

**Hydrologic Modeling for a Subwatershed within Wells Creek
Watershed, as Calculated Utilizing
GIS and HydroCad™ 3.02 Technology**

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ABSTRACT

The use of a geographic information system was utilized in combination with HydroCAD 3.02, a storm event modeling system, to effectively model a watershed in storm event conditions. Natural Resource Conservation Service (NRCS) curve numbers were derived by associating land use/cover, as interpreted from 1993 1:15,840 scale infra-red aerial photos, and hydraulic soil conditions in a GIS to be utilized as input in HydroCAD.

Land use/cover conditions, in conjunction with the presence or absence of NRCS water retention structures, are direct functions of the hydrologic health of the watershed. Five different models were developed and executed in HydroCAD, each with a different land use scenario and each run against four different NRCS Type II rainfall events of 1", 2", 6" (100 year rainfall event), and 9" (NRCS emergency spillway event). The resulting stream discharges that each model produced were dependent on how well a watershed allowed for the infiltration of runoff water, as noted by low weighted curve numbers, which was essentially dependent on the land use. Pre-European development was noted to have a substantially healthier watershed scenario than current land use conditions today.

INTRODUCTION

Historically, the use of models has been an important evolutionary step in hydrology disciplines as in other scientific disciplines. Hydrologic models may be simply thought of as "representations of physical hydrological systems" (Watson and Burnett, 1995) or more generally as any "accurate simulation...of a thing or process...that is difficult to observe directly" (American Geological Institute, 1974). Models have become very important in hydrology for many different reasons; however, it is important to remember that models are to be used merely as tools in the overall cognitive process and should not be used as a replacement for sound hydrologic knowledge and interpretation (Watson and Burnett, 1995).

Hydrologic modeling began as actual physical models that represented a smaller scale version of real world conditions. These, when conditions required large elaborate models, could become very expensive and time consuming to build. Electric-analog models, still used today, were the next advance in hydrological modeling and essentially combined mathematical similarities between the controlling variables of ground water and the controlling variables that govern the flow of electricity (Watson and Burnett, 1995). The largest disadvantage of electric-analog models is that they tend to be limited to the constraints of the actual situation modeled and, therefore, relatively hard to modify to accommodate different hydrological conditions, which would necessitate the design and construction of an entirely different model (Watson and Burnett, 1995).

Today hydrologic modeling, as based on well founded numerical models which include sound hydrologic theory, is almost exclusively done with a computer. The main advantages of using a computer to model hydrologic conditions, as opposed to manual interpretation or the previously described models, are as follow: 1) computers can store vast amounts of data efficiently; 2) computers provide the user with the ability to organize and manipulate data effectively according to differential criteria; 3) computers can present trends and perspectives from huge quantities of data that may be overlooked when nonautomated techniques are utilized; and 4) computers allow users to enter data into complex sequences of formula to derive various outputs (Watson and Burnett, 1995).

Previous Work in Hydrological Modeling

In the recent past, many hydrologists and engineers have utilized United States Department of Agriculture Soil Conservation Service (now the Natural Resource Conservation Service) hydrologic models in professional work because of their easy to apply approach (McCuen, 1982). The most widely used of these are the Technical Report 20 (TR-20) computer model and the Technical Report 55 (TR-55) Graphical Method and Chart Method. TR-20 was created to develop route hydrographs through reservoirs and channel reaches, runoff hydrographs, and to separate or to combine hydrographs at confluence (McCuen, 1982). Two main advantages of the program are its ability to run multiple analyses per run, so that various alternatives can be evaluated at a time, and the relatively small amount of data needed to accurately run the model (McCuen, 1982). The Graphical Method, chapter five of TR-55, is a method for describing peak discharge and combines the time-of-concentration (hr.) with the unit peak discharge ($cfs/mi^2/in$). The Chart Method, also described in TR-55, was developed to model and predict the effect of development on the peak discharge rate as based on a Type-II storm distribution and a 24-hour storm event volume (McCuen, 1982).

With the advent of more technologically advanced tools, such as geographic information systems, three dimensional modeling, and advances in digital terrain modeling, new methods and options of hydrological modeling are available from a field of research that is growing rapidly and even considered an art (Beven and Moore, 1993). Andrew Binley and Keith Beven (1991) have recently taken advantage of recent advances in computer hardware technology and numerical algorithms to develop an analysis of the complex flow paths in heterogeneous

catchments at the Institute of Environmental and Biological Science, University of Lancaster. This type of application could potentially be used to analyze problems associated with the transportation of chemical substances in soils, particularly, those of localized origin. In the past, this type of study has been hindered by the temporal and spatial complexity associated with saturated soils in an heterogeneous setting; however, herein lies the hydrologic link between unsaturated surface soils and saturated subsurface soils. Here, models such as SHE and The Institute of Hydrology Distributed Model (IHDM) are utilized to model such complex conditions. This type of analysis is essentially based on defining each cell in a grid system and then performing a variety of calculations to arrive at desired results. This type of hydrologic model can potentially be used to calculate the movement of contaminants in a subsurface environment within catchment discharges.

Dean Djokic and David R. Maidment (1990), Department of Civil Engineering, University of Austin, have utilized a geographic information system (ArcInfo) to analyze a storm water environment in urban conditions, including stormwater intakes and drainage networks, in conjunction with surface terrains. A triangulated irregular network (TIN) is used to define land surface terrain to determine necessary parameters for flow calculations by design. Three data bases were built to determine whether pipes and inlets can convey 10 and 25-year design flows with the rational method. Each of the three databases represents one of three basic elements of the urban hydrologic representation including: 1) inlets, as defined as points; 2) drainage network, as defined with lines; and 3) surface terrains, as defined with the TIN structure. Digital terrain models have been developed in a GIS in the past that analyze watershed boundaries, drainage patterns, and simplified flow calculations. Djokic and Maidment, have used the digital terrain model capabilities to develop a model for an urban environment. More similar to the Wells Creek subwatershed model, presented herein, is the work performed by Drayton, Wilde, and Harris (1990), School of Civil Engineering, University of Wales College of Cardiff, in which case they developed a rainfall and runoff model in a GIS (ArcInfo).

Drayton, Wilde, and Harris have interpreted data collected from remote sensing techniques, satellite images, to gather data that were entered into an information land cover containing 50 x 50 m cells. Topographic parameters were derived from digital elevation models (DEM) and other more conventional data were acquired by digitizing information from maps. The collective data were then combined in a GIS for data analysis and manipulation. The GIS was

then used to calculate curve numbers, as will be expanded upon herein, according to USDA NRCS parameters, which were ultimately used to calculate runoff in a watershed environment. The DEMs provided drainage routes taken by runoff from cell to cell. A distinct advantage of this type of model is that different land covers, as defined temporally, can be used from historical remote sensing data, as can future changes in the watershed. This study was very similar to the one discussed herein; however, it differs in that GIS was used in conjunction with a storm water modeling system for the Wells Creek subwatershed model, while Drayton, Wilde, and Harris developed their model completely within the constraints of the GIS.

Using satellite images to develop land cover to calculate curve numbers has also been performed by Slack and Welch (1980), as well as Rango *et al.* (1983), National Aeronautics and Space Administration (NASA) and the US Army Corps of Engineers. Slack and Welch developed such a land coverage containing four different land type classifications (agriculture vegetation, bare ground, open water, and woodland) and developed curve numbers within two unit values when compared to CNs calculated by more conventional techniques. Rango *et al.* calculated a 5% error in land cover estimation by satellite from basin resolution, which was considered an insignificant difference when compared to CNs derived from conventional techniques.

Wells Creek Subwatershed Hydrologic Model

The Wells Creek watershed is one of the remnants of southeastern Minnesota's glacial history. Wells Creek runs about eighteen miles long in a valley between Red Wing and Lake City, Minnesota and flows into the Lake Pepin Section of the Mississippi through the historical town of Old Frontenac, which lies between the two cities. Its watershed covers about 52,000 acres and is typical of rural areas along the Mississippi River Valley that contain a combination of woodland and agriculture (Wells Creek Watershed Partnership, 1995). The actual model developed in this study includes a western tributary, 25,450 feet in length, and its associated watershed (a subwatershed of the Wells Creek Watershed) which itself covers 3,362.52 acres.

A model can be used to represent the basic way that rainfall and runoff interact with the watershed during a storm event. During a rain storm, the water either infiltrates into the ground, evaporates, or runs off the surface of the watershed (HydroCAD, 1991). The study of

runoff in a watershed is important because it can cause adverse effects such as flooding and soil erosion. It is for this reason that it is important to predict under what conditions runoff occurs with the least resistance and under what conditions it is absorbed, thereby allowing one to predict where damage will occur and under what circumstances. The effects of runoff can be reduced by using ponds to hold stormwater and release it at a specified rate, widening channels to reduce flooding, and/or changing a land use coverage to hold water so that it will infiltrate into the ground (HydroCAD, 1991). Once completed, a model can be used to make predictions, as a tool from which to gather information, and a source of insight from which professionals can offer sound and well founded design recommendations as opposed to educated guesses (Watson and Burnett, 1995).

This study actually includes five different models, which essentially contain one land use scenario and four different rainfall events each, effectively producing twenty different land use/rainfall scenarios. The first land use scenario, Model A, contains a land coverage representative of land use conditions found today. This initial scenario; however, does not contain any water retention structures. Model B includes the same land use coverage found in Model A, in addition to National Resource Conservation Service (NRCS) water retention structures. Model C represents a hypothetically improved land use scenario which also includes water retention structures. Model D and Model E both represent historical conditions in the watershed. Model D represents a land use scenario that could be found prior to European immigration (pre-1850) and Model E includes a land use scenario indicative of about 1900 including a time of peak wheat production in the watershed in the summer season. The only parameters changed from one model to the next are the land uses and the addition or removal of water retention structures. This is done so that the effects that different types of land use scenarios have of hydrologic conditions can be easily assessed as all other parameters in the models remain as constants.

The study essentially includes data development and manipulation and use of a stormwater modeling system (HydroCAD 3.0) to run the scenarios. A geographic information system was used for the data development and manipulation phase by utilizing the data base management, mapping, and calculation functionalities of the system. Hydrologically speaking, land uses are represented in the model by a curve number (CN) which is essentially a number derived by associating a specific land use with a specific hydraulic soil type, as outlined by USDA NRCS convention. The GIS was used to derive different groups of CNs for different models. Other

measurements were calculated from a United States Geological Survey 7 1/2' quadrangle, field measurements, aerial photos, and data as calculated from the GIS. Once the data bases per model were built and the data needed for parameters as defined by HydroCAD were filled, the model runs were executed. The desired output is five models, each containing four rainfall events, that each produce different hydrologic properties.

METHODOLOGY

Development of the Wells Creek subwatershed model required the use and input of several different disciplines and techniques. Essentially, the project can be separated into three phases of data collection and data development procedures including: 1) data acquisition and development; 2) GIS analysis and manipulation; and 3) the use of a storm event modeling system to model the watershed. The basic flow of the analysis entailed interpretation and association of aerial photos with hydraulic soil data to calculate rainwater runoff coefficients (curve numbers) in a GIS, a break down of the watershed into its basic elements, and a detailed definition of these elements. These elements were collected in the field and calculated in the GIS, for input into the storm event modeling system. These procedures set the stage for the use of HydroCAD to run several land type scenarios against several different rainfall events to note the way in which the watershed either did or did not retain rainfall, and to further help define approximately how much rainfall the watershed could effectively handle. The three data development phases mentioned above will be expanded upon below.

Data Acquisition and Development

Before any computer aided calculations or modeling could be performed, three spatial data sets needed to be built and/or collected including: 1) definition of study area; 2) interpretation of aerial photos to define land type; and 3) acquisition of hydraulic soil type within the study area (Note: The later two will be used collectively to calculate curve numbers).

The watershed was initially defined by a standard watershed identification procedure of using a writing utensil to trace the highest points of topology that immediately enclose a local stream. This was performed on a 1968 7 1/2 minute USGS quadrangle map (Fig. 1). For future rectification into a GIS, twelve tic marks were placed well outside the study area