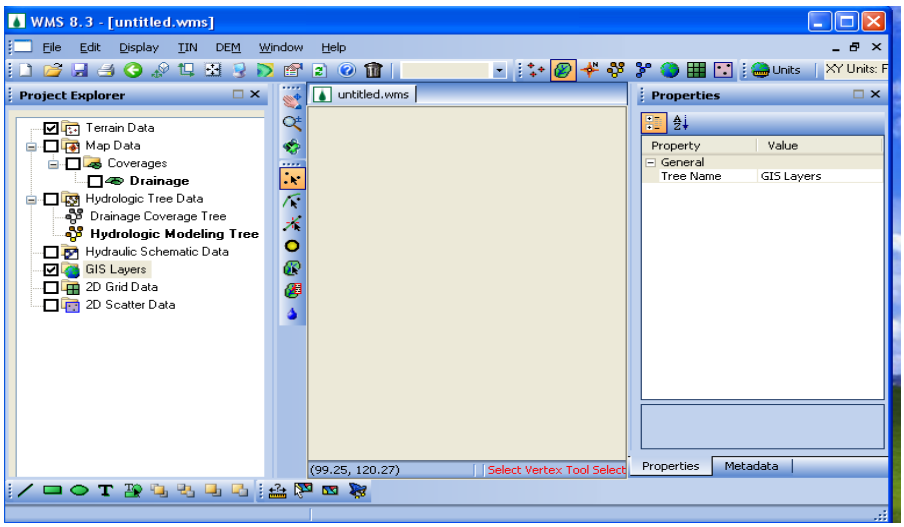


Figure 9: WMS interface and main modules

4.5.2 AN EXAMPLE USING WMS

✓ Set up the basin data parameters: Watershed delineation and hydrologic features: (based on elevation layer, DEM, TIN), identification for some of hydrologic feature as flow path and accumulations, area and length measurements, Tc as shown in figure 10.

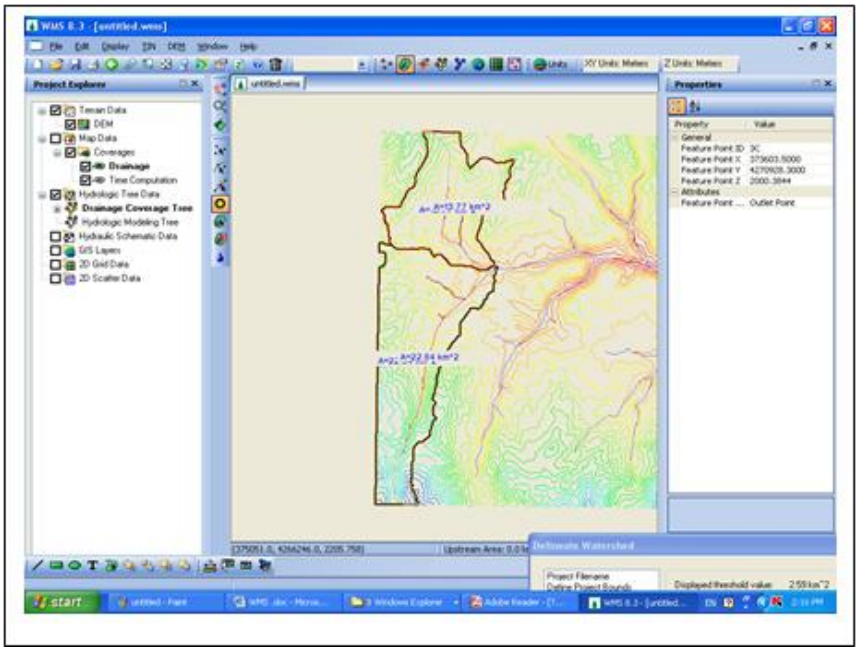


Figure 10: watersheds delineation and some hydrologic features based on elevation layer

- ✓ Setup up for the simulation models interfaces with WMS (i.e. HEC-HMS Model)
- ✓ Define the hydrologic input parameters, methods and layers required as shown in figure 11.
- ✓ Hydrologic computations: (Tc, Lag time,..)
- ✓ Export simulation to specified model (i.e.HEC-HMS): (define metrologic and control specification, viewing the results)

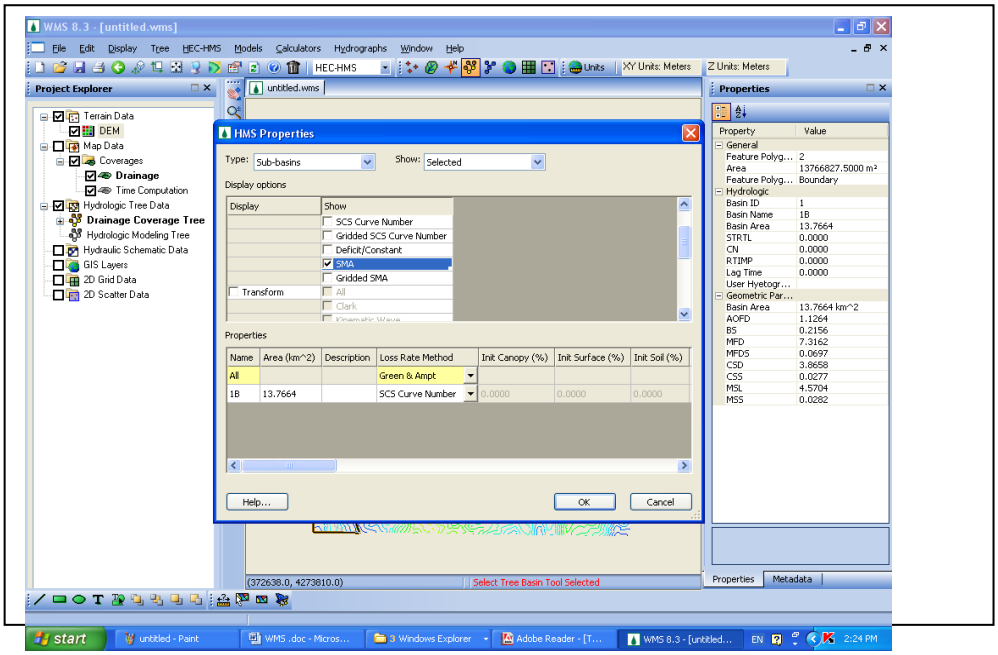


Figure 11: Define the input parameters and methods required for i.e. HEC-HM

4.5 AN OVERVIEW OF STORM WATER MANAGEMENT AND DESIGN AID "SMADA" SOFTWARE

This software is a complete hydrology package included as a number of separate executable files. These programs work together to allow hydrograph generation, pond routing, storm sewer design, statisitical distribution and regression analysis, pollutant loading modeling, matrix calculation, and others.

4.5.1 AN EXAMPLE USING SMADA

- ✓ Generation of Hydrograph for the same input data used in HEC-HMS through the following quick procedure:
- ✓ Watershed characteristics as shown in figure 12.
- ✓ Entry of Rainfall data as shown in figure13.

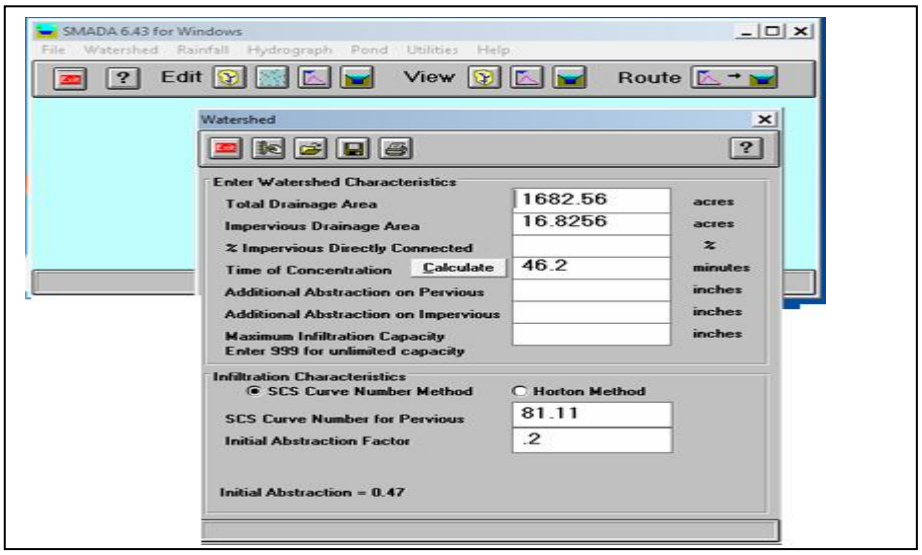


Figure 12: watershed characteristics

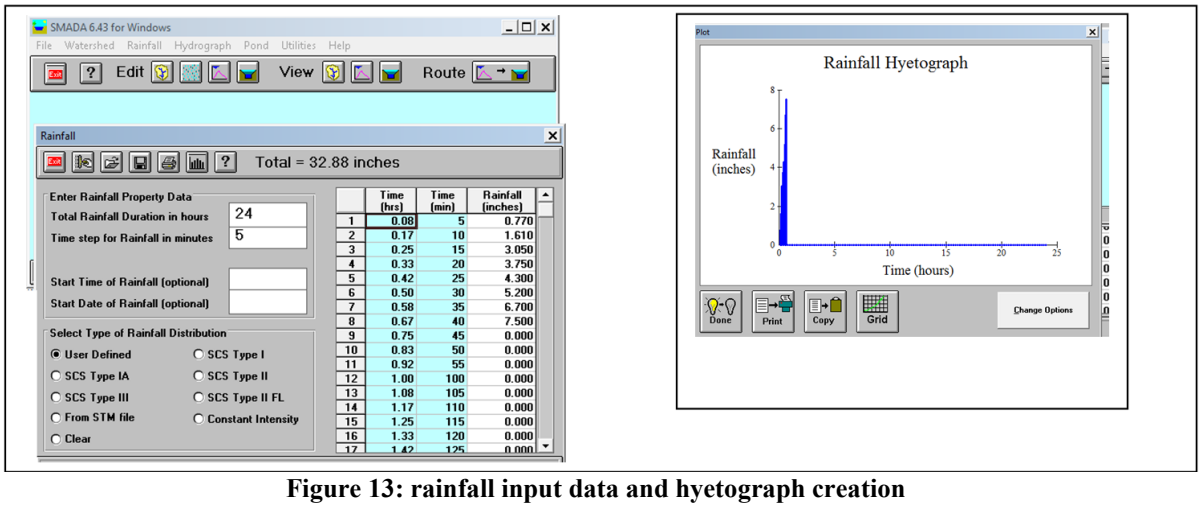


Figure 13: rainfall input data and hyetograph creation

- ✓ Run the model.
- ✓ View the results: Graphs and reports
- ✓ (i.e. Hydrograph generation and UH as shown in figure 14.

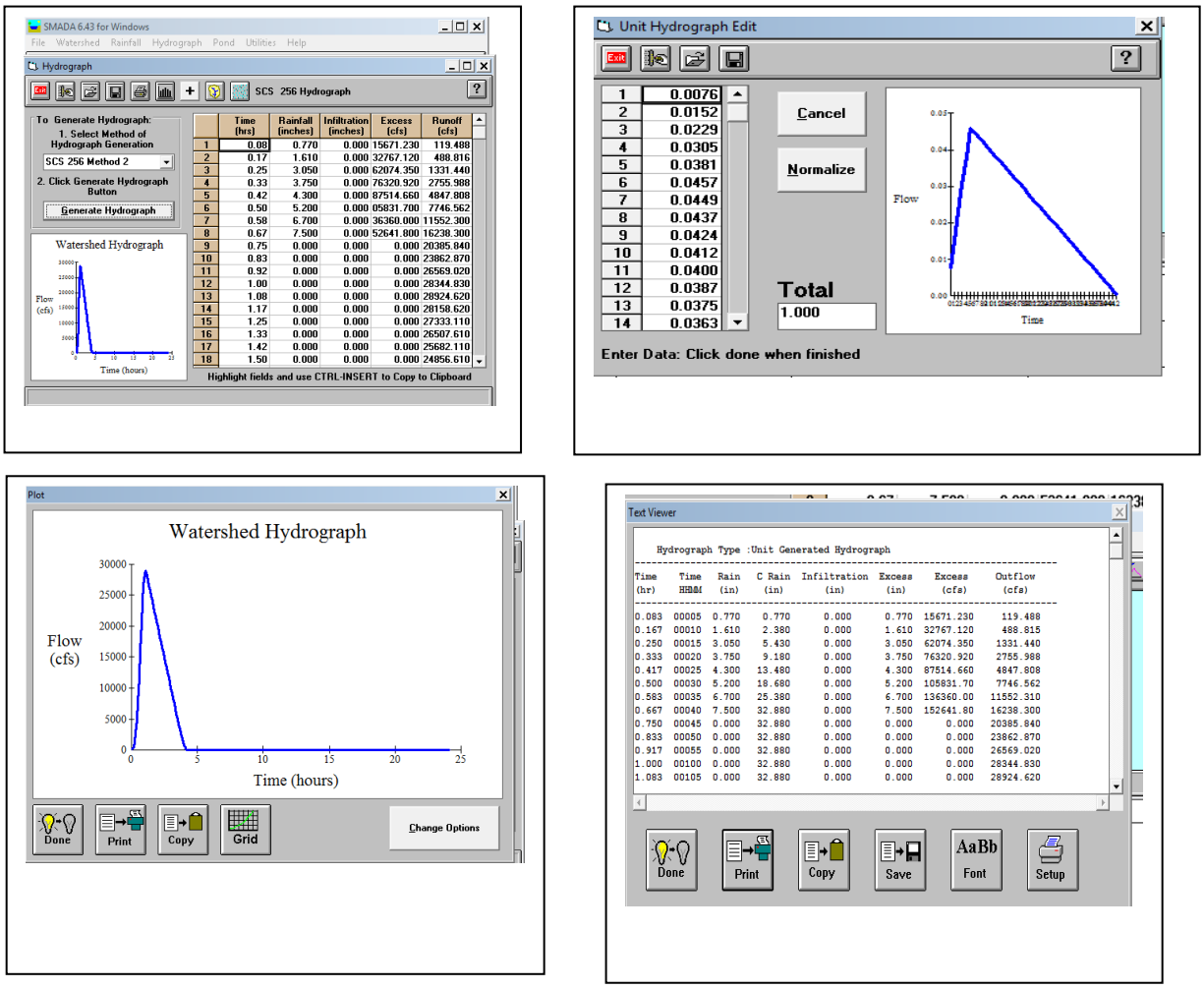


Figure 14: generated Graphs and reports (i.e. Hydrograph generation and UH)

V. CONCLUSIONS

- ✓ The HEC_HMS model is potentially a model that will be easier to work with than HEC-1.
- ✓ The HMS format will enable the user to modify and experiment the model in organized way.
- ✓ The ability of HMS to produce graphics and tables in the Windows format will make hydrologic modeling much more accessible and productive for engineers being trained today.
- ✓ The HMS Program is a valuable tool for predicting and managing human impact

on the rainfall-runoff response at points of interest within a watershed.

- ✓ Results from the HMS program can be used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology, and systems operation.
- ✓ SMADA software is good model in representing hydrologic data and representing the results.
- ✓ SMADA also has a valuable environment for many hydrologic calculations required to run such UH and others.
- ✓ WMS is potential and powerful software that allow manipulation and dynamically link model creation from different data types through its module's tools.
- ✓ WMS modern software that perform watershed delineations, basins area, hydrologic computations.

- ✓ This term paper has demonstrated how the distributed model behaves differently in simulating the hydrologic problems in which the spatial representation of the processes is important.

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