Spring 2010

Analysis of Streamflow in the St. Croix River: A Hydrologic Model

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A Hydrologic Model

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I. Abstract

This project assesses how streamflow is affected by anthropogenic changes to the environment, looking specifically at the St. Croix River Basin. In 2004 the United States Geologic Survey (USGS) published a report on streamflow in the St. Croix River at two gaging stations: Danbury and St. Croix Falls. The streamflow at the upstream station near Danbury, Wisconsin remained stable over time, while an increase was observed at the station in St. Croix Falls, WI further downstream. In order to evaluate this disparity, this project utilizes a GIS hydrologic model to analyze the factors expected to be influencing the flow rate. Of primary focus are the effects of land use changes, including urbanization (an increase in impervious surfaces), land cover and agricultural practices, as well as other sources of increased runoff. Data came primarily from state and federal agencies, and the Soil and Water Assessment Tool (SWAT) is the hydrologic model used. The result of this process is an analysis of the influence of anthropogenic factors on streamflow.

II. Introduction

The St. Croix River Basin in Minnesota and Wisconsin has seen many changes over the past century. From logging to agricultural and urban development, the land cover and hydraulic functions of the basin have been impacted significantly. This paper aims to identify the reasons for these changes as well as to assess their manifestations in the hydraulic functions of the St. Croix River. The main inspiration for this project was a report published by the United States Geologic Survey (USGS) in 2004 discussing a positive change in the streamflow of the St. Croix between the Danbury and St. Croix Falls gaging stations, both located in Wisconsin (Lenz 2004). The downstream station at St. Croix Falls had a much higher flow than that recorded at the upstream station at Danbury. Anthropogenic changes to the landscape were suspected to be responsible. In accordance with the questions posed in the USGS report, the following research question was posed for this project: How are changes in land use, including urbanization, land cover and agricultural practices affecting runoff and streamflow in the St. Croix River Basin?

As a protected river under the Wild and Scenic Rivers Act of 1968, the St. Croix River is an important natural feature in the Upper Midwest. In order to maintain its health and status, research concerning the river is increasingly important. Prior to this project, there was little to no comprehensive attempt to model the St. Croix River Basin, particularly with an emphasis on what role is played by land use/land cover (LULC) changes in the area. There has been more interest recently in gaining a better understanding of how anthropogenic activities are affecting the basin, but there is still a need for a more thorough research. The goal of this paper is to explain the ways in which human activities prevalent in the St. Croix River Basin over the past century have altered watershed function. Included in the history of the area is extensive logging and development. Therefore, an examination of the literature concerning the impacts of activities associated with logging, such as damming, channelization, and dam removal/restoration is included, following a general history of the study area.

The majority of this paper will focus on using the Soil and Water Assessment Tool (SWAT) to recreate the St. Croix River Basin's hydrologic system. As with all models, there is a certain amount of error and miscalculation associated with SWAT. The main issue faced with using SWAT for this project concerns a miscalculation of flow, possibly due to an underestimation of infiltration. This resulted in streamflow data with much higher than expected peak and intermediary flows, and lower than expected base flows. Additionally, a lack of available data made a century-long temporal analysis of streamflow changes infeasible. Due to these limitations, the original aims of this project were revised. Instead of focusing on performing a temporal and spatial analysis, the project became geared more towards establishing the basis of future analysis. This includes the compilation of a database containing GIS layers necessary for SWAT analysis and others that inform a greater understanding of the St. Croix River Basin. Additionally, a greater understanding of how SWAT works is established, including how the model can be used for an analysis of how the area's hydrologic functions are impacted by anthropogenic changes.

III. Study Area Overview: History of the St. Croix River Basin

Flowing 165 miles from the Upper St. Croix Lake to the Mississippi River at Point Douglas, the St. Croix River drains 7,650 square miles of terrain and serves as the boundary between Minnesota and Wisconsin (Dunn 1979). As one of the first American rivers to be designated a National Scenic Riverway by the U.S. National Park Service, the St. Croix is preserved as one of the most recreationally used and environmentally appreciated rivers in the United States (McMahon 2002). The entire St. Croix River Basin covers sixteen counties, including Aitkin, Anoka, Carlton, Chisago, Isanti, Kanabec, Mille Lacs, Pine, and Washington Counties in Minnesota; and Bayfield, Burnett, Douglas, Pierce, Polk, St. Croix, and Washburn Counties in Wisconsin. Figure 1 on the following page shows the extent of the basin as well as the major tributaries of the St. Croix River and the locations of the Danbury and St. Croix Falls gage stations.

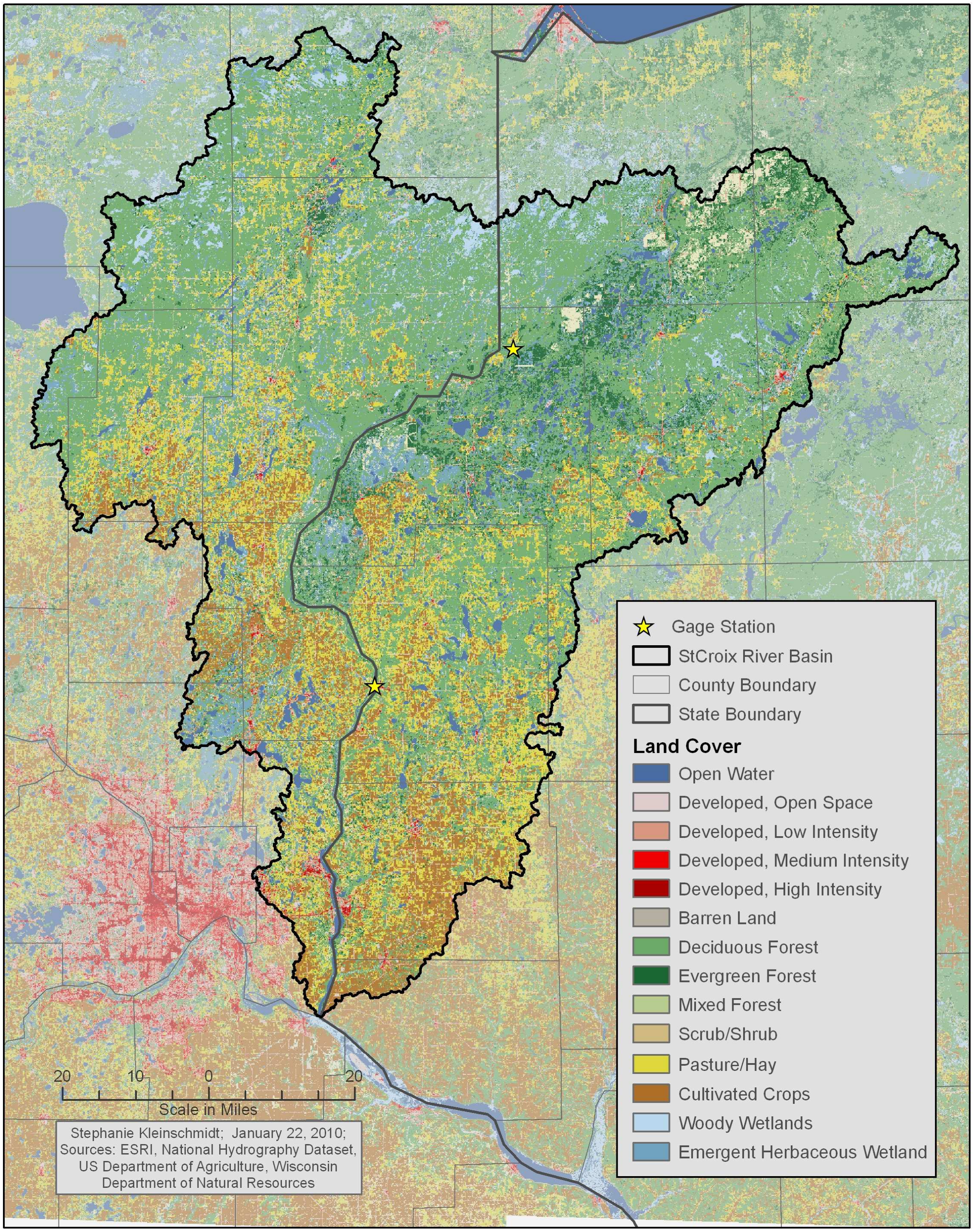
Figure 1 - St. Croix River Basin Reference Map

St. Croix River Basin

The upstream and downstream reaches of the river vary considerably, from how they originated to how they have been used throughout history. The river itself was actually formed by two separate glacial lakes, Glacial Lake Grantsburg and Glacial Lake Duluth, hundreds of thousands of years ago. Figure 2 on the following page shows the land cover in the river basin from the 2001 National Land Cover Dataset. Within the St. Croix River Basin, indicated by a black boundary, it can be seen that land cover varies visibly between the upstream and downstream sections of the St. Croix River. The upper reach is characterized by fast flowing water, pines and generally sandy soil unfit for cultivation (Dunn 1979). This can be seen in Figure 2 as the predominantly green area in the Northwest third of the basin. The darkest green is evergreen forest, which comprises a slim fraction of the largely deciduous and mixed forests shown in the lighter shades of green. Additionally, there is a lack of agricultural land, which can be explained by the poor soil quality among other things.

The lower reach, however, is wide and slow moving with rich soil (Dunn 1979). In Figure 2 it can be seen that the downstream portion of the basin is dominated by pasture/hay and cultivated crops, reflecting the knowledge that the soil quality is much better than that of the upper reaches of the river. Despite comprising parts of a single river, the upper and lower reaches of the St. Croix differ dramatically. The rest of the basin is composed of a mixture of cropland, deciduous forests, open water, and patches of urban development. The river valley’s history is as varied as the river itself and includes intertribal Native American conflicts, the fur trade, European colonization, logging and damming, and today recreation (McMahon 2002).

Figure 2 – St. Croix River Basin Land Cover, 2001



Understanding the history of the St. Croix River Basin is significant to this project, because the changes in the use and development of the area have caused pronounced impacts on the river system and surrounding environment. Knowing how the landscape has been changed over time, from pre-European settlement conditions to being protected under conservation legislation, allows for an effective analysis of the factors contributing to a disparity in streamflow change within the basin.

Pre-settlement Conditions

Prior to the signing of the 1837 Chippewa Treaty, which opened the St. Croix area to Euro-American settlement, only Native American tribes lived there (U.S. Park Service 2009). The Dakota (Sioux) and Chippewa were the primary tribes, and engaged in more or less consistent warfare (Dunn 1979). This continued even with (and perhaps especially due to) the presence of the fur trade beginning in the late 1700s (Dunn 1979). Besides the social effects that the fur trade had on Native American tribes and Euro-Americans, the environmental impact of intense hunting of grazing animals such as deer, as well as beavers, was significant in changing the St. Croix River valley's vegetation and ecosystems (McMahon 2002). As these animals decreased in number, the open prairie land on which they grazed gave way to vegetative succession, replacing the prairie with Maple-basswood forests along the St. Croix River (McMahon 2002). Both the new forests and those preserved up until European settlement would later be exploited by the logging industry. Having been allowed to grow largely unchecked for centuries, the forests served as ideal sources of timber.

Logging and Damming

It wasn’t until the 1830s that interest in the upper St. Croix as a source of timber picked up (McMahon 2002). Through the construction of dams and booms, and the blasting of rock at strategic locations, the logging industry made the most intensive use of the St. Croix in the river’s history. In the 1850s logging reached its zenith, with the establishment of the St. Croix Boom Company in 1851 (Dunn 1979). This company was the first to take a more systematic approach to logging. The town of Stillwater, WI became the center of the industry, exemplifying how many towns sprang up as a result of logging in the St. Croix River Valley and throughout the US. Perhaps the most intrusive form of control used by the logging industry on the St. Croix and other logging rivers was damming.

In 1889 the St. Croix watershed alone held nearly 70 dams created for purposes associated with the movement and containment of logs (McMahon 2002). Most of these dams were only small headwater dams characteristic of the types of impoundments used for logging. Despite their size, small dams can have a dramatic effect on river function when present in large numbers (McMahon 2002). The damming of and persistent, intensive log driving on the St. Croix and its tributaries caused streamflow to increase significantly, especially directly downstream of logging dams, resulting in considerable streambank erosion (McMahon 2002). Another commonly used structure was the wing dam, which was built out from the shore to control the flow of the river, and guide logs along desired paths and past obstructions (McMahon 2002).

Perhaps the single most consequential dam built on the St. Croix itself was Nevers Dam, built eleven miles upstream of St. Croix Falls in 1890 (Braatz 2003). It was significantly larger than any other dam that had been built, extending 614 feet across and backing up the river for ten to fifteen miles upstream (McMahon 2002). The dam was one of the most historic aspects of the logging industry in the region, yet little physical evidence of the dam remained past 1955 when most of the structure was torn down (McMahon 2002). By the time the last log went down the St. Croix in 1914, vast areas of land had been cleared and debris had been left piled on the ground, leaving those areas susceptible to significant forest fires (Sharrow 2008). Although the role of the St. Croix River itself in the logging industry ended at that time, timber harvest in the basin would continue through the end of the twentieth century (Anderson, 1996).

The mark left by the logging industry in the St. Croix River valley was substantial. Within half a century the majority of centuries-old forests surrounding the river had been cleared, resulting in an extreme ecological shift in the area. Intensive logging paired with forest fires disrupted the natural reseeding processes of the forest and prevented the return of old-growth trees that had been over-cleared (McMahon 2002). For example the white pine was the most notable species lost, with over 4,000 square miles cleared for use as timber (McMahon 2002). Reseeding attempts proved unsuccessful, giving way to new species of trees and therefore new ecosystems entirely. Another major effect logging had on the St. Croix River valley was to draw settlers to the area. Just as fur trading had left its permanent mark on the St. Croix landscape, so did logging.

The extensive stream network of the Upper Midwest that enabled such a successful logging industry also paved the way for successful agricultural settlement. The decades following the 1850s found exponential growth in movement of people into the area, and the beginnings of an influx of immigrants to the US in the area (McMahon 2002). By the early 1900s agriculture had found its roots in the St. Croix River valley, but desire for further expansion faced challenges from the forestry movement (McMahon 2002). Nevertheless, the area continued to be developed for use as agricultural land and later recreation.

Recreation and Preservation

As more conflicts arose in the area concerning how the land should be used, there grew a need for an organized means of negotiating these issues. This came in the form of the St. Croix River Association (SCRA), which was established in 1911 (Dunn 1986). More specifically the SCRA grew out of concern on the part of people who saw the river as an opportunity for recreation and tourism, as well as sportsmen and local residents. Up until that point, recreation and tourism weren't seen as the most viable assets of the St. Croix River. In the mid 1800s the area became much more accessible to travelers via railroads and as a result began to attract some tourism. This tourism was limited however, and aside from steamboat use, recreation on the St. Croix itself was also relatively inconsequential at that time. Conversely, by the early 1900s power companies became much more interested in harnessing the St. Croix River for electrical hydropower generation. Companies such as the Minneapolis General Electric Company, the Minnesota Electric Company and the Northern States Power Company were a few that set up operations along the river (McMahon 2002).

Hydropower operations are not without their environmental costs though, and such industry caused local stakeholders to become apprehensive. The SCRA made the preservation of the river for recreation and general enjoyment their mission, although the specific goals of the different members were not always complementary. While sportsmen wanted flowing water and pools suitable for fishing, others wanted wide channels suitable for recreational/tourism-minded boating (McMahon 2002). As tourism and recreation in the area grew through the early twentieth century, the resulting economic gains moved those interests to the forefront of public concern for how the St. Croix River should be preserved.

A pivotal change in the conservation of the river came in 1968. In that year President Lyndon B. Johnson signed the Wild and Scenic Rivers Act, preserving the Upper St. Croix as a wild river (Dunn 1986). Additionally, in 1970 the St. Croix River State Forest was established, adding further protection to the river. The intention for the park was for its bounds to run along the river on either side. The issue with this plan was that much of this area was already developed as residential, riverfront property (McMahon 2002). This created issues between local residents and the National Park Service that wouldn't be resolved fully for several decades (McMahon 2002). Later in 1972 the Lower St. Croix National Scenic Riverway was established in an effort to curb the suburban sprawl that was extending out from the Twin Cities, exemplifying the changing anthropogenic pressures on the area's natural resources (McMahon 2002).

Agricultural Development and Urbanization

Although agriculture was not systematically practiced on a large scale during the early years of the logging industry, people began buying land and settling in the latter half of the nineteenth century, and agricultural development began to increase (Anderson

1996). This change was especially prevalent in the lower St. Croix valley, which is characterized by better quality soil amenable to farming. The number of farms and total acres of farmland in that area grew dramatically until the 1940s, when they peaked and started on a downward trend that continues today (Anderson 1996). The implications of this development include a loss and fragmentation of forested land and wetlands. In Wisconsin alone there has been a loss of at least 4.7 million acres of wetland areas since the 1830s when there were reportedly around 10 million acres of wetland areas (Anderson 1996).

At around the same time agricultural development reached its zenith in the area, population growth began to take off. Following World War II population boomed in the area, as did the associated urbanization. Between 1960 and 1990 population in the lower St. Croix valley itself doubled from around 142,486 to 294,206 people in the counties comprising that area (Anderson 1996). Table 1 on the following page shows how population in the sixteen counties of the St. Croix River Basin, specifically the percentage of the population that is rural versus urban (US Census Bureau 1990, 2000). Between 1990 and 2000 population increased in every county, and the percentage of the population living in urban areas rose in six of the sixteen counties, as well as overall.

Cities such as Stillwater that had served as hubs of activity for the logging industry became increasingly urbanized throughout the end of the twentieth century, with low-density residential development extending outward into the surrounding areas (Anderson 1996). Although low-density development does not have the same magnitude of environmental impacts as high-density, urban development, it can still significantly affect the surrounding landscape. As with all development, it can result in the very least in increased runoff and decreased evapo-transpiration. Additionally, any focused human settlement requires the importation of resources and the exportation of waste, and often serves as a significant source of water and air pollution (Anderson 1996). The patterns in population growth and the decrease of agricultural land area continue today, indicating that an understanding of how associated land use changes affect river systems and the environment in general will continue to be important for years to come.

Table 1 – 1990, 2000 Rural & Urban Population Comparison (US Census Bureau)

	1990			2000		
County	**Total Population**	**Percent Urban**	**Percent Rural**	**Total Population**	**Percent Urban**	**Percent Rural**
Aitkin	12,425	0.0%	100.0%	15,301	0.0%	100.0%
Anoka	243,641	91.9%	8.1%	298,084	85.6%	14.4%
Bayfield	14,008	0.0%	100.0%	15,013	0.0%	100.0%
Burnett	13,084	0.0%	100.0%	15,674	0.0%	100.0%
Carlton	29,259	34.2%	65.8%	31,671	36.6%	63.4%
Chisago	30,521	0.0%	100.0%	41,101	36.0%	64.0%
Douglas	41,758	66.1%	33.9%	43,287	61.6%	38.4%
Isanti	25,921	19.7%	80.3%	31,287	26.5%	73.5%
Kanabec	12,802	22.7%	77.3%	14,996	20.3%	79.7%
Mille Lacs	18,670	19.9%	80.1%	22,330	17.8%	82.2%
Pierce	32,765	45.1%	54.9%	36,804	38.4%	61.6%
Pine	21,264	12.3%	87.7%	26,530	11.3%	88.7%
Polk	34,773	7.6%	92.4%	41,319	6.9%	93.1%
St. Croix	50,251	32.5%	67.5%	63,155	43.2%	56.8%
Washburn	13,772	0.0%	100.0%	16,036	16.5%	83.5%
Washington	145,896	78.7%	21.3%	201,130	81.9%	18.1%
Total	**740,810**	**57.3%**	**42.7%**	**913,718**	**58.9%**	**41.1%**

Whereas 50 years ago concerns in the area hinged on increasing tourism and agriculture, the mid to late 1900s saw a marked increase in concern for development, extending beyond summer homes to include residential communities and even cities. These dynamic uses of and attitudes towards the St. Croix River mark the general trends in thoughts of the American public; from logging to recreation to development, the St. Croix has served as a critical part of the history of the Midwest. Understanding the history of the St. Croix River Basin has particularly important ramifications for this project, because it provides the background for how land use changes could have caused the disparity seen in streamflow within the basin.

IV. Literature Review: Effects of Logging on River Systems

As a region rich in timber, the St. Croix River Basin has seen intensive deforestation and river alteration by the logging industry. Over the course of half a century loggers made changes to the river system that more than quadrupled its original transportation capacity from 165 miles to 820 miles of usable log floatways (McMahon 2002). This provides an excellent example of how great the magnitude of changes made to the river is. In order to optimize a river system for use in log transportation, channels are narrowed and straightened using piers and wing dams, the bed structure is homogenized, and dams are constructed to regulate flows (Nilsson 2005). These alterations make floating logs much easier, because they remove obstructions and increase flow velocity. However, they have marked effects on the river systems they aim to control. The three major categories of impacts logging has are geomorphic, ecologic, and hydrologic. These impacts are similar for all types of river modifications, but there are some differences between channelization and damming. In order to understand the overall impact of anthropogenic activities on a river system, it is useful to consider the total geomorphic, ecologic and hydrologic effect of the logging industry, specifically involving channelization and construction of dams.

i. Channelization

Channelization is a technique of river modification that is utilized for a variety of purposes. For rivers intended for use as log floatways, the effects of channelization differ from those associated with other types of channelization, because only the specific portions of a river where logs get stuck in transit, such as rapids or riffles, need to be altered (Nilsson 2005). Riffles are shallow stretches of a river that form between deeper pools, causing choppier water ("Pool and Riffle" 2010). However, these discrete, segment-based changes can result in cumulative effects on the entire river (Nilsson 2005). For example, the flora and fauna in reaches with high flows are often diverse, differing from those in slower moving reaches. Accordingly, the alteration or narrowing of these channels can cause a loss of biodiversity in the river as a whole, a decline in land-water interaction, an increase in streamflow velocity, and an increase in the erosion of streambanks (Nilsson 2005).

Channelization can involve the blasting of boulders, rocky outcrops and large woody debris; the installation of wing dams, stone piers and splash dams; and the construction of flumes for avoiding steep or turbulent reaches (Nilsson 2005). All of this is done to make it easier for logs to be floated downstream efficiently. Changes to the channel normally begin during dam construction due to altered water and sediment flows (Brandt 2000). Generally, the geomorphic changes to a river caused by channelization include decreased channel roughness, steeper streambank gradients, and shorter overall flowpath distances (Nilsson 2005). While these geomorphic changes contribute to the transportation of logs, they also homogenize the channel and cause a number of secondary changes that significantly alter the river system. When a stream is straightened, water is able to flow more quickly and easily, and there is typically an increase in shear stress on the streambed and banks, as well as an increase in the sediment transport (Nilsson 2005). Shear stress occurs when something slides along a plane parallel to the sliding material. Shear stress and sediment transport lead to increased rates of erosion of the channel, greater instances of sedimentation and flooding in downstream reaches, and, if they were present before channelization, riffle-pool sequences are disrupted (Nilsson 2005). Once removed, boulders, rocky outcrops, and large woody debris are hard to reintroduce to a river with the intention of recreating the pre-channelization state. It is possible to add some variation back to the channel's morphology, however this form of restoration really only serves the purpose of lessening the future impact of past anthropogenic channel alterations (Nilsson 2005). This establishes yet another different set of physical characteristics that the river will eventually work into a new state of equilibrium quite different from the pre-interference state. The geomorphic alterations made will continue to lead to changes in the ecology and hydrology of the river system.

Within the St. Croix River Basin, channelization and other physical alterations contribute to more variable hydrology ("Water Quality in the Upper Mississippi River Basin – Major Findings" 2005). Mainly, this manifests itself in higher peak flows during storm events and more variably dynamic flows. Streamflow increases and decreases more rapidly, creating greater extremes in water volumes. During the 1800s and early 1900s when logging was prevalent in the area, channelization was used to enable easier movement of logs downstream. However, when the St. Croix River became protected under the Wild and Scenic Rivers Legislation in 1968, restrictions were placed on slope modification (Minnesota Department of Natural Resources 1997).

The increased regulations placed on the St. Croix River significantly alter the way in which future development or flow alteration can occur. The history of the river is wrought with physical alterations associated with the logging industry and more recent development. Accordingly, in order to maintain near-natural conditions within the river system, such alterations must not only be taken into account, but potentially remedied or removed where possible. These concerns transfer directly to the issue of damming along the riverway and adjoining tributaries, which left perhaps the most pronounced hydrologic legacy of the logging industry's activities in the region.

ii. Construction of Dams

There is no question that building a structure that obstructs a river's flow will have lasting effects on the entire river system. Undisturbed alluvial channels exist in a naturally maintained equilibrium that evolved over thousands of years (Brandt 2000). The damming of these channels causes the sudden disturbance of this equilibrium, completely upsetting the natural river system function and defining a new state of equilibrium, or as is often the case, disequilibrium (Nilsson 2005).

The reasons for constructing a dam generally center on human-related needs, such as storing and distributing water, providing hydropower for the generation of electricity, and regulating flow for more efficient transportation of goods. In this way, dams can be extremely beneficial to society. They can prevent and control flooding, distribute water for irrigation purposes, and provide water for urban and industrial use (Rosenberg 1997).

Conversely, dams have the potential to be harmful not just to the environment, but also to society. Dams often disrupt the natural distribution of water and sediment, causing a loss of water for irrigation and urban water supplies downstream, as well as a loss of soil fertility (Rosenberg 1997). Additionally, the productivity of wildlife, especially fish, can be adversely impacted. By obstructing the river channel, a dam alters all aspects of its function, including flow of water, sediment, nutrients, energy and biota (Ligon 1995). These effects are felt as close as immediately downstream from the impoundment, and as far away as at the mouth of the river (Rosenberg 1997).

In general, dams are constructed to control flooding and sediment deposition, generate electric power to supply water for municipal and industrial needs, or for a combination of purposes (Brandt 2000). The downstream effects of hydroelectric power production can extend over large spatial extents and long periods of time, altering natural hydrologic and ecosystem processes (Rosenberg 1997). In Northern temperate zones, hydroelectric developments generally retain the higher spring flows and release above normal flows in the winter, when there is a greater demand for energy (Rosenberg 1997). The general physical and chemical changes to downstream areas associated with large-scale streamflow modification include: the destruction of wetlands, increased salinity and saltwater infusion, decreased sediment inputs and the eventual loss of coastal deltaic areas and deltaic levees, and the loss of nutrient inputs to estuaries in the spring (Rosenberg 1997).

Dams built on rivers that are used as log floatways tend to be smaller structures compared to those intended for other purposes such as power generation (McMahon 2002). Examples of some structures associated with logging operations include wing dams, which only extend partway into a river channel and force water to flow in the faster-moving center of the channel, small headwater dams and log booms, which are barriers placed in the channel to catch and redirect logs. Although large dams have a significant influence on the hydrologic cycle due to their sheer size and capacity, small- and medium-sized dams, such as those used in logging operations, often contribute more to river fragmentation, because they are generally found in greater densities (Chin 2008). The fragmentation caused by small- and medium-sized dams is enough to disrupt ecosystem function (Chin 2008). Additionally, dams have a variety of other ecological, geomorphic and hydrologic effects on the river networks they impair. Impacts are different for every dam, depending on situational factors, such as the latitudinal location of the dam and its size/type (Rosenberg 1997). Similarly, the resulting effects of dam removal and associated restoration efforts are unique for every impoundment and therefore must be considered on a case-by-case basis for effective analysis.

Effects on Streamflow

When a dam is constructed, its most obvious and immediate impact is that of limiting the natural flow of water and sediment, resulting in a reduction of both. Accordingly, a decrease of peak discharges, sediment-carrying capacity and stream power generally accompany dam construction and operation (Brandt 2000). In addition, the flow patterns of a stream can change dramatically with damming (Brandt 2000). It is normal for there to be fluctuations in streamflow over time, the most prominent being the annual shift from high flows during the wet season to lower flows during the dry-season. With the construction of dams, specifically those that retain water for use in the generation of electricity, these natural patterns are often dramatically altered.

Diurnally, dams often release more water during the daytime, when it is necessary to generate more electricity to meet demand, than during the nighttime, when there is less demand (Brandt 2000). Annually, wet-season flows are often retained for release during the dry season, when more water is needed for irrigation or consumption, which is completely opposite the natural fluctuation in streamflow (Brandt 2000).

Effect on Sediment Transport

Dams also act as substantial barriers to sediment transport. This can have negative implications for the lifetime of the reservoir and impoundment themselves, as well as for the deposition of sediment downstream (Brandt 2000). To a large degree, the magnitude of these changes depends on the size and location of the dam. If the reservoir is large, a large proportion of the sediment flow can be trapped, greatly reducing the amount released to downstream areas (Brandt 2000). This trapping can also affect the grain size of sediment discharge, because larger particles are more likely to be caught, causing only finer grains to continue downstream (Brandt 2000). If the reservoir is located in an area with a greater propensity for soil erosion, especially in tropical or arid regions, sediment trapping can cause severe changes to the geomorphology of both upstream and downstream fluvial systems (Brandt 2000). Because of the potential that exists for the excessive deposition and trapping of sediment behind impoundments to decrease the life of the reservoir, there have been a number of techniques developed to alleviate it. Two of the most common methods used are: sediment sluicing and sediment flushing.

Sediment sluicing involves allowing sediment to be carried downstream with the water running through a dam before it is deposited within the reservoir (Brandt 2000). This technique keeps sediment loading relatively equal to that of normal flows (Brandt

2000). In sediment flushing, sediment had already been deposited within the reservoir. It is then eroded and transported through outlets in the dam when the water level is lowered within the reservoir to encourage the erosivity of the outflow (Brandt 2000). This can result in far above normal levels of sediment to be released at a single time, causing sediment transportation rates to be equal to or higher than those of natural flows (Brandt 2000).

Although these may seem like reasonable methods of alleviating the strain of sediment deposited within a reservoir while preserving the natural processes of sediment transport, even if the volume of sediment discharged is large, the composition of this sediment is often so fine that it does not contribute to river channel creation (Brandt 2000). Based on the importance of there being variation in sediment grain size in order to build and maintain the morphology of a stream channel, it is important to consider the composition of sediment flowing downstream prior to dam construction when studying the effect of the dam on geomorphic processes post-construction. The effect that a dam has on downstream reaches can vary significantly based on differences in the water and sediment flows comprising the dam input, as well as how they interact with the downstream channel (Brandt 2000). Additionally, the number of dams on a given stream can also drastically impact how the stream system responds to such development (Brandt 2000).

Small Dams and the Effects of Fragmentation

Although the vast majority of dams in the US are small- or medium-sized, they tend to be clustered within the same river systems, causing an intensification of the barriers they present to natural hydrologic function (Chin 2008). The greater density of these smaller dams thus results in significantly more fragmentation than a single, larger dam would cause (Chin 2008). This fragmentation decreases the ratio of riparian vegetation to unit of stream area, thereby restricting land-water interactions (Nilsson 2005). Losing this connection causes significant changes to river ecology, because the habitats of the diverse flora and fauna that depend on that relationship are fragmented, often resulting in a loss of some species altogether and creating a lack of biodiversity. Some restoration efforts in such areas following dam removal focus on developing nursery habitats in order to reestablish the relationship between the riparian vegetation and the river (Nilsson 2005).

Other restoration efforts that don't involve dam removal incorporate efforts to create a 'closer-to-natural' environment. This can be achieved through regulating flows in such a way to mimic natural "run-of-river" flows. For example, the St. Croix Falls dam is located upstream of one of the few remaining populations of winged mapleleaf mussels worldwide ("Hydropower Dams" 2010). The sometimes-erratic flows of such a dam, particularly the above-normal peak flows, directly threaten the continuing presence of the mussel population inhabiting downstream areas. Due to the size and use of the St. Croix Falls dam for hydropower operations, removal is not a viable option. In this instance, "run-of-river" flows were re-established in an effort to strike a balance between preserving downstream ecosystems while maintaining the hydropower functions of the dam ("Hydropower Dams" 2010)

iii. Dam Removal and Restoration

Considerations Prior to Dam Removal

When assessing the reasons a river channel and its associated ecosystems have experienced significant changes, damming cannot be automatically assumed to be the only or primary factor. It is therefore important to use a number of criteria to determine if the damming was indeed the source of the changes. Williams and Wolman (1984) determined a series of criteria that can be used for this purpose while conducting investigations on rivers in the US (Brandt 2000). The criteria Williams and Wolman used are: (1) adverse effects are greatest closest to the dam; (2) low flow characteristics indicate that the stream channel was generally stable prior to construction; (3) erosion of upstream and downstream sections differs, with the riverbed downstream tending to erode while the riverbed upstream remains relatively unchanged; and (4) calculating pre-dam streambed elevations from degrading channels produces unrealistically high elevations (Brandt 2000). If these criteria are met, then the geomorphic and hydrologic changes that a river has experienced can be attributed to consequences of damming, but otherwise more investigation is needed.

The process of determining whether a dam should be removed is often complicated by a number of factors, including the interests of groups/individuals involved in its operation or the local environment (both natural and built). The initial consideration of the viability of removing a dam generally occurs when a dam has reached an age where the cost of repairing or replacing it outstrips the benefits of its continued operation. The Wisconsin Department of Natural Resources (DNR) has three main criteria for discerning whether dam removal is the best option, which are included in state statutes: (1) the dam is no longer safe, (2) the dam has been abandoned by its owner, and less commonly (3) environmental concerns necessitate dam removal ("Dam Removal – WDNR" 2008). Often it is smaller dams that are removed, resulting in less pronounced impacts on the river system than the removal of a large dam would.

Impacts of Restoration

Just as the ecological, geomorphic and hydrologic effects of various river modifications vary so too do the corresponding processes and impacts of restoration attempts. Dams have been decommissioned with greater frequency over the past century. Although the reasons differ in each case, there are a number of primary reasons that make the destruction of the structure a better option than performing maintenance on it. These include concerns relating to safety, the cost of remediation, and the environmental impacts of keeping the dam in operation (Neave 2009). However, simply removing a dam is not enough to return a river system to its pre-dam construction state. Additionally, the changes that occur following dam removal have not been studied as thoroughly as the effects of dam construction and operation, making any dam removal and restoration project an experiment with little to no scientific background to serve as a guide (Neave 2009). As dams in the US near the end of their operational design lives, as 85% percent will by 2020, such research will be in even greater demand (Neaves 2009). Although this field is still evolving, there is a lot known about how a river system might respond to the decommissioning of an impoundment. In Wisconsin, the DNR identifies several significant benefits of dam removal, including the renewal of continual fish habitat, normal temperature routines, water clarity and oxygen levels, normal sediment and energy flows, and ecosystem biodiversity ("Dam Removal – WDNR" 2008). Each dam that is proposed for decommissioning must undergo an environmental assessment that determines the risks and benefits of its removal.

Ecologically, there are positive implications of dam removal, including an increase in biodiversity (Neaves 2009). However, significant changes in streamflow and sediment loading could adversely affect ecosystems (Neaves 2009). For example, for impoundments with large reservoirs that drastically limit the natural flow of water and sediment, removing the dam will cause an increase in the amount of water and sediment a downstream reach receives. This has the potential to severely upset any adaptations made by the river system to lower flows, disturbing established ecosystems.

Geomorphologically, the river channel upstream from the dam can be dramatically changed as a result of incision following dam removal, altering the flow rate and erosion of streambeds further downstream (Neaves 2009). In wide and deep channels, significant sediment mobilization following dam removal can cause channel erosion and incision (Neaves 2009). Smaller streams with certain streambed materials, including cobbles, boulders and bedrock, have been found to be relatively resistant to geomorphic changes following removal (Neaves 2009). This indicates the need for consideration of a stream's physical characteristics in plans for dam removal.

The anthropogenic changes that have been made to the St. Croix River Basin are substantial, at times inflicting permanent damage. Understanding how the landscape has changed and how these changes have in turn altered the hydrologic functions of the basin is important to producing an accurate model. The background to the area was critical to informing the methodology used for this project, specifically in selecting a model and deciding what was important to include in the final database. Additionally, without knowledge of the physical ramifications of how the study area has been shaped in the past, it would have been impossible to understand the reasons behind trends that exist in the results, or to propose solutions to problems encountered during analysis. Hydrologic systems such as that of the St. Croix River Basin are extremely complex, and therefore the many factors that impact them must be understood in order to form a successful simulation.

V. Methodology

Due to the multifaceted and complex nature of how watersheds function, using a model is the best way to estimate the effects of many different, yet interrelated factors on streamflow. Specifically, hydrologic models estimate parameters, which cannot be measured directly, to as close to their observed values as possible (Zhang 2008). This project seeks to examine specific aspects of watershed processes, focusing on how streamflow is affected by anthropogenic changes to land cover and natural stream geology. The Soil and Water Assessment Tool (SWAT) was used to simulate the effects of these changes to the St. Croix River Basin, with a focus on spatial and temporal patterns. To provide for the integration of GIS data into the SWAT model, the graphical user interface ArcSWAT was used within ArcInfo. In order to achieve the analyses, several simulations were run, with variations made in parameter values in an attempt to get the model outputs to match observed values as closely as possible. Although this project initially aimed to provide a spatial and temporal analysis of streamflow change in the St. Croix River Basin, new goals were formed in response to a lack of necessary LULC data These include focusing more on understanding how SWAT works, and establishing an accurate base simulation as well as a comprehensive database.

i. Model Selection and Overview

In order to determine the most suitable model for achieving the project goals, several hydrologic models were evaluated for their appropriateness. Through this evaluation two well-respected hydrologic models were selected as potential candidates: the Soil and Water Assessment Tool (SWAT), and the Hydrologic Modeling System (HEC-HMS). Both models simulate runoff and other watershed functions in large- and small-scale watershed networks, as well as work in conjunction with pre-processing programs that operate within ArcMap to provide seamless integration of GIS data into modeling. However, there are some key differences that distinguish the two models from each other, primarily concerning their intended applications.

HEC-HMS

HEC-HMS was developed by the United States Army Corps of Engineers (USACoE) Hydrologic Engineering Center (HEC) to run precipitation-runoff simulations for a variety of applications in dendritic watershed systems ("HEC-HMS"). The literature cites use of the HEC-HMS primarily for studying single flood events or drainage systems in urban areas (Sensoy 2007, Zhang 2008). Although HEC-HMS can be used to study precipitation-runoff processes in larger study areas, such as the St. Croix River Basin, it is not designed to quantify the effects of land management practices on such areas. Due to the importance of this element to the project, HEC-HMS is not the most appropriate choice.

SWAT

The SWAT model was developed for the United States Department of Agriculture's (USDA) Agricultural Research Service (ARS) by Dr. Jeff Arnold (Nietsch 2005). It is primarily intended as a means of quantifying the effect of land management practices on river basin or watershed processes such as streamflow, sediment yield and agricultural chemical yields (Nietsch 2005). The model requires specific, physical data. Based off of these data the model can simulate the movement of water, sediment and various chemicals (Nietsch 2005). Through the integration of such data, the SWAT model allows the user to control which hydrologic processes to study, allowing for the selection of which locally determined and pertinent variables to examine. The model can be run over long periods of time, as opposed to being limited to the short-term duration of a single flood event, as is the case for many other hydrologic models (Nietsch 2005). Although many applications of the SWAT model deal with issues of water quality as well as sediment and chemical loading, the model was used in this project to simulate how changing land uses/covers (LULC) within the study area have affected streamflow in the St. Croix River over time. The SWAT model was chosen over HEC-HMS because of its ability to take land management practices into account when simulating long-term streamflow trends and hydrologic processes over a relatively large basin.

ii. Data and ArcSWAT Preprocessing

In conjunction with the SWAT model, ArcSWAT was used to preprocess GIS data. ArcSWAT is an extension to the SWAT model that runs within ArcGIS. It provides a graphical user-interface that allows for GIS data to be easily formatted for use in SWAT model simulations. Necessary software and data are readily accessible and can be found for free online largely from governmental agencies (see USGS <http://www.usgs.gov/pubprod/data.html#data>, and the USDA <http://soildatamart.nrcs.usda.gov/>). Other similar preprocessing programs were considered, however ArcSWAT was chosen because it is produced by the same organization that produces SWAT, and because it can also be used to organize and view model outputs. ArcSWAT breaks preprocessing into three main steps: Watershed Delineation, Hydrologic Response Unit (HRU) Analysis, and Weather Data Definition. One of the benefits of using ArcSWAT to preprocess data for the SWAT model is that the amount of data required depends on the level of analysis desired. For a basic simulation, only a few datasets are required. Each section requires specific datasets and allows for additional user-provided datasets to be added in order to allow for a more complex analysis. In order to understand how each section works within the modeling process, it is important to understand the conceptual framework of each step, as well as what data are used and how they are integrated into ArcSWAT. Therefore, first a general overview of the data used for this project will be provided, and then the three major steps of ArcSWAT preprocessing will be covered in depth.

Overview of Data

A significant portion of this project involved the collection, organization, and formatting of data. Prior to this project, there did not exist a single, centralized database that housed all available data for use in the model, as well as more general datasets that are useful for understanding the study area and are relevant to the research topic. Data were primarily found online from national and state level governmental organizations, as well as from universities (See the Technical Appendices). All data were projected into NAD 1983 UTM Zone 15N, as they all cover the same area within Minnesota and Wisconsin, which falls within Zone 15. Most data collection was completed before the SWAT model was selected; therefore further formatting was required to prepare them for specific uses within the model. Each menu of the ArcSWAT extension in ArcMap requires different data layers to run. A detailed list of data and sources can be found in the Technical Appendices.

As previously stated, ArcSWAT breaks preprocessing into three main sections: Watershed Delineation, HRU Analysis, and Weather Data Definition. The outputs from these steps are then used as inputs for the SWAT simulation. Figure 3 on the following page shows a basic flowchart of how GIS layers are integrated into ArcSWAT and prepared for a simulation of the SWAT model. The major components of the model, Watershed Delineation, HRU Analysis, and Weather Data Definition, are described in the following paragraphs.

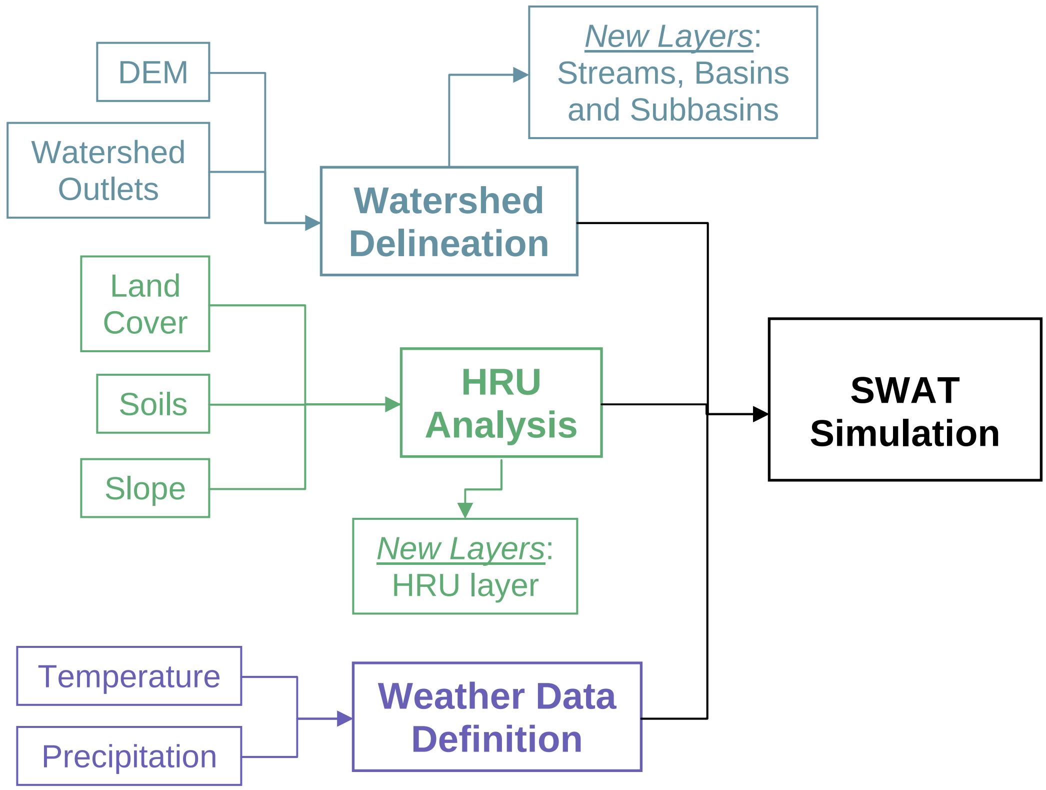


Figure 3 - Flowchart of ArcSWAT Preprocessing Steps

Watershed Delineation

The 'Watershed Delineation' section of ArcSWAT's data preprocessing allows for the formatting of data in preparation for dividing the watershed into subunits. This is particularly useful when there are distinct areas within the watershed that are primarily of one land use or soil type. Subdivision allows for the differentiation of these areas, so that the associated impact on hydrology can be more accurately measured and studied (Neitsch 2005). The primary division made is on the subbasin level, and is determined based on the relative spatial location of each subbasin, the direction of hydrologic flow and the natural divisions of stream networks determined by elevation. A digital elevation model (DEM) is the only required dataset for this step. The DEM used for this project came from the USGS' National Elevation Dataset (NED). Several smaller DEMs were combined into one dataset using the 'mosaic' tool in ArcInfo so that the single outputted dataset would cover the entire study area. Originally a DEM with ten-meter accuracy was used, however this proved to provide an unnecessary level of detail given the size of the study area, therefore a thirty-meter accuracy DEM was used instead to speed up processing times (Jim Almendinger, personal communication, February 15, 2010).

Another important function of the Watershed Delineation section is to determine where streams are located and how they are networked within the subbasin. This information is then used to determine where subbasin boundaries are located. It is important that this designation is fairly accurate in order to have a successful model simulation. It is possible to determine stream locations solely from the preloaded DEM, but to ensure the best fit of stream networks to the DEM a user-supplied stream layer can be 'burned-in.' For this project, the stream data used originated from the National Hydrography Dataset (NHDPlus), which is highly detailed, takes into consideration elevation data, and is known to have minimal errors (NGTOC Web Team 2010). *Reach* and *MonitoringPoint* layers are created for the ArcSWAT-determined stream network and the inlet/outlets, respectively.

Outlet and inlet definition, along with reservoir placement, is the last major section of Watershed Delineation. While ArcSWAT determines the majority of stream intersection points, some editing is required. Firstly, some 'linking stream outlets' were deleted if they fell within a reservoir that should belong in a single subbasin. Secondly, a user-supplied table of outlet locations was imported and integrated into the ArcSWAT-determined points layer. These outlet locations were determined based on the most downstream points of watershed boundaries that were intersected by a major stream channel. The watershed boundary data were obtained from dissolving the USDA-produced HUC-8 subwatershed boundaries. HUC-8 refers to the length of the hydrologic unit code for a boundary file, which in this case is eight digits. This serves as an indication of the scale at which the boundaries were determined, with an 8-digit code meaning ‘hydrologic cataloging units’ were used at a scale of 1:24,000 (“Hydrologic Unit Information” 1998). All hydrologic boundary files were obtained from the USDA in order to maintain continuity between boundary definitions, which tend to vary slightly depending on the data source. All user-supplied points are added to the *MonitoringPoint* layer. The outlet/inlet definition for this project resulted in the generation of 192 subbasins. The data used for the watershed delineation were kept constant throughout all of the model runs, as it was assumed that the elevation and hydrologic unit boundaries would not change significantly over the temporal scope of the project.

ArcSWAT groups lakes, reservoirs, retention ponds, and other large waterbodies under the same ‘reservoir’ category. At the end of watershed delineation, the user has the option to designate the location of reservoirs within each subbasin. Only one reservoir can be added for each subbasin, so if there are multiple present, their respective areas and volumes must be aggregated and considered part of a single feature. For this project, the twenty to twenty five largest lakes/reservoirs that intersected the streams layer created by ArcSWAT and fell within the St. Croix River Basin boundary were queried out of the NHDPlus waterbodies layer. Points were then added in ArcSWAT over the locations of these features.

HRU Analysis

The HRU Analysis section takes land use, soil and slope data, and divides each subbasin into hydrologic response units, with specific combinations of the three layers' respective characterizations. The layer produced by this process is crucial to the ultimate analysis performed by the SWAT model, because it determines the land-soil category assigned to each HRU. This category determines how land will respond to precipitation, runoff, infiltration and other hydrologic processes during the simulation. Each subbasin can then have one or more major HRUs defined within it.

The following three datasets are required inputs for the HRU Analysis section of ArcSWAT setup: land cover, soils, and slope. Land use data were obtained from the USGS' 2001 National Land Cover Database (NLCD) for that year. The 1992 NLCD layer as well as historical data relevant for the period from 1970 to 1985 was also included in the project geodatabase, although they were not used for model simulation. ArcSWAT requires that land cover data be accompanied by a look-up table with attribute information for each specific land cover type, and provides these tables for the 1992 and 2001 NLCD layers. Any other LULC data desired for use in the model require user-supplied look-up tables that are formatted to fit the ArcSWAT's requirements.

Soil data used for the SWAT model are typically obtained from one of two databases produced by the National Resources Conservation Service (NRCS): the SSURGO database contains highly detailed soil classifications available at the county level, and the STATSGO database contains more generalized classifications available at the state level. SSURGO data is cited in the literature as preferable to STATSGO due to its higher level of specification, however Pine County in Minnesota did not have sufficient spatial data associated with it in the SSURGO database at the time this project was done. Due to the large area Pine County covers in the middle of the study area, the SSURGO data could not be used. Therefore, the STATSGO soils layer was used for model simulations, particularly because the spatial data and corresponding lookup table are included with the ArcSWAT software. However, it is important to note that the raster file that comes with the ArcSWAT software must be projected into the coordinate system used in the project (NAD 1983 UTM Zone 15N). Additionally, although SSURGO data provides a greater degree of detail, which is useful for simulations in smaller watersheds, it does not provide a significant advantage for the simulation of large basins such as that of the St. Croix River (Jim Almendinger, personal communication, February 15, 2010). Therefore, the STATSGO data is appropriate for use in this project, although if sufficient SSURGO data were available, they should be used instead. The last layer needed for the HRU Analysis setup is slope, which is determined from the DEM supplied during watershed delineation.

Once each layer is loaded, they must be overlaid to determine the HRU features. For every unique combination of slope, land use and soil class an HRU will be created, although within the study area there can be multiple HRUs with the same combination. The user has the option to have ArcSWAT produce an HRU shapefile during this process, but it is not necessary for later analyses. The next step is to define how HRU classifications will be aggregated/transferred to the subbasin level. In order to end up with between 500 and 1000 HRUs in the entire study area, as was suggested by Jim Almendinger (personal communication, February 15, 2010), the ‘Multiple HRUs’ option was chosen for defining HRUs. This option allows the user to select a threshold for each category individually, starting with land use, then soil class, and finally ending with slope. Every land use that occupies a percentage of the subbasin (or absolute area, depending on the type of threshold chosen) that falls below the designated threshold is removed. This is then done for soil classes and slopes. The purpose of this step is to remove minor land uses/soil classes/slopes and to control the number of HRUs defined in the study area. For this project, the thresholds were manipulated uniformly until an appropriate number of HRUs resulted. Initially, a 10% threshold was used, but this proved to result in too many HRUs, so 15% was chosen. The final number of HRUs produced for this project was 737.

Weather Data Definition

The final major section of preprocessing done in ArcSWAT is ‘Weather Data Definition’. National weather station data are available as part of the ArcSWAT software, or user-provided weather data in tabular form can be used. Although the ArcSWAT software includes a national level dataset of weather data, locally collected data from weather gage stations within the St. Croix River Basin and surrounding area were used to provide greater accuracy. Weather data necessary for running a basic SWAT simulation are precipitation as well as maximum and minimum temperatures for each weather station. Because precipitation is so crucial to the simulation of watershed function, providing local precipitation data at the very least is important. Temperature data are also supplied for this project.

Data were obtained from the Utah Climate Center at Utah State University (available at: <http://climate.usurf.usu.edu/products/data.php>), and were collected by the National Weather Service's (NWS) Cooperative Observer Program (COOP). In line with the requirements for SWAT inputs, precipitation was measured in millimeters and temperature in degrees Celsius (Winchell 2009). When downloading data for use in the weather tables, individual gage stations were chosen based on their relative locations within and around the study area, and whether they had consistent levels of data available from 1920 through 2008. The stations chosen were: Danbury, Hinckley, Mora, River Falls, Cambridge, St. Croix Falls, Spooner, Moose Lake, Solon Springs, and Cumberland. The stations located at Danbury and St. Croix Falls were particularly important, as they served as the comparison points to data collected by the USGS (Lenz 2004). Once database setup is complete in ArcSWAT, the designated weather station locations are added to the *MonitoringPoint* layer created during Watershed Delineation.

Creation of Input Files

The last step before a SWAT simulation can be run is to write all of the input files required by SWAT and produced from the preprocessed data from ArcSWAT. Once they are written, individual files can be edited through ArcSWAT, or externally. Because it is cumbersome to edit information for each subbasin, reservoir, etc. individually in ArcSWAT, tables were linked to an Access database, and automatically updated based on predetermined queries. Making edits to a selection of these files is crucial to producing more accurate SWAT simulations and outputs (Jim Almendinger, personal communication, February 15, 2010). The files updated for this project are: *mgt1*, *res* and *gw* (management, reservoir and groundwater input tables, respectively). Many of the modifications aim to correct the SWAT model's under-exaggeration of soil infiltration.

Without these changes, the base flows simulated by SWAT are lower than actual levels, and the peak flows are much higher than actual levels. Several combinations of modifications were tried. What follows is the best attempt using values deemed appropriate while meeting with Jim Almendinger (personal communication, February 15, 2010).

The *mgt1* table contains attributes for every HRU defined during HRU Analysis. There is also an *mgt2* table, but it is not edited, because modifications are required only if crop rotations are taken into consideration when designating agricultural land types. In the *mgt1* table, only the ‘CN2’, or curve number, field is changed. By decreasing the values in this field, by 25% for this project, greater infiltration is accounted for, correcting part of the SWAT underestimation.

The *res* table contains information for every reservoir designated during Watershed Delineation. The major change made to this table is updating the normal, principal and emergency surface areas and volumes for each reservoir. Normal surface areas were collected from Lake Survey Maps from the Minnesota and Wisconsin Departments of Natural Resources, as were the normal volumes for many lakes/reservoirs. However, whereas the surface area was always provided on these maps, the volume was not. Therefore the missing volumes were calculated using the surface area and calculus techniques for calculating the volume of solids (using the topographic elevation data provided on each map). The principal volume was calculated to be 15% less than the corresponding normal value, and the emergency volume was calculated to be 15% greater than the corresponding normal value. Within the *res* table, the ‘NDTARGR’ field, which is the number of days it takes water to travel from the reservoir to the target storage, is also modified (Nietsch 2004). For this project, 'NDTARGR' was set to 2 for every reservoir. Another specific field that is edited is 'RES_K', which was set to 0.3. 'RES_K' is the capacity of the reservoir bottom to allow water to move through it (Nietsch 2004).

The *gw* table holds ground water information, including infiltration specifications. The values in three fields are updated in this table. The first is 'RCHRG_DP', which is the deep aquifer percolation fraction (Nietsch 2004). This accounts for the amount of water that disappears from the system into the deep aquifer, with values between 0.0 and 1.0. For this project, 'RCHRG_DP' is set to 0.3. The second field that is updated is 'GW_DELAY', which is the number of days it takes water to leave the lowest soil profile to get to the water table (Jim Almendinger, personal correspondence, February 15, 2010). For this project, 'GW_DELAY' was set to 15. The last field in the *gw* table that was modified was 'ALPHA_BF', which explains the response land has to recharge, with larger values representing a quicker response on a scale of 0.0-1.0 (Nietsch 2004). For this project, 'ALPHA_BF' was set to 0.3. Changing this value results in a change in the steepness of the declines from peak flows to base flows (shrinking or stretching).

Through modifying the input tables, the user has much more control over how the results of model simulations will look. No model is completely accurate, so using external data and manually modifying parameters is important to ensure a more accurate simulation of real-world systems. After tables are updated, they must be rewritten into the ASCII format required by the SWAT model for inputs, which is done by ArcSWAT (Winchell 2009). This command can be found in the 'Edit SWAT Input' menu as 'Rewrite SWAT Input Files.'

iii. Analysis Methods Using SWAT

Based on available data, analyses were performed to compare the streamflow rates at Danbury and St. Croix Falls gage stations to each other, and to the USGS data. Parameters were tweaked to create the base scenario, which attempts to simulate real, observed conditions.

Base Scenario

The base scenario runs for the six-year period from 2000 to 2005. It was found that starting the simulation in 1999 rather than in 2000 produced better, more complete streamflow data for early 2000, so the simulation was actually started in 1999, while only data from 2000 on was graphed and included in the results. This was determined after several model runs, where it became apparent that the model required some time to warm up before more accurate results could be obtained. The NLCD 2001 was used, as it is the most accurate LULC data available. The parameter values discussed in *Creation of Inputs* (under *ii. Data and ArcSWAT Preprocessing* in the Methodology section) were set to corresponding values found in that section. In order to obtain more detailed results, a daily time-step was selected. Once the simulation was run, output tables were uploaded into a database and linked to a second Access database, where pertinent information was selected out and graphed.

iv. Presentation of Data in Results Section

The results of the model simulations for the Danbury and St. Croix Falls gage stations were compared to the USGS data collected for the same two stations for the 2004 report (see Lenz 2004). This was done in order to establish the credibility of the model results. Modeled streamflow information was determined from the "Flow_out" field for each subbasin. For this project, only the streamflow data at the Danbury and St. Croix Falls gage stations were considered. Data are presented for each station in graphical form by day for each year of interest, as well as aggregated into monthly averages over the five-year period. A series of summary tables is also provided.

VI. Problems and Limitations

Prior to analyzing the results of the SWAT simulations, it is important to discuss the problems and limitations encountered during the course of this project. The original goal was to provide a spatial and temporal comparison of streamflow data within the St. Croix River Basin, looking at changes in upstream vs. downstream reaches of the river over the past century. This ended up being largely revisited, due to limitations placed on the project by data quality and availability, as well as flow calculation errors within SWAT. As mentioned earlier, establishing a substantial base for future analysis, as well as understanding how SWAT works and can be applied to this project became the focus of this project.

Data Availability & Quality

One of the major limitations of this project was the quality and availability of data pivotal to accomplishing model simulations of land cover changes and streamflow. LULC data was the main issue. In order to accurately compare the changes in land uses within the basin over time, an accurate set of data was pivotal. However, the most accurate and recent dataset of this nature is the 2001 NLCD, which differs drastically in how it categorizes land cover from the next most recent dataset, the 1992 NLCD (even though they were both compiled by the USGS). A comparison of these datasets has the capability of producing inaccuracies due to the difference in categorization schemes underlying them. Additionally, the oldest historical land cover dataset found was only relevant for the time period from 1970 to 1985, and the scheme used to categorize land cover was further simplified and dissimilar to that of the NLCD layers. Because of the central importance of LULC data to the comparison of changes in land cover within the basin over time, the lack of available data of a consistent and appropriate quality critically hindered the extent to which land cover change over the past century could be quantified in its effect on streamflow.

Another source of data issues was the lack of available spatial SSURGO soil data for the entire study area. As previously stated, the SSURGO dataset provides much greater detail than the STATSGO dataset. The need to use STATSGO data may have resulted in a loss of accuracy in the infiltration simulated by SWAT based on the dataset's generalized soil categorization scheme. The SSURGO data are currently being updated and could be utilized for future research.

SWAT Flow Calculation Errors

SWAT is a widely accepted model that is often utilized for applications similar to the subject of this project. However, no model is without its shortcomings. Between the 2000 and 2005 versions of SWAT, several changes were made to compensate for some of these shortcomings, but there are still remaining problems with its simulation of real-world watershed function. The main issue with SWAT encountered in this project, centers on inaccurate flow estimation. This was found on both a spatial and temporal level. While the SWAT model generally underestimated streamflow at the upstream gage station at Danbury, it dramatically overestimated streamflow at the downstream gage station at St. Croix Falls. This could be the result of several factors. It is hypothesized in this paper that the inaccuracies in the streamflow data are largely the result of an underestimation and general miscalculation of infiltration, which SWAT has been noted as having issues with (Almendinger 2007). According to Almendinger, the preprocessing of data in ArcSWAT is responsible for some of these problems.

An additional issue involves closed depressions, which are remnants of the glacial history of the Upper-Midwestern study area, are ‘filled’ during DEM processing in the Watershed Delineation step to aid in the determination of subbasin boundaries (Almendinger 2007). The loss of these depressions results in the disregard for the water that enters them and continues on to contribute to groundwater recharge. One way to account for this is to edit the Ponds and Wetlands table, which allows for the allocation of portions of the surface water to drainage into either a pond or a wetland – SWAT allows for one of each per subbasin (Almendinger 2007). Due to the presence of significant wetland areas in the lower portion of the St. Croix River Basin (see Figure 2), allocating ponds and wetlands could produce much more accurate results.

A second means of obtaining more accurate infiltration is to fine-tune the reservoirs within the study area. For this project, approximately twenty of the largest lakes/reservoirs were included. However, the volume of around half of these waterbodies was estimated, and the size cutoff that determined inclusion was arbitrarily chosen. It is possible that adding more waterbodies would improve the estimation of infiltration and hydrologic functions within the model. Additionally, the emergency and principal volumes were estimated to be 15% greater than and less than the regular volume, respectively. Obtaining and using actual values for these fields could also improve accuracy. The proposed solutions to the limitations explained in this section were not incorporated into the final SWAT simulation for this project, but could be useful for future research, as is discussed in the conclusions section of this paper.

VII. Results and Discussion

The SWAT model outputs include four main summary tables of information for the subbasins, HRUs, reaches and reservoirs (*output.sub*, *output.hru*, *output.rch* and *output.res*, respectively). When using ArcSWAT these tables can be loaded into a Microsoft Access database for analysis purposes after the model simulation is complete. The output table utilized for this project was the reaches table (*output.rch*). There are two parts to the results of this project. The first part is a database with all of the data collected and formatted for use in the SWAT model, as well as some additional data that provide background information. These data are detailed in the Technical Appendices. The other part of the results contains the outputs of the SWAT model simulations, which are organized in summary tables and graphs. All values in the tables and graphs are in cubic feet per second (cfs or ft^3/s).

i. Discussion of Graphs

The graphs in this section are the comparison of USGS streamflow data to the streamflow data simulated by the SWAT model at the Danbury and St. Croix Falls gage stations, which were built into the model as subbasin outlets. Simulations were run from 1999 to 2004, with only data from the years 2000-2004 graphed. This was done because the first few months of data in 1999 had lower streamflow values than would be expected; therefore a buffer of one year was given before outputs were analyzed. Overall, the streamflow data simulated by the SWAT model were characterized by lower base flows and significantly higher peak flows than the observed streamflow data collected by the USGS. The overarching trends of the simulated data do generally match the observed data closely, although often at different magnitudes. The SWAT streamflow data for the Danbury site matched the USGS streamflow data much better than that of the St. Croix Falls site. Namely, at the St. Croix Falls site, SWAT simulated many more extreme peaks at much higher magnitudes than the USGS data recorded.

Monthly Mean Flows

At the St. Croix Falls station, the peak in the SWAT data occurs in June, while the peak in the USGS data occurs in April. Overall, the SWAT model underestimated the mean monthly flows at Danbury compared with what was recorded by the USGS, and overestimated the mean monthly flows at St. Croix Falls. At both stations, base flows were underestimated and peak flows were overestimated. Additionally, annual trends in peak flows in the simulated data at St. Croix Falls lined up less consistently with the USGS data than it did at Danbury. Table 2 shows the average monthly streamflow comparison between Danbury and St. Croix Falls for each month across the five year time period from 2000-2004. Averages are calculated for streamflow data simulated by the SWAT model and the streamflow data recorded by the USGS. The SWAT mean flows at Danbury are always lower than is reflected in the USGS data, while at St. Croix Falls they are much higher – at the least they are double the USGS mean flows, and as much as ten times more. Graph 1 shows the mean monthly flows at Danbury for both the USGS and SWAT streamflow data over the five-year period from 2000-2004. Graph 2 shows the same information for St. Croix Falls. As seen in the graphs and Table 2, average streamflow peaks occur earlier in the year at Danbury, as is reflected in the USGS data, and peaks at St. Croix Falls appear to be pushed to later in the year. This is also reflected in Tables 3 and 4, which show the maximum and minimum daily flows at Danbury and St. Croix Falls, respectively, for each year of data collection. Values are calculated for both the SWAT and USGS data. As seen in the two tables, there is a large degree of difference within the SWAT data, both between the maximum and minimum values for each year, and between years. This variability is not seen to the same degree in the USGS data. Tables 3 and 4 also reflect the trends in timing of peak flows seen in Graphs 1 and 2, with average maximum flows at Danbury occurring in line with what is seen in the USGS data, and with average maximum flows at St. Croix Falls occurring later in the year.

The reason for this disparity is not completely clear, however some hypotheses are proposed here. Firstly, it could be due to the fact that Danbury is located further upstream, with fewer tributaries intersecting the main channel above the station, while St. Croix Falls is located much further downstream, with many tributaries and major channels intersecting the main channel above the station. If the SWAT model is miscalculating flow and infiltration, the errors seen in the Danbury data could be exacerbated in the St. Croix data due to a snowball effect. Secondly, land cover is much different upstream of the Danbury than it is between Danbury and St. Croix Falls, as is discussed in the *Study Area Overview* section of this paper.

Summary Tables

Table 2 – Monthly Mean Flow Comparison for 2000-2004 (cfs)

Month	Mean Flow (cfs) - Danbury		Mean Flow (cfs) - St. Croix Falls	
	SWAT	USGS	SWAT	USGS
January	145.80	879.74	5,144.78	2,293.55
February	118.09	916.34	4,426.71	2,366.55
March	186.33	1,216.32	6,515.95	3,930.13
April	810.36	2,559.34	18,559.49	12,413.18
May	644.20	2,066.32	51,482.77	8,916.19
June	665.42	1,478.41	67,020.22	6,726.73
July	709.88	1,221.70	38,689.52	5,238.06
August	589.29	1,039.57	26,936.66	3,391.03
September	547.93	984.75	21,672.68	3,307.53
October	500.17	1,165.21	22,434.82	3,795.81
November	352.54	1,216.88	11,196.35	4,071.53
December	200.34	1,004.26	6,329.48	2,919.61

Table 3 – Danbury Maximum and Minimum Flow Comparison (cfs)

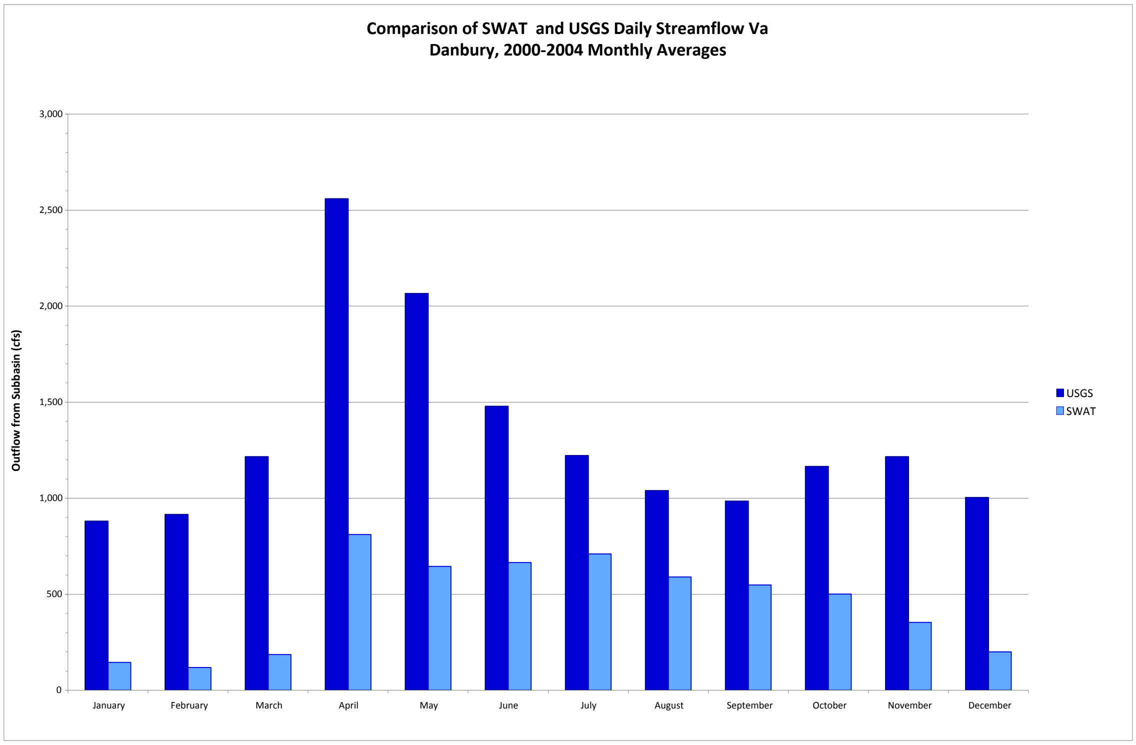
Danbury – 2000-2004				
Year	SWAT		USGS	
	Maximum	Minimum	Maximum	Minimum
2000	5,809.26	24.82	2,420.00	571.00
2001	18,349.50	19.65	10,600.00	750.00
2002	10,043.49	103.40	7,360.00	800.00
2003	4,855.77	62.08	4,690.00	593.00
2004	4,876.96	25.03	4,030.00	680.00

Table 4 – St. Croix Falls Maximum and Minimum Flow Comparison (cfs)

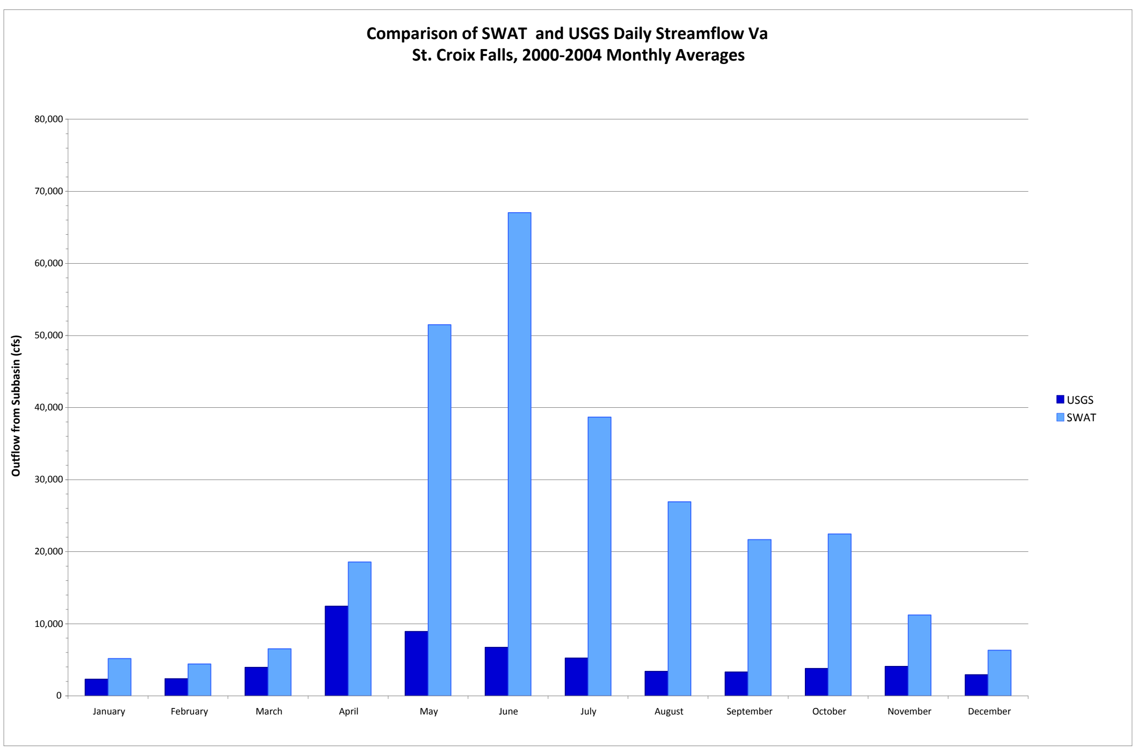
St. Croix Falls – 2000-2004				
Year	SWAT		USGS	
	Maximum	Minimum	Maximum	Minimum
2000	247,485.18	2,253.08	8,690.00	1,510.00
2001	406,118.67	2,323.00	59,500.00	1,770.00
2002	407,531.25	4,375.49	32,300.00	1,940.00
2003	449,555.71	4,763.95	22,200.00	1,690.00
2004	483,810.93	2,727.35	21,400.00	1,650.00

Mean Flow Graphs – Danbury & St. Croix Falls

Graph 1



Graph 2

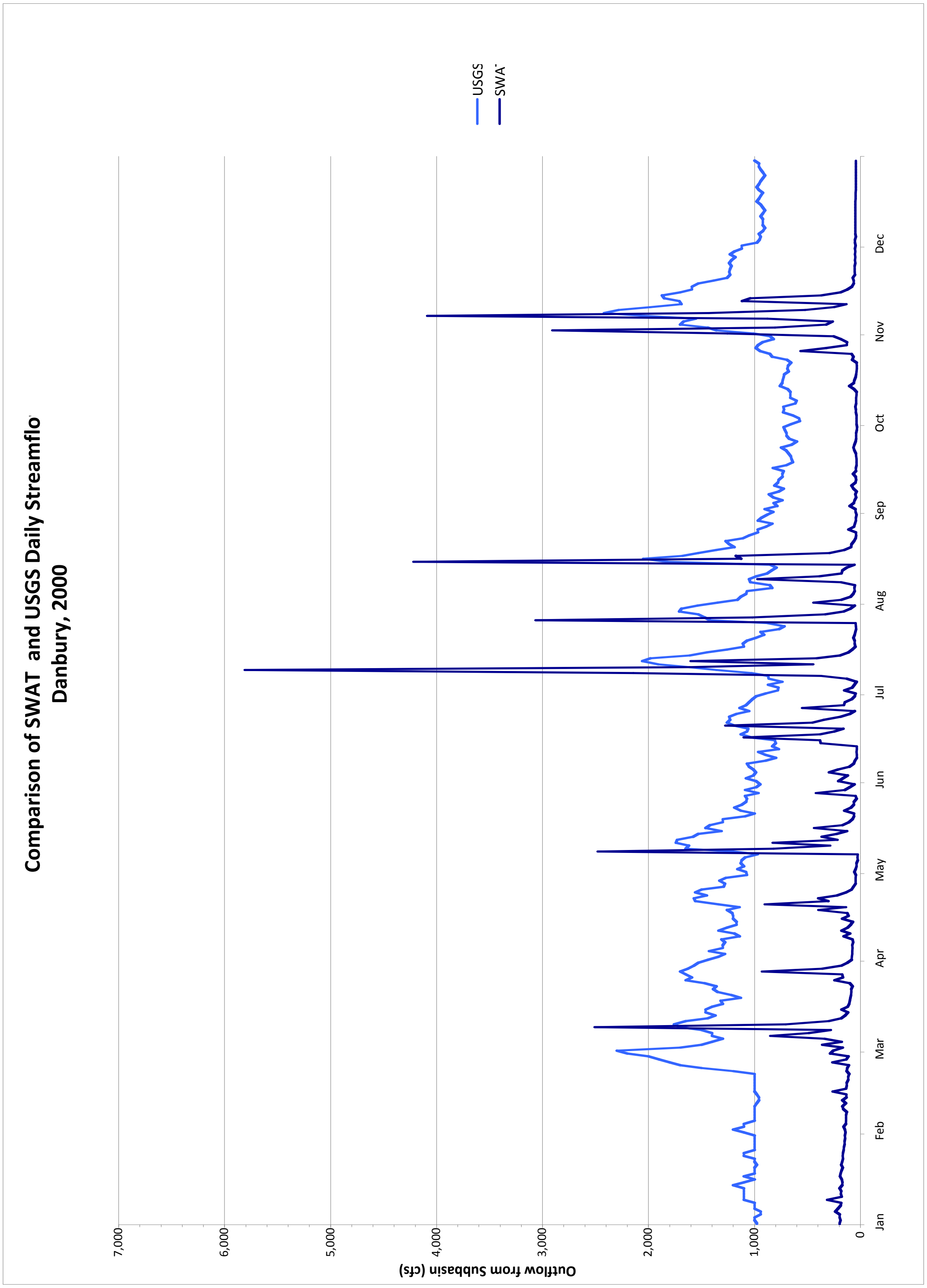


Danbury

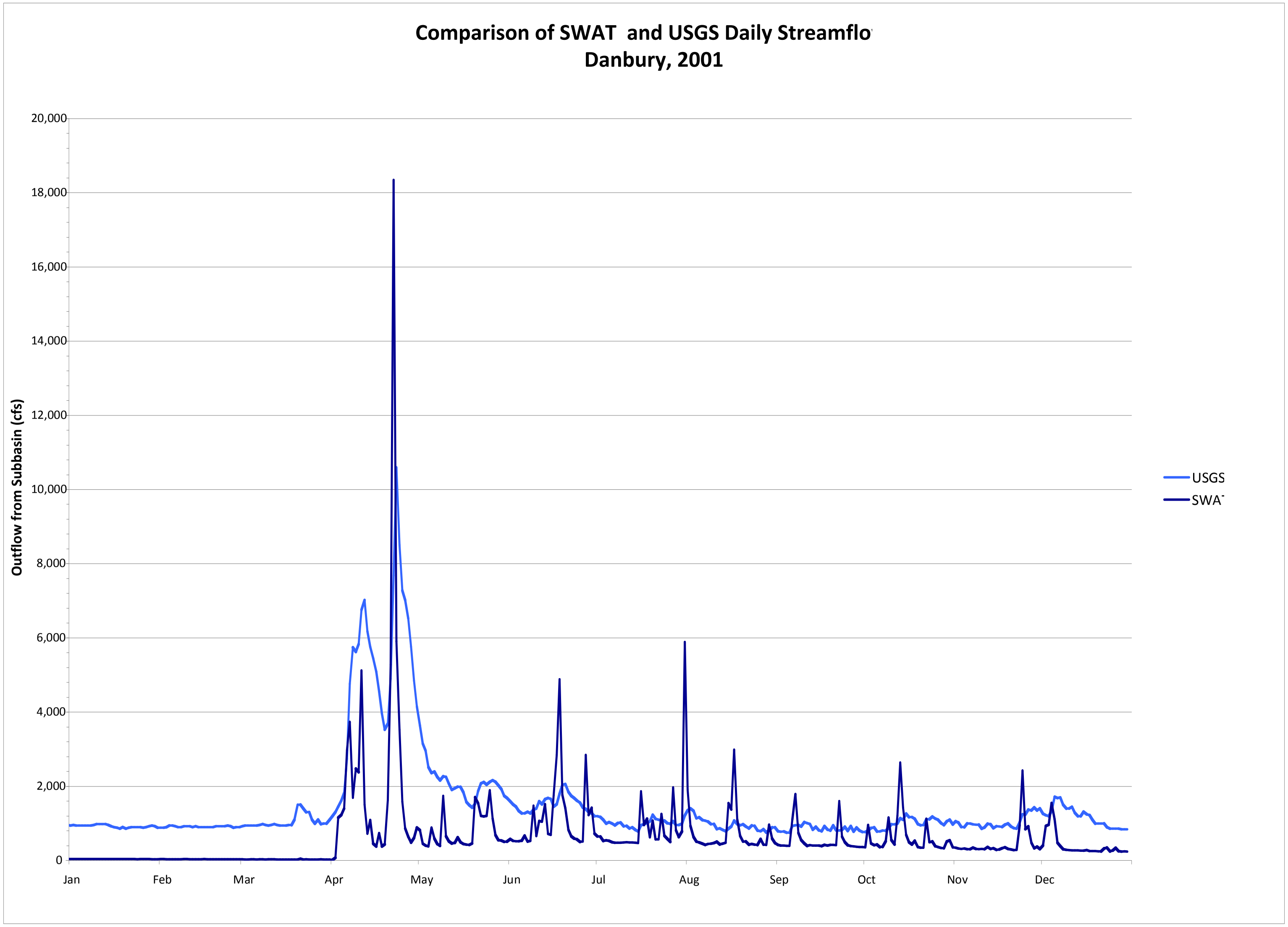
Graphs 3-7 on the following five pages show the streamflow data recorded by the USGS and the streamflow data simulated by the SWAT model at the Danbury gage station for the years 2000-2004, respectively. Overall, the timing of the peak and base flows observed in the SWAT results match the timing of the peak and base flows seen in the USGS data. However, for both peak and base flows, the magnitude is off. The simulation produced streamflow data with peak flows that are often significantly higher than those observed in the USGS data. Conversely, the simulation produced base flows that are always lower than the USGS data shows. Simulated data for the years 2001 and 2002 (Graphs 4 and 5, respectively) most closely matched the trends of the actual streamflow data compared to the other years. For 2003 and 2004, the simulated streamflow data have many more peaks, with the maximum flows occurring later in the year than those in the USGS data. In 2003, the maximum flow occurs in late September instead of in mid-May. In 2004, the maximum flow occurs at the very end of July instead of in late April. On average, the maximum mean peak flow occurred in April, which was the same for the USGS streamflow data, as seen in Table 2 and Graph 1.

Danbury – Graphs for Individual Years

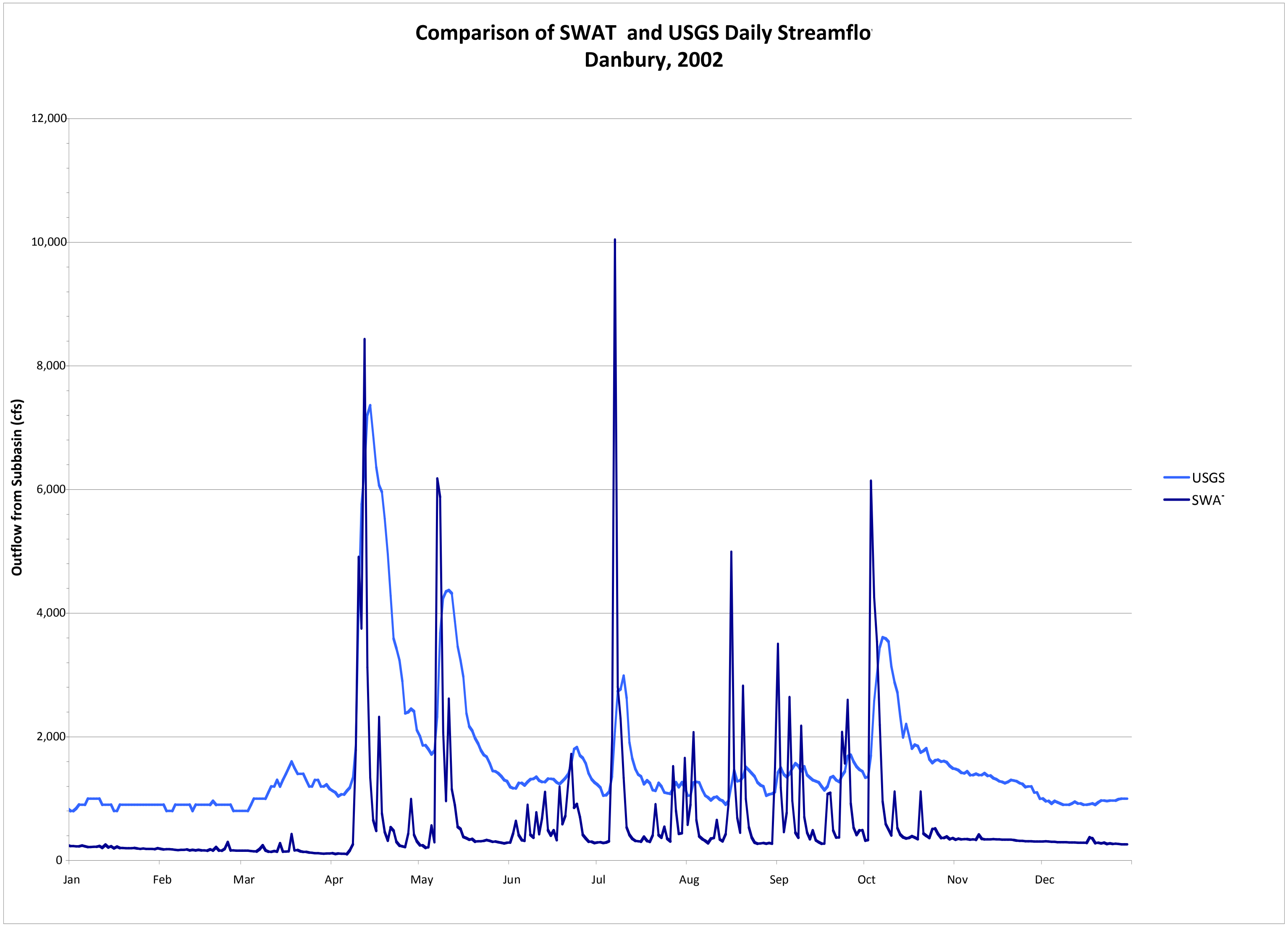
Graph 3



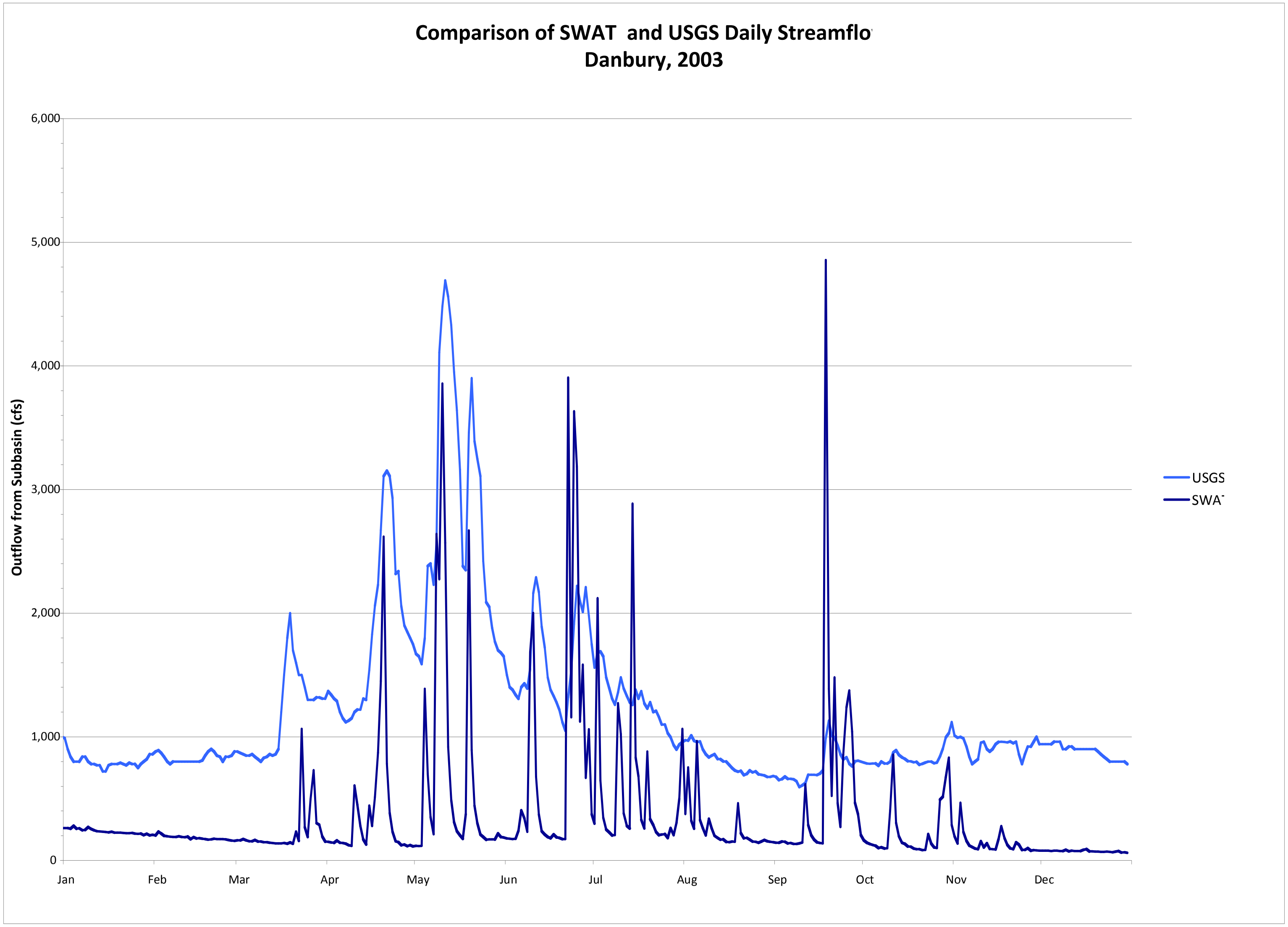
Graph 4


Comparison of SWAT and USGS Daily Streamflo
Danbury, 2001
Outflow from Subbasin (cfs)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
USGS
SWA

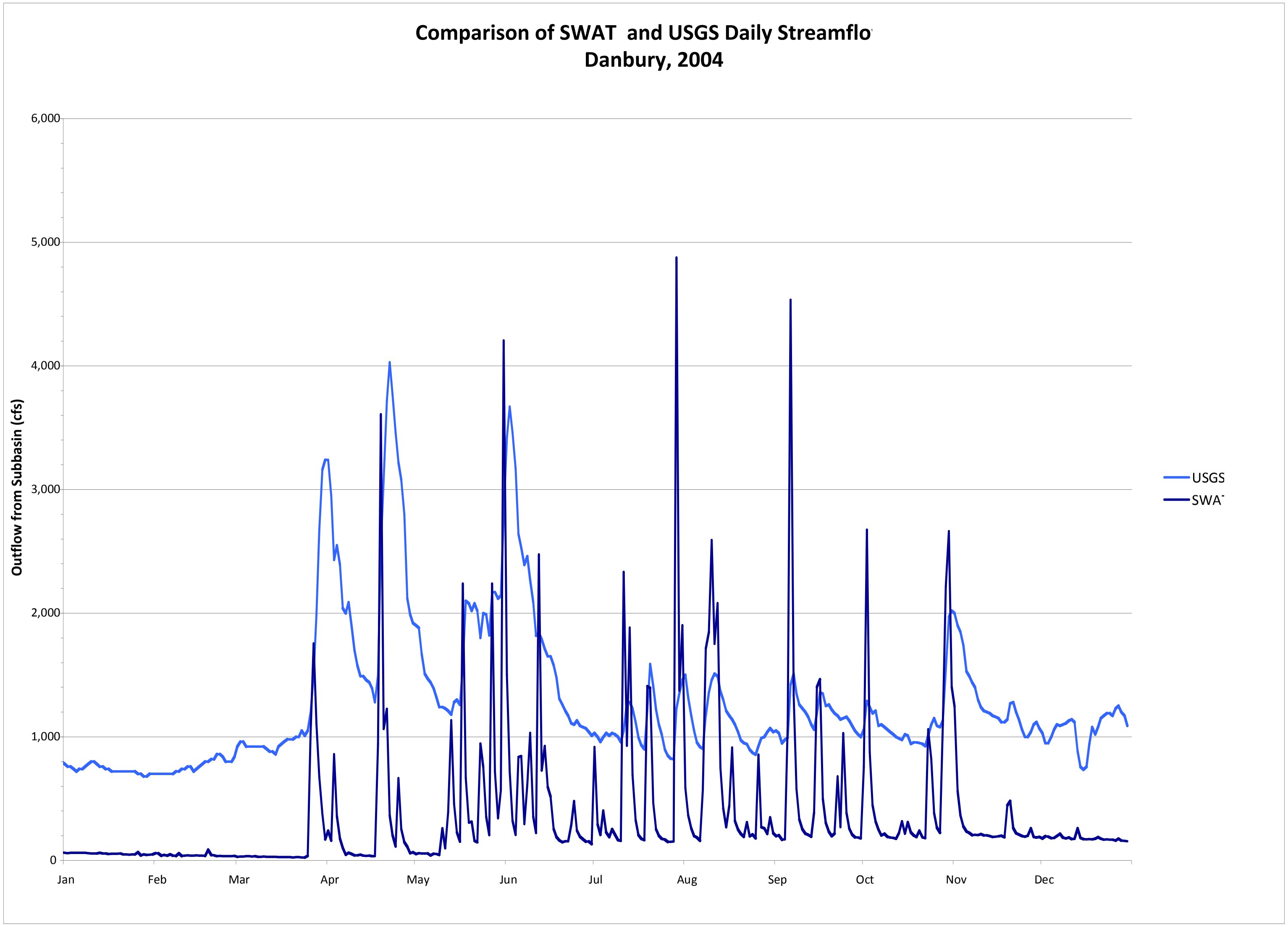
Graph 5


Comparison of SWAT and USGS Daily Streamflo
Danbury, 2002
Outflow from Subbasin (cfs)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
USGS
SWA

Graph 6


Comparison of SWAT and USGS Daily Streamflo
Danbury, 2003
Outflow from Subbasin (cfs)
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
USGS
SWA

Graph 7



Comparison of SWAT and USGS Daily Streamflo
Danbury, 2004
Outflow from Subbasin (cfs)
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
USGS
SWA

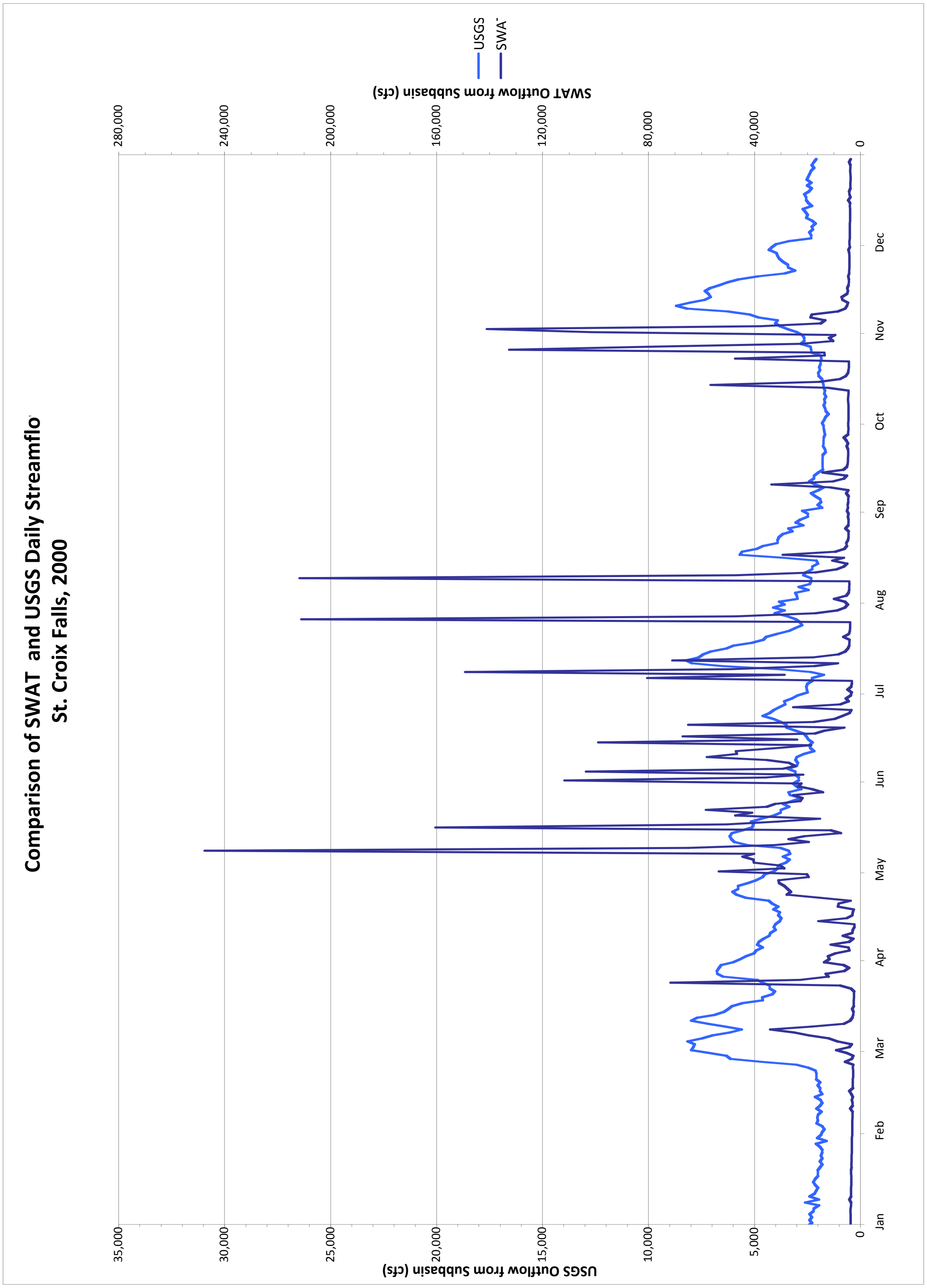
St. Croix Falls

Graphs 8-12 on the following five pages show the streamflow data recorded by the USGS and the streamflow data simulated by the SWAT model at the St. Croix Falls gage station for the years 2000-2004, respectively. The USGS and SWAT data are on separate axes, due to the magnitude difference. This is done so that discounting magnitude, general trends in timing of peak and base flows can be matched up more effectively. Compared with the simulated streamflow data at the Danbury station, the data for the St. Croix Falls station had much more variability between base and peak flows, as well as more generally in relation to the data recorded by the USGS. Although the timing of major peaks lines up some of the time, that is not the overarching trend.

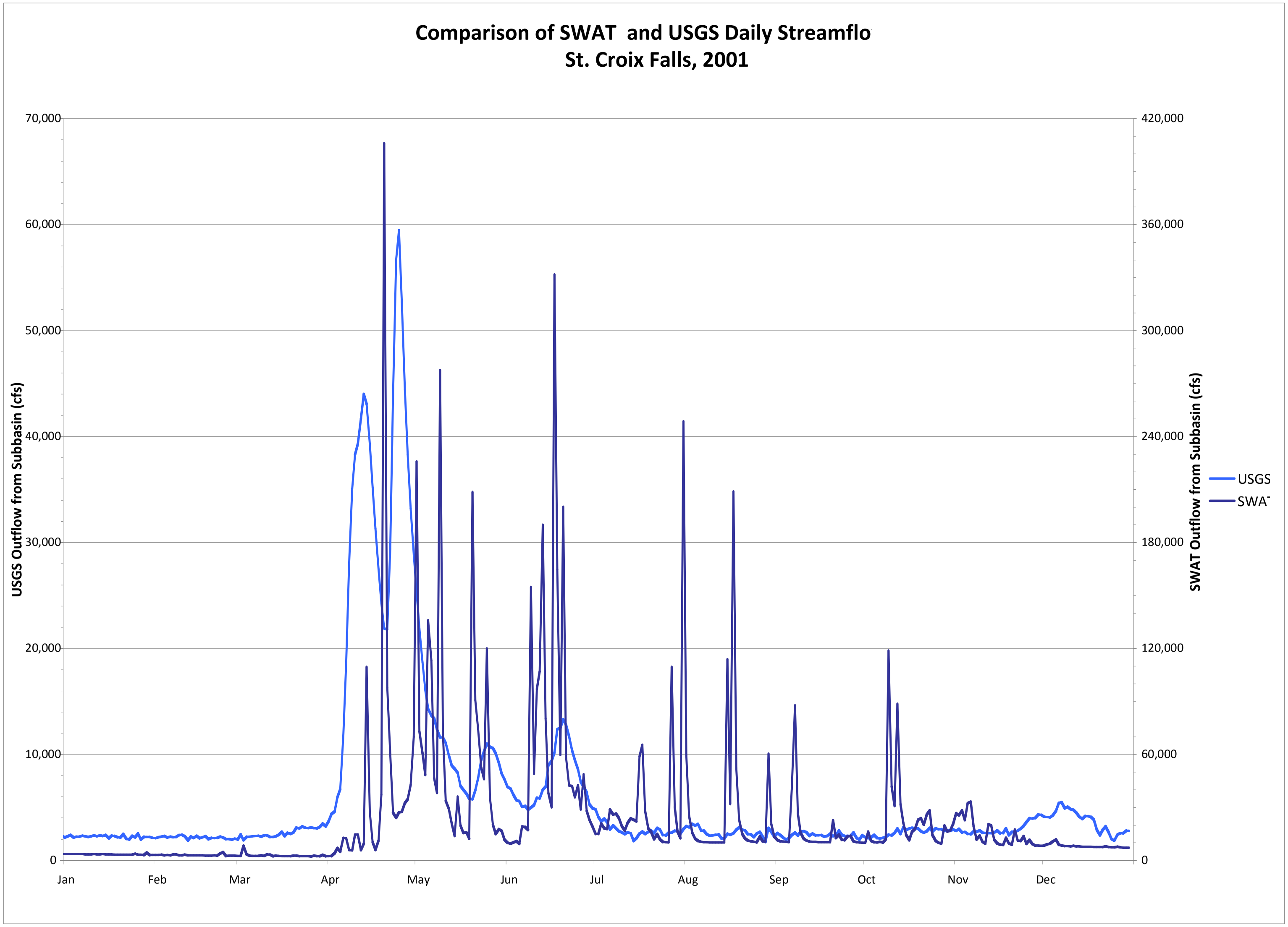
Unlike the streamflow simulated at Danbury, the streamflow data for St. Croix Falls does not on average match up with the USGS data. Data from 2001, shown in Graph 9, most closely matches the USGS data. However, even in that year several peaks occur in later months, when USGS data shows a tapering off of flows. For example, SWAT data shows significant peaks in June, late July, and August. In 2002, streamflow generally builds until July, when it peaks before eventually tapering off in the second half of the year, as seen in Graph 10. Whereas the USGS data shows that the peak monthly mean flow occurs in April, the SWAT data suggests that on average it occurs in June. This can be seen in Table 2 and Graph 2. Graph 2 also gives an excellent visual of how monthly mean flows appear to be shifted to occurring later in the year. Additionally, the magnitude of the SWAT data at St. Croix Falls increases positively from 2000 to 2004, whereas the magnitude of the USGS data reaches its highest peaks in 2001 and then decreases through 2004. These results paired with the knowledge of the SWAT model errors raise interesting questions for why there is a disparity between simulated and actual data. *Suggestions for Future Research* in the *Conclusions* section addresses these questions.

St. Croix Falls – Graphs for Individual Years

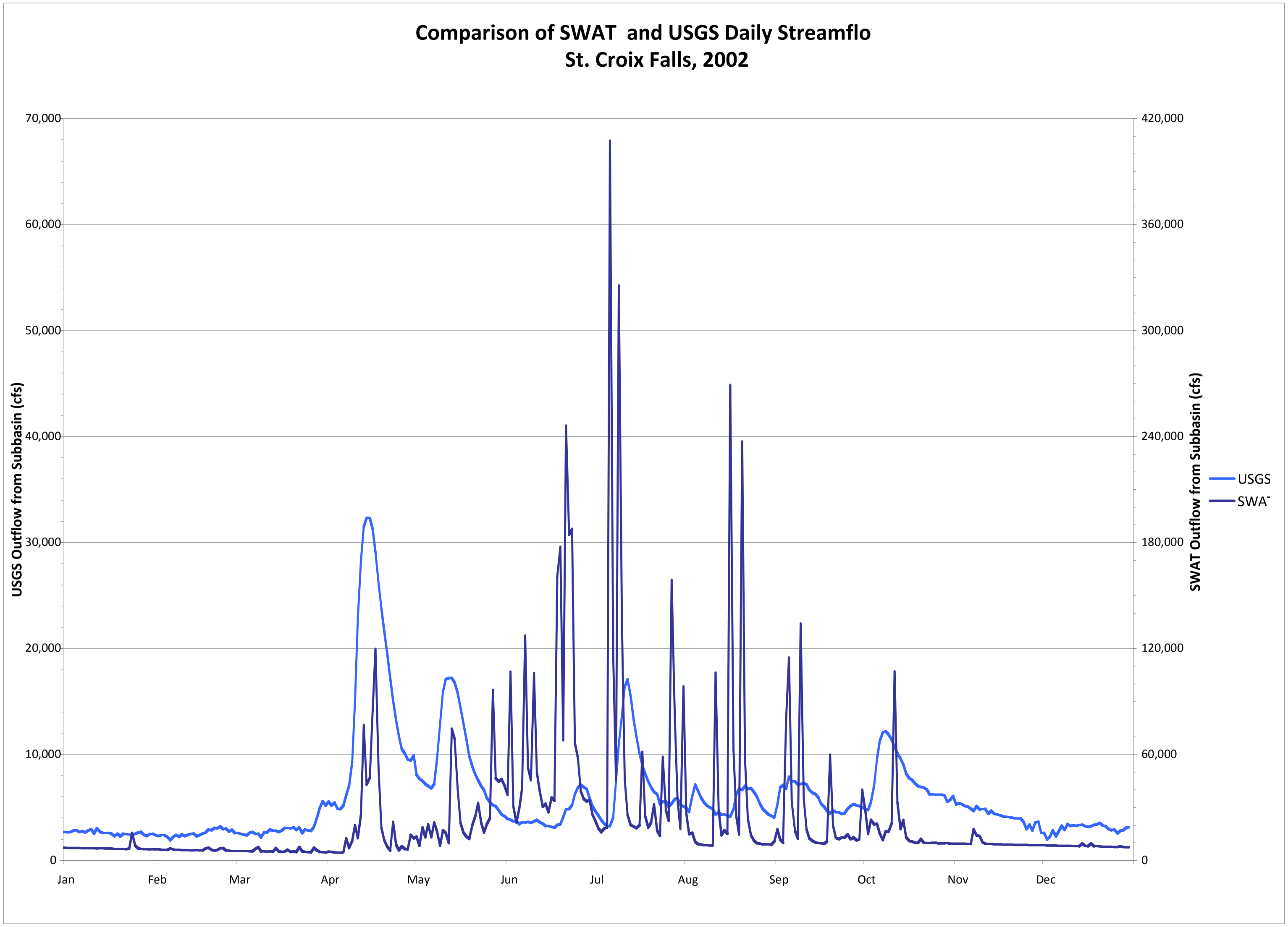
Graph 8



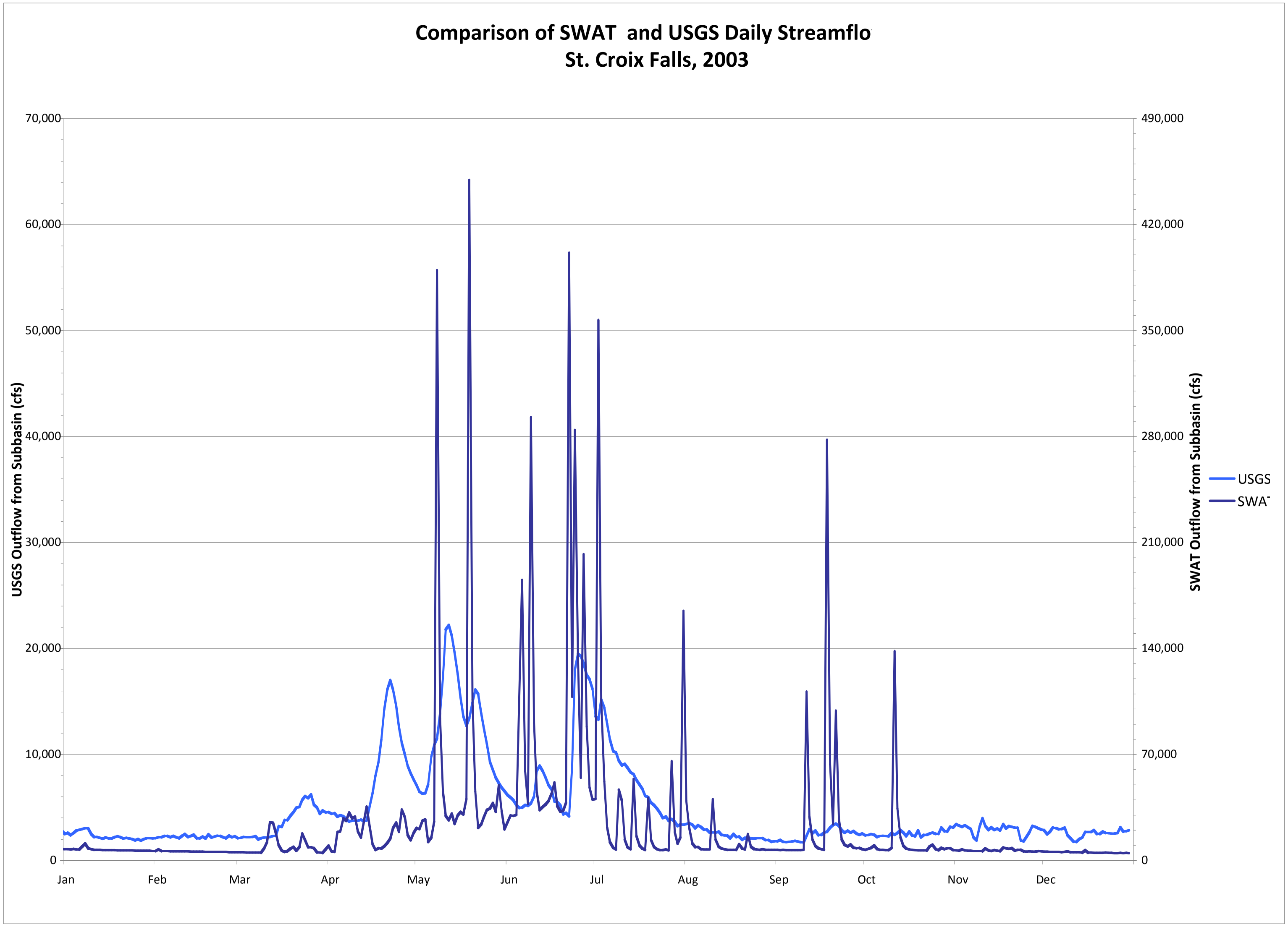
Graph 9


Comparison of SWAT and USGS Daily Streamflo
St. Croix Falls, 2001
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
USGS Outflow from Subbasin (cfs)
420,000
360,000
300,000
240,000
180,000
120,000
60,000
0
SWAT Outflow from Subbasin (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
USGS
SWA

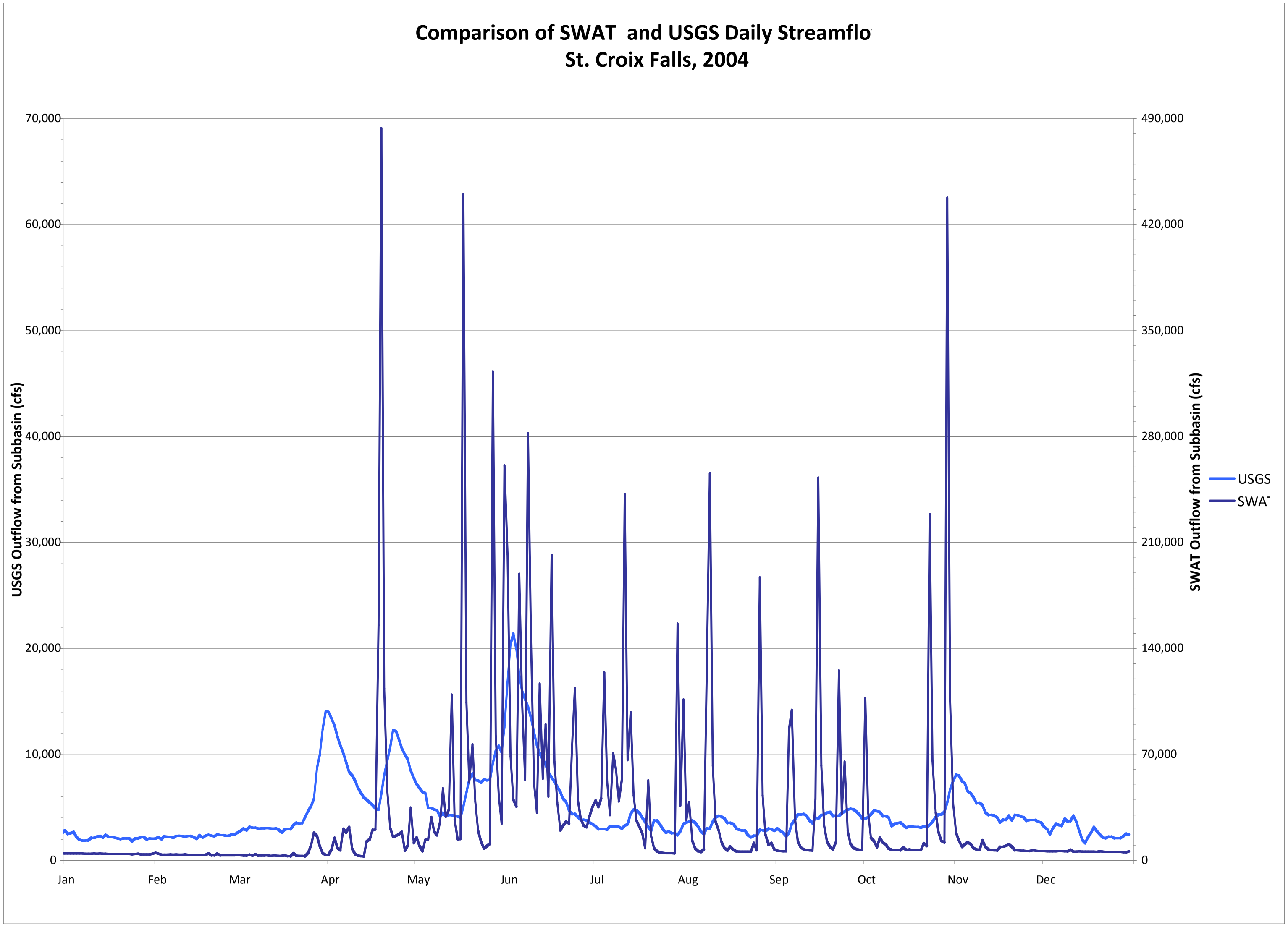
Graph 10


Comparison of SWAT and USGS Daily Streamflo
St. Croix Falls, 2002
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
USGS Outflow from Subbasin (cfs)
420,000
360,000
300,000
240,000
180,000
120,000
60,000
0
SWAT Outflow from Subbasin (cfs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
USGS
SWA

Graph 11


Comparison of SWAT and USGS Daily Streamflo
St. Croix Falls, 2003
USGS Outflow from Subbasin (cfs)
SWAT Outflow from Subbasin (cfs)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
490,000
420,000
350,000
280,000
210,000
140,000
70,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
USGS
SWA

Graph 12


Comparison of SWAT and USGS Daily Streamflo
St. Croix Falls, 2004
USGS Outflow from Subbasin (cfs)
SWAT Outflow from Subbasin (cfs)
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
0
70,000
140,000
210,000
280,000
350,000
420,000
490,000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
USGS
SWA

ii. Revisiting the Research Question

As stated at the beginning of this paper, the research question behind this project was: How are changes in land use, urbanization, presence of impervious surfaces, and population affecting runoff and streamflow in the St. Croix River Basin? This project sought to address this question through the use of a hydrologic model, the Soil and Water Assessment Tool, in conjunction with GIS to model the relationship between anthropogenic changes to the landscape and streamflow. It was hypothesized in accordance with suggestions made in the USGS report (see Lenz 2004) that over the past century streamflow had increased at the downstream St. Croix Falls gage station while remaining relatively stable at the upstream Danbury gage station due to changes in land cover in this period. In order to evaluate this hypothesis, a temporal comparison of streamflow rates at the Danbury and St. Croix Falls stations spanning the last century was to be completed. However, answering this question in its original form became infeasible for a number of reasons, including data unavailability and errors in the flow calculations done by SWAT. Instead, this project focuses more on forming an understanding of the usefulness of the SWAT model for such an application, as well as on establishing the data and resources necessary to carrying out the originally intended analysis.

VIII. Conclusion

The St. Croix River Basin has seen dramatic changes over the past century. Logging, agricultural development, and restoration projects have all in turn resulted in alterations not only to the land, but also to the river systems and hydrologic functions of the basin. The protection of the St. Croix National Scenic Riverway necessitates research on all aspects of the river system to ensure current and future development doesn't adversely impact the river's health. This paper has presented a history of the St. Croix River Basin, analyzed the literature on the hydrologic effects of logging and damming, and provided a thorough overview of the SWAT model and its limitations. The scope and timeline of this project restricted the completion of its original goals – namely the lack of accurate land cover data going back to the beginning of the 20th Century made a temporal analysis of streamflow change over time infeasible. Additionally, the scope of this project didn't allow for implementation of many additional features of SWAT that may increase the effectiveness of the model at simulating the St. Croix River system. These include taking into consideration crop rotation in land use characterization, defining ponds/wetlands in appropriate subbasins, updating and expanding reservoir/waterbody definition, and further manipulating parameters. As discussed in the *Methodology* and *Results and Discussion* sections, this project ultimately focused on developing an understanding of the study area through the establishment of an extensive database, and on the usefulness of hydrologic models, particularly the Soil and Water Assessment Tool, in evaluating the effects of land use change on streamflow in the St. Croix River Basin.

i. Contributions of this Project

This project made important contributions to the understanding of the role surrounding river networks play in the preservation of the St. Croix River. Prior to this project, there did not exist a comprehensive database useful not only to a general spatial understanding of the basin and its hydrologic functions, but also to the successful modeling of those functions. All data are uniformly formatted where appropriate, contain up-to-date metadata and are catalogued, so that they can be easily accessed by future researchers, or by people who are generally interested in understanding more about the area.

In order to use the outputs of the SWAT model as a means of explaining the changes in streamflow data recorded by the USGS over the past century, without having access to data going back that far in time, alternative methodology should be used. By manually manipulating land cover variables to include more urban/developed coverage or less forest coverage, the hypothesis in the 2004 USGS report that land cover change is causing the disparity in streamflow in upstream vs. downstream reaches could be effectively analyzed.

ii. Suggestions for Further Research

An important part of this project was identifying how answering the research questions was complicated by the quality and availability of data, as well as by errors within SWAT itself. These limitations and problems were discussed in depth in the *Problems and Limitations* section. As mentioned in that section, the land cover data caused many issues. Within the scope of this project, it was not feasible to create versions of the NLCD layers that could be compared to each other. Nor was it feasible to derive a version of the historical land cover dataset with a categorization scheme comparable to the NLCD datasets. In order to use the SWAT model to evaluate the effect of LULC change over the past century, not only would suitable datasets relevant to the beginning of the twentieth century need to be acquired, but a uniform categorization scheme would need to be established for all LULC datasets used.

Additionally, the SWAT alterations cited by Almendinger (2007) as conducive to more accurate results should be incorporated into the model. Proposed methods/solutions include: determining the percentage of alternative agricultural cover out of total, loosely defined, agricultural land and then accounting for alfalfa and corn-soybean crop rotation cycles; utilization of ponds/wetlands definition; and in general, more extensive fine-tuning of model parameters. Finding a more accurate representation of natural streamflow patterns and magnitudes using SWAT would require these changes to be made. Crop rotations should be determined based on the percentages of main variations in types of crops found in the study area instead of using the generic category typically assigned to the majority of agricultural land. This should result in a more accurate response of areas with an agricultural land cover to water (Almendinger 2005). To further account for more accurate rates of infiltration, the ponds and wetlands table should be updated to reflect the prevalence of these features in the study area and the important hydrologic functions they perform.

Lastly, an alternative to using historical data to provide the temporal comparison of the effects of land use changes on streamflow could be to manually alter the percentages of land covers of particular interest when setting up a model simulation. One of the central inspirations for this project was the 2004 USGS report (see Lenz 2004), and as is stated earlier it is hypothesized within that report that the changes in streamflow experienced at the St. Croix Falls station was the result of land cover change. Namely, an increase in urban/developed land, an increase in agricultural land and a decrease in forested land were signaled as possible causal factors. To explore the possibility of such a relationship between land cover change and streamflow existing, the percentage of these land uses within the study area could be manually increased or decreased. Therefore, instead of trying to recreate historic conditions from inaccurate LULC data, the effect of land cover changes experienced over the last century can be quantified based on manual alteration of land cover percentages. Based on the work done in this project, more comprehensive analyses of the St. Croix River Basin can done, furthering the hydrologic understanding of the area.

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X. Technical Appendices – Description of Data

The Technical Appendices contain listings for all data included in the final project geodatabase. The first part to this section is an outline of how the geodatabase is organized. The second part is the technical appendix for spatial data, and finally the third part is the technical appendix for tabular data.

Organizational Flowchart

ESRI_Data

- Documents
  - *Counties_Metadata.xml*
  - *MNWI_States_Metadata.xml*
  - *States_Metadata.xml*
  - *StCroix_Counties_Metadata.xml*
- Spatial
  - *MNWI_Counties.shp*
  - *MNWI_Counties_Erase.shp*
  - *MNWI_States.shp*
  - *North_America_Background.shp*
  - *States.shp*
  - *StCroixBasin_Counties.shp*

LMIC_Data

- Documents
  - *MN_Rivers_Metadata.xml*
- Spatial
  - *MN_Rivers.shp*

NHDPlus_Data

Documents

NHDPlus_Metadata.xml

Stream_Gages_Metadata.xml

Spatial

-Drainage

Catchment.shp

Catchment_StCroixBasin.shp

-Flow

fac_stcroix

fac_utm

fdr_stcroix

fdr_utm

-Hydrography

NHD_Area.shp

NHD_Area_StCroixBasin.shp

NHD_Flowline.shp

NHD_Flowline_StCroixBasin.shp

NHD_Line.shp

NHD_Line_StCroixBasin.shp

NHD_Waterbody.shp

NHD_Waterbody_LakePond_StCroix.shp

NHD_Waterbody_StCroix_Largest.shp

-Stream_Gage

Stream_Gages.shp

Stream_Gages_StCroixBasin.shp

Tabular

Catchment_Attributes.dbf

Flowline_Attributes_NLCD.dbf

Flowline_Attributes_Temp_Precip.dbf

Headwater_Node_Area.dbf

NRCS_Data

SSURGO

-Documents

MNWI_Soil_Metadata.xml

-Spatial

MNWI_Soil_Survey_Area_Boundary.shp

mnwi_ssurgo

MNWI_SSURGO.shp

MNWI_SSURGO_STATSGO.shp

-State_Data

MN_SSURGO

--County_Data

Aitkin_Soils_2008 (*all further county soils folders have same files)

-Documents

Aitkin_Soil_Metadata.xml

readme.txt

-Spatial

Aitkin_Soil_Survey_Area_Boundary.shp

Aitkin_SSURGO.shp

-Tabular

-Zipped_Files

Anoka_Soils_2008

Benton_Soils_2008

Carlton_Soils_2009

Chisago_Soils_2008

CrowWing_Soils_2006

Dakota_Soils_2008

Goodhue_Soils_2008

Hennepin_Soils_2008

Isanti_Soils_2008

Kanabec_Soils_2008

MilleLacs_Soils_2009

Morrison_Soils_2009

Pine_Soils_2006

Ramsey_Soils_2008

Sherburne_Soils_2009

StLouis_Soils_2008

Washington_Soils_2009

Wright_Soils_2008

--Documents

MN_Soil_Metadata.xml

--Spatial

MN_Soil_Survey_Area_Boundary.shp

MN_SSURGO.shp

--Tabular

MN_Aitkin_soildb_2003.mdb

MN_Anoka_soildb_2003.mdb

MN_Benton_soildb_2003.mdb

MN_Carlton_soildb_2003.mdb

MN_Chisago_soildb_2003.mdb

MN_CrowWing_soildb_2003.mdb

MN_Dakota_soildb_2003.mdb

MN_Goodhue_soildb_2003.mdb

MN_Hennepin_soildb_2003.mdb

MN_Isanti_soildb_2003.mdb

MN_Kanabec_soildb_2003.mdb

MN_MilleLacs_soildb_2003.mdb

MN_Morrison_soildb_2003.mdb

MN_Pine_soildb_2003.mdb

MN_Ramsey_soildb_2003.mdb

MN_Sherburne_soildb_2003.mdb

MN_soildb_2003.mdb

MN_StLouis_soildb_2003.mdb

MN_Washington_soildb_2003.mdb

MN_Wright_soildb_2003.mdb

WI_SSURGO

--County_Data

Ashland_Soils_2009 (*all further county soils folders have same files)

-Documents

Ashland_Soil_Metadata.xml

readme.txt

-Spatial

Ashland_Soil_Survey_Area_Boundary.shp

Ashland_SSURGO.shp

-Tabular

-Zipped_Files

Barron_Soils_2009

Bayfield_Soils_2009

Burnett_Soils_2009

Douglas_Soils_2008

Dunn_Soils_2009

Pierce_Soils_2009

Polk_Soils_2009

Rusk_Soils_2009

Sawyer_Soils_2009

StCroix_Soils_2009

Washburn_Soils_2008

--Documents

WI_Soil_Metadata.xml

--Spatial

WI_Soil_Survey_Area_Boundary.shp

WI_SSURGO.shp

--Tabular

WI_Ashland_soildb_2002.mdb

WI_Barron_soildb_2002.mdb

WI_Bayfield_soildb_2002.mdb

WI_Burnett_soildb_2002.mdb

WI_Douglas_soildb_2002.mdb

WI_Dunn_soildb_2002.mdb

WI_Pierce_soildb_2002.mdb

WI_Polk_soildb_2002.mdb

WI_Rusk_soildb_2002.mdb

WI_Sawyer_soildb_2002.mdb

WI_StCroix_soildb_2002.mdb

WI_Washburn_soildb_2002.mdb

STATSGO

-ArcSWAT_Data

Spatial

statsgo_grd

Tabular

-Documents

MNWI_Soil_Metadata.xml

-Spatial

Missing_SSURGO_Counties_Map.shp

Missing_SSURGO_Map.shp

Missing_General_Soil_Map.shp

-State_Data

MN_STATSGO

--Documents

MN_Soil_Metadata.xml

readme.txt

version.txt

--Spatial

MN_General_Soil_Map.shp

--Tabular

--Zipped_Files

WI_STATSGO

--Documents

readme.txt

version.txt

WI_Soil_Metadata.xml

--Spatial

WI_General_Soil_Map.shp

--Tabular

--Zipped_Files

USDA_Data

Documents

HUC_250k_Metadata.xml

WBD_HU8_ReadMe.txt

WBD_Metadata.xml

WBD_ReadMe.txt

Spatial

HUC_250k.shp

StCroix_Basin_Boundary.shp

StCroix_Basin_Boundary_15mi_Buffer.shp

StCroix_Subbasin_Boundary.shp

StCroix_Subbasin_Boundary_15mi.shp

StCroix_Watershed_Boundary.shp

Subbasin_Boundary.shp

Subwatershed_Boundary.shp

Watershed_Outlets.shp

Tabular

SWAT_Watershed_Outlets.dbf

Zipped_Files

USGS_Data

Land_Cover

-Historic_1970-1985

Documents

Historic_Metadata.xml

Spatial

hist_landcov

hist_stcroix

Historic_Land_Cover.shp

Historic_Land_Cover_StCroixBasin.shp

Tabular

historicaltables.xls

Zipped_Files

-NLCD_1992

Documents

Spatial

nlcd1992_utm

Zipped_Files

-NLCD_2001

Documents

Spatial

nlcd2001

Zipped_Files

USU_Data

Spatial

Weather_Stations.shp

Tabular

-Precipitation

Cmbrdg.dbf

Cmbrlnd.dbf

Danbury.dbf

Hinckley.dbf

MooseLk.dbf

Mora.dbf

RvrFalls.dbf

SlnSpngs.dbf

Spooner.dbf

StCrxFls.dbf

Weather_Stations.dbf

-Precipitation

Cmbrdg.dbf

Cmbrlnd.dbf

Danbury.dbf

Hinckley.dbf

MooseLk.dbf

Mora.dbf

RvrFalls.dbf

SlnSpngs.dbf

Spooner.dbf

StCrxFls.dbf

Weather_Stations.dbf

Precipitation.xls

Temperature.xls

USUClimateData.xlsx

Weather_Stations.dbf

WIDNR_Data

Documents

MNWI_Rivers_Metadata.xml

WI_Rivers_Metadata.xml

Spatial

Clam_River.shp

MNWI_Rivers.shp

Namekagon_River.shp

StCroix_River.shp

Trade_River.shp

WI_Rivers.shp

Wood_River.shp

Technical Appendix

Spatial Data

Layer Name	Type	Source	Date	Additional Formatting	Description
Aitkin_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2007-2008†	Projected	Soil survey area boundary (a single polygon) for Aitkin County in Minnesota
Aitkin_SSURGO.shp	Shapefile	NRCS	2007-2008†	Projected	SSURGO map units for Aitkin County in Minnesota
Anoka_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2004-2008†	Projected	Soil survey area boundary (a single polygon) for Anoka County in Minnesota
Anoka_SSURGO.shp	Shapefile	NRCS	2004-2008†	Projected	SSURGO map units for Anoka County in Minnesota
Ashland_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2009†	Projected	Soil survey area boundary (a single polygon) for Ashland County in Wisconsin
Ashland_SSURGO.shp	Shapefile	NRCS	2006-2009†	Projected	SSURGO map units for Ashland County in Wisconsin
Barron_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	1999-2009†	Projected	Soil survey area boundary (a single polygon) for Barron County in Wisconsin
Barron_SSURGO.shp	Shapefile	NRCS	1999-2009†	Projected	SSURGO map units for Barron County in Wisconsin
Bayfield_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2005-2009†	Projected	Soil survey area boundary (a single polygon) for Bayfield County in Wisconsin
Bayfield_SSURGO.shp	Shapefile	NRCS	2005-2009†	Projected	SSURGO map units for Bayfield County in Wisconsin

Benton_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2007-2008†	Projected	Soil survey area boundary (a single polygon) for Benton County in Minnesota
Benton_SSURGO.shp	Shapefile	NRCS	2007-2008†	Projected	SSURGO map units for Benton County in Minnesota
Burnett_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2004-2009†	Projected	Soil survey area boundary (a single polygon) for Burnett County in Wisconsin
Burnett_SSURGO.shp	Shapefile	NRCS	2004-2009†	Projected	SSURGO map units for Burnett County in Wisconsin
Carlton_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2009†	Projected	Soil survey area boundary (a single polygon) for Carlton County in Minnesota
Carlton_SSURGO.shp	Shapefile	NRCS	2006-2009†	Projected	SSURGO map units for Carlton County in Minnesota
Catchment_StCroixBasin.shp	Shapefile	NHDPlus	2005*	Clipped from *Catchments.shp* using *StCroix_Basin_Boundary_15mi_Buffer.shp*	Catchment boundaries within a 15mi radius of the St. Croix River Basin
Catchments.shp	Shapefile	NHDPlus	2005	None	Catchment boundaries for NHDPlus04 and 07
Chisago_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2003-2008†	Projected	Soil survey area boundary (a single polygon) for Chisago County in Minnesota
Chisago_SSURGO.shp	Shapefile	NRCS	2003-2008†	Projected	SSURGO map units for Chisago County in Minnesota
Clam_River.shp	Shapefile	WIDNR	1994	Clipped from WIDNR Rivers layer (not included in database) and projected	Clam River, from Louise Sharrow's work in the Summer of 2008
Dakota_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2008†	Projected	Soil survey area boundary (a single polygon) for Dakota County in Minnesota
Dakota_SSURGO.shp	Shapefile	NRCS	2006-2008†	Projected	SSURGO map units for Dakota County in Minnesota

dem_30m	Raster GRID	USGS	--	Mosaiced smaller DEMs, projected with 30 meter grid size selected	30-meter accuracy DEM covering the St. Croix River Basin
Douglas_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2005-2008†	Projected	Soil survey area boundary (a single polygon) for Douglas County in Wisconsin
Douglas_SSURGO.shp	Shapefile	NRCS	2005-2008†	Projected	SSURGO map units for Douglas County in Wisconsin
Dunn_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2003-2009†	Projected	Soil survey area boundary (a single polygon) for Dunn County in Wisconsin
Dunn_SSURGO.shp	Shapefile	NRCS	2003-2009†	Projected	SSURGO map units for Dunn County in Wisconsin
fac_stcroix	Raster GRID	NHDPlus	2005*	Clipped from *fac_utm* using *StCroix_Basin_Boundary_15mi_Buffer.shp*	Flow accumulation raster GRID dataset for the St. Croix River Basin
fac_utm	Raster GRID	NHDPlus	2005*	Mosaiced' from NHDPlus04 and 07, projected	Flow accumulation raster GRID dataset for NHDPlus04 and 07
fdr_stcroix	Raster GRID	NHDPlus	2005*	Clipped from *fdr_utm* using *StCroix_Basin_Boundary_15mi_Buffer.shp*	Flow direction raster GRID dataset for the St. Croix River Basin
fdr_utm	Raster GRID	NHDPlus	2005*	Mosaiced' from NHDPlus04 and 07, projected	Flow direction raster GRID dataset for NHDPlus04 and 07
Goodhue_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2007-2008†	Projected	Soil survey area boundary (a single polygon) for Goodhue County in Minnesota
Goodhue_SSURGO.shp	Shapefile	NRCS	2007-2008†	Projected	SSURGO map units for Goodhue County in Minnesota
Hennepin_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2002-2008†	Projected	Soil survey area boundary (a single polygon) for Hennepin County in Minnesota
Hennepin_SSURGO.shp	Shapefile	NRCS	2002-2008†	Projected	SSURGO map units for Hennepin County in Minnesota

hist_landcov	Raster GRID	USGS	1970-1985*	Created using "Feature to Raster" tool on *Historic_Land_Cover.shp*	Historic (not NLCD) land cover for 1970-1985
hist_stcroix	Raster GRID	USGS	1970-1985*	Created using "Feature to Raster" tool on *Historic_Land_Cover.shp*	Historic (not NLCD) land cover for 1970-1986 for the St. Croix River Basin
Historic_Land_Cover.shp	Shapefile	USGS	1970-1985*	Merged and projected 5 shapefiles to form a single shapefile	Historic (not NLCD) land cover for 1970-1987
Historic_Land_Cover_StCroixBasin.shp	Shapefile	USGS	1970-1985*	Clipped from *Historic_Land_Cover.shp* using *StCroix_Basin_Boundary_15mi_ Buffer.shp, and* dissolved on LANDUSE and LUCODE fields	Historic (not NLCD) land cover for 1970-1986 for the St. Croix River Basin
HUC_250k.shp	Shapefile	USDA	1994	Projected	Hydrologic unit boundaries at the subbasin level, at a scale of 1:250,000, developed using GIRAS
Isanti_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2005-2009†	Projected	Soil survey area boundary (a single polygon) for Isanti County in Minnesota
Isanti_SSURGO.shp	Shapefile	NRCS	2005-2009†	Projected	SSURGO map units for Isanti County in Minnesota
Kanabec_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2009†	Projected	Soil survey area boundary (a single polygon) for Kanabec County in Minnesota
Kanabec_SSURGO.shp	Shapefile	NRCS	2006-2009†	Projected	SSURGO map units for Kanabec County in Minnesota
MilleLacs_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2009†	Projected	Soil survey area boundary (a single polygon) for Mille Lacs County in Minnesota
MilleLacs_SSURGO.shp	Shapefile	NRCS	2006-2009†	Projected	SSURGO map units for Mille Lacs County in Minnesota
Missing_SSURGO_Counties_Map_Units.shp	Shapefile	NRCS	--	Clipped *MNWI_General_Soil_Map.shp* using *StCroixBasin_Counties*	STATSGO map units in counties missing from the SSURGO datasets

Missing_SSURGO_Map_Units.shp	Shapefile	NRCS	--	Features 'erased' from *Missing_SSURGO_Counties_Map_Units.shp* from *StCroixBasin_SSURGO.shp*	STATSGO map units in counties missing from the SSURGO datasets, cleaned up
MN_General_Soil_Map.shp	Shapefile	NRCS	--	Projected	SSURGO map units for Minnesota
MN_Rivers.shp	Shapefile	LMIC	2000	Unknown	Minnesota rivers, from Louise Sharrow's work in the Summer of 2008
MN_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	--	Projected	Soil survey area boundary (a single polygon) for Minnesota
MN_SSURGO.shp	Shapefile	NRCS	--	Projected	SSURGO map units for Minnesota
MNWI_Counties.shp	Shapefile	ESRI	2000†	Clipped from nationwide layer, projected	Counties in Minnesota and Wisconsin
MNWI_Counties_Erase.shp	Shapefile	ESRI	2000†	St. Croix Basin area cut out of *MNWI_Counties* using the 'Erase' tool	Counties in Minnesota and Wisconsin, excluding areas falling within the St. Crix River Basin
MNWI_General_Soil_Map.shp	Shapefile	NRCS	--	Merged from state-level data	SSURGO map units for Minnesota and Wisconsin
MNWI_Rivers.shp	Shapefile	LMIC, WIDNR	2000*	Merged *MN_Rivers.shp* and all WIDNR river shapefiles listed in this appendix	Main rivers in Minnesota and Wisconsin, from Louise Sharrow's work in the Summer of 2008
MNWI_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	--	Merged from county-level data	SSURGO soil survey area boundary (a single polygon)
MNWI_SSURGO.shp	Shapefile	NRCS	--	Merged from county-level data	SSURGO map units for Minnesota and Wisconsin

MNWI_SSURGO_STATSGO.shp	Shapefile	NRCS	--	'Append' tool used to merge *MNWI_SSURGO.shp* and *Missing_SSURGO_Map_Units.shp*	All available SSURGO map units for Minnesota and Wisconsin, with STATSGO map units filling in gaps
MNWI_States.shp	Shapefile	ESRI	2000†	Dissolved based on state name from *MNWI_Counties.shp*	Minnesota and Wisconcin state boundaries
Morrison_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2003-2009†	Projected	Soil survey area boundary (a single polygon) for Morrison County in Minnesota
Morrison_SSURGO.shp	Shapefile	NRCS	2003-2009†	Projected	SSURGO map units for Morrison County in Minnesota
Namekagon_River.shp	Shapefile	WIDNR	1994	Clipped from WIDNR Rivers layer (not included in database) and projected	Namekagon River, from Louise Sharrow's work in the Summer of 2008
NHD_Area.shp	Shapefile	NHDPlus	2005*	Projected	Polygon hydrography features (rapids, dams, etc. – not waterbodies)
NHD_Area_StCroixBasin.shp	Shapefile	NHDPlus	2005*	Clipped from *NHD_Area.shp* using *StCroix_Basin_Boundary_15mi_ Buffer.shp*	Polygon hydrography features (rapids, dams, etc. – not waterbodies) within 15 miles of the St. Croix River Basin
NHD_Flowline	Shapefile	NHDPlus	2005*	Projected	Polyline hydrography features (streams, rivers, etc.)
NHD_Flowline_StCroixBasin.shp	Shapefile	NHDPlus	2005*	Clipped from *NHD_Flowline.shp* using *StCroix_Basin_Boundary_15mi_ Buffer.shp*	Polyline hydrography features (streams, rivers, etc.) within a 15 mile radius of the St. Croix River Basin
NHD_Line.shp	Shapefile	NHDPlus	2005*	Projected	Polyline hydrography features (dams, rapids, locks, etc.)
NHD_Line_StCroixBasin.shp	Shapefile	NHDPlus	2005*	Clipped from *NHD_Line.shp* using *StCroix_Basin_Boundary_15mi_ Buffer.shp*	Polyline hydrography features (dams, rapids, locks, etc.) within a 15 mile radius of the St. Croix River Basin

NHD_Waterbody.shp	Shapefile	NHDPlus	2005*	Projected	Polygon hydrography features (lakes, ponds, swamps/marshes, etc.)
NHD_Waterbody_LakePond_StCroix.shp	Shapefile	NHDPlus	2005*	Query of 'LakePond' or 'Reservoir' FTYPE that intersect *NHD_Flowline_StCroixBasin.shp*	Lakes, ponds and reservoirs that fall within the St Croix River Basin and intersect rivers/flowlines
NHD_Waterbody_StCroix_Largest.shp	Shapefile	NHDPlus	2005*	Selected ~20 largest waterbodies from *NHD_Waterbody_LakePond_StCroix.shp* that intersected *MNWI_Rivers.shp* and *StCroix_Basin_Boundary_15mi.shp*	~20 largest waterbodies within 15 miles of the St. Croix River Basin that intersect main stream channels
nlcd1992_utm	Raster GRID	USGS	1988†	Projected	Land cover from the 1992 NLCD covering the St. Croix River Basin
nlcd2001_utm	Raster GRID	USGS	2001	Projected	Land cover from the 2001 NLCD covering the St. Croix River Basin
North_America_Background.shp	Shapefile	ESRI	2000†	Projected	Country boundaries in North America (excluding the US), parts of Central America and the Caribbean
Pierce_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2009†	Projected	Soil survey area boundary (a single polygon) for Pierce County in Wisconsin
Pierce_SSURGO.shp	Shapefile	NRCS	2006-2009†	Projected	SSURGO map units for Pierce County in Wisconsin
Polk_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2001-2009†	Projected	Soil survey area boundary (a single polygon) for Polk County in Wisconsin
Polk_SSURGO.shp	Shapefile	NRCS	2001-2009†	Projected	SSURGO map units for Polk County in Wisconsin
Ramsey_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2008†	Projected	Soil survey area boundary (a single polygon) for Ramsey County in Minnesota

Ramsey_SSURGO.shp	Shapefile	NRCS	2006-2008†	Projected	SSURGO map units for Ramsey County in Minnesota
Rusk_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2009†	Projected	Soil survey area boundary (a single polygon) for Rusk County in Wisconsin
Rusk_SSURGO.shp	Shapefile	NRCS	2006-2009†	Projected	SSURGO map units for Rusk County in Wisconsin
Sawyer_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2009†	Projected	Soil survey area boundary (a single polygon) for Sawyer County in Wisconsin
Sawyer_SSURGO.shp	Shapefile	NRCS	2006-2009†	Projected	SSURGO map units for Sawyer County in Wisconsin
Sherburne_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	1998-2009†	Projected	Soil survey area boundary (a single polygon) for Sherburne County in Minnesota
Sherburne_SSURGO.shp	Shapefile	NRCS	1998-2009†	Projected	SSURGO map units for Sherburne County in Minnesota
States.shp	Shapefile	ESRI	2000†	Projected	US state boundaries
StCroix_Basin_Boundary.shp	Shapefile	USDA	2008*	Dissolved features in *StCroix_Subbasin_Boundary.shp*	St. Croix River Basin boundary
StCroix_Basin_Boundary_15mi_Buffer.shp	Shapefile	USDA	2008*	Buffered features in *StCroix_Basin_Boundary.shp* by 15 miles	15 mile buffer of St. Croix River Basin boundary
StCroix_River.shp	Shapefile	WIDNR	1994	Clipped from WIDNR Rivers layer (not included in database) and projected	St. Croix River, from Louise Sharrow's work in the Summer of 2008
StCroix_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	1998-2009†	Projected	Soil survey area boundary (a single polygon) for St. Croix County in Wisconsin

StCroix_SSURGO.shp	Shapefile	NRCS	1998-2009†	Projected	SSURGO map units for St. Croix County in Wisconsin
StCroix_Subbasin_Boundary.shp	Shapefile	USDA	2008*	Queried features in *Subbasin_Boundary.shp* that are part of the St. Croix River Basin	Subbasin boundaries in the St. Croix River Basin
StCroix_Subwatershed_Boundary.shp	Shapefile	USDA	2008*	Clipped features in *Subwatershed_Boundary.shp* using *StCroix_Basin_Boundary_15mi_Buffer.shp*	Subwatershed boundaries in the St. Croix River Basin
StCroix_Watershed_Boundary.shp	Shapefile	USDA	2008*	Dissolved features in *StCroix_Subwatershed_Boundary.shp* based on "HUC_10_Name" field	Watershed boundaries in the St. Croix River Basin
StCroixBasin_Counties.shp	Shapefile	ESRI	2000†	Clipped from *MNWI_Counties.shp* using *StCroix_Basin_Boundary_15mi_Buffer.shp*	Counties within a 15 mile radius of the St. Croix River Basin
StCroixBasin_SSURGO.shp	Shapefile	NRCS	--	Clipped from MNWI_SSURGO.shp using StCroix_Basin_Boundary_15mi_Buffer.shp	SSURGO map units within a 15 mile radius of the St. Croix River Basin
StLouis_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2007-2008†	Projected	Soil survey area boundary (a single polygon) for St. Louis County in Minnesota
StLouis_SSURGO.shp	Shapefile	NRCS	2007-2008†	Projected	SSURGO map units for St. Louis County in Minnesota
Stream_Gages.shp	Shapefile	NHDPlus	2005*	Projected	Stream gage locations, point features
Stream_Gages_StCroixBasin.shp	Shapefile	NHDPlus	2005*	Clipped from Stream_Gages.shp using StCroix_Basin_Boundary_15mi_Buffer.shp	Stream gage locations within a 15 mile radius of the St. Croix River Basin, point features
Subbasin_Boundary.shp	Shapefile	USDA	March, 2008	None	Hydrologic unit boundaries down to the subbasin level

Subwatershed_Boundary.shp	Shapefile	USDA	March, 2008	None	Hydrologic unit boundaries down to the subwatershed level
Trade_River.shp	Shapefile	WIDNR	1994	Projected	Trade River, from Louise Sharrow's work in the Summer of 2008
Washburn_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2003-2008†	Projected	Soil survey area boundary (a single polygon) for Washburn County in Wisconsin
Washburn_SSURGO.shp	Shapefile	NRCS	2003-2008†	Projected	SSURGO map units for Washburn County in Wisconsin
Washington_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	2006-2009†	Projected	Soil survey area boundary (a single polygon) for Washington County in Minnesota
Washington_SSURGO.shp	Shapefile	NRCS	2006-2009†	Projected	SSURGO map units for Washington County in Minnesota
Watershed_Outlets.shp	Shapefile	USDA	2008*	Created in ArcSWAT based on features in *StCroix_Watershed_Boundary.shp* during Watershed Delineation and exported	Watershed outlet locations (point layer) for St. Croix River Basin
Weather_Stations.shp	Shapefile	USU	--	Imported xy-coordinates from an Excel table	Locations of gage stations within the St. Croix River Basin, used for SWAT weather data definition
WI_General_Soil_Map.shp	Shapefile	NRCS	--	Projected	SSURGO map units for Wisconsin
WI_Rivers.shp	Shapefile	WIDNR	1994	Merged WIDNR shapefiles for St. Croix, Namekagon, Trade, Wood, and Clam Rivers	Rivers in Wisconsin, from Louise Sharrow's work in the Summer of 2008
WI_Soil_Survey_Area_Boundary.shp	Shapefile	NRCS	--	Projected	Soil survey area boundary (a single polygon) for Wisconsin
WI_SSURGO.shp	Shapefile	NRCS	--	Projected	SSURGO map units for Wisconsin

Wood_River.shp	Shapefile	WIDNR	1994	Clipped from WIDNR Rivers layer (not included in database) and projected	Wood River, from Louise Sharrow's work in the Summer of 2008

YYYY* = Year data were originally published, however mdoifications were made during this project more recently

YYYY† = Date refers to ground condition

-- = date unkown, or layer is formed by merging several layers with different dates

Technical Appendix

Tabular Data

Flie/Field Name	Description
Catchment_Attributes_NLCD.dbf	*NLCD attribute data for Catchment.shp and Catchment_StCroixBasin.shp*
Catchment_Attributes_Temp_Precip.dbf	*Temperature and precipitation attribute data for Catchment.shp and Catchment_StCroixBasin.shp*
Flowline_Attributes_Flow.dbf	*Flow attribute data for NHD_Flowline.shp and NHD_Flowline_StCroixBasin.shp*
Flowline_Attributes_NLCD.dbf	*NLCD attribute data for NHD_Flowline.shp and NHD_Flowline_StCroixBasin.shp*
Flowline_Attributes_Temp_Precip.dbf	*Temperature and precipitation attribute data for NHD_Flowline.shp and NHD_Flowline_StCroixBasin.shp*
Headwater_Node_Area.dbf	*Information for the headwater nodes*
historicaltables.xls	*Contains historical land cover summary tables for the upper, lower, and combined St. Croix River Basin, from Louise Sharrow's work in the summer of 2008 - unkown source.*
MN_Aitkin_soildb_2003.mdb[1]	*SSURGO tabular database for Aitkin County. Below is a list of tables included in database.*
chaasto	American Association of State Highway Transportation Officials (AASHTO) classification(s) for the referenced horizon
chconsistence	Descriptions of soil consistence (rupture resistence, plasticity, stickiness) for the referenced horizon
chdesgnsuffix	Designation suffix(es) for the referenced horizon
chfrags	Lists the mineral and organic fragments that generally occur in thr referenced horizon
chorizon	List of horizon(s) and related data for the referenced map unit component
chpores	Lists voids (pores) for the referenced horizon
chstruct	Lists individual soil structure, grade, and shape terms for the referenced horizon

chstructgrp	Lists the ranges of soil structure for the referenced horizon
chtext	Notes and narrative descriptions related to the referenced horizon
chtexture	Lists individual textures, or terms using in lieu of texture, for the referenced horizon
chtexturegrp	Lists the range of textures for the referenced horizon
chtexturemod	Lists the texture modifier(s) for the referenced horizon
chunified	*Unified Soil Classification(s) for the referenced horizon*
cocanopycover	Lists the overstory plants that typically occur on the referenced map unit component
cocropyld	Lists commonly grown crops and their expected range in yeilds when grown on the referenced map unit component
codiagfeatures	Lists the typical soil feature for the referenced map unit component
coecoclass	Identifies the ecological sites typicall associated with the referenced map unit component
coeplants	Lists the plants, either rangeland or forestland plants, that typically occur on the referenced map unit component
coerosionacc	Lists the kinds of accelerated erosion that occur on the referenced map unit component
coforprod	Lists the site index and the annual productivity in cubic feet per acre per year of forest overstory species that typically occur on the referenced map unit component
coforprodo	Lists the site index and annual productivity of forest overstory species in other units that typically occur on the referenced map unit component
cogeomordesc	Lists the geomorphic features on which the referenced map unit component typically occurs
cohydriccriteria	Lists the hydric soil criteria met for those referenced map unit components that are classified as a "hydric soil"
cointerp	Lists the predictions of behavior and limiting features for specified uses made for the referenced map unit component
comonth	Lists the monthly flooding and ponding characteristics for the referenced map unit component

component	Lists the map unit components identified in the referenced map unit, and selected properties for each component
copm	Lists the individual parent material(s) for the referenced map unit component
copmgrp	Lists the concatenated string of parent material(s) in which the referenced map unit component formed based on entries in the Component Parent Material table (*copm*)
copwindbreak	Lists the windbreak plant species commonly recommended for the referenced map unit component
corestrictions	Lists the root restrictive feature(s) or layer(s) for the referenced map unit component
cosoilmoist	Describes the typical soil moisture profile for the referenced map unit component
cosoiltemp	Describes the typical soil temperature profile for the referenced map unit component
cosurffrags	Lists the organic or mineral fragments that generally occur on the surface of the referenced map unit component
cosurfmorphgc	Lists the typical geomorphic position(s) of the referenced map unit component, in three dimension terms
cosurfmorphhpp	Lists the geomorphic position(s) of the referenced map unit component, in two dimensional hillslope profile terms
cosurfmorphmr	Lists microrelief feature(s) associated with the referenced geomorphic (microfeature) feature shown in the Component Geomorphic Description table (*cogeomordesc*)
cosurfmorphss	Lists the geomorphic shape(s) of the referenced map unit component, in slope shape terms
cotaxfmmin	Lists the mineralogy characteristics, as defined in Soil Taxonomy, that apply to the referenced map unit component
cotaxmoistcl	Provides clear identification of the intended taxonomic moisture class, as defined in Soil Taxonomy, that apply to the referenced map unit component
cotext	Contains notes and narrative descriptions for the referenced map unit component
cotreestomng	Lists the trees commonly recommended for managing on the referenced map unit component
cotxfmother	Lists the other taxonomic characteristics that apply to the referenced map unit component

distinterpmd	Records the set of NASIS fuzzy logic interpretations which were generated for the map unit components included in a set of distribution data
distlegendmd	Records information about the legends or soil survey areas selected for inclusion in a set of distribution data
distmd	Records information associated with the selection of a set of data for distribution to some entity of information system external to NASIS
featdesc	Records the description of all spot features that occur in a soil survey area
featline	Records all of the spot features of a soil survey area that are represented as one or more lines
featpoint	Records all of the spot features of a soil survey area that are represented as one or more points
laoverlap	Lists the geographic areas that are coincident with the soil survey area identified in the Legends table (*legends*)
legend	Identifies the soil survey area that the legend is related to, and related information about that legend
legendtext	Contains notes and narrative descriptions related to the referenced legend
mapunit	Identifies the map units included in the referenced legend
mdstatdomdet	Records the individual comain members for all domains associated with the tabular data set
mdstatdommas	Records the metadata that pertains to a domain as a whole, for all domains associated with the tabular data set
mdstatidxdet	Records what columns of a table make up a particular index
mdstatidxmas	Records the metadata that pertains to an index as a whole, for all indexes defined for the tabular dataset
mdstatrshipdet	Records the pairs of join columns that define a particular relationship
mdstatrshipmas	Records the metadata that pertains to a relationship as a whole, for all relationships defined for the tabular dataset
mdstattabcols	Records the metadata for all columns of all tables that make up the tabular data set
mdstattabs	Records metadata about the tables that make up the tabular data set

month	A lookup table for months of the year
muaggatt	Records a variety of soil attributes and interpretations that have been aggregated from the component level to a single value at the map unit level
muaoverlap	Lists the map units that exist in the overlap between the entire soil survey and the referenced geographic area in the Legend Area Overlap table (*laoverlap*)
mucropyld	Lists commonly grown crops and their expected yields for the referenced map unit as a whole
mutext	Contains notes and narrative descriptions related to the referenced map unit
sacatalog	Records the primary dynamic cetadata associated with a soil survey area
sainterp	Records information about the soil interpretations that were generated for a soil survey area
sdvalgorithm	Records the valid algorithms for aggregating soil property values or soil interpretation results to the map unit level
sdvattribute	Each record in this table corresponds to either an intrinsic soil property or a soil interpretation that is available in the Soil Data Viewer application
sdvfolder	The records in this table represent the folders and subfolders by which soil attributes (SDV rules) are grouped and displayed in the Soil Data Viewer application
sdvfolderattribute	Resolves the many-to-many relationship between Soil Data Viewer folders and soil attributes (SDV rules)
MN_soildb_2002.mdb2	*Contains the same fields/information as <state_abbreviation>_<county_name>_soildb_2003.mdb tables do, for STATSGO*
NHD_Waterbody_StCroix_Largest.dbf	*Corresponds to the* NHD_Waterbody_StCroix_Largest.shp*, contains ~20 largest waterbodies that intersect a major stream channel, within the St. Croix River Basin*
Precipitation (Folder)	*Contains tables for each weather station listed in* Weather_Stations.dbf*, with a field for date and precipiation (PCP). Weather stations included are: Cambridge* (Cambrdg.dbf), *Cumberland* (Cmbrlnd.dbf), *Danbury* (Danbury.dbf), *Hinckley* (Hinckley.dbf)*, Moose Lake* (MooseLk.dbf)*, Mora* (Mora.dbf)*, River Falls* (RvrFalls.dbf)*, Solon Springs* (SlnSpngs.dbf)*, Spooner* (Spooner.dbf)*, and St. Croix Falls* (StCrxFls.dbf). *Also included is the* Weather_Stations.dbf *table*

Precipitation.xls	*Contains the USU COOP precipitation data for each weather station*
SWAT_Monitoring_Points.dbf	*Contains a complete set of watershed inlets and outlets, as well as reservoirs (including user-supplied outlets) used in SWAT simulation for this project*
SWAT_Watershed_Outlets.dbf	*Contains information for each watershed outlet corresponding to features in Watershed_Outlets.shp, with xy-coordinates, latitute, longitude, and TYPE fields. The TYPE field value for all entries in this table is "O" for Outlet. Created based off of watershed outlet locations in StCroix_Watershed_Boundary.shp*
Temperature (Folder)	*Contains tables for each weather station listed in W*eather_Stations.dbf*, with a field for date, maximum temperature, and minimum temperature. Tables included are the same as in the* Precipitation *folder*
Temperature.xls	*Contains the USU COOP temperature data for each weather station*
USUClimateData.xls	*Contains the originally downloaded USU COOP precipitation and temperature data for each weather station*
Weather_Stations.dbf	*Contains names and xy-coordinates of weather stations used in Weather Data Definition, from USU COOP weather data*

[1] This database and associated text files are available for all counties and each state included in this project - including Minnesota and Wisconsin; the Minnesota counties: Anoka, Benton, Carlton, Chisago, Crow Wing, Dakota, Goodhue, Hennepin, Isanti, Kanabec, Mille Lacs, Morrison, Pine, Ramsey, Sherburne, St. Louis, Washington, and Wright; and the Wisconsin Counties: Ashland, Barron, Bayfield, Burnett, Douglas, Dunn, Pierce, Polk, Rusk, Sawyer, St. Croix, and Washburn. Descriptions of each field are taken from "SSURGO Metadata - Tables" - for refernce information, see the Bibliography. The databases and text files for Wisconsin and its associated counties are for 2002 instead of 2003, so the file/database name varies accordingly

[2] This database and associated text files contain similar information to the SSURGO database/files and is available in this project for Minnesota and Wisconsin