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

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CONTENTS

LIST OF FIGURES

(continued)

LIST OF TABLES

(continued)

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

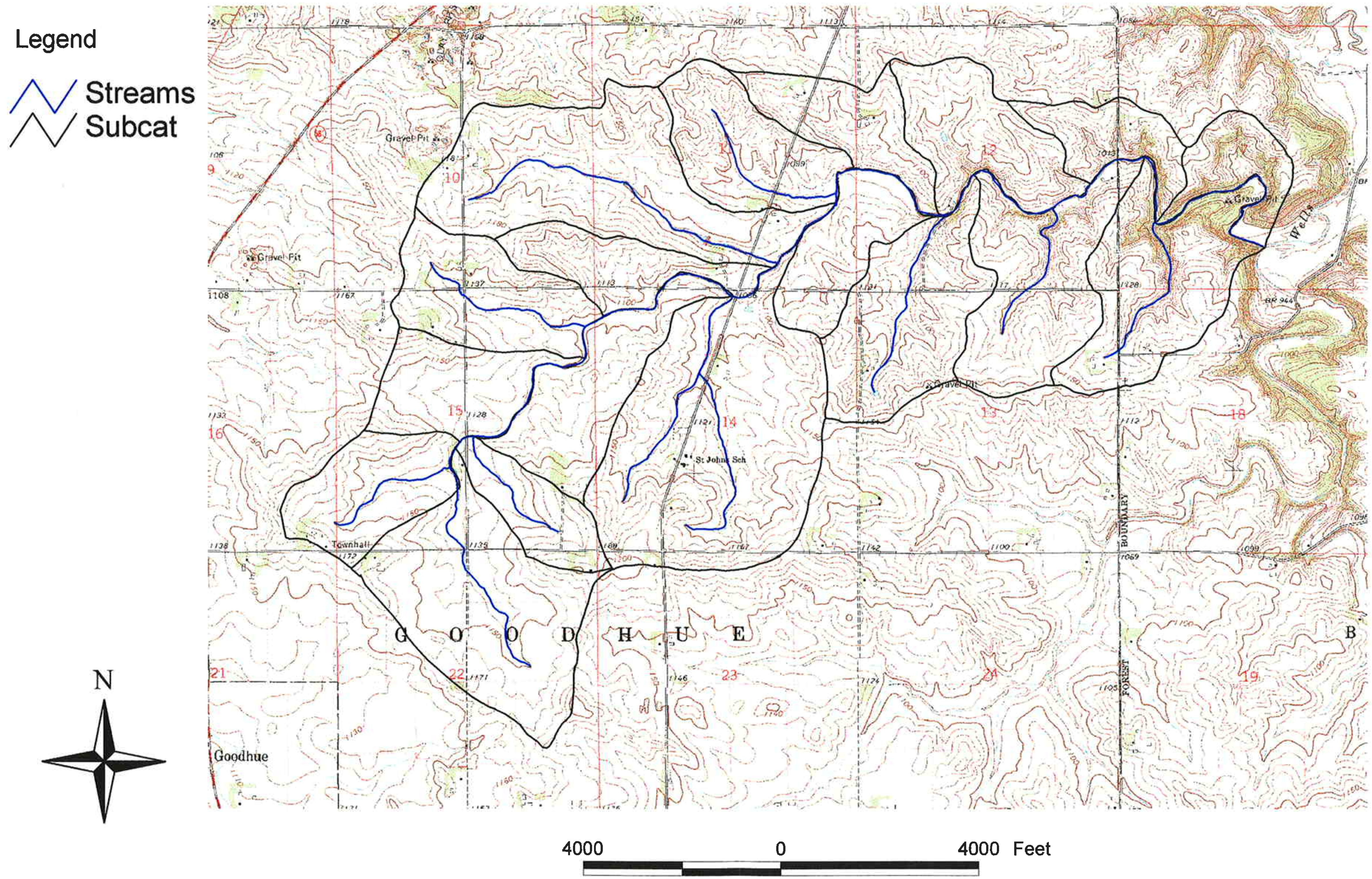

Figure 1: Definition of watershed and subwatersheds from a 7 1/2" quadragle (Digital Ortho-Quad (DOQ) shown here)

boundary in the form of a rectangle. Universal Transverse Mercator values (UTMs) were then read from the quadrangle and noted per tic for future use in the GIS; in which place, they will be used to correlate the computer representation to real world coordinates.

After the study area was defined, aerial photos of the same area were acquired. These were six 1:15,840 scale 9 1/2" infra-red photos taken on 10 October of 1993. These photos were interpreted at the Resource Studies Center of St. Mary's University by standard photo-interpreting procedures. Because of the nature of the curvature of the lens used to take the photos and other distorting variables, such as any pitch or roll that the plane had while the pictures were taken, only the center portions of the aerial photos were used for more accurate interpretation. Aerial photos are taken with a 60% overlap from one to the next and a 30% edgelap from side-to-side. To define the work area photos were overlain by superimposing the same features on top of one another and drawing a line at the mid point between the edge of each photo. This procedure was performed for all four sides a photo.

Once the work areas were defined on each of the six photos, a stereo-scope was utilized to make the features on the photos appear in three dimensions. Different land covers and uses were differentiated from one another and traced with a 4 x 0 technical pen. Land uses on the photos were classified to those needed for definition in HydroCAD, which incidentally, uses the same classification as the NRCS. Classes used included: 1) Fallow; 2) Row crops; 3) Small grain; 4) Close-seeded or broadcast legumes; 5) Pasture; 6) Meadow; 7) Brush; 8) Woods-grass combination; 9) Woods; and 10) Farmsteads. These cover types were also broken down into crop type (straight row, contoured, or crop residue) and the hydrologic condition; either good or poor, which was defined by how well the land was covered. An abbreviated classification was developed for this project which was essentially used to expedite labeling of polygons on the photos and the attributing of data into the GIS; for instance, good, straight row-row crops were abbreviated "2AG", meaning: 2 = row-crops, A = straight rows, and G = Good. To aid in the definition of crop types and to "field check" the initial assessments, color aerial photo slides were obtained from the Goodhue County NRCS taken in July of the same year. This allowed crops to be viewed in two seasons and two light spectrums.

This immediately proved to be more difficult than anticipated in that crop coverages in a fall photograph are hard to separate as there are more signatures to identify. There are several professional photo interpreters in south-eastern Minnesota; however, none of them specialize in agriculture lands that reside out of the Mississippi river valley. To establish a fairly accurate standard of classifying key signatures for each crop type, Rory Vose, of the Resource Studies Center, and Larry Robinson, Kevin Hopp, and Janis Rusher, of the EMTC, supplied expertise to identify a few known signatures. Beyond this a set of normal color slides were obtained from the Goodhue County NRSC that had been taken in July of the same year. Because the initial infra-red photos were taken in October, several crops were in the process of being cultivated and harvested, effectively doubling the amount of photo signatures to be identified. The normal color photos from July provided a key as to what a crop's signature did look like prior to its harvest so that it could be identified. Due to crop rotation practices, this method of cross checking different sets of photos was also used as a form of ground truthing.

A zoom-transfer scope was then used to trace all the newly defined polygons onto the same medium; in this case a sheet of mylar overlain onto the quadrangle containing the watershed boundary definition. The zoom-transfer machine allows the user to change the scale and shape of the photos to match that of the quadrangle and to also view them both at the same time so that items on the photos can be traced onto the mylar and labeled. The final product was one rectified sheet that contained all labeled land use definitions from all six photos as a single coverage, all within the bounds on the watershed. This was used later as a medium from which to digitize from for input into a GIS.

The hydraulic soil group for the watershed was obtained by correlating a table of soil names and hydrologic classifications, obtained from the St. Paul NRCS office, and the soil names for the study, as obtained from the Goodhue County Soil Survey. The data collected and created up to this point were now ready to use as input to the GIS.

Analysis of Data in a Geographic Information System

GIS technology was utilized for several purposes for this project including: 1) development of maps denoting study area, existing land cover types, and hypothetical and historical land cover types; 2) use as a data management tool to calculate and organize curve number data and its subsequent attribution to its spatial location; and 3) use for manipulating curve number and land use type data for hypothetical scenarios used as models in HydroCAD.

Before any calculations could be performed, the data had to be entered into the system. First the study area was defined in the GIS and linked to real world coordinates. This set the framework for all future data entry so that it could all be overlain onto the same real world location. The boundary of the study area outlined onto the quadrangle (Fig. 1) was digitized and projected and transformed in the GIS. The projection and transforming process sets the map data, initially in table units, to real world coordinates which in this case was Projection UTM, Zone 15, Units meters, and Spheroid Clarke 1866. The stream within the watershed was also digitized as was one township road. A roads coverage, already in real world coordinates, was obtained from DOT data and clipped to that of the boundary of the study area.

Before digitizing the land use from the mylar coverage, the digitizer environment was coordinated to that spatial area of the now rectified study area. Once this was done the coverage could also be digitized into the GIS and directly into a rectified coverage. Once the land use data were in the system spatially, they were attributed by manually selecting all polygons of the same classification and then attributing them to their land cover type into a table for further use; this process was used for all land use types.

Two maps were initially made; one showing the study area including the land uses from 10 October of 1993 and one showing the work area and existing CRP and RIM lands as of 1995 delineated by the Department of Natural Resources (enclosed). These were also digitized from a quadrangle. These maps were primarily developed to spatially show the study area and to denote initial land use conditions in the watershed.

Curve numbers were assessed by using a NRCS table to cross reference a particular land cover type with a particular hydrologic soil type to note the associated curve number (CN). In a GIS, each polygon has its own data table (Polygon Attribute Table or PAT) that contains information about it including, among other items, hydraulic soil type and land cover type. An empty item was added to this PAT so that it could be attributed with CNs. This was done by selecting all the land coverages of one type and all the soil types of one class, and then attributing that polygon with the appropriate associated curve number; once again, this process was repeated for all the polygons.

At this point the requirements of the storm water modeling system (HydroCAD) needed to be analyzed to determine what specifically was required from the existing data in the GIS. HydroCAD represents a watershed as a series of subcatchments, reaches, and ponds. These are represented simply as different shapes in HydroCAD but need an extensive amount of information to accurately represent real world conditions. The watershed was broken up into

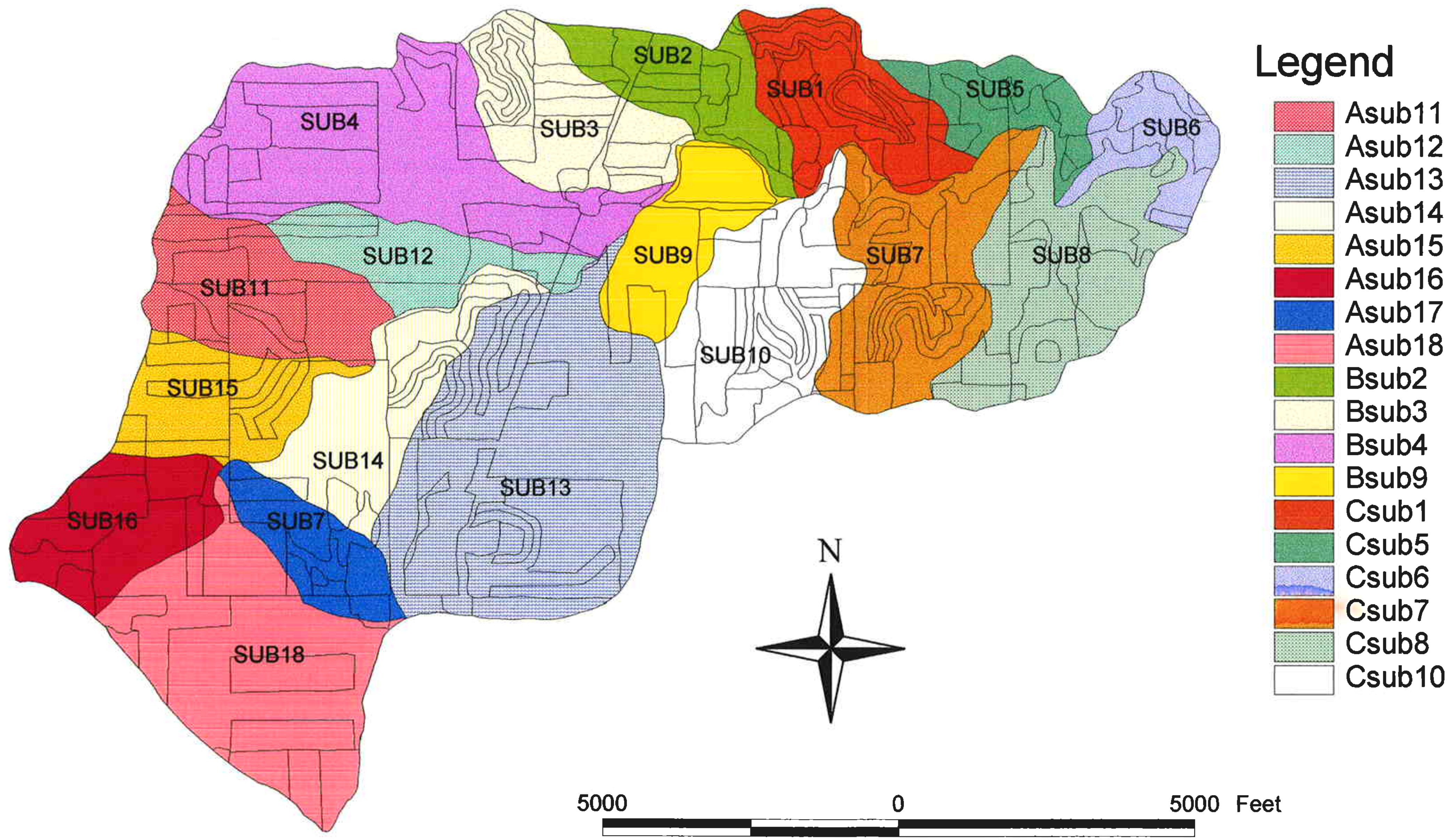

Figure 2: Spatial definition of subcatchments, according to NRCS classification, as defined for HydroCAD

eighteen different subcatchments by the same method described above to determine watershed boundaries (Fig. 2).

Each subcatchment requires one weighted curve number as calculated from the collective curve numbers contained within. A coverage was made by digitizing in the subcatchment boundaries and then using this to "split" the land use coverage into eighteen separate coverages (subcatchments) so that calculations could be performed on each. Weighted curve numbers were obtained by calculating the area of each land use (each with its own CN) within the total known area of each subcatchment and dividing the total area by the area of that land use. Each land use within each subcatchment now had a percentage that was multiplied by its CN to give weighted CNs for each land use. These numbers were then summed per subcatchment. Essentially, this ensures that larger land use polygons within the subcatchment give more hydrologic influence to the subcatchment's CN than smaller land use polygons. These calculations are all done in the GIS and then are stored as potential input for HydroCAD.

This project required five different models including four different land use scenarios (Note: Each different land use coverage produced different CNs when correlated to the hydraulic soil type and therefore different weighted CNs for the relative subcatchments). Each different land use coverage was developed in the GIS so that the relative CNs could be calculated by the same method described above. The first two models contained land use conditions as they were in 10 October of 1993 (Fig. 3). The third model required a hypothetically improved land use scenario. To develop this coverage the Goodhue County NRCS was contacted for recommendations of improved land uses. Ultimately the coverage was composed of the following land use improvements: 1) streams that ran through pasture lands were buffered by 100 ft. and these buffers were then attributed as woodland areas; 2) streams that ran through crop land were buffered by 30 ft and then subsequently attributed as grassland or meadow; and 3) any fallow lands were replaced by meadows to represent those areas enrolled in a reserve program such as the Conservation Reserve Program (Fig 4).

The fourth land use (Model D) scenario was to represent conditions prior to European immigration (pre-1850). This was once again done by first consulting the Goodhue County NRCS to assess what types of lands were previously in the study area prior to 1850. The study area was previously primarily a meadow area with a few more wooded areas than are present today. Therefore, all cropland areas were recalculated to contain meadow attributes and all pasture land, which can be mostly found in areas adjacent to streams and on steeper un-

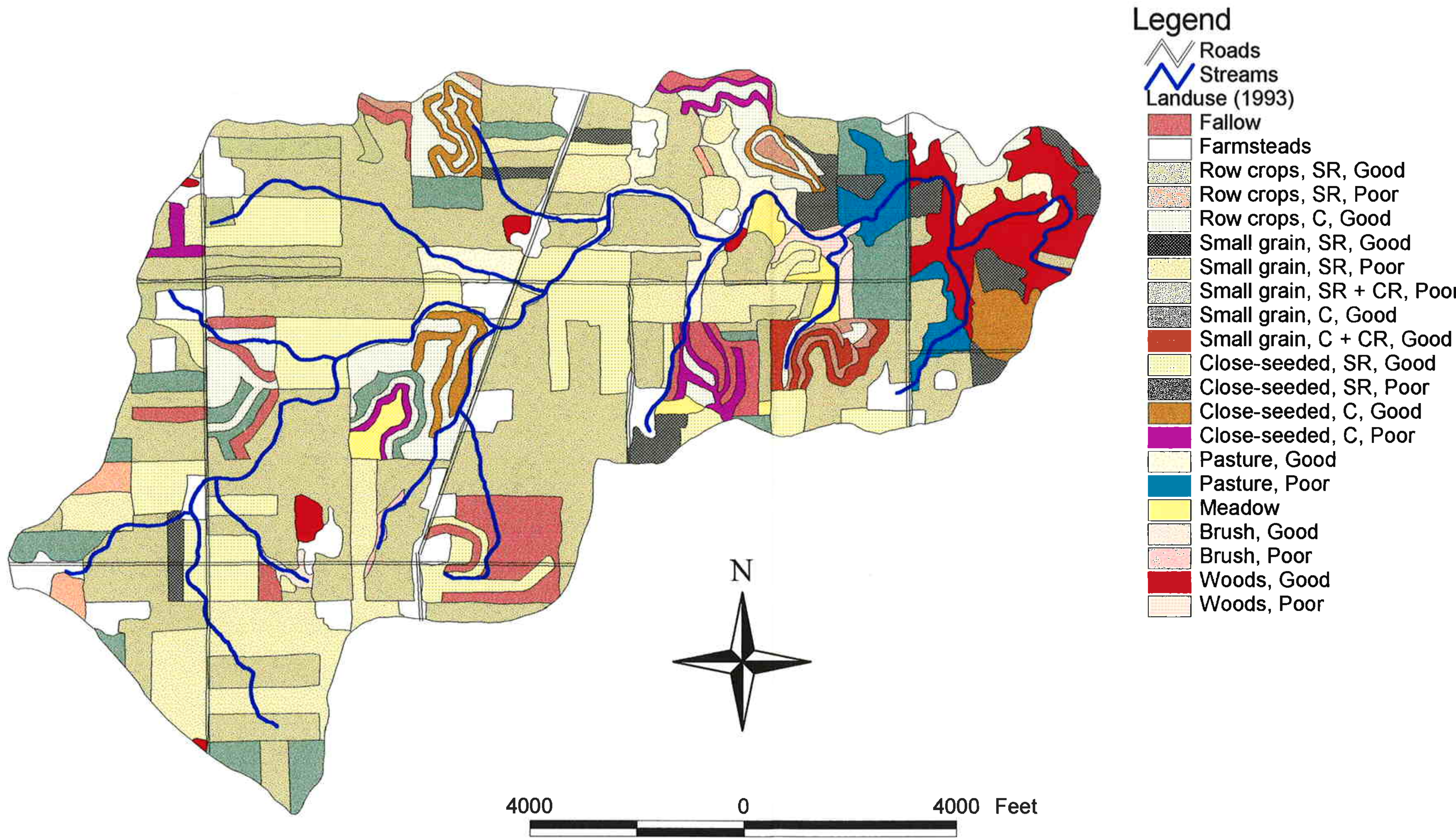

Figure 3: Existing land use conditions in watershed (as interpreted from October 1993 aerial photos), as used in Models A and B

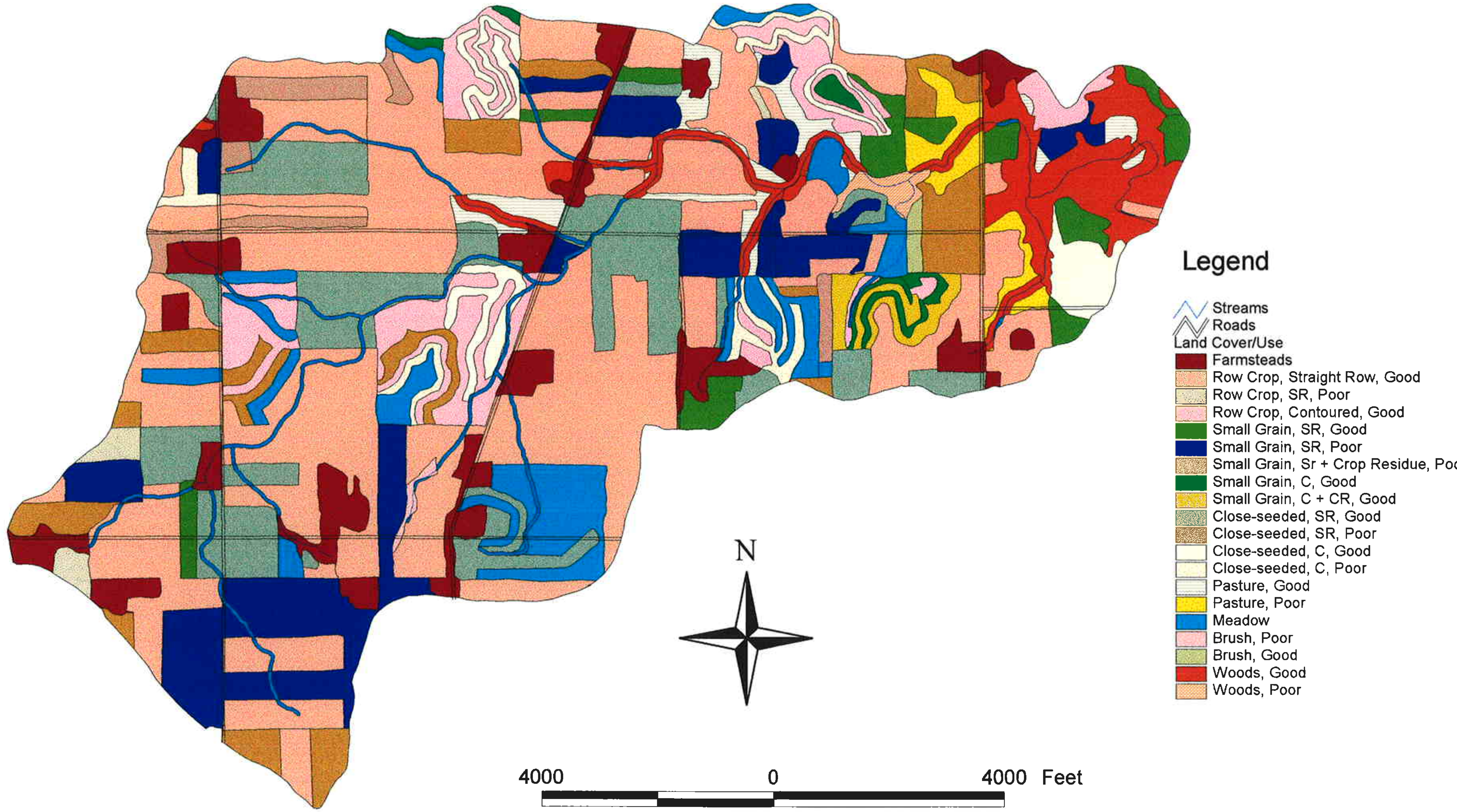

Figure 4: Hypothetical land use improvements in watershed, as used in Model C

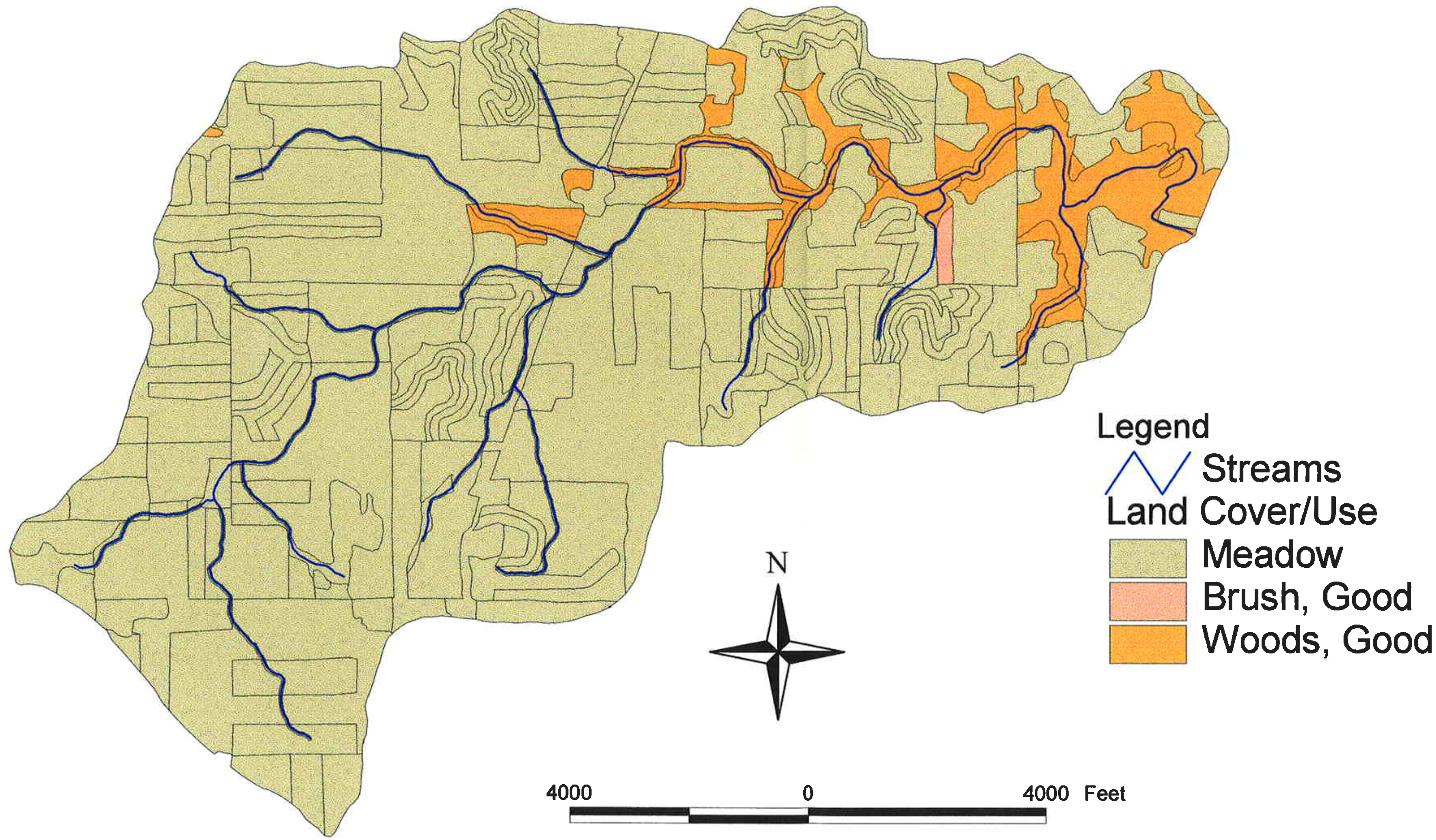

Figure 5: Generalized pre-1850 land cover, as used for Model D

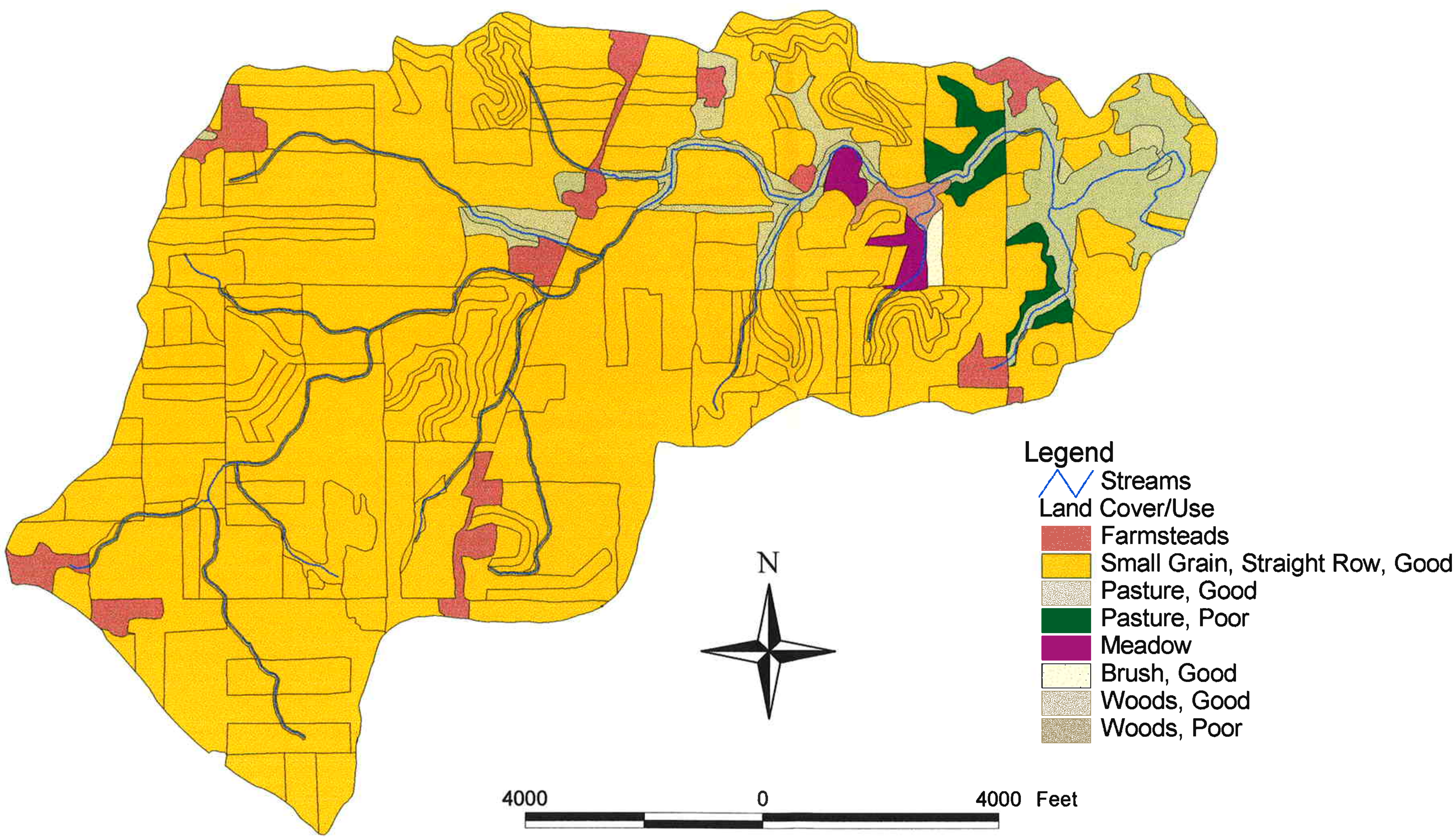

Figure 6: Generalized conditions in watershed during peak wheat production, as used in Model E

tillable lands, were recalculated to woodlands (Fig. 5). The fifth scenario (Model E) was to contain land use hydraulic conditions to represent that of peak wheat production during the summer season prior to harvest. This was done by replacing all cropland of today with that of small grain attributes and leaving all pastured lands much as they are today, at that time, most of the woodland that could be cut had been, and the farmers and residents of that time were forced to go over to the Wisconsin side to harvest timber (Fig. 6; Stegar, Personal Correspondence, 1997). Once again the above mentioned procedure for calculating subcatchments' weighted curve numbers was repeated for *each* land use scenario and the subsequent summed weighted curve numbers were then recorded for later use in HydroCAD.

HydroCAD also required hydraulic lengths for each subcatchment, lengths of all the tributaries within the subcatchments, and lengths of all reaches (sections of the main stem of the river). These length measurements were performed in the ArcEdit capabilities of ArcInfo by either selecting the stream and listing its length or by drawing a line (as was the case for the subcatchment lengths) and noting that line's length. HydroCAD also required the area per subwatershed, which could easily be assessed by listing the PAT of each of the separate subcatchments.

Entry and Execution of Land Use Scenarios in HydroCAD 3.0

As alluded to above, HydroCAD 3.0 was the storm water modeling system used in this study. Prior to this project, the HydroCAD manual was studied to get a feel for what type of data were needed for the models to run accurately. The first step in setting up a representation of a watershed in HydroCAD is to define the watershed spatially.

HydroCAD 3.0 only allows ten structures per diagram or screen. For this reason three to four screens were used for each land use scenario (Appendix A and B). For Models A, D, and E, three screens were used to set up the watershed spatially. Models B and C both contained NRCS water retention structures which in turn necessitated the use of a fourth screen to represent the watershed plus the additional structures. As mentioned above, the spatial watershed representation is broken down into subcatchments, reaches, and ponds. Once these are organized spatially and accepted, they can be attributed with data that each require.

Subcatchments require Tc (time of concentration) methods to be chosen from a list of many that HydroCAD provides. For this project, the Curve Number (Lag) Method was used to represent the time that the rainfall took to fall on the subcatchment, run over the landscape, and to reach the end of the subcatchment where it meets the main stem. If the subcatchment also contained a tributary, the Parabolic Channel Method was also used in conjunction with the Curve Number Method to calculate Tc. Subcatchments are also defined with the summed weighted curve numbers mentioned above, a land slope, stream length, stream slope, hydraulic length, Manning's number (n), and channel dimensions. Of these, area (acreage), CNs, stream length, and hydraulic length were calculated or obtained from the GIS. The land slope and stream slope were obtained from a quadrangle by, in the case of land slope, averaging several slope measurements taken per subwatershed and, in the case of the stream, taken directly from the quad by dividing its relief by its length. The channel measurements were measured in the field and Manning's numbers were obtained by observing each channel and referencing its associated Manning's number (n) in the HydroCAD manual.

Reaches in HydroCAD require length, slope, channel dimensions, and Manning's numbers (n). Of these, length was obtained from the GIS, slope was obtained from measurements taken from a quadrangle, and Manning's numbers (n) were referenced after viewing the stream. Once again the channel dimensions were obtained by recording observations in the field. HydroCAD requires the bottom width of the channel, and the top width, as well as the slopes of the sides which were calculated from data collected in the field.

In addition to the previously mentioned structures, pond parameters were needed in Models B and C. Ponds were added in to the existing layout of the watershed by moving the existing structures, in order to allow for room and correct sequencing of ponds and "creating" a pond in the diagram. Two pond structures were added and were called Luhmann's Pond 1 and 2 after whose property they were on (see enclosed map). One pond was added to Diagram 1 of Model B and C and one pond was added to Diagram C of each Model B and C (Appendix B). For the actual specifications of each pond, the Goodhue County NRCS was visited. The specifications of each pond were obtained from original schematic specifications from when the ponds were actually built. Parameters needed per pond are Invert Elevation (ft.) (elevation of the top of the discharge pipe or culvert), Diameter of culvert (inches), Manning's number (n), Length (ft.), Slope of pipe/culvert, Ke (Entrance Loss Coefficient), Cc (Contraction Coefficient), Tail water elevation (ft), Flood Elevation (ft), and Starting Elevation (ft.) (Table 4). The entry screen in HydroCAD for pond parameters contains a table for which pond elevations and associated volumetric acreages are to be entered, also obtained from the engineering specifications associated with each pond.

Links are structures that HydroCAD provides to link one Diagram, usually containing about ten structures, to another. This allowed the whole watershed to run as one continuous system so that the CAD system did not detect any breaks among the four different diagrams. For a more detailed description of procedures performed in HydroCAD refer to Appendix F.

Once all the parameters for all the structures had been described and checked over several times, the model was ready to run in association with different rainfall events. The initial set of curve numbers entered corresponded to the land type of 1993. This was used for initial model runs to see if the discharge (Q_T) was realistic. The Lake City Department of Natural Resources; Division of Waters was also contacted to compare the initial discharge with that of known discharges of similar sized watersheds flowing into Wells Creek. Once the results were accepted the model was ready for the prepared sets of data associated with the five different land use coverages.

Each of the five land use coverages were run against a 1", 2", 6" (100 year flood event), and 9" (NRCS emergency spillway) rainfall event. Model A represents land use conditions in 1993 without any ponds or retention structures and Model B contained the same land use coverage data but did contain water retention structures (Appendixes A and B respectively). Model C contained curve numbers associated with a hypothetically improved land use situation, as alluded to above (Appendix C). Model D and E represent scenarios of pre-European development and peak wheat production respectively (Appendixes D and E). Full reports have been printed out including hydrographs and discharge plots for Models A and B and can be noted in Appendices A and B respectively. To eliminate redundancy, reports for Models C, D, and E, were printed to an ASCII text file and can be viewed in the associated diskette. Summary results, in the form of hydrographs and discharge plots, can be noted in Appendixes C, D, and E.

DISCUSSION/ RESULTS

The Hypothesis in this study is that a watershed, once modeled in a computer and attributed with detailed descriptions, with different land covers, will produce different runoff and discharge characteristics. To prove this, five different land use scenarios were created as models and compared to note what specific changes occurred once the land cover type was changed and water retention structures were added. The land cover types used in this study were different enough that one could make an educated guess as to which one will have the highest runoff, and therefore the greatest stream discharge, and which one will absorb the most rainfall. The following discussion will present analysis procedures, potential sources of error, and rainfall runoff and stream discharge results of each individual model, and then provide some summary observations among the five watershed models.

All of the measurements taken from the field and obtained from GIS analysis, were used for all five of the models and left unchanged so that the effects from the one changing variable, the curve numbers, could be isolated and interpreted with ease. Therefore, the initial setup of the first model set the stage for all subsequent models.

The first model developed contained, as mentioned earlier, a land cover type that was to represent conditions in the watershed as they are today (Fig. 3) and was also used as a control from which to measure the other land use types against, being either better or worse in terms of hydrologic runoff. The actual land uses were obtained by interpreting aerial photos that were taken in October of 1993.

At this point, as outlined in the Methodology, data constants, to be used for all the watershed models, were gathered and curve numbers were calculated for each model (Table 1).

Collection of data in the field included acquisition of stream dimensions of both those within the subcatchments and those of the actual reaches. This potentially introduced another source of error in the model. The tributary of Wells Creek described in this project, is an intermittent flowing stream. Because the stream channels were dried up at the time of measurement and extremely overgrown, in most cases, the channel itself was difficult to identify and therefore to measure. Several streams in the tail water section of the watershed would be considered extinct, as they had been included in crops for some time and displayed almost no signs that a stream had been there. For purposes of this study however, any error in channel measurement will have no effect on comparing one model to the next in that they all contain the same channel measurements as constants, which therefore cannot introduce any error (Tables 1 & 2).

Subcatch-ment	Area (Acres)	∑W_CN (see Table 8)	Land Slope (ft.)	Stream Length (ft.)	Stream Slope	Hydraulic Length (ft.)	Channel (ft.)
Sub1	158.83	73.94	0.039			2861.21	
Sub2	115.81	73.95	0.033			1902.29	
Sub3	161.8	74.52	0.028	3541.25	0.014	4653.25	8.5' x 8"
Sub4	358.76	74.94	0.046	7197.04	0.011	8309.04	1' x 6"
Sub5	87.7	72.45	0.14			2497.34	
Sub6	82.88	62.7	0.137			1369.5	
Sub7	226.23	72.42	0.031	3195.55	0.031	4445.55	11' x 2.3'
Sub8	231.18	69.74	0.049	3511.71	0.043	4761.71	10' x 1'
Sub9	116.99	73.79	0.042			2087.96	
Sub10	220.53	74.99	0.026	4095.39	0.017	4595.39	3' x 1'
Sub11	170.86	75.72	0.024	3765.05	0.016	4765.05	1' x 4'
Sub12	108.8	76.2	0.026			2956.72	
Sub13	479.99	77.53	0.020	5028.81/	0.016	6400	1.5' x 0.5'
(2 tribs)				5985.07	0.013		3' x 5"
Sub14	164.87	73.95	0.035			756.84	
Sub15	130.92	78.09	0.02			2848.3	
Sub16	140.12	76.39	0.024	2891.98	0.014	4133	1' x 1'
Sub17	87.65	73.84	0.021	2798.02	0.018	4232	1' x 1'
Sub18	318.6	76.07	0.018	4895.64	0.008	7214	1' x 1'

Table 1: Table of constants used in description of all the subcatchments in all models, except for the curve numbers which were calculated separately for each model in a GIS. CNs for scenario one are shown here.

A final source of potential error is less tangible and is a potential problem for any study whose data encounters several development phases. The quality of data in studies such as this can degrade from development phase to development phase. Watson and Burnett (1995) state, "It is apparent that with each generation of data manipulation the modeled information is removed one step further from the reality of the original field condition...". This is assumed to have introduced a minimal source of error; however, as most of the field measurements were unaltered, even through the last runs of scenarios, to ensure that land use effects on runoff could be isolated.

Stream Segment	Length (ft.)	Slope (ft./ft.)	Bottom Width x Depth (ft.)	Manning's Number (n)	Side Slopes (ft./ft.)	
Reach 1	8825.59	0.0055	4' x 2'	0.035	0.13	0.13
Reach 2	2040.76	0.005	1' x 3.1'	0.035	0.51	0.51
Reach 3	3068.66	0.003	1' x 3.1'	0.035	0.51	0.51
Reach 4	3008.21	0.009	1' x 2'	0.03	0.50	.050
Reach 5	3743.45	0.021	5.8' x 2'	0.03	0.69	0.69
Reach 6	4764.13	0.008	4.1' x 0.5'	0.035	0.06	0.06

Table 2: Reach descriptions as used in each of the Models.

Peter Smart, Applied Microcomputers Systems (HydroCAD), was contacted several times to ensure that the hydrologic theory, as represented in the computer, was sound and to also ensure that the results from the first couple runs of the model were realistic and did not contain sources of error as introduced by the author. Bill Huber, Department of Natural Resources; Division of Waters, was contacted to make sure that the initial land use model ouput was comparable to real world conditions. Because there are not usually storm events such as those used in this study, especially the 2", 6", and 9" storm events, an actual measurement could not be obtained from the end of the watershed and used for calibration. For this reason discharges from that of adjacent, similarly sized watersheds were compared to the discharge from this watershed under land use conditions of today.

<u>Results of Each of the Five Models</u>

Model A- Current Land Use Scenario without Ponds

As mentioned above, the first land use scenario used was that of existing conditions today and is referred to herein as Model A (Fig. 3). At this point no water retention structures were introduced into the model and no hypothetical land use alterations were added or removed. The one inch rainfall event provided a peak discharge of 10.0 cfs (Note: Changes in Y axis from hydrograph to hydrograph throughout). No discharge was noted coming out of the end of the watershed until 13.8 hours of rainfall and peaked at 18.68 hours (Table 3; Fig. 7).

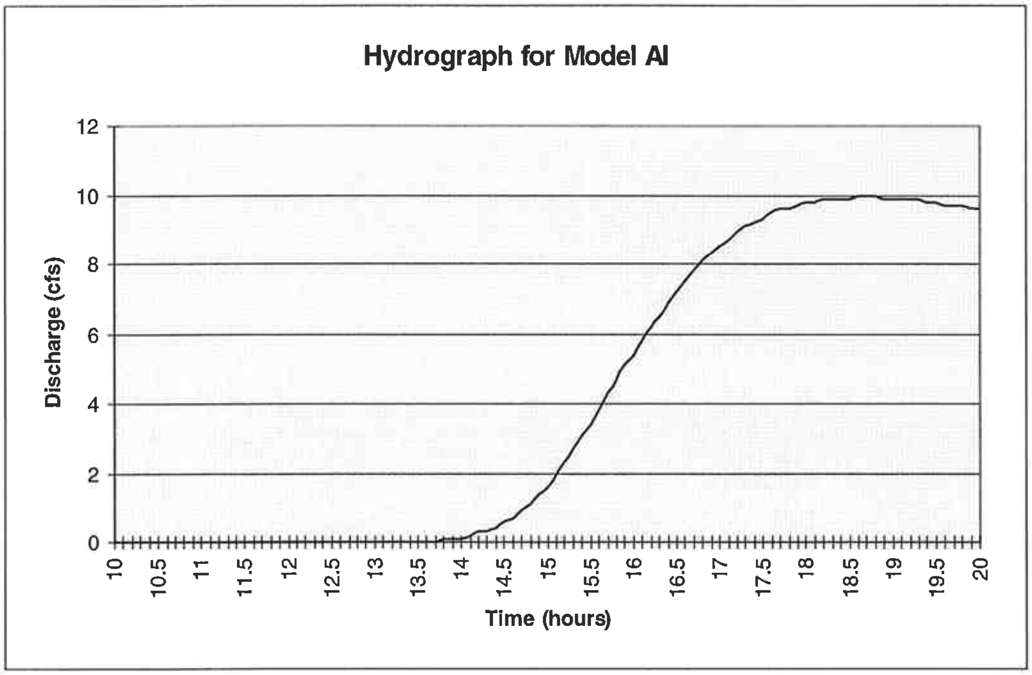

Figure 7: Hydrograph depicts a current land use scenario without water retention structures and a 1" storm event.

The two inch rainfall event followed a substantial, but expected, increase in flow due to the fact that much more of the soil is saturated with water, effectively increasing the amount that runs off the surface, ultimately adding to the main stream. In this case, discharge was first noted at the beginning of the twelfth hour and increased at a much swifter pace until a peak discharge of 176.8 cfs at 15.03 hours was reached, at which point the discharge slowly decreased to 69.6 cfs in the twentieth hour (Appendix AII; Fig. 8).

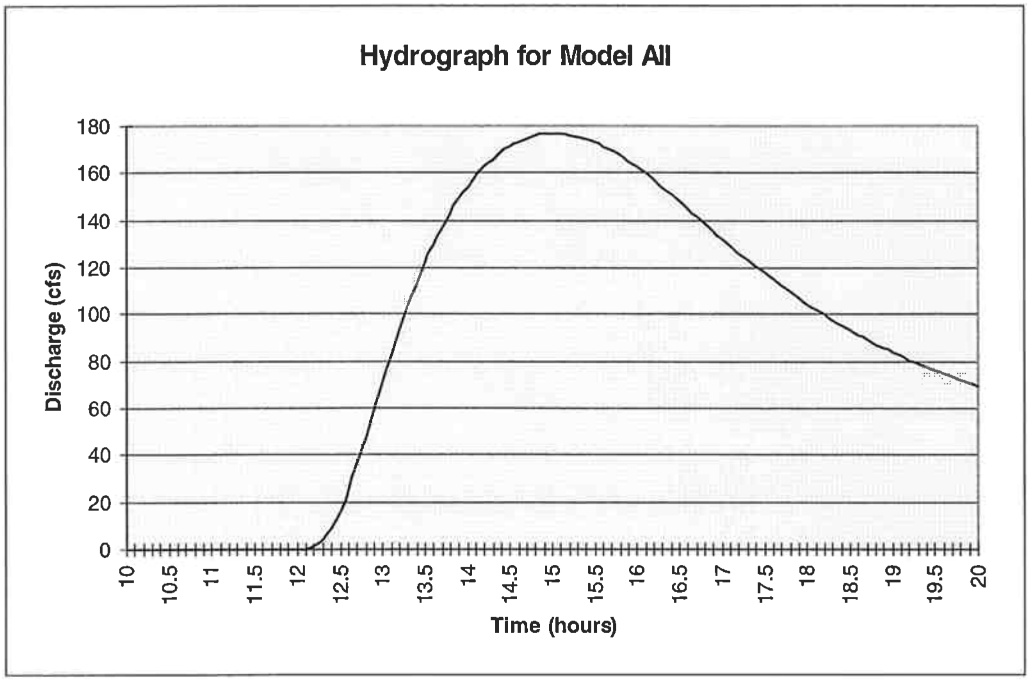

Figure 8: Hydrograph depicts a current land use scenario without water retention structures and a 2" storm event.

The six inch rainfall per 24 hours once again showed a substantial increase, in that an peak outflow of 1934.6 cfs was noted at 14.01 hours. Out flow was first noted at 10.10 hours which is also substantially earlier than the above two rainfall periods. After twenty hours of rainfall the stream was still discharging 406.1 cfs (Fig. 9).

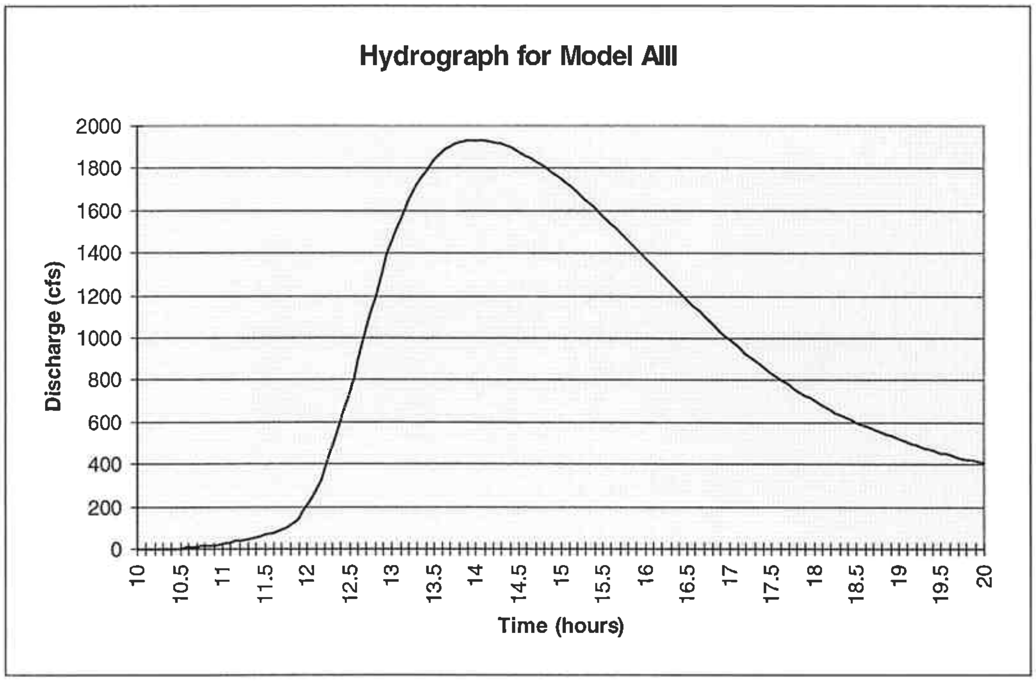

Figure 9: Hydrograph depicts a current land use scenario without water retention structures and a 6" storm event.

The nine inch rainfall event was producing an outflow in the tenth hour of 0.5 cfs which quickly grew to 3590.8 cfs in 13.89 hours and at the twentieth hour the watershed was still producing 672.4 cfs (Fig. 10). See Appendix AI - AIV for detailed descriptions of all four rainfall events in Model A and associated hydrographs.

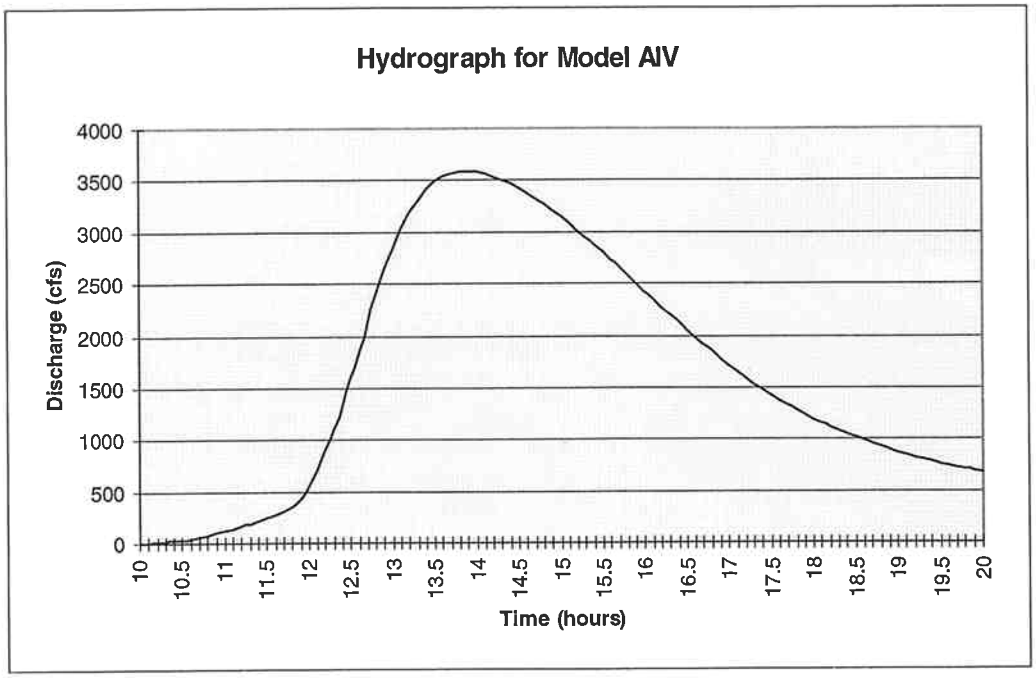

Figure 10: Hydrograph depicts a current land use scenario without water retention structures and a 9" storm event.

Rainfall event: NRCS Type II	Discharge Outflow Peak (cfs)	Time Outflow Peak (hrs)	Time Initial Flow (hrs)
1" /24 hr.	10.0	18.68	13.8
2" /24 hr.	176.8	15.03	12.1
6" /24 hr.	1934.6	14.01	10.1
(100 yr. rainfall)			
9" /24 hr.	3590.8	13.98	10.0

Table 3: Denotes peak discharges in existing land use conditions during four different rainfall events (Model A).

Model B- Current Land Use Scenario with Ponds

The second land use scenario contained the same land use curve numbers, as calculated for the first model (A); however, two water retention structures, or ponds, were added (Fig. 3). These ponds were modeled after two existing structures and are referred to as Luhmann's Ponds 1 and 2. Specifications of the ponds were obtained from Goodhue County NRCS engineering schematics (Table 4.)

Pond	Luhmann Pond #1 (Sect. 11)	Luhmann Pond #2 (Sect. 12)
Invert (ft.)	99.5	60
Diameter (in.)	15	12
Manning's Number (n)	0.024	0.024
Length (ft.)	60	57
Slope (ft./ft.)	0.03	0.17
Ke (Entrance Loss Coefficient)	0.9	1.08 (used 0.9)
Cc (Contraction Coefficient)	0.9	0.9
Tail Water Elevation (ft.)	97.5	50.5
Flood Elevation (ft.)	107.0	63.0
Starting Elevation (ft.)	96.0	50.0

Table 4: Denotes Pond structures as used in Models B and C. Pond specifications were obtained from Goodhue County NRCS engineering schematics.

The two ponds are designed to collect water from a subcatchment and to store and release it at a specific rate as specified by a culvert of a certain invert elevation, tail water elevation, length, and diameter (Table 4). This will reduce the amount of discharge and stress that is entered into the stream. This can be noted in Model B by noting the outflow per rainfall event as compared to Model A.

In Model B a rainfall event of one inch per 24 hours produces an outflow of 8.7 cfs. The watershed did not start producing discharge until 13.9 hours, which then peaked at 18.85 hours (Table 5; Fig. 11).

The two inch rainfall period produced a peak discharge of 153.6 cfs and first appeared at the mouth of the watershed at 12.1 hours, and then peaked at 15.27 hours (Fig. 12).
The six inch rainfall event produced a peak outflow of 1669.9 cfs at 14.00 hours while the nine inch event produced 3111.5 cfs at 13.83 hours (Table 5; Fig. 13 and 14). All four of these events produced 13% lower cfs than those produced in the watershed with the same land use without water retention structures (Appendix BI through BIV).

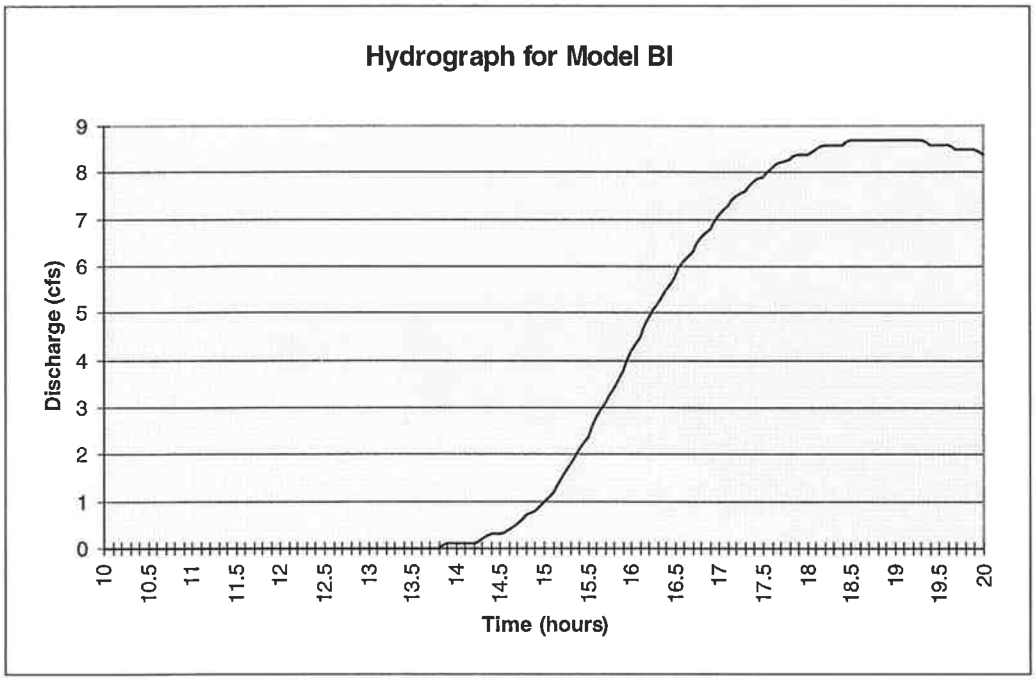

Figure 11: Hydrograph depicts a current land use scenario *with* water retention structures and a 1" storm event.

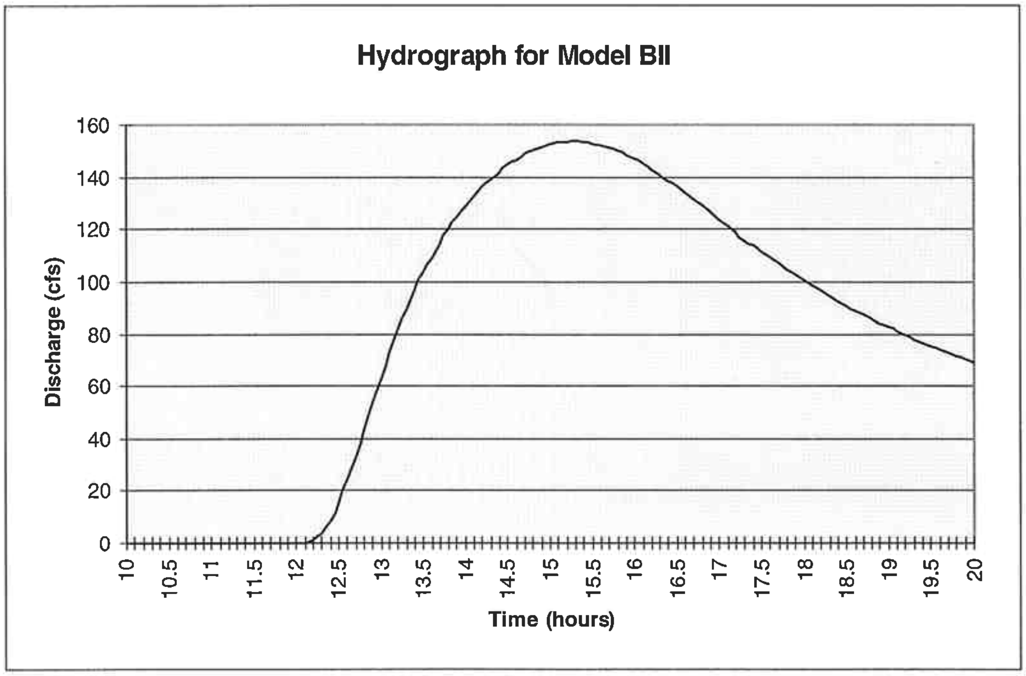

Figure 12: Hydrograph depicts a current land use scenario *with* water retention structures and a 2" storm event.

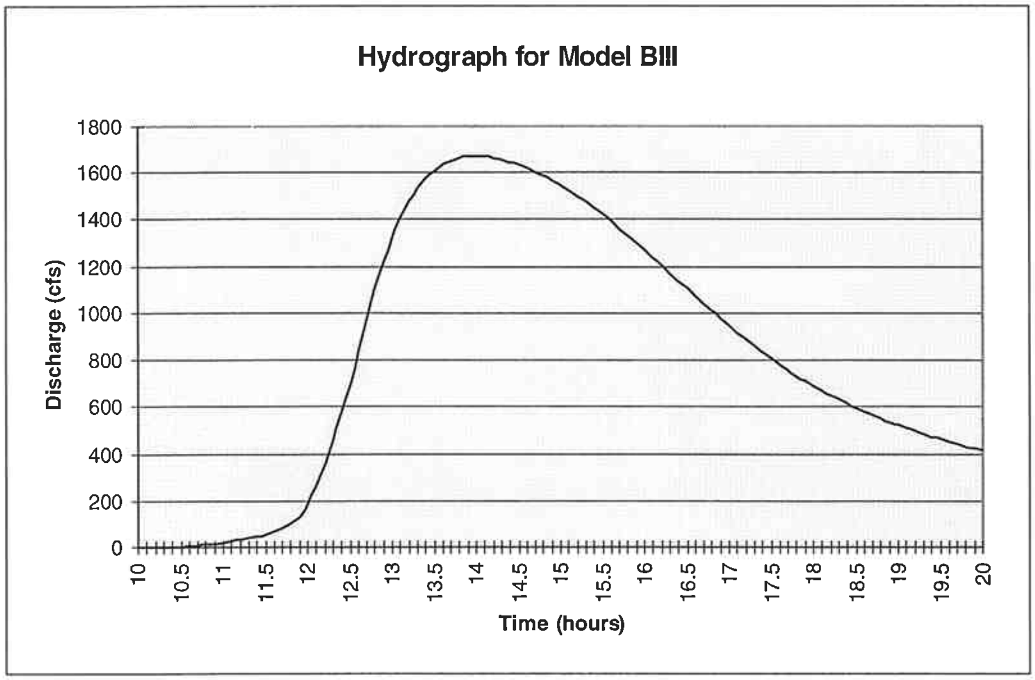

Figure 13: Hydrograph depicts a current land use scenario *with* water retention structures and a 6" storm event.

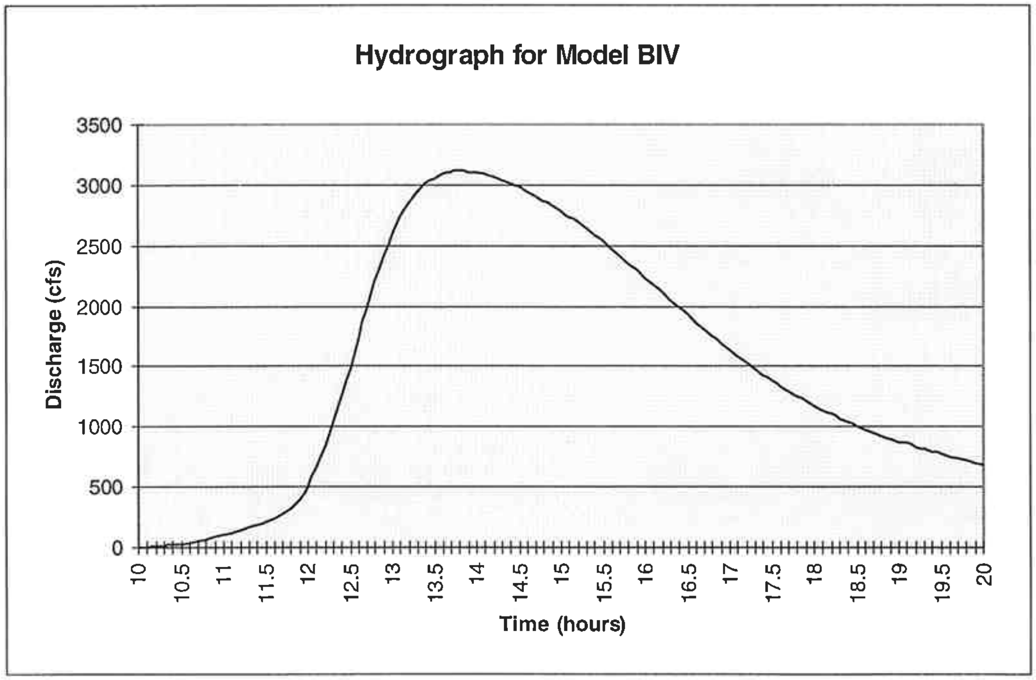

Figure 14: Hydrograph depicts a current land use scenario *with* water retention structures and a 9" storm event.

Rainfall event: NRCS Type II	Discharge Outflow Peak (cfs)	Time Outflow Peak (hrs)	Time Initial Flow (hrs)	% change in Peak Discharge from Model A
1" /24 hr.	8.7	18.85	13.9	13
2" /24 hr.	153.6	15.27	12.1	13
6" /24 hr. (100 yr. rainfall)	1669.9	14.0	10.1	13
9" /24 hr.	3111.5	13.83	10.0	13

Table 5: Denotes peak discharges for Model B containing water retention structures.

Model C- Hypothetically Improved Land Use Scenario

Model C contains an improved land use scenario (Note: Development as outlined in Methodology). It essentially contains a 30 foot buffer around all streams that reside within cropland, updated from cropland to grassland, and a 100 foot buffer around streams that reside within pastured areas, updated to contain woodland in good condition (Fig. 4). All fallow lands formerly in the coverage were updated to meadows to represent conservation programs such as the CRP or RIM. Model C also contains pond structures as outlined in Model B (Table 4). These changes produced a substantial improvement from Model B. In Model C the one inch rainfall event produced a peak discharge of 3.2 cfs at 20.0 hours which simply shows that much more of the rainfall that fell on the watershed was retained by the more healthy land covers (Fig. 15). This outflow is also produced 68% less cfs than that from Model A (Table 6). With a more saturated soil, the two inch rainfall event produced a discharge of 104.1 cfs at 14.70 hours whereas the six inch event produced a peak discharge of 1472.3 cfs at 13.83 hours (Fig. 16 and 17).

A nine inch rainfall event produced a peak outflow of 2821.9 at 13.73 hours which is 289.6 cfs less than Model B, which did not contain the simple land use improvements (Table 6; Appendix CI through CIV; Fig. 18).

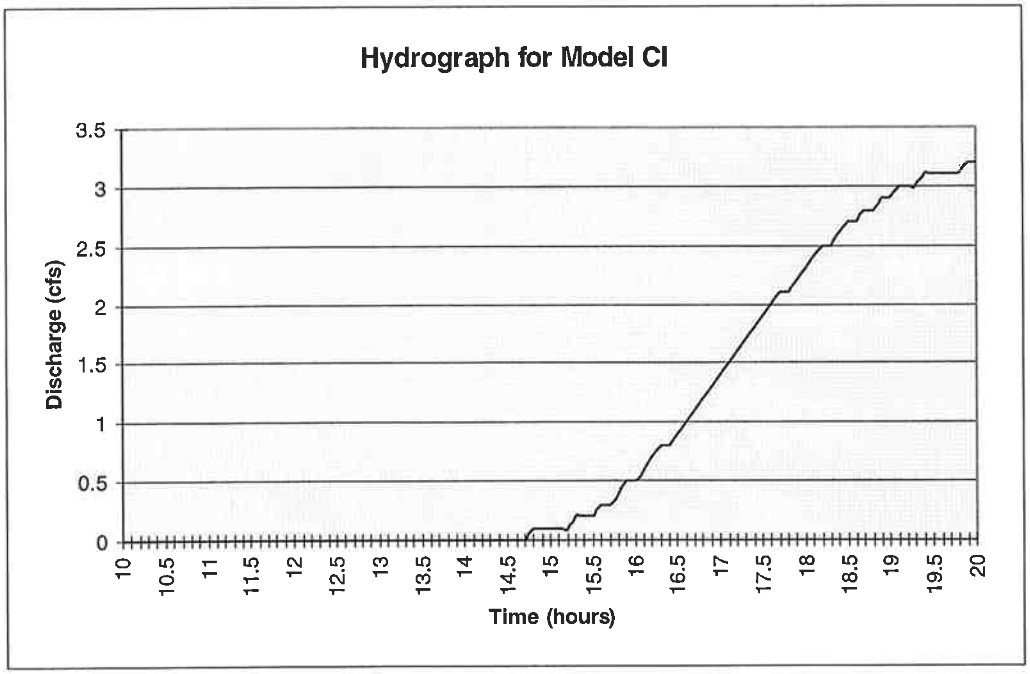

Figure 15: Hydrograph depicts a hypothetically improved land use scenario *with* water retention structures and a 1" storm event.

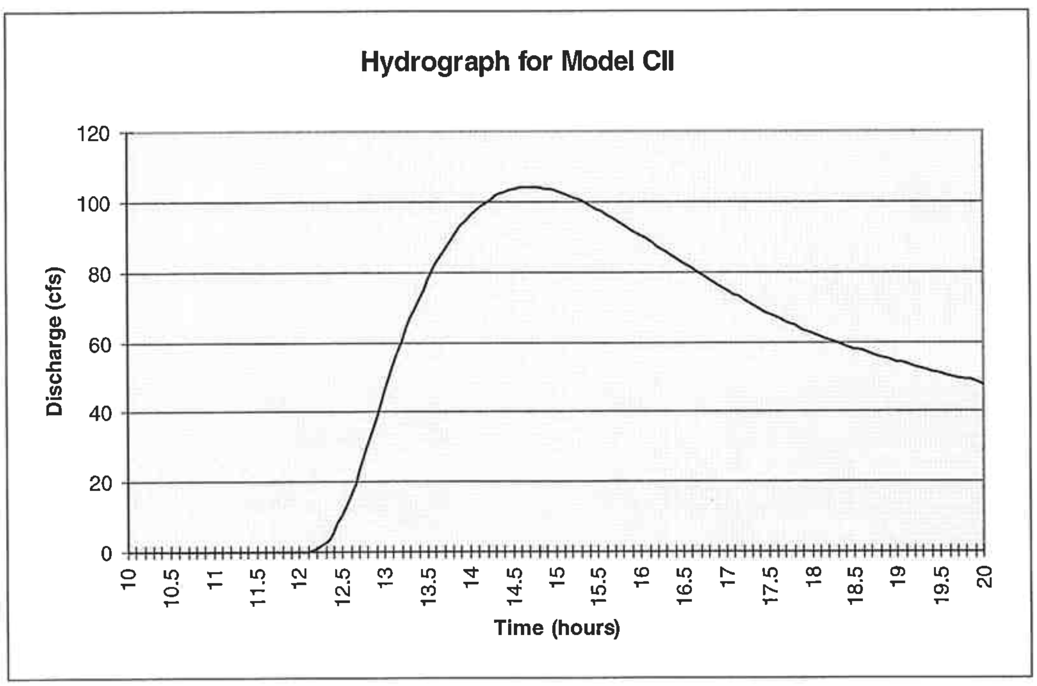

Figure 16: Hydrograph depicts a hypothetically improved land use scenario *with* water retention structures and a 2" storm event.

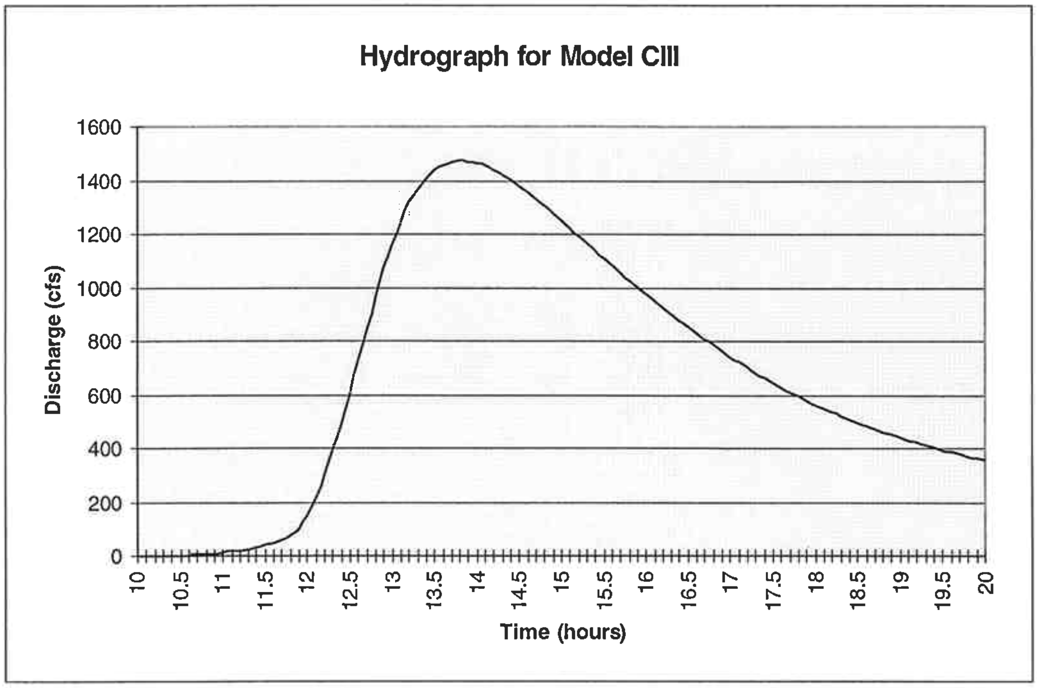

Figure 17: Hydrograph depicts a hypothetically improved land use scenario *with* water retention structures and a 6" storm event.

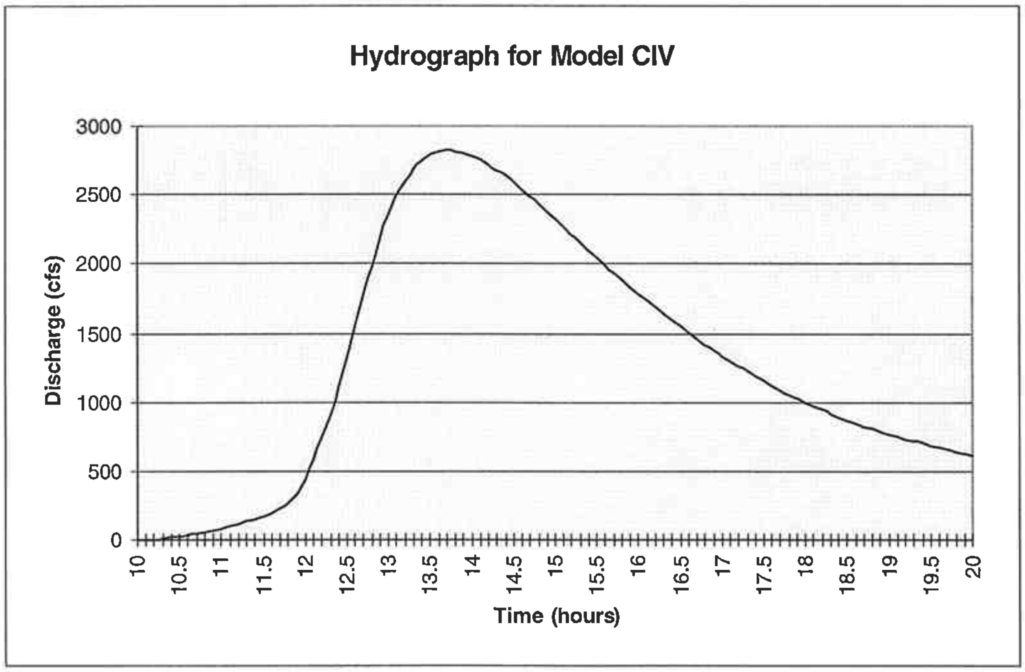

Figure 18: Hydrograph depicts a hypothetically improved land use scenario *with* water retention structures and a 9" storm event.

Rainfall event; NRCS Type II	Discharge Outflow Peak (cfs)	Time Outflow Peak (hrs)	Time Initial Flow (hrs)	% change in Peak Discharge from Model A
1" /24 hr.	3.2	20.0	14.8	68
2" /24 hr.	104.1	14.7	12.1	41
6" /24 hr. (100 yr. rainfall)	1472.3	13.83	10.1	23
9" /24 hr.	2821.9	13.73	10.0	21

Table 6: Substantial reduction in discharge due to improved land use conditions (Model C).

Model D- Prior to European Immigration (pre-1850)

Model D contains a land use scenario that represents the watershed prior to European Settlement (pre-1850; Fig. 5). This was achieved by consulting Tom Steger at the Goodhue County NRCS office for historical information regarding past conditions of the watershed. The ensuing coverage was developed to contain meadows in all areas that had previously contained any croplands, and woodlands in areas that had contained pasture lands. This coverage would, theoretically, represent the best case scenario for the watershed as it is a representation of what had evolved there naturally. Along with having a very low CN of 58, meadow grasses have the ability to absorb vast amounts of water into their stems and root systems (Stegar, Personal Correspondence, 1997).

A one inch rainfall event in Model D produced a discharge of 0.00 cfs, reflecting the fact that the watershed could absorb 100% of the rainfall (Table 7). The two inch rainfall event produced a peak discharge of only 11.9 cfs at 20.0 hours, which is a 92.2 cfs reduction from that produced in the hypothetically improved land use model (Fig. 19) and 93% less cfs than that produced from Model A (Table 7).

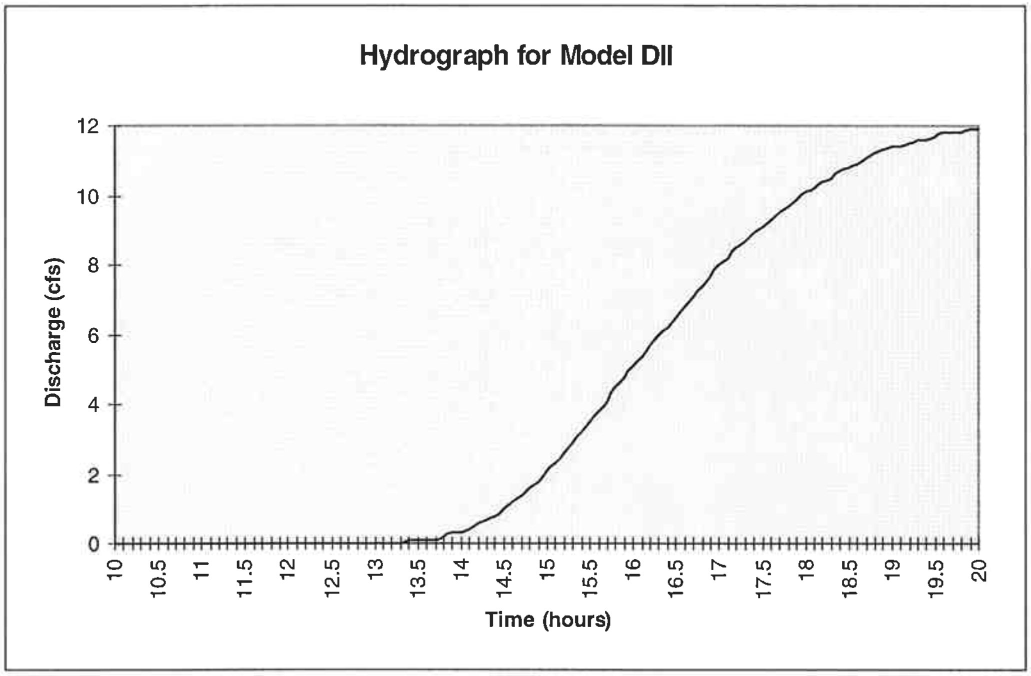

Figure 19: Hydrograph depicts a land use scenario representative of a pre-European immigration (pre-1850) scenario *without* water retention structures and a 2" storm event.

A six inch rainfall event produced an outflow of 811.2 cfs in 14.60 hours and a nine inch event produced 1910.8 cfs in 14.39 hours (Figs. 20 and 21).

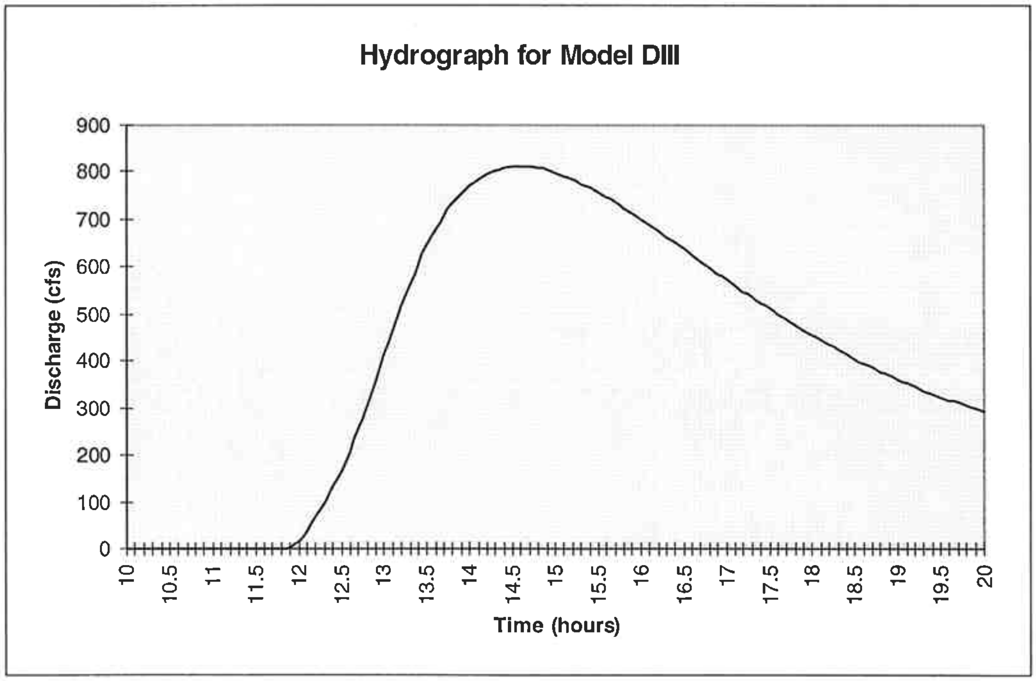

Figure 20: Hydrograph depicts a land use scenario representative of a pre-European immigration (pre-1850) scenario *without* water retention structures and a 6" storm event.

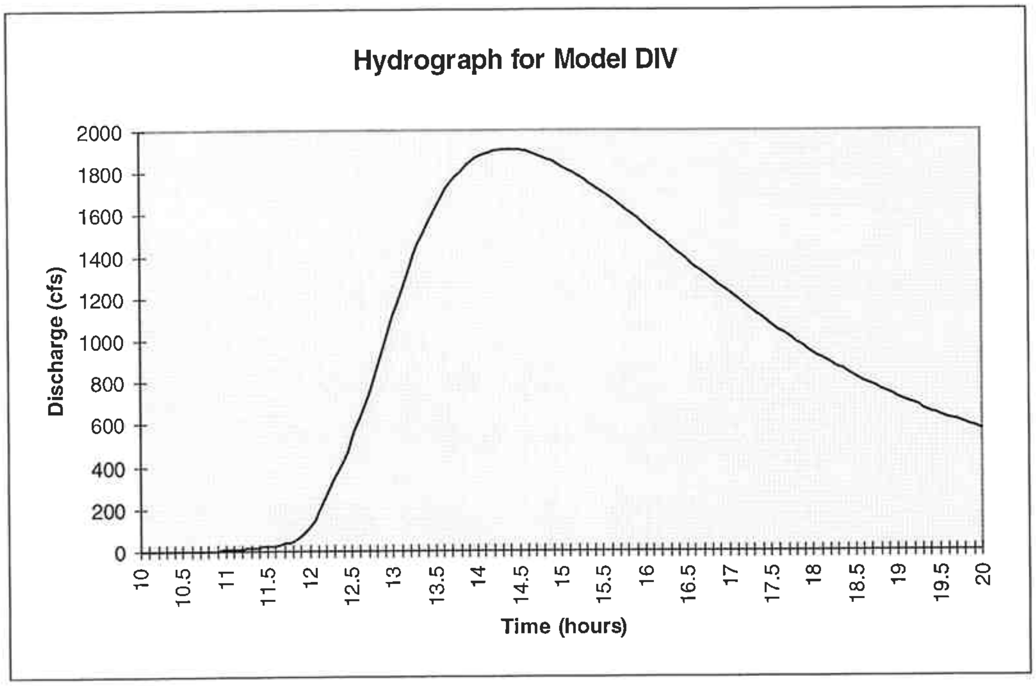

Figure 21: Hydrograph depicts a land use scenario representative of a pre-European immigration (pre-1850) scenario *without* water retention structures and a 9" storm event.

Clearly all of these discharges are vast improvements when compared to any of the other models discussed (Appendix DI through DIV).

Rainfall event: NRCS Type II	Discharge Outflow Peak (cfs)	Time Outflow Peak (hrs)	Time Initial Flow (hrs)	% change in Peak Discharge from Model A
1" /24 hr.	0.00	0.00	0.00	100
2" /24 hr.	11.9	20.0	13.4	93
6" /24 hr.	811.2	14.6	11.6	58
(100 yr. rainfall)				
9" /24 hr.	1910.8	14.39	10.3	46

Table 7: Hydrologic peak discharge conditions in the watershed prior to 1850 or European development (Model D).

Model E- Watershed During Peak Production (late 1800's)

In the late 1800's and early 1900's, European farmers in the watershed planted almost exclusively wheat, which is referred to herein as peak wheat production period. To develop this coverage in a GIS for CN calculation, all crop land was set equal to small grain and the pasture lands were left as pasture (Fig. 6). During this time period the farmers had harvested most of the timber and were now traveling to the Wisconsin area to harvest. The model shows hydrologic conditions while the wheat was planted and before harvest. Land in this condition is in a healthy hydrologic state. Once the wheat had been harvested, one can be sure that the hydrologic condition would decrease greatly, in that the land type would have an increase in a curve number average from 72.99 to about 85. No retention structures are used in this scenario (refer to Appendix EI through EIV for hydrographs and associated tables).

Model E, representing conditions as outlined above, produces 6.1 cfs at 20.00 hours and the two inch rainfall event produces 146.6 cfs at 14.78 hours (Fig. 22 and 23). These two rainfall events produced 39 % and 17% less cfs than that produced in Model A (Table 8).

The six and nine inch rainfall events produce peak outflows of 1812.0 cfs at 13.93 hours and 3406.2 cfs at 13.83 hours respectively (Table 8; Figs. 24 and 25).

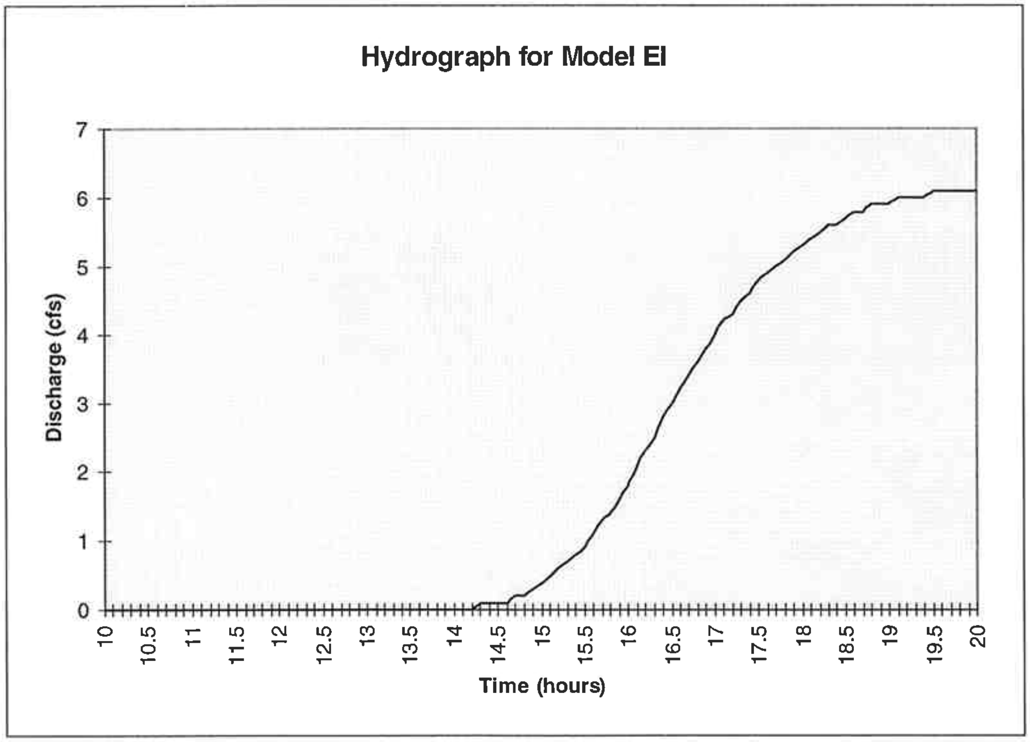

Figure 22: Hydrograph depicts a land use scenario representative of peak wheat production period, in the watershed *without* water retention structures, and a 1" storm event.

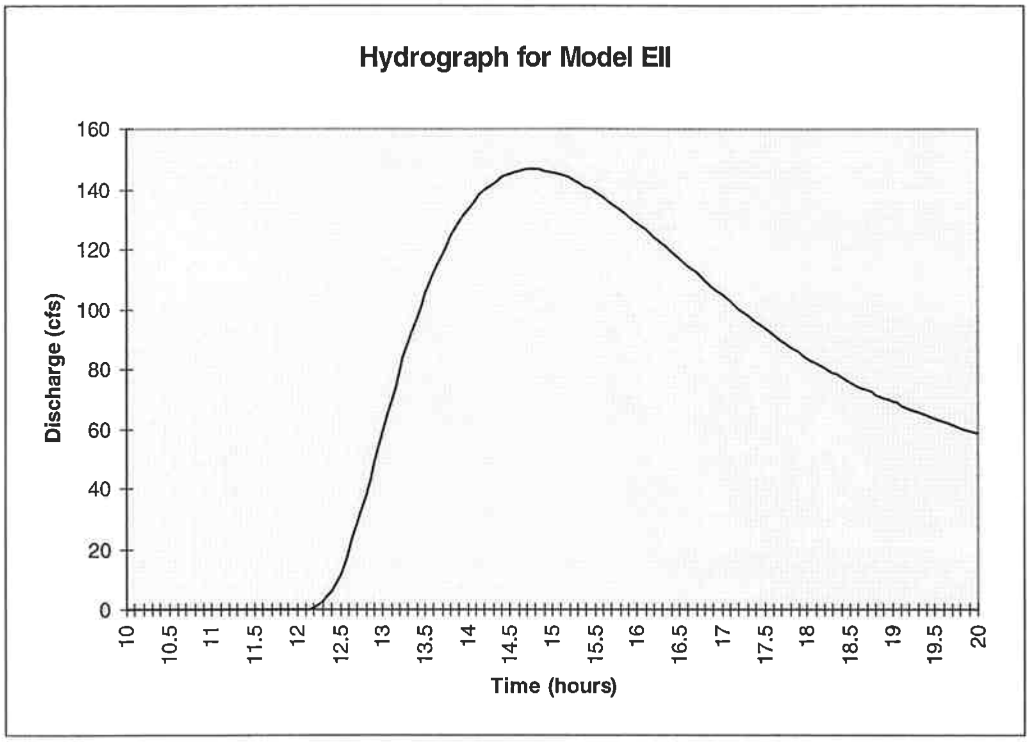

Figure 23: Hydrograph depicts a land use scenario representative of peak wheat production period, in the watershed *without* water retention structures, and a 2" storm event.

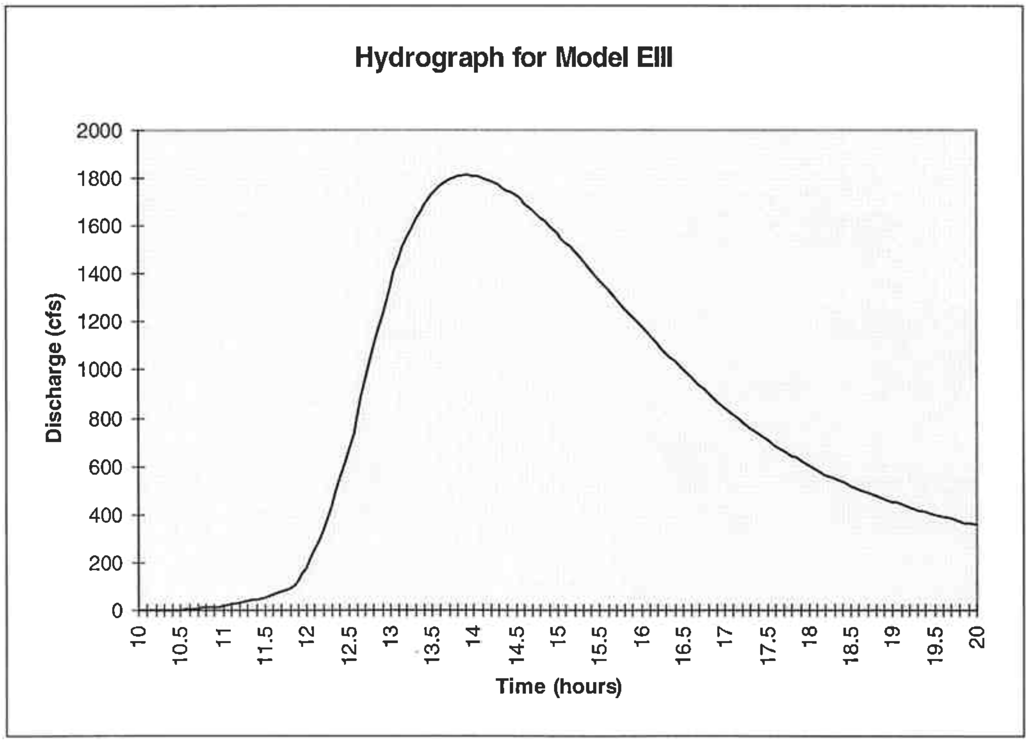

Figure 24: Hydrograph depicts a land use scenario representative of peak wheat production period in the watershed *without* water retention structures and a 6" storm event.

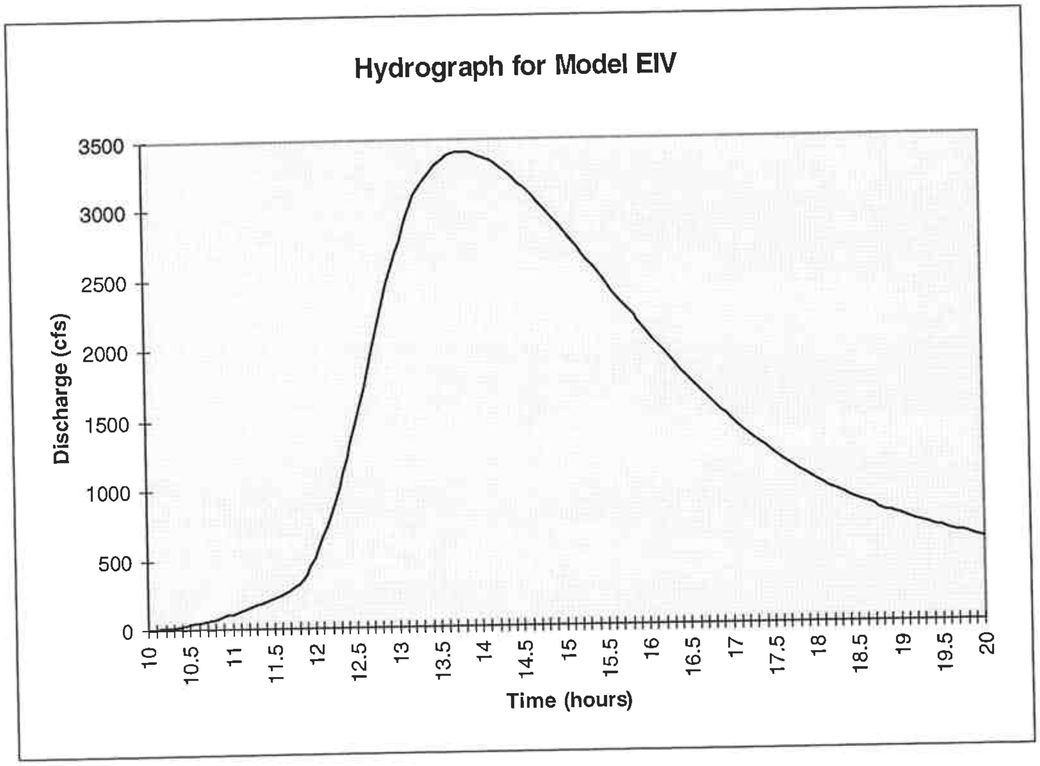

Figure 25: Hydrograph depicts a land use representative of peak wheat production period in the watershed *without* water retention structures and a 9" storm event.

Rainfall event: NRCS Type II	Discharge Outflow Peak (cfs)	Time Outflow Peak (hrs)	Time Initial Flow (hrs)	% change in Peak Discharge from Model A
1" /24 hr.	6.1	20.0	14.3	39
2" /24 hr.	146.6	14.78	12.1	17
6" /24 hr. (100 yr. rainfall)	1812.0	13.93	10.1	6
9" /24 hr.	3406.2	13.83	10.0	5

Table 8: Denotes hydrologic peak discharge conditions during peak wheat production period prior to harvest (Model E).

Comparison of Models

After one glances through the model summaries above, it becomes quite clear that land use/cover has a major influence on the way in which rainfall is managed in a watershed. It should be noted once again that the only parameters changed throughout these models are the curve numbers, related to land use, and the addition or removal of water retention structures. One can predict how well the land use scenario will perform based on how low an average of curve numbers contained within that land scenario coverage is. A relatively low curve number would indicate that water will be absorbed more efficiently in the watershed, whereas a higher curve number average would result in more runoff and less infiltration (Table 9).

One can also note that there is a direct relationship between curve number averages, per watershed, and discharges, in that the lower the average for that watershed the lower the discharge will be, and the higher the average the higher the amount of discharge will be (Table 9).

Model B shows the direct benefits that can be obtained from pond structures within a watershed environment. (Note: There was a 1.3 cfs reduction in discharge in a 1" rainfall period and a 23.2 cfs reduction in the 2" rainfall event.) There was also a decrease in the difference between the 1" and the 2" discharges, within each model (from Model A to Model B from 166.8 cfs to 144.9 cfs respectively) showing that the watershed becomes better equipped to handle larger amounts of water in the same period of time. When this is combined with some modest land use changes, Model C, the effects become amplified as there is a 6.8 decrease in cfs, in a 1" rainfall event from Model A to Model C due to improved land use (Table 10). Here again the difference between the 1" and 2" rainfall events, within each model, decreases with improved land use, from 144.9 cfs to 100.9 cfs.

Subcatchment	CNs - Models A & B (October 1993)	CNs - Model C (Improved 1993)	CNs - Model D (Pre-1850)	CNs -Model E (Peak Wheat late 1800's)
Sub1	73.94	71.32	57.94	72.86
Sub2	73.95	73.41	59.84	72.33
Sub3	74.52	73.94	58.4	73.72
Sub4	74.94	73.35	59.01	73.73
Sub5	72.45	72.01	59.21	71.33
Sub6	62.7	62.68	56.07	62.5
Sub7	72.42	69.96	57.89	71.71
Sub8	69.74	69.06	57.78	69.26
Sub9	73.79	73.48	57.72	73.45
Sub10	74.99	69.74	57.79	73.53
Sub11	75.72	71.44	58	75
Sub12	76.2	75.87	59.09	74.93
Sub13	77.53	68.55	58.79	74.95
Sub14	73.95	74.3	58	74.99
Sub15	78.09	70.93	58	75
Sub16	76.39	75.91	59.76	74.89
Sub17	73.84	72.73	57.99	74.99
Sub18	76.07	75.69	58.38	74.75
Average	**73.96**	**71.91**	**58.31**	**72.99**

Table 9: Average of curve numbers as an indicator of how well a watershed will support runoff infiltration. For instance, Model D will clearly support runoff infiltration better than that of any other model (Refer to Fig. 2 for spatial subcatchment description).

Model D is essentially a great exaggeration on the improvements taken in Model C. Instead of the pastures simply containing 100' wooded buffers, they are completely replaced by woodland and the 30' grassland buffers have been extended to cover the whole watershed. Here, imitating natural conditions has direct proven benefits. A discharge of 0.00 cfs during a 1" rainfall clearly highlights the hydrologic degradation that is present in today's conditions that have a discharge of 8.7 cfs. The percentage change in peak discharge when Model A is compared to Model D also illustrates a dramatic decline in cfs (Table 9). Summary data for all five models can be found in Tables 10 through 13.

Rainfall event; NRCS Type II	Model A Peak Q_T (cfs)	Model B Peak Q_T (cfs)	Model C Peak Q_T (cfs)	Model D Peak Q_T (cfs)	Model E Peak Q_T (cfs)
1" /24 hr.	10.0	8.7	3.2	0.00	6.1
2" /24 hr.	176.8	153.6	104.1	11.9	146.6
6" /24 hr. (100 yr. rainfall)	1934.6	1669.9	1472.3	811.2	1812.0
9" /24 hr.	3590.8	3111.5	2821.9	1910.8	3406.2

Table 10: Peak discharges for each Model per rain fall event.

Rainfall event; NRCS Type II	Model A Peak Q_T (hrs)	Model B Peak Q_T (hrs)	Model C Peak Q_T (hrs)	Model D Peak Q_T (hrs)	Model E Peak Q_T (hrs)
1" /24 hr.	18.68	18.85	20.0	0.00	20
2" /24 hr.	15.03	15.27	14.7	20	14.78
6" /24 hr. (100 yr. rainfall)	14.01	14.0	13.83	14.60	13.93
9" /24 hr.	13.98	13.83	13.73	14.39	13.83

Table 11: Time of peak discharge for each Model per rain fall event.

Rainfall event; NRCS Type II	Model A Initial Q_T (hrs)	Model B Initial Q_T (hrs)	Model C Initial Q_T (hrs)	Model D Initial Q_T (hrs)	Model E Initial Q_T (hrs)
1" /24 hr.	13.8	13.9	14.8	0.00	14.3
2" /24 hr.	12.1	12.1	12.1	13.4	12.1
6" /24 hr. (100 yr. rainfall)	10.1	10.1	10.1	11.6	10.1
9" /24 hr.	10.0	10.0	10.0	10.3	10.0

Table 12: Time of initial flow for each Model per rain fall event.

Rainfall event; NRCS Type II	Model B	Model C	Model D	Model E
1" /24 hr.	13	68	100	39
2" /24 hr.	13	41	93	17
6" /24 hr. (100 yr. rainfall)	13	23	58	6
9" /24 hr.	13	21	46	5

Table 13: Percent change in peak discharge from Model A for each model per rainfall.

CONCLUSION

The creation of the Wells Creek subwatershed models was primarily performed to attain several land use scenarios that would, in turn, force the watershed to function in different ways. The model was also created; however, to test the feasibility and usefulness of such a model. Completion of the five models discussed above, and the results that they provided, should be considered testament to the feasibility of such a modeling study.

The use of a geographical information system provided much assistance in the preparation of data for this study especially in calculating weighted curve numbers. This process, while fairly straightforward, can be very time intensive, especially in a project such as this one, in which case several different sets of weighted curve numbers are necessitated. The GIS also proved to be a great data management tool in that all data were stored in attribute tables. These were easily updated and easily related to spatial features to aid in the cognitive process associated with the development of each scenario. Viewing and altering each land scenario spatially helps greatly in understanding what steps to take and in what order to take them. Obviously, a GIS is also very useful in the map development phase which ultimately helps potential users of a study, such as this one, to understand more clearly what the author is discussing.

HydroCAD 3.0 also proved to be a very valuable tool in modeling a watershed. It is laid out in a very straight forward manner and can be fairly easily manipulated, such as adding or removing ponds, when changes are needed. There are several more up-to-date packages on the market today that would make watershed modeling easier yet, including newer versions of HydroCAD and an ArcInfo compatible package called Geostorm. Geostorm removes redundant data entry procedures, such as entering data both into a GIS and then into a storm water modeling system, as it can read the data directly from the parent application (ArcInfo). HydroCAD 3.0 however, fulfilled all the analysis products that were required for this study and should still be regarded as a valuable tool. As eluded to earlier, the depth of study that one does in HydroCAD can vary, in that one can enter data that represents summary information about the watershed and create a model, or one can take very specific measurements in the field to describe the watershed, as is the case with the TR-55 modeling options.

The data produced by the before-mentioned models clearly show the correlation between good land use practices and a healthy watershed. This study also highlighted the fact that hydrologic conditions and infiltration rates change throughout the year, and from season to season. This is perhaps best observed in Model E, peak wheat production, in that the watershed in fairly healthy while the vegetation is in the ground; however, autumn conditions would certainly imitate a barren watershed representing a watershed composed almost entirely of freshly harvested lands and highly erodable soil. In the future this particular model, in HydroCAD, can be used and altered to model other land use scenarios other than those used in this project.

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