Report for 2000OH9G: Methodology for Estimating Total Maximum Daily Load in Watersheds with Considerable Ground-Water Surface-Water Interaction

There are no reported publications resulting from this project.

Report Follows:

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Title: Methodology for Estimating Total Maximum Daily Load in Watersheds With Considerable Ground-Water Surface-Water Interaction

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Problem and Research Objectives

Significant improvements to the nation's water quality have been achieved through the implementation of point-source technology-based pollution control measures and the enforcement of the National Pollution Discharge Elimination System (NPDES). However, non-point sources (NPS) remain as major sources causing or contributing to water quality impairment because of difficulty in quantification and/or control. Section 303(d) of the Clean Water Act mandated the establishment of the Total Maximum Daily Load (TMDL) for impaired waters as a means to address the combined impact of both point and non-point source pollution (USEPA 1999a). The holistic approach for watershed protection requires consideration of water quality of the different water bodies that exist in the watershed and the interaction between them and in the development of TMDL. Ground-water surface water (GW/SW) interaction is an important factor in the transport of dissolved nutrients and pesticides and subsequent contamination of rivers and aquifers (Gardener 1999).

This study addresses an important gap in knowledge with respect to water quality impairment: the transport of contaminants from non-point sources in a coupled GW/SW system and the development of TMDL under such conditions. Its goal is to elucidate the impact of non-point source pollution on surface- and ground-water quality in large watersheds. The study has been structured around two main tasks. Task I focuses on contaminant fate and transport in ground water and the development and implementation of the TMDL concept for surface water under threat from ground water contamination. Specifically, the modeling capability of the Soil Water Assessment Tool (SWAT) will be expanded using numerical models for flow and transport in ground water. In Task II, a comprehensive water quality model will be created for the Great Miami River Basin to demonstrate how the modeling approach can be used to develop TMDLs.

Task specific study objectives are as follows:

- Task I.1: Implementation of the Ground-Water Fate and Transport Module into SWAT.
- Task I.2: Verification and Testing of the Model and Development of the GIS Interface.
- Task II.1: Development and Calibration of a SWAT Model for the Great Miami River.
- Task II.2: Development of a Ground-Water Quality Model for the Miami Buried Valley Aquifer.
- Task II.3: Integrated Model Calibration and Verification
- Task II.4: Refinement of the Integrated Model and Interpretation of the Modeling Results.
- Task II.5: Report Preparation and Future Work.

Methodology

The proposed work is intended to address the transport of contaminants from non-point sources in a coupled GW/SW system and the development of TMDL under such conditions. Currently, most modeling efforts carried out in support of TMDL assessments rely on EPA's Better Assessment Science Integrating Point and Non-point Sources (BASINS) system in which three surface water models (QUAL2E, TOXIROUTE, and NPSM) are incorporated with the SWAT model. None of the above models address the transport of pollutants through shallow ground water.

In Task I, a fate and transport module is being developed for the SWAT model. Based on the Modular Three-Dimensional Finite-Difference Ground-Water Flow Model MODFLOW, the module will be capable of simulating physical and chemical processes controlling the transport of dissolved compounds in ground water and the possible release into surface water. The model demonstration in this study will involve the 7350 mi^2 MIAMI-NAQWA study unit, which encompasses basins of three tributaries of the Ohio River: the Great Miami River, the Little Miami River, and Mill Creek (Figure 1).

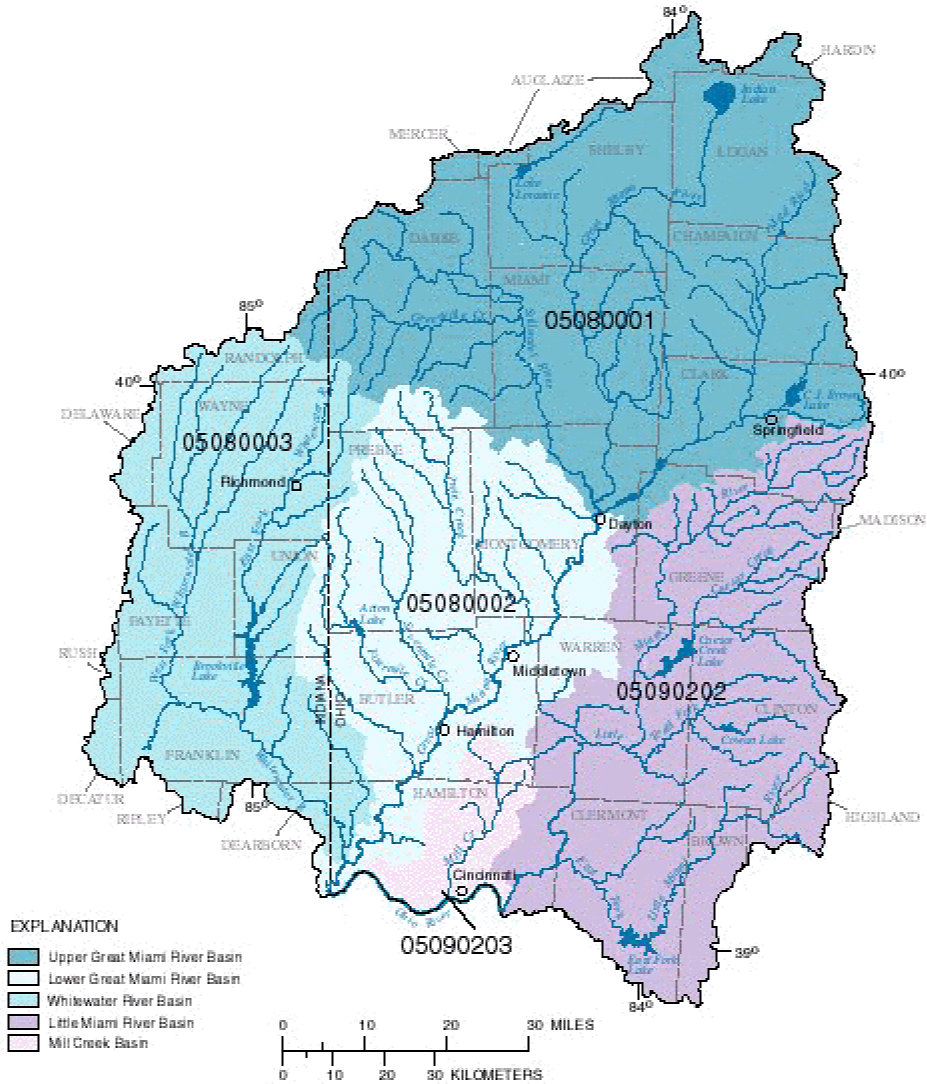


Figure 1. Location Map of the Great and Little Miami River Basins, Ohio and Indiana

To verify the fate and transport components of the developmental module, a comparison is being made against readily available models such as BASINS and WMS. The model area selected for this verification is the 656mi^2 Mad River sub basin of the Great Miami River Basin (Koltun 1995). Its headwaters are in Logan County and it flows south and west through Champaign, Clark, and Greene counties to its confluence with the Great Miami River in Montgomery County (Figure 2).

The Task II comprehensive water quality model that will be developed for the Great Miami River Basin will use data from the MIAMI-NAWQA study, USGS ground water models (Dumouchelle 1998), and others (Ritzi et al, 1994; IT 1993; and HydroGeoLogic 1998). Data will be compiled in a Geographic Information System (GIS) database by expanding BASINS or WMS to incorporate ground water modeling parameters.

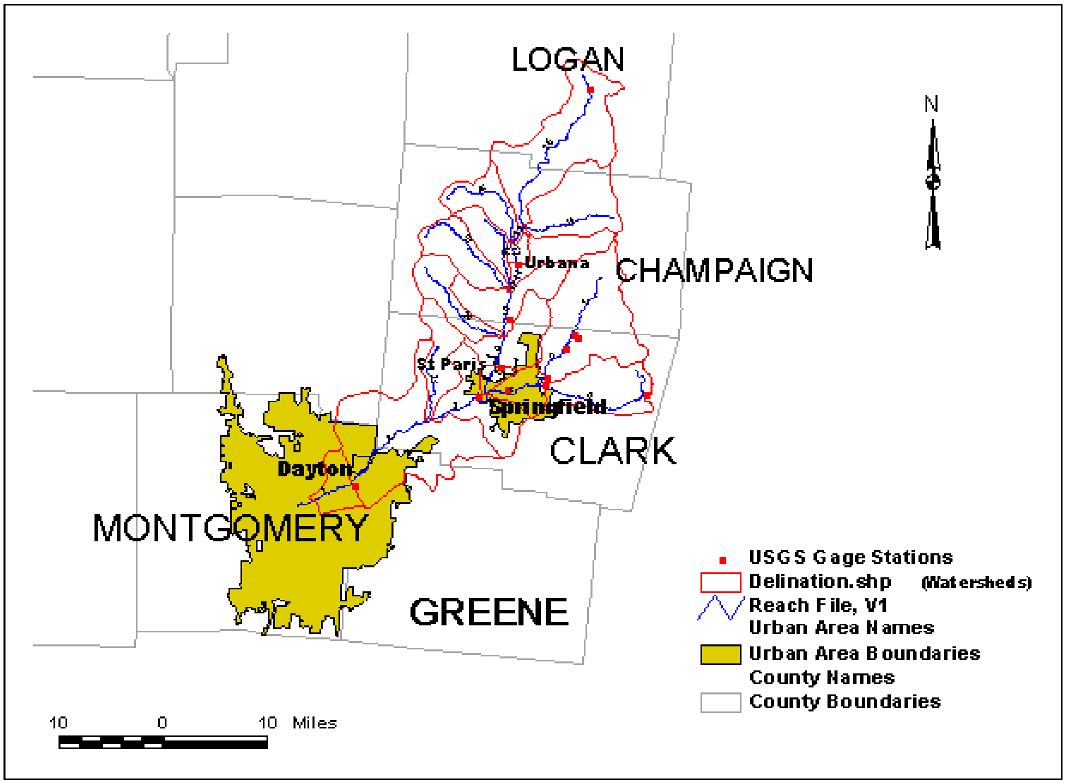


Figure 2. The Mad River Sub Basin

Principal Findings and Significance

Following the schedule timeline presented in the subject research proposal, the preponderance of project activities has focused on Task I since the September 2000 award date. Specifically, the BASINS and WMS models are being applied to the Mad River sub-basin area in preparation of the verification of ground water fate and transport components being developed for the SWAT module.

<u>BASINS System Overview</u>

Currently, BASINS 2.0 is being used on this project. It is a multipurpose environmental analysis system for use by regional, state, and local agencies in performing water- and water-quality-based studies (Lahlou et al, 1998). The BASINS system combines the following six components to provide the range of tools needed for performing watershed and water quality analysis:

- National Environmental Databases

- Assessment Tools
- Utilities
- Watershed Characterization Reports
- Water Quality Stream Models
- Non-Point Source Model (NPSM) and Postprocessor

The BASINS physiographic data, motoring data, and associated assessment tools are integrated in a customized geographic information system (GIS) environment, ArcView 3.2. Modeling tools include in-stream models (QUAL2E and TOXIROUTE) and NPSM, which includes the Hydrological Simulation Program – Fortran (HSPF), version 11.

The NPSM is a planning-level watershed model that is used for estimating in-stream concentrations resulting from loadings from point source and non-point sources. It is an extremely flexible tool for modeling the impact of land use associated non-point source pollution on downstream water quality (Lahlou et al, 1998). Features supported by NPSM include:

- Estimation of non-point source loadings from mixed land uses
- Estimation of the fate and transport processes in streams and one-dimensional lakes

The NPSM postprocessor facilitates the display and interpretation of output data derived from model applications.

WDMUtil is an easy to use program provided by BASINS that allows the importation of available meteorological data into WDM files and performs needed operations to create the time-series data for NPSM/HSPF (USEPA 1999b). This allows the user to add valuable local meteorological data rather relying on the limited set of meteorological data stored in BASINS. Data from the Pandora and Dayton WSO Airport, Ohio meteorological stations are used in the Mad River sub basin evaluation.

BASINS Version 3.0 is now in beta release. In addition to several new data and functions, 3.0 has added the SWAT model. The installation program installs WinHSPF, a new interface to HSPF Version 12 that is replacing NPSM from BASINS 2.0; and GenScn, a model post processing and scenario analysis tool that is used to analyze output from HSPF and SWAT. This beta version demonstrates a fundamental change in the developmental philosophy of BASINS. BASINS 3.0 will be distributed as a core system and several extensions. This modular and open architecture will allow users to customize their BASINS projects, more easily upgrade systems, and develop extensions for BASINS.

The Mad River Sub Basin

The Mad River sub basin as delineated in the BASINS model occupies 645 mi^2 of the eastern portion of the Upper Great Miami River Basin and includes the Mad River and eight major tributaries (Figure 2). It ranges in elevation from 457 m (1499 ft) above MSL in the northeastern corner of the sub basin to 235 m (784 ft) MSL in the vicinity of Dayton, Ohio (Figure 3). Land use in the study area is greater than 75% agricultural and approximately 15% urban or built up (Figure 4). The remaining 10% is comprised of forest land and water cover.

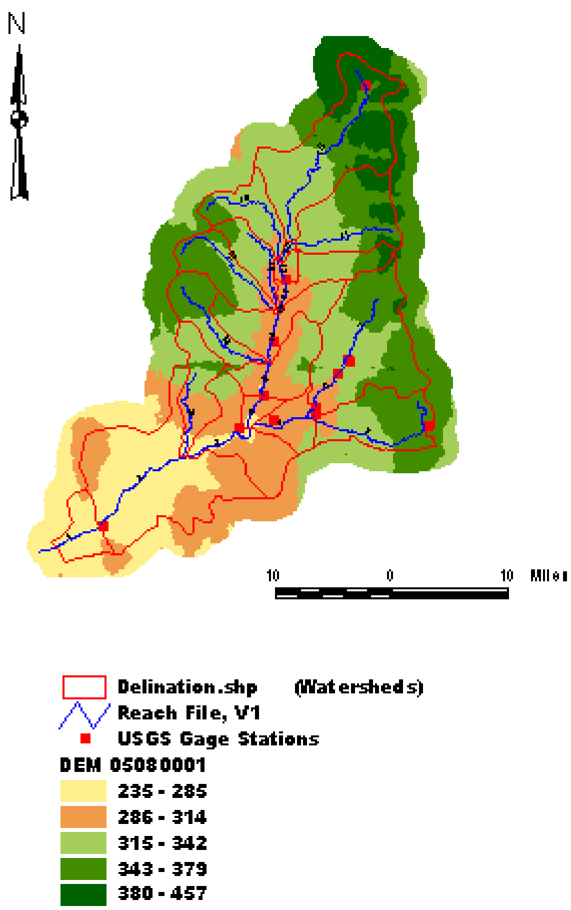


Figure 3. DEM Elevations Within the Mad River Sub Basin

A total of 20 individual watersheds ranging in size from approximately 0.01 to 106 mi^2 were delineated within the Mad River sub basin based on topographical information and/or the location of USGS stream gaging stations (Table 1; Figure 5). Each watershed contains a segment of or tributary to the Mad River ranging in length from 0.4 to 21 miles (Table 1; Figure 5). Watershed 6, which was delineated before data were available listing the inactive status of the gaging station, contains two segments of Buck Creek (segments 6 and 7). The active USGS gaging stations in the Mad River sub basin are located at Dayton (03270000), Springfield (03269500), St. Paris (03267900), and Urbana (03267000).

Preliminary NPSM Model Results

Preliminary NPSM and postprocessor results have been completed for the Mad River sub basin. Initial efforts have focused on calibrating and validating stream flow data for the Mad River sub basin. However, two factors have become apparent that presently limit the usefulness of the 2.0 BASINS/NPSM model:

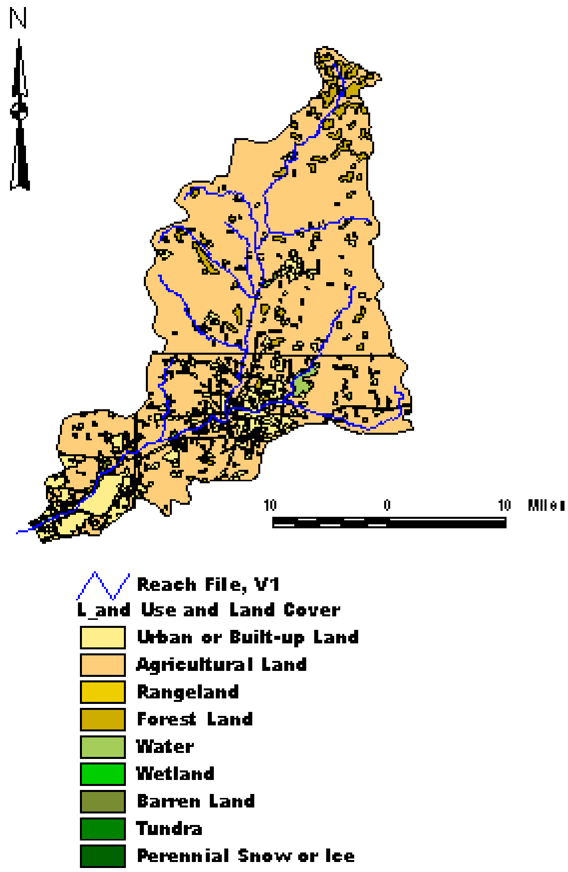


Figure 4. Land Use and Cover Within the Mad River Sub Basin

- While there is no limit to the number of watersheds that the BASINS/NPSM model will run, there is a limit of 200 total operations. The number of operations depends on the number of land use types, number of watersheds, number of reaches, etc. (Choudhury, 2000). Consequently, it has not been possible to run the NPSM model for the entire 20 watersheds within the Mad River sub basin. Only 10 combinations of watersheds can be successfully run at one time.

- In launching the NPSM, there are only 6 individual discharge years (1991 to 1996) that can be selected for Permit Compliance System (PCS) data to be incorporated into the model. Combined with limitations on the number and years of record of the USGS gaging stations in the Mad River sub basin, restrictions are placed on the time span for which water quality analyses within the study area can be performed, and available years of record for calibration and validation.

Table 1. Delineated Mad River Watersheds and Associated Stream Segments

Watershed Designation	Area (mi^2)	Stream Segment	Length (mi)	Mean Flow (cfs)
5080001001	16.7	Mad River	6.2	633.9
5080001002	105.9	Mad River	10.6	633.9
5080001003	38.4	Mad River	7.8	522.6
5080001004	16.3	Buck Creek	5.9	139.4
5080001005	40.8	Beaver Creek	15.7	42.3
5080001006	80.5	Buck Creek	14.4*	75.8
5080001008	6.1	Mad River	3.8	340
5080001009	29.8	Mad River	3.3	340
5080001010	32.7	Mad River	4.8	256.7
5080001011	21.9	Mad River	3.2	156.1
5080001012	4.6	Mad River	2.1	156.1
5080001013	1.5	Mad River	2.3	101
5080001014	47.4	Kings Creek	9.8	29.7
5080001015	83.2	Mad River	21	64.4
5080001016	23.7	Muddy Creek	12.1	36.6
5080001017	0.1	Nettle Creek	0.4	82.3
5080001018	16.5	Anderson Creek	8.6	32.8
5080001019	28.1	Nettle Creek	12.6	47.9
5080001020	25.5	Chapman Creek	12.3	46.8
5080001021	25.4	Donnels Creek	9.4	51.2
	645.1			

*Watershed contains stream segments 6 and 7

An example of preliminary, uncalibrated 1992 NPSM model results for discharge on the Mad River at Dayton, Ohio, are presented on Figure 6. This can be compared to the 1992 Mad River discharge as recorded at the USGS gaging station 03270000 at Dayton, Ohio (Figure 7), and precipitation at the Dayton WSO Airport (Figure 8). (The outflow point for the NPSM model is located at the USGS gaging station.) If the above limitations can be resolved, the NPSM model results will be calibrated with the USGS stream gage result by adjusting individual model parameters, especially percent land use category perviousness and stream cross section characteristics. In addition, all pertinent watershed information will be updated to confirm model accuracy.

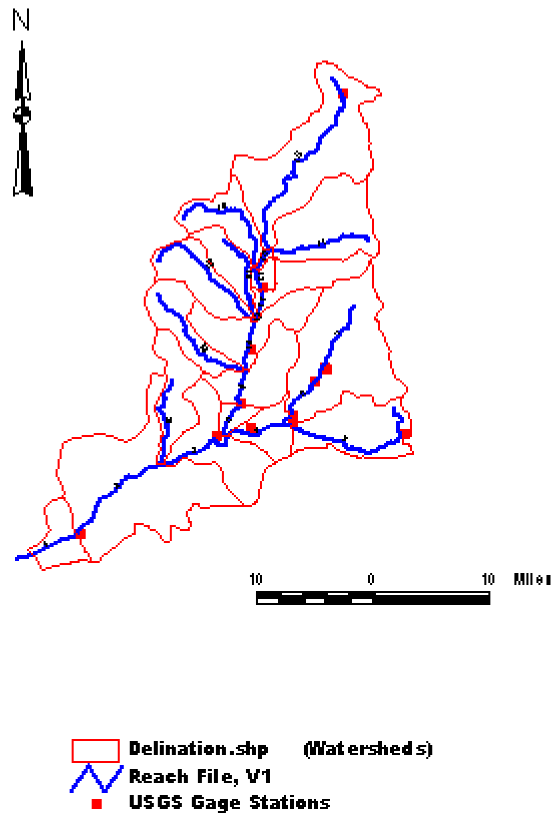


Figure 5. Mad River Sub Basin Watersheds and USGS Stream Gaging Stations

Prospective Project Approach

The limitations of the BASINS/NPSM model discussed above may be insuperable. Consequently, an attempt was made to directly apply the HSPF program to the Mad River sub basin for estimating instream concentrations resulting from loadings from point and non-point sources. However, a major disadvantage of HSPF is that it has no graphical user interface (GUI) and the user must manually create a user control input (UCI) files, which inform HSPF of modules (e.g., watershed and land use delineation, meteorological inputs, etc.) to be used in the model run, watershed and stream network connectivity, and model parameters. Given the complexities of HSPF and the number of

Figure 6. Preliminary 1992 NPSM Model Discharge for Mad River at Dayton, Ohio

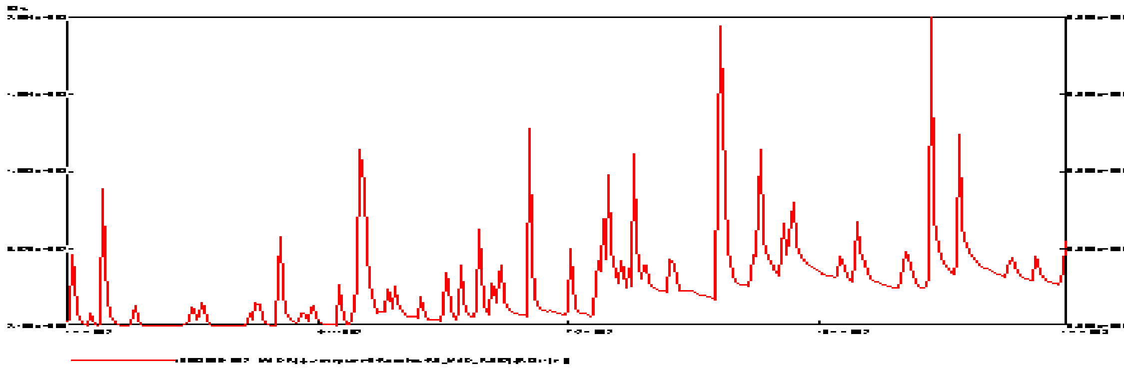


Figure 7. 1992 Discharge for Mad River at Dayton, Ohio, USGS Gaging Station 03270000

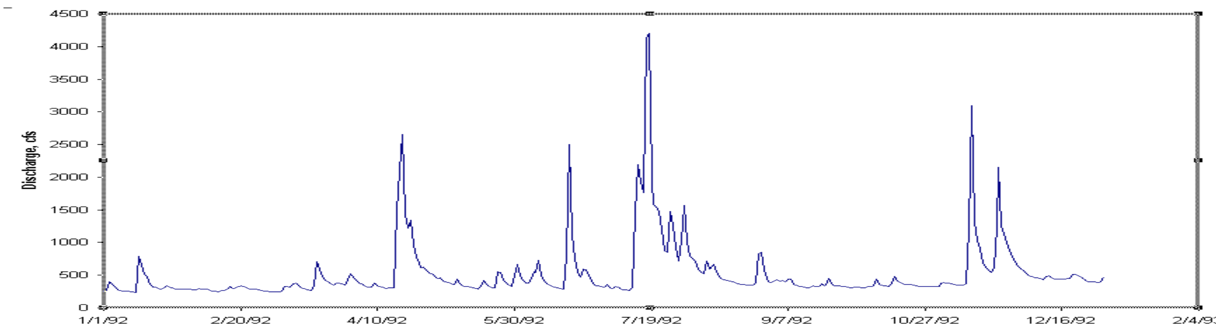
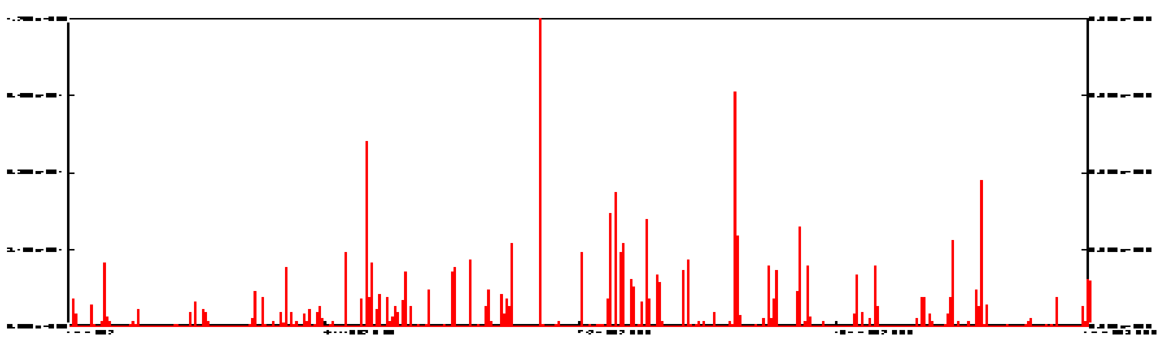


Figure 8. 1992 Dayton WSO Airport Precipitation (in/hr)



tasks it can perform, the manual nature of HSPF can present serious obstacles that require an extremely high level of user knowledge and effort.

An alternative to the multipurpose BASINS system, which integrates the HSPF program with a GIS environment, is the Watershed Management System (WMS). This system has been now been interfaced with HSPF to provide graphical representation of HSPF data as well as automate the definition of many of the required parameters. The strength of WMS as a modeling environment lies in the digital terrain modeling functions that can be used for automated watershed delineation, geometric parameter computation, hydrological parameter computation, and result visualization using GIS data, Digital Elevation Models (DEMS), or Triangulated Irregular Networks (TINs). Efforts are now underway to apply WMS to the Mad River sub basin study area. Many of the data files generated with the BASINS modeling effort can be used directly in WMS. This compatibility should streamline efforts in developing the watershed model.

The successful modeling of the Mad River sub basin using WMS and verification of the fate and transport components of the developmental SWAT module will mark an integral step in the completion of the multiple project tasks and study objectives for estimating the TMDL in the Great Miami River Basin.

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