CONSTRUCTING A HYDROLOGIC MODEL OF THE ICHAWAYNOCHAWAY CREEK WATERSHED

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Abstract. The Ichawaynochaway Creek is a major tributary to the Flint River, which flows through one of the most important and productive agricultural lands in southwest Georgia. Understanding the basin's hydrologic response to natural perturbations such as precipitation, and artificial impacts of surface and groundwater withdrawal is important to the environmental and economic well being of the basin. An HSPF hydrologic model has been formulated to simulate the system's behavior upon such perturbations. The model has been calibrated against two independently observed in-stream flow data sets at two different locations. The "goodness of fit" is reasonably good, with the Correlation Coefficient, the Coefficient of Determination, and the Nash-Sutcliffe Model Efficiency Coefficient all being satisfactory. Upon satisfactory calibration, the model can be used to generate unimpaired incremental in-stream flow, which will be fed into a surface water hydrologic model accessing artificial effects on both water quantity and water quality.

INTRODUCTION

Ichawaynochaway Creek is a major tributary to the Flint River at its lower reaches. It is of interest because of significant amount of agricultural irrigation within the watershed, sites of sensitive mussel populations along its tributaries, and the fact that it is a part of the larger Apalachicola-Chattahoochee-Flint (ACF) River system that is experiencing a legal water allocation dispute.

In the late 1990's, as a result of the ACF Comprehensive Water Resources Study, the Army Corps of Engineers (COE) developed an Unimpaired Flow data set for the entire ACF Basin. This data set served as the very basis for any further analysis (including modeling) of water resources allocation in the basin. However, as the data set served as a fine base for analyzing the whole basin, it does not directly provide information detailed enough for the analysis of the much smaller Ichawaynochaway Creek watershed. One way of getting the hydrologic information is to distribute the Unimpaired Flow data set to specific locations in the Ichawaynochaway watershed by using ratio of drainage areas. Another is to assemble an independent hydrologic (rainfall-runoff) model of the watershed and have it calibrated. Because of the existence of two gauging stations with relatively long history of records in the watershed, which enables a quality calibration of a hydrologic model, the authors decided to choose the latter alternative.

STUDIED AREA

Ichawaynochaway Creek originates from northeast of Cuthbert, Georgia. It flows south-southeast as its tributaries, the Pachitla Creek, Chickasawachee Creek, and Big Cypress Creek join in respectively, before it confluences with the Flint River 13 miles southwest of Newton. The length of the creek is 65 miles. The Ichawaynochaway Creek Watershed is identified as Hydrologic Unit 03130009 by the United States Geological Survey (USGS). It incorporates almost the entirety of Calhoun County, big portions of Baker, Randolph, and Terrell Counties, and small parts of Clay, Dougherty, Early, Miller, Stewart, and Webster Counties. The watershed is located in southwest Georgia with a drainage area of 1,040 square miles. The stream network of the watershed is shown in Fig. 1.

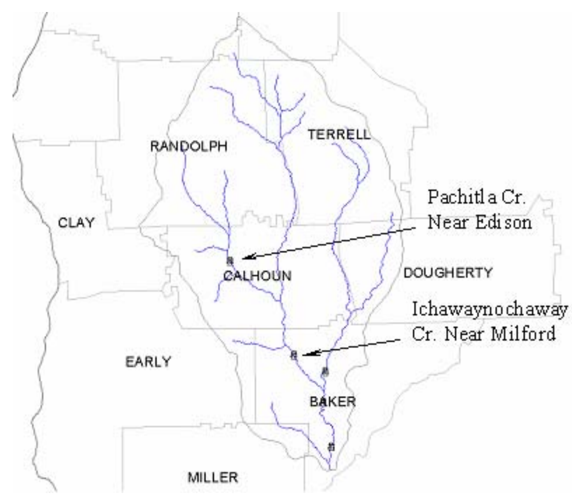


Fig. 1 Ichawaynochaway Creek Watershed

There are a number of USGS gauging stations in this watershed. Some of these stations have relatively long history of hydrologic records, which enables a hydrologic model representing this watershed to be assembled and calibrated. The two gauging stations where recorded data will be used in the calibrations are Pachitla Creek near Edison, GA (02353400), and Ichawaynochaway Creek near Milford, GA (02354000). Gauging Station 02354000 has a contributing drainage area of 620 square miles, within which Gauging Station 02353400 controls 188 square miles. The locations of the gauging stations are also shown in Fig. 1.

The land uses in the watershed include cropland and pastureland, with cropland being the predominant land use, covering over 270 thousand acres. Also in this watershed, there is nearly 280 thousand acres of forest, over 110 thousand acres of wetland, and 8 thousand acres of water. Development in the watershed is limited (NRCS, 2004). The watershed is located in the Southern Coastal Plains resource area, its soils are diverse and suited for producing a variety of crops. The topography of the watershed varies from gently sloping uplands to rolling valleys and level plains. Udults soils dominate the watershed (NRCS, 2004).

The major and most productive aquifer in the Flint River Basin is the Upper Floridan Aquifer. As one of the major tributaries of the Flint River in the river's lower part, Ichawaynochaway Creek shares this aquifer in the southern half of its watershed. Besides this aquifer, Claiborne Aquifer and Clayton Aquifer underlie the northern half of the basin. The Clayton Formation mainly underlies the Claiborne Aquifer in the basin. Claiborne Formation crops out in stream valleys of the northern Ichawaynochaway basin and underlies the Upper Floridan Aquifer in the southern half of the basin (McFadden and Perriello, 1983).

Agricultural irrigation is the largest water use in the watershed. Water use is heavy. In the north half of the basin, major sources for irrigation is surface water. Claiborne and Clayton Aquifers are the major groundwater sources for irrigations. In the middle part of the watershed, groundwater use for irrigation increases. The Upper Floridan Aquifer is present in this part of the watershed, but major groundwater sources are still Claiborne and Clayton Aquifers. Further south, Upper Floridan Aquifer becomes thicker and thicker, and its production higher and higher. Most groundwater uses come from the Upper Floridan Aquifer in this part of the watershed.

MODEL REPRESENTATION

An integrated modeling framework, Better Assessment Science Integrating Point and Nonpoint Sources (BASINS 3.0) developed by United States Environmental Protection Agency (USEPA), has been chosen to represent the studied basin, because of the convenience it provides in gathering and analyzing data, delineation of the studied watershed, and post-simulation process. The hydrologic model used in analyzing the studied area is Hydrologic Simulation Program Fortran (HSPF) developed by Aqua Terra Consultants (Bicknell et al., 2001).

Under the BASINS framework, a studied watershed is divided into smaller partitions called sub-basins. These sub-basins are connected together with reaches of stream. Each of the sub-basins has its own response given a forcing function (in this case a series of precipitation events, and meteorological conditions). The magnitude and features of the responses are determined by the hydrologic processes of each of the sub-basins. These processes include interception by ground vegetation, retention of surface depressions, surface runoff, infiltration into soil layers, interflow of water, percolation into deeper soil layers, and evaportranspiration of plants. In the hydrologic model HSPF, these processes are represented by a variety of parameters that are to be determined by calibration. Surface runoff of each of the sub-basins goes to its respective reach and becomes a part of in-stream flow. The entire watershed is then connected with the network of reaches. If the sub-basins and reaches are divided such that the downstream end of a reach corresponds to a gauging station where observation is available, then calibration of the model using observed and simulated in-stream flow at that location is possible.

The Ichawaynochaway Creek watershed was delineated into 17 sub-basins connected by a stream network shown in Fig. 2. The delineation has been carried out so that two of the most productive USGS gauging station sites, together with stream sites with sensitive mussel species, correspond to the furthermost downstream point of some of the sub-basins. This enables both the calibration and future scenario analysis of in-stream flow at the important sites.

The amount of monthly surface water withdrawal over the entire watershed has been estimated using surveyed application rates and permitted irrigation acreage. The amount for each sub-basin was then calculated using the drainage ratios. In the calibration process, these amounts of water were subtracted from the simulated flow to reflect what human impacts might have had during the period simulated.

Meteorological (mainly precipitation) data of multiple stations inside and around the studied basin have been used as forcing functions to the model. Fig. 3 shows the locations of these gauges. A series of Thiessen polygons have been developed to divide the watershed so that the data from each of the rain gauges can be assigned to the corresponding sub-basins.

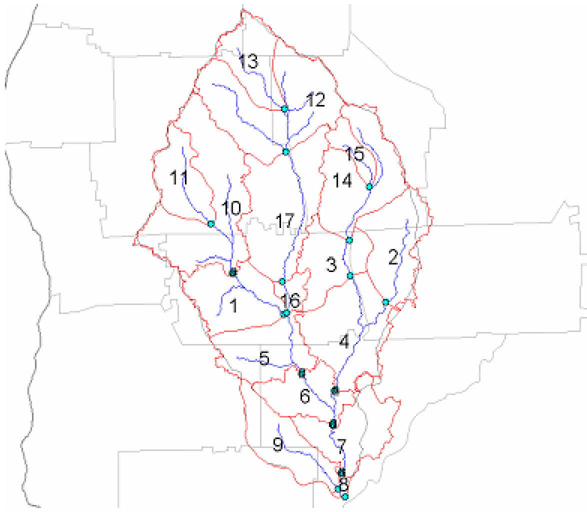


Fig. 2 Delineation of the Ichawaynochaway Creek Basin

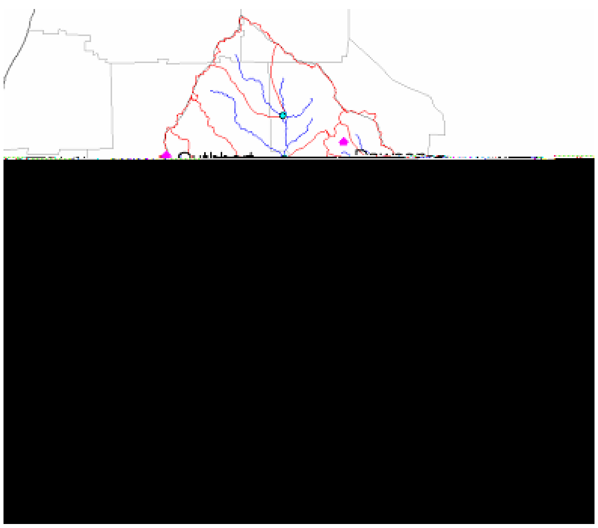


Fig. 3 Meteorological Stations in and around the Watershed

The schematic representation of the sub-basins and reaches is shown in Fig. 4.

CALIBRATION RESULTS AND DISCUSSION

The objectives of the calibration process have been to adjust the parameters for the sub-basins so that the simulated in-stream flow time series replicate what has been observed. The notion underlying this practice is that once the simulated variable successfully replicates the observation, the model's structure and its parameters are considered representative of the system being simulated. Although this notion is open to arguing because of uncertainty related to interdependency of a large number of various parameters, if the simulated in-stream flow (basis for developing unimpaired flow) resulting from different parameter sets are close enough to one another, the results are good enough for the purpose of this study.

The calibration involves adjustment of parameter values for different segmentations of the watershed, determined by locations of gauging stations, with each segment having 8 types of land uses (forest, agriculture, urban, wetland, water, barren, range, and unknown). The calibration has been evaluated by comparing simulated in-stream flow time series with observed ones. The "goodness of fit" has been gauged by three different calibration indices, namely Correlation Coefficient (CC), Coefficient of Determination (COD), and Nash-Sutcliffe Model Efficiency (NS).

The authors carried out a calibration and achieved the following indices. (1) CC = 0.87; (2) COD = 0.75; and (3) NS = 0.74. For simulations with daily time intervals, these statistics indicate that the calibration result is good (Aqua Terra Consultants and Utah State University, 2004). The parameter values are mostly in the range specified by literature (United States Environmental Protection Agency, 2000).

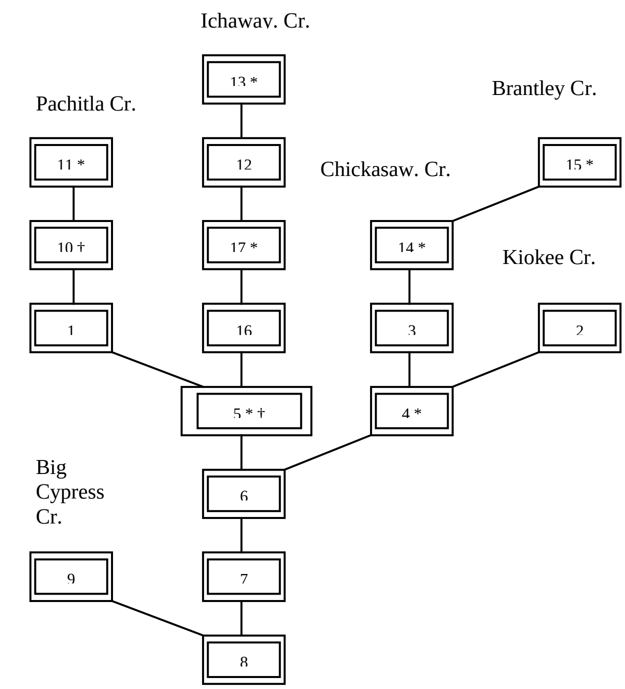
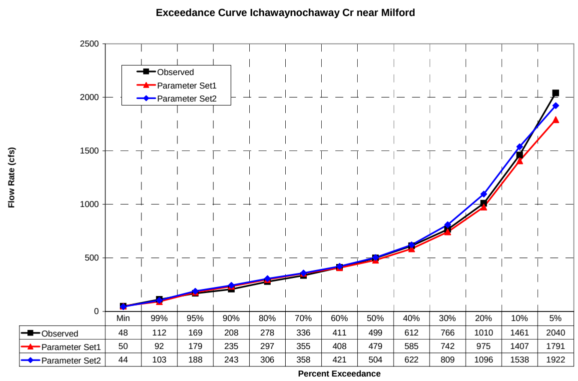


Figure 4. Schematic HSPF model representation of the Ichawaynochaway Creek Basin

Note: (1) The reaches are numbered in accordance with the delineation shown in Fig. 2; (2) an * indicates the reach is a point of interest (mussel population survey site); (3) a † indicates the reach is a site for hydrologic calibration.



	Min	99%	95%	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%
Observed	48	112	169	208	278	336	411	499	612	766	1010	1461	2040
Parameter Set1	50	92	179	235	297	355	408	479	585	742	975	1407	1791
Parameter Set2	44	103	188	243	306	358	421	504	622	809	1096	1538	1922

Figure 5. Duration Curves of Stream Flow at Ichawaynochaway Creek near Milford

The duration curves of both the observed flow and the simulated flow at Ichawaynochaway Creek near Milford are shown in Fig. 5. It can be seen that the duration curves of the simulated flow closely resembles the observed one. Fig. 6 shows the observed and simulated chronological events for a selected period. Reasonably good matching can be observed.

With the existence of the large number of parameters, uncertainty is an inevitable issue. In fact, the authors observed that another set of parameters, which is different from the one obtained from calibration, could also provide calibration indices that are comparable to the ones initially obtained from calibration. Consequently, it is not surprising that one may question the structure and both parameter sets of the model. However, surface water response (in-stream flow) is our main focus, and simulated in-stream flow time series from the two parameter sets are very close to each other. Given the length of the simulated period of record (over two decades) and a variety of both natural and arbitrary perturbations, it is safe to say that the most important state variable in the model is robust and insensitive to the differences between these two parameter sets.

CONCLUSION

The Ichawaynochaway HSPF Model has been calibrated with ample data of both in-stream flow and meteorological events. The calibration indices indicate that the effort is successful. Simulated in-stream flow of both gauged and un-gauged (but important) locations is available. Further study of the watershed's hydrology and water resources management is made possible as a result of this effort.

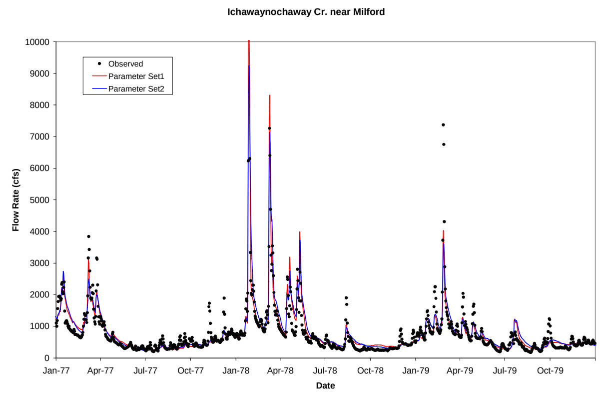


Figure 6. Observed and Simulated Stream Flow at Ichawaynochaway Creek near Milford

This model can be used to develop in-stream unimpaired flow. Doing so simply requires breaking the linkage between the stream network and returning of estimated surface water withdrawal and potential surface water (in-stream) reduction caused by groundwater withdrawal. Once the unimpaired flow data set is developed, other water resources management models can also be used to address issues in the watershed.

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