Validation of ILLUDAS in four drainage basins in Florida

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Abstract

The PC version of the stormwater runoff model ILLUDAS was used to simulate quantity of urban stormwater runoff in four sites in South Florida, each with a specific predominant land use (i.e., low density residential, high density residential, highway and commercial). Seventy-two storm events were used for model calibration and 26 independent rainfall events were used for model verification. Calibrated input parameters are presented with the objective of providing modelers with a way to select appropriate input parameters to be used in similar studies. Predicted hydrographs by this model compared well with measured ones.

1 Introduction

The need for accurate estimates of runoff hydrographs from urban areas has increased throughout the years, not only because of the need to properly design drainage structures, but also due to the need for predicting transport of pollutants, as a result of the growing concern and legislation against urban nonpoint source pollution (Tsihrintzis and Hamid\textsuperscript{1,2,3}).
The use of hydrologic models has become more popular in the last few decades to complement or substitute extensive field data collection. Models are essential in the planning, design and decision making. The use of a model depends on: the nature of the problem, available data, complexity of watershed and drainage system, requirement of a specific model by a permitting agency, availability of model support and documentation, ease of use and familiarity with the concepts used in it, and type of computer requirements (Bedient and Huber\(^a\)). Some of the most commonly used hydrologic models are the US Army Corps of Engineers HEC-1 and STORM, EPA’s SWMM and HSPF, US Geological Survey’s DR3M, Federal Highway Administration’s FHWA, and QQS (Tsihrintzis and Hamid\(^1\)). Extensive testing has been done on the applicability of many of the most popular hydrologic models currently in use. The research also includes the use of Geographic Information Systems (GIS) in combination with hydrologic models for more precise input of watershed characteristics and behavior (Tsihrintzis et al.,\(^5\,6\,7\) Terstriep and Lee\(^8\)).

However, hydrologic models can be used with a high degree of confidence only if they are properly calibrated. This paper presents the calibration and verification results of the computer model ILUDRAIN (PC Version of the Illinois Urban Drainage Area Simulator ILLUDAS) in four South Florida sites, each one having a specific predominant land use, using measured rainfall hyetographs and runoff hydrographs by the US Geological Survey (USGS).

2 Background

ILUDRAIN was developed by CE Software (CE Software\(^9\)). It is the PC version of the Illinois Urban Drainage Area Simulator (ILLUDAS) which was originally developed by the Illinois State Water Survey, Champaign, Illinois (Terstriep and Stall\(^10\,11\)). The program is written in BASIC and runs on IBM-PC and compatible computers.

This model has two application modes (CE Software\(^9\)): the new design mode and the evaluation mode (the second was used here). The new design mode is used to determine the design flow and the required pipe size for each reach of the drainage system, based on real or synthetic storms. The evaluation mode can compute the flow capacity of existing reaches and possible overflow on the ground surface (i.e., water that cannot enter the storm drain) if any of the reaches are undersized for the given storm event.
Application of the model requires that the watershed is divided into subareas and each subarea contributes to one of the reaches of the storm sewer network. The input data includes: hyetograph, total area, directly connected paved area, impervious area that is not directly connected and contributing grassed portion of each subarea, length and slope of the longest possible flow path for impervious and pervious areas, pipe dimensions, slopes and roughness coefficients, and soil type. The model has two different routing options: the time shift or lag of the entire hydrograph without storage considerations (which was used here), and the implicit solution of the continuity equation for storage routing (which is recommended for large drainage systems with significant conduit storage).

3 Description of study areas and data

Rainfall and corresponding runoff data were measured at four watersheds, representing typical land uses, located in South Florida. These include commercial, high density residential, low density residential, and highway. Physical characteristics of the basins and the storm drainage network, and measured hyetographs and hydrographs were obtained from reports by the US Geological Survey (Mattew et al., Hardee et al., Miller, Miller et al., Doyle and Miller). This data set has been used in previous studies and is summarized by Tsihrintzis and Hamid, Tsihrintzis and Sidan, Hamid, and Sidan.

Briefly, the commercial site is located in Broward County, Florida. The total area is 20.40 acres with 19.98 acres (97.9%) of hydraulically effective impervious area. The land use is a shopping center with adjacent parking lots. Twenty-seven rainfall events, with total depths ranging from 0.17 to 2.16 inches, were used for validation of the model. The high density residential watershed consists of an apartment complex located in Dade County, Florida. The drainage area is 14.74 acres and includes 10.44 acres (70.8%) of impervious area with 6.48 acres of hydraulically effective impervious area. Sixteen rainfall events, with depths ranging from 0.53 to 2.85 inches, were used for validation. Single family housing occupies the low density residential basin which has an area of 40.76 acres. The impervious area is 17.90 acres (43.9%) with 2.41 acres of hydraulically effective impervious area. Twenty-five rainfall events, ranging from 0.10 to 2.47 inches, were used for validation of the model. It was reported by Doyle and Miller (1980) that the hydraulically connected impervious area (HEIA) is the one that contributes most of the runoff for storms with rainfall depth
up to 0.8 inch. The highway basin has an area of 58.26 acres which includes
a 3,000-foot segment of a six-lane divided highway with adjacent business
establishments and open lots. It is located in Broward County, Florida. The
impervious area is approximately 21.13 acres (36.3%) with 10.53 acres of
hydraulically effective impervious area. Twenty-eight storm events, with
total depths ranging from 0.06 to 2.50 inches were used for the validation
process. It was estimated by Doyle and Miller (1980) that for this site, only
the HEIA contributes to runoff for storms with rainfall of 1.5 inches or less.

4 Validation results

The validation of ILUDRAIN included calibration using data from 70 storm
events and verification using 26 events different from those used for
calibration. As calibration parameters were used the impervious and
pervious initial abstraction and the pipe friction slopes, which were adjusted
as follows: (1) The impervious initial abstraction was varied between 0 and
0.15 inches and the pervious initial abstraction between 0 and 0.30 inches
to match the predicted runoff volume to the measured one. (2) The friction
slope $S_f$ for all the drainage elements was changed to match the predicted
hydrograph peak with the measured one. This was done by multiplying the
reach slope $S_o$ by a ratio $S_f/S_o$ between 1 and 5 (based on the known
geometry of the drainage system). This was done because the model
assumes that the friction slope is always equal to the drainage element
slope. Based on this process, values for each calibration variable were
computed for each site which were then used in the verification.

The peak flow, runoff depth, time to the peak and time base (width) of
the predicted hydrographs were compared to the measured values. In
general, the predictions for most storms showed very good agreement with
the measured hydrographs. The predictions for the single-peak hydrographs
were generally better than for the multi-peak hydrographs, specially for
storms with relatively higher flows. For most multi-peak hydrographs, the
predictions showed very good agreement for the highest peak but not for the
secondary peaks.

In order to determine the accuracy of the predictions at each site, two
methods were used: (1) The percent normalized error between predicted and
measured values for each of the four parameters describing the hydrograph
(i.e., peak flow, runoff depth, time to peak and time base) was calculated for
each tested storm, and then the mean percent normalized error of all storms
was computed for each parameter. (2) graphs were prepared of observed
versus predicted values of runoff, peak flow, time to peak and time base, and regression straight lines were fitted through the data to compare its slope with the 1:1 slope line (perfect match). When this slope is greater than 1.0, it means that there is overall over-prediction and when the slope is less than 1.0, there is under-prediction by the model. The correlation factor $R^2$ of the regression line was also used. This factor indicates how much the data is scattered around the regression line. A value of 1.0 for $R^2$ means that all the data points are falling on the regression line. As this value decreases the data points are more spread out from the regression line. Thus, the closer the slope and correlation factor of the regression line are to 1.0, the better the predictions are.

As mentioned, independent storm events from those used in the calibration were used for verification of ILUDRAIN. The values of pervious and impervious abstraction and the friction to pipe slope ratio ($S_p/S_o$) found in the calibration process for each site were used in the verification runs of each site. The predictions were tested for accuracy using the same statistical tools previously described in the calibration (i.e., the mean normalized error and the slope and correlation coefficient of the previous regression lines).

The predicted peak flows were only slightly over-predicted for most storms. The runoff depths were slightly under-predicted in most cases except in one case where it was greatly over-predicted. The predicted times to peak matched the measured ones for most storms with very few exceptions. In most cases, the predicted time base was very close to the measured one.

A typical hydrograph from the verification runs is shown in Figure 1 for the commercial site. The method provides excellent predictions of peak flow, runoff depth, time to peak and time base even for secondary peaks in the multi-peak hydrograph for the commercial site. At the high density residential site, the hydrographs showed very good agreement for all parameters except for secondary peaks which were over-predicted. The peak flow, runoff depth, time to peak and time base were slightly under-predicted for most storms at the low density residential site. The peak flows and runoff depths were slightly over-predicted and the times to peak and time base were slightly under-predicted for most of the storms of the highway site. The mean percent normalized errors for the peak flow, runoff depth, time to peak and time base, respectively, for the four sites were: for the commercial site: 16.65%, 14.88%, 5.72%, and -13.30%; for the high density residential site: 42.25%, 73.40%, 11.11% and 0.00%; for the low density residential site: 26.67%, -33.21%, -35.60% and -10.21%; for the highway site: 32.61%, 4.68%, -12.90% and -15.04%. The higher percent errors for
peak flow and runoff depth were found for storms with very small flow, but in all the sites, as the flow increased the predictions were better for all the parameters.

The slopes and correlation factors of the regression line for the verification runs for the four hydrograph parameters and the four sites were 1.0 or close to 1.0, indicating good predictions for most of the sites. The overall slopes and correlation factors show that peak flows, the runoff depths, the times to peak and time base are generally slightly under-predicted having regression lines with a slopes of 0.97, 0.97, 0.97 and 0.87 respectively. They all show very good fit with the regression line.
5 Conclusions

Estimation of the runoff volume and peak discharge in developing and existing urban areas is an essential aspect in effective stormwater management design and evaluation. The predictions from the computer model used in this study, ILUDRAIN, showed good agreement with the measured data. However, the predictions were generally better for more impervious sites (i.e., commercial and high density residential), thus, more careful calibration of initial abstraction is necessary when modeling highly pervious areas. This model should strongly be considered as an alternative depending on the availability of the data, the size of the watershed and on the requirements of the user.

References


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