A HYDROLOGIC MODEL FOR ASSESSING THE INFLUENCE OF WETLANDS ON FLOOD HYDROGRAPHS IN THE RED RIVER BASIN

DEVELOPMENT AND APPLICATION

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INTRODUCTION

After every major flood in the Red River Valley, questions concerning the value of wetlands in mitigating flood damages are debated. The situation was no different after the devastating flood of 1997 in the valley. The seemingly conflicting role of wetlands for flood control versus their agricultural benefits came into sharp focus. Questions often come up regarding the economic merits of restoring wetlands for flood control. The integrated effect of wetlands that are distributed throughout the watershed on the hydrographs of tributaries and along the mainstem are not understood very well by the researchers and public. There is a compelling need to investigate the impact of wetlands on flooding in the valley on a scientific basis. In order to quantitatively assess the effectiveness of wetlands in flood control, we need to model the hydrology of wetlands and the watersheds in which they are located. As a first step, the currently available hydrologic models are reviewed for their capability, or lack of it, for representing the integrated effect of wetlands on flooding in a separate report titled "A Review of Models for Investigating the Influence of Wetlands on Flooding" (Bengtson and Padmanabhan, 1999) hereafter referred to as Report I. The development and application of a hydrologic model for investigating the integrated effect of wetlands on flooding in the Red River Valley is described in this report, "A Hydrologic Model For Assessing the Influence of Wetlands on Flood Hydrographs in the Red River Basin: Development and Application" (Padmanabhan and Bengtson 1999), hereafter referred to as Report II.

CHOICE OF MODEL

Several watershed hydrologic models were considered including HEC-1, PRMS, HSPF, AGNPS. The following factors influenced the selection of the model for the study.

1. Capability to simulate major hydrologic processes during a flood event,
2. Capability to vary the parameters spatially,
3. Capability to simulate the attenuation of flood flows due to wetlands,
4. Capability to simulate explicitly the flood storage available in wetlands depending on a variety of initial water levels,
5. Capability to simulate watersheds with drainage area greater than 1000 mi^2, and
6. Capability to interface with GISs and DEMs for proper preparation of input data and for post processing of the results.

The HEC-1 model was chosen for the study, basically because it offers the most of the methods for simulating the major hydrologic processes occurring during a flood event without the complications of involving those hydrologic processes which may not have significant effects during floods. It is possible to account for the spatial variability of parameters and physical properties in a watershed if the subbasins are small enough so that their hydrologic properties can be assumed to be homogeneous. During flood conditions, such a capability may be more than adequate to represent the hydrologic processes involved. HEC-1 offers a variety of overland routing techniques allowing considerable flexibility in modeling flood hydrographs. The flood storage capacity of wetlands can be modeled using diversions, the reservoir routing capability of HEC-1, or initial and ongoing abstraction of precipitation falling on the watershed. It also has the capability of modeling large watersheds falling within the range of this study - 1600 to 2000 mi^2. The Corps of Engineers have developed specific preprocessor and postprocessor software incorporating GIS for HEC-1. One of the best is WMS (Watershed Modeling System), an integrated terrain and hydrologic modeling program to delineate subwatershed and subbasin boundaries from DEMs. This program is useful in developing subbasin parameters and distributing precipitation over the watershed. Preexisting DEM coverages can be imported into WMS. For detailed discussion on the capabilities of the models considered for selection, refer to the companion Report I (Bengtson and Padmanabhan, 1999.)

MODELING STRATEGY

Currently, when modeling flood flows, wetlands are typically represented as special topographic surface areas with different runoff characteristics. This will account for their influence on the runoff volume generated by the watershed, but will not account for their influence on the watershed hydrographs by way of their capability to store water. However, the antecedent water level in the wetland, the elevation controlling the outflow from the wetland, and the depth-storage and depth-outflow relationships of the wetland will influence the hydrograph at the outlet of the watershed.

Unlike the past practice, it is clear that a detailed topographic representation of the watershed and a model capable of routing flow through numerous storage depressions may be necessary to study the impact of wetlands on flooding. High-resolution digital terrain models with sufficient resolution to capture the depressions with reasonable accuracy are necessary for this purpose. However, even if these models were available, it is unlikely that it would be practical to model a watershed containing tens of thousands of existing and drained wetlands and reflect the storage characteristics of each. It is necessary, therefore, to lump wetland storage. Lumping was done on a subwatershed scale in this study.

The watershed is subdivided into several subwatersheds. The storage capacity of drained wetlands located in each subwatershed was estimated using an equation developed from a US Bureau of Reclamation study of wetlands in the Devil’s Lake basin. Some of the GIS database coverages created for this study were utilized with the WMS interface to develop some of the watershed characteristics, such as average slope and flow distances. It was not possible to directly develop the HEC-1 model from the GIS coverages within WMS, but WMS's graphical interface greatly simplified the task of building the model schematic and the data entry. The input data file is generated as the model is built using graphical elements such as subwatersheds, outlets, and streams. Figure 1 shows a watershed and its representation in HEC-1 including subwatersheds, outlets, diversions, junctions, and reservoirs.

Initially, it was planned to represent the wetlands in each subwatershed as a reservoir at the outlet of the subwatershed. The overland flows and streamflows would be routed through the reservoir, reflecting the combined storage capacity of the restored drained wetlands. However, some subwatersheds contained a relatively small storage capacity with respect to the flows arriving at the outlet, and would quickly be filled and overwhelmed. Also, it is unlikely that all flows in a subwatershed will be intercepted by the restored drained wetlands, while placing the reservoir at the outlet assumes that all subwatershed flow will be routed through the reservoir. This approach has been used to model individual wetlands but may not be appropriate to model combined wetland storage. Figure 2 shows how this approach would be represented in HEC-1.

The storage capacity of restored drained wetlands could also be represented as part of the initial and ongoing abstraction from precipitation falling on the watershed. The portion of precipitation abstracted reflects the amount of water infiltrating the soil, intercepted by vegetation, and filling small depressions. There are several methods for determining the initial abstraction of precipitation. None of them is really suitable to model explicitly the effect of wetland storage. The only method that allows the user to completely control the amount and rate of infiltration is the uniform loss method. An initial amount of abstracted precipitation can be specified which must be satisfied before excess precipitation begins to run overland to the subwatershed outlet, and a continuing uniform rate of abstraction can also be specified. There are two problems with using this method. The storage capacity could be reflected in the initial abstraction amount, but this would mean that the wetland storage would be utilized before any overland runoff began. In reality, the initial abstraction due to infiltration would occur, excess rainfall would begin to flow overland, and begin to fill the wetland storage over a period of time depending on the size of the area that contributes flow to the wetland. Some or all of the wetland storage could be specified as part of the ongoing uniform loss rate, but this limits the effects of storage to the actual length of the precipitation event. For short duration events (24-hour or less) the wetland storage may be utilized before significant surface runoff might actually reach the wetlands and begin to fill the storage.

To circumvent this problem, the concept of flow diversion may be used. Using diversions allows considerable flexibility in that various rates of diversion can be modeled, and the rate of diversion flows can be set as some fraction of the flow arriving from upstream. Setting the diversions as a fraction of arriving

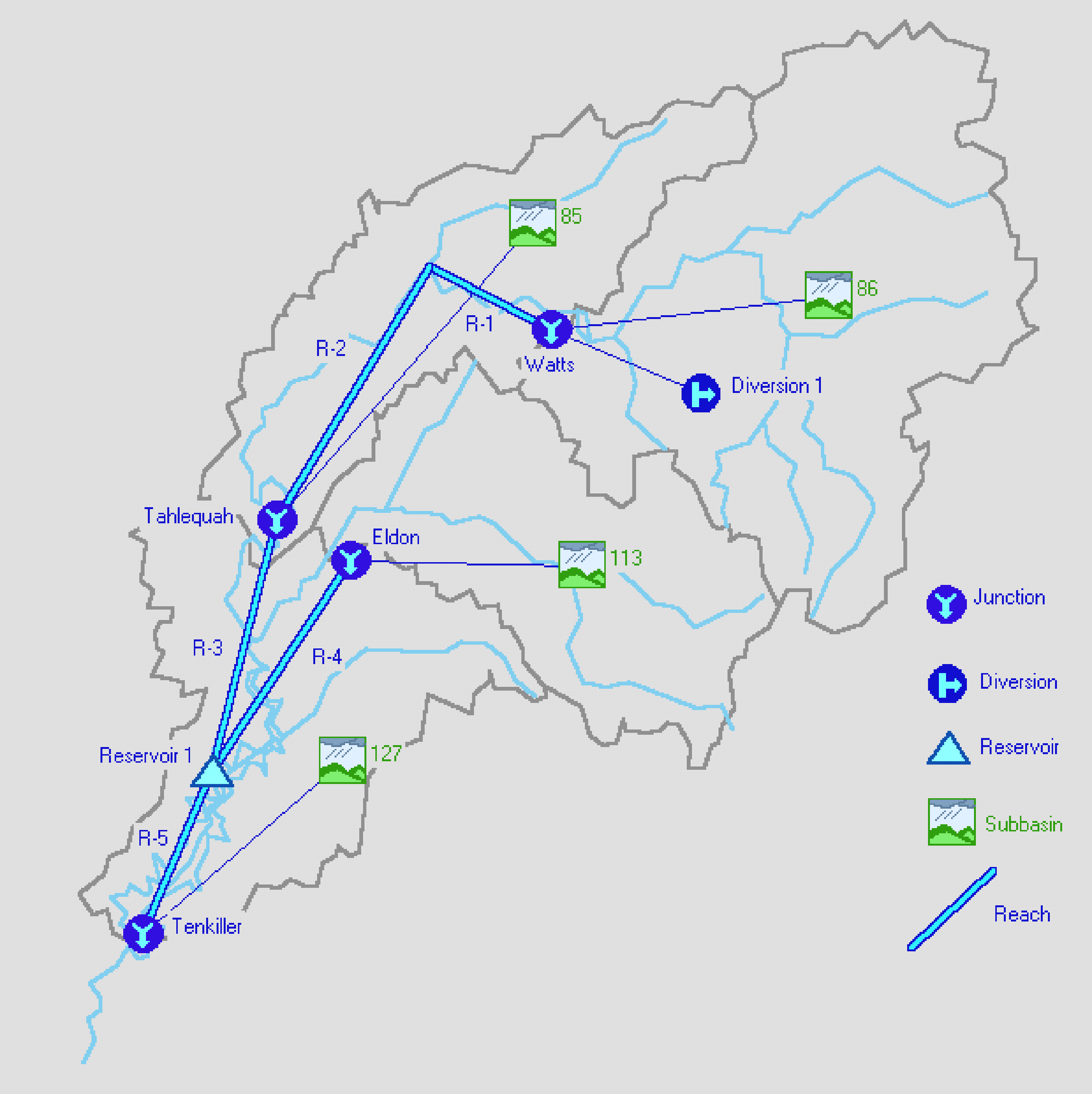
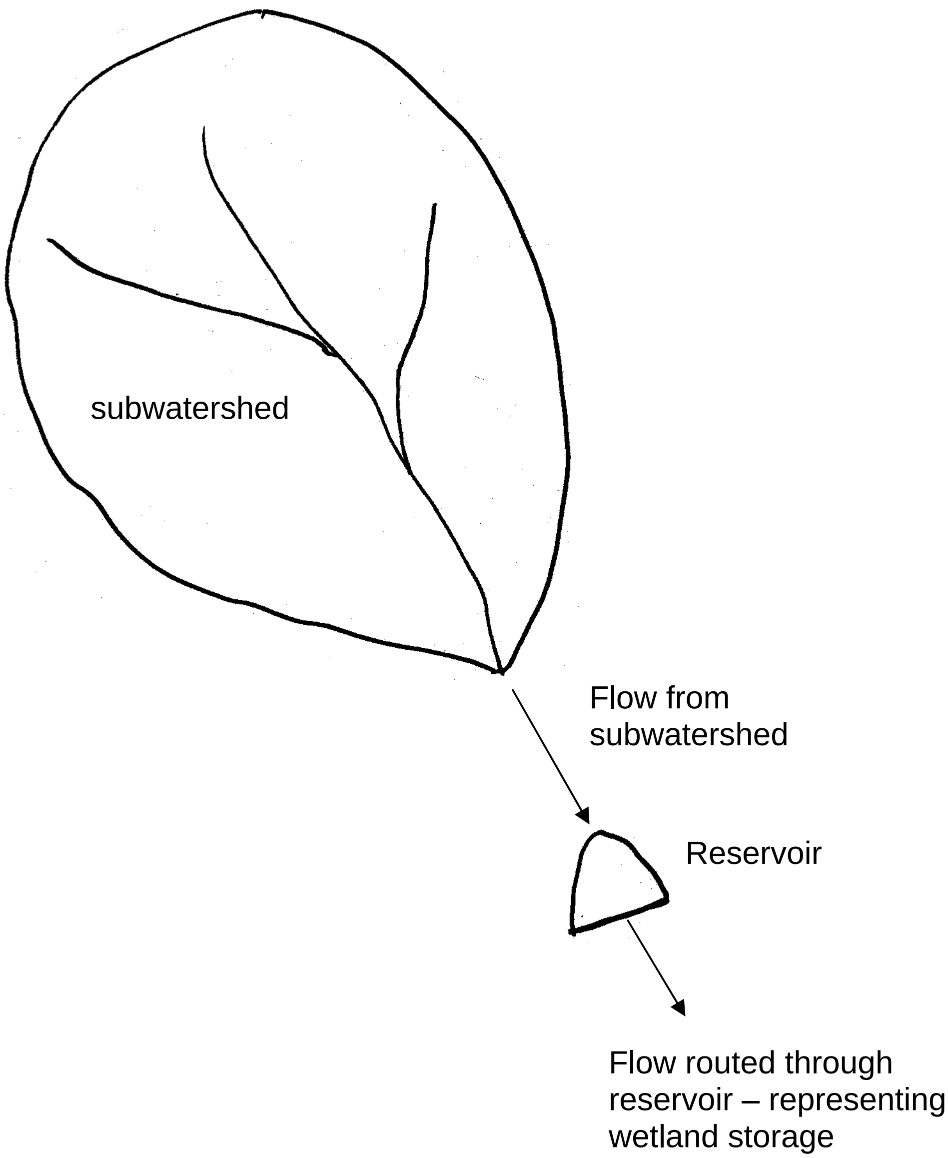


Figure 1. Representation of a watershed in HEC-1.

Figure 2. Subwatershed with wetland storage modeled as a reservoir at the subwatershed outlet



flow can reflect the subwatershed area that contributes flow to the wetlands. The timing of flow diversions can be controlled by not allowing diversions to occur until a certain flow magnitude is reached, such as 50% of the peak flow. The total amount of diversion can be set to equal the storage capacity of the wetlands. Once the wetland storage capacity is satisfied, all remaining flow is routed downstream. Flow diversions can be temporary or permanent. For temporary diversions, such as the case where a river channel splits, the diversion hydrograph is saved and included at a downstream location. Permanent diversions will be used to model wetland storage. Figure 3 shows how diversion flows are represented in HEC-1. Part or all of the overland flow and streamflow that arrives at the mouth of a subbasin can be diverted.

CHOICE OF WATERSHEDS FOR PILOT STUDY

Two watersheds, one on the North Dakota side and the other on the Minnesota side, Maple River watershed and Wild Rice River Watershed respectively were selected for the study. The following criteria were used for the selection.

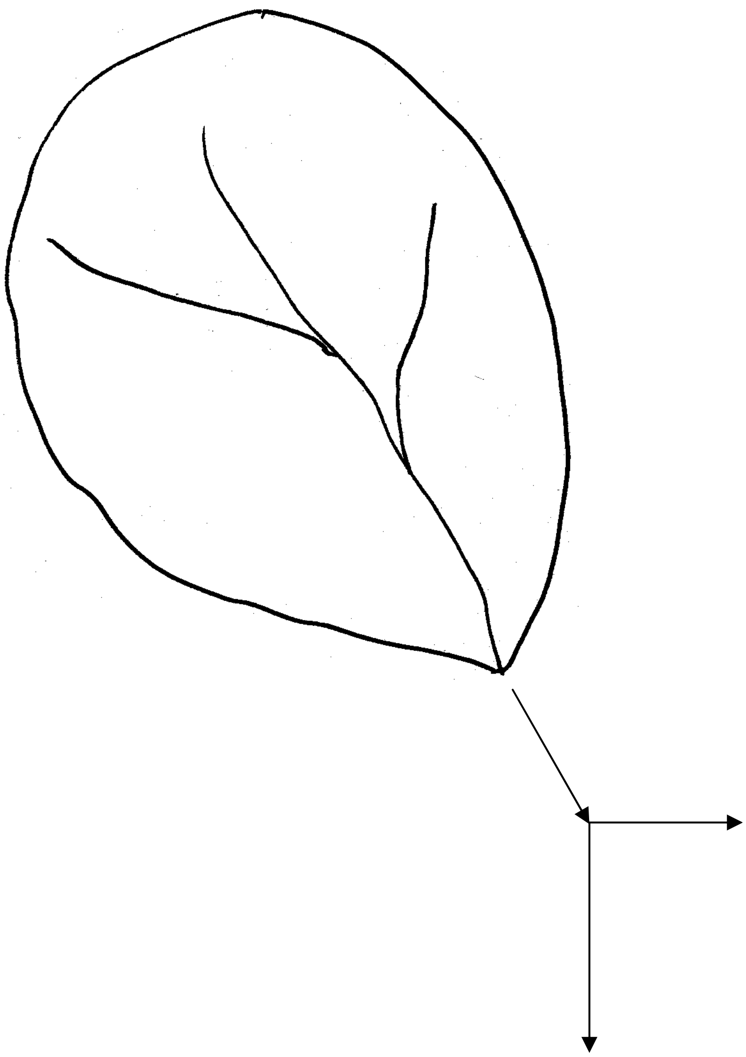
1. Availability of substantial number of wetlands distributed throughout the watershed,
2. Availability of digital elevation coverage with sufficient resolution,
3. Availability of a number of drained wetlands,
4. Availability of reasonable number of gages, and
5. Availability of land use and soils data.

The boundaries of the watersheds and the stream gaging stations are shown in figures 4 and 5. Each watershed has a drainage area of approximately 1600 square miles.

In the Maple River watershed there are approximately 2187 drained wetlands with an estimated storage volume of 2500 to 3000 ac-ft. They are distributed in three distinct zones in regard to the direction of flow of the river, namely the lake plain, the beach or moraine region, and the upland or lake-washed till plain. The main watershed was divided into 48 subwatersheds. Digital elevation models (DEMs) based on the USGS 1:250,000 scale maps were available for the entire watershed. DEMs based on the USGS 7-1/2 minute quadrangles were available for portions of the watershed.

In the Wild Rice River watershed there are approximately 4145 drained wetlands with a storage volume of 14100 to 28100 ac-ft. They are similarly distributed in three distinct zones as the Maple River watershed. The main watershed was divided into 80 subwatersheds. DEMs for the entire watershed were available based on the USGS 1:250,000 scale maps.

Figure 3. Subwatershed with wetland storage modeled as a diversion at the subwatershed outlet



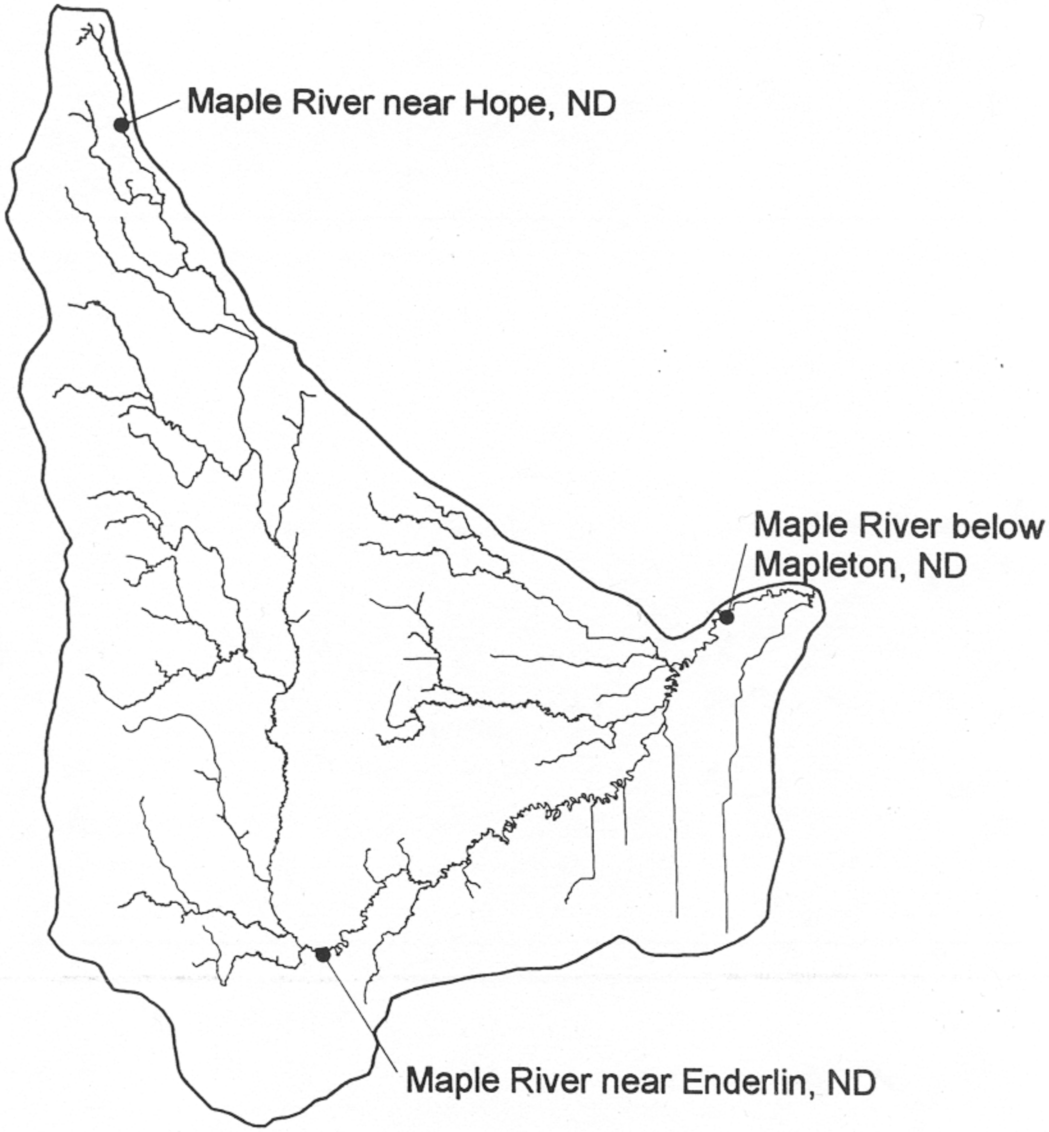


Figure 4. Maple River watershed with USGS streamflow gage stations.

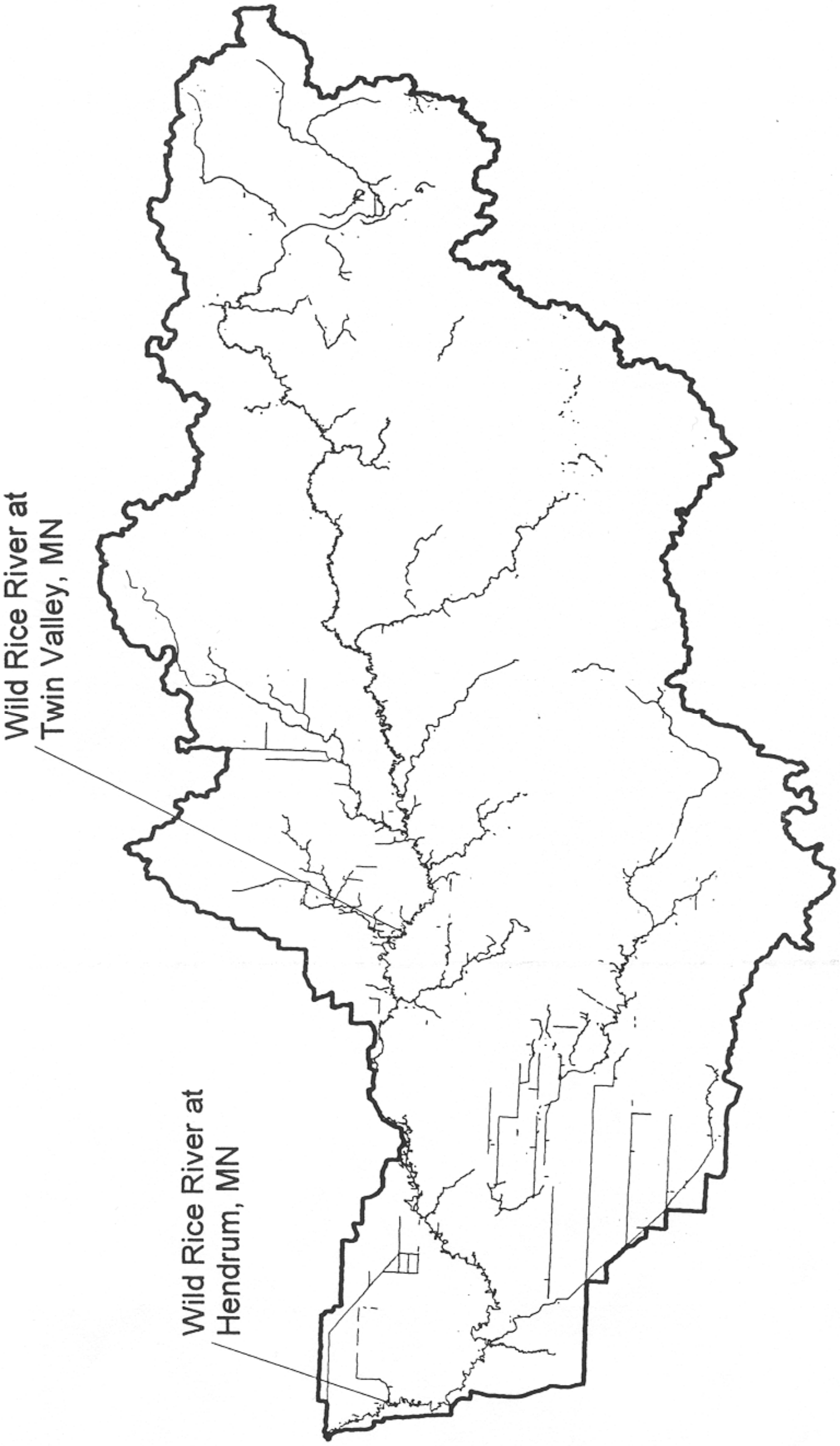


Figure 5. Wild Rice River watershed with USGS streamflow gage stations.

Table 1 provides the distribution of various types of wetlands in the selected watersheds. Not only does the Wild Rice River watershed contain 2.3 times greater total wetland surface area than the Maple River watershed, the drained wetlands represent 5.5 times more surface area in the Wild Rice River watershed. Table 2 provides the estimated volume of drained wetlands in the watersheds and their flood absorptive capacity in regard to five major annual floods in those watersheds. Flood absorptive capacity is calculated by dividing the wetland storage volume by the volume of flood water. This assumes that the wetlands would be empty at the beginning of the flood event, which is unlikely if the preceding period has been wet. For the largest recorded flood event in the Maple River watershed, which occurred during the summer of 1975 due to several large rainstorms occurring over a period of several days, 1.9 to 2.3 percent of the flood volume could theoretically be contained by restoring the drained wetlands. This is unlikely to significantly lower the peak discharge and stage for the watershed, and thus unlikely to significantly reduce flood damages for the watershed as a whole. The estimated storage represented by the drained wetlands in the Wild Rice River watershed would hold an estimated 4.6 – 9.1 % of the flood volume for the 1997 snowmelt flood. Reducing the flood volume by this amount may not lead to similar percent changes in flood stage, since once the river has overflowed its banks, a 1-foot decrease in stage requires a much larger decrease in flowrate due to the much wider flood plain cross-sectional area.

For additional information on the selected watersheds, refer to another companion report of this project "The Collection of GIS - Based Data in the Maple (ND) and Wild Rice (MN) River Watersheds of the Red River Valley ", Final Report, May 1999.

GIS DATABASE AND OTHER DATA

A GIS database was assembled for each of the selected watersheds. Land use, wetlands and soils data from existing sources were collected and entered in the database. The idea is to process the data further to compute parameters required for the hydrologic model HEC-1. For more details about the GIS database, refer to "The Collection of GIS - Based Data in the Maple (ND) and Wild Rice (MN) River Watersheds of the Red River Valley ", Final Report, May 1999, a report on another aspect of this study.

The land use coverage for the Maple River watershed was obtained from the ND GIS repository, generated by the EPA in 1977 at a scale of 1:250,000. Most of the watershed is crop/pasture or rangeland as defined by the Anderson Land use code. There are small percentages of developed land, forest, water, and wetlands. Land use classification by subwatershed for the Maple River watershed can be found in Table A-1 in Appendix A.

Table 1. Wetlands in the Maple and Wild Rice Watersheds - surface area

Watershed	Wetland surface area in acres						
	Permanent	Semi-Permanent	Seasonal	Temporary	Drained	Impoundments	Total
Maple		10749	16566	13809	2757	390	44271
Wild Rice	3573	14521	30936	38374	15217	287	102908

Table 2. Estimated Wetland volumes and absorptive capacities for the 5 largest flood events in the Wild Rice and Maple River Watersheds

Watershed	Flood Date	Peak Flow, cfs	Volume, ac-ft	Estimated Volume of Drained Wetlands, ac-ft		Absorptive Capacity of Drained Wetlands, % of Flood Volume[3]	
				NDWC[1]	USBR[2]	NDWC	USBR
Maple River	7/2/75	11300	131812	2524	3033	1.91	2.30
	4/16/97	6620	187690			1.34	1.62
	4/11/69	6070	98852			2.55	3.07
	4/18/75	4540	84804			2.98	3.58
	6/17/53	4060	38510			6.55	7.87
Wild Rice River	4/18/97	10300	306892	14098	28065	4.59	9.14
	4/10/78	9220	182251			7.74	15.4
	4/21/79	8650	211375			6.67	13.28
	4/15/69	8140	138965			10.15	20.2
	7/5/75	7630	152735			9.23	18.37

[1] Volume computed based on an equation developed from data obtained from Ludden, Frink, and Johnson (1983)
[2] Volume computed based on an equation developed from data obtained from the US Bureau of Reclamation Pilot Project (1999)
[3] Absorptive capacity = volume of wetlands divided by flood volume

Hydrologic soil classifications (types A, B, C, and D) for the Maple River watershed were obtained in a map format from the consulting firm Moore Engineering, Fargo, ND (Volk, 1998). The maps had been prepared from 1:24,000 scale NRCS soils maps and were screen digitized into a GIS database and coverage. About 4% of soils were classified as type A, having a low runoff potential, with the majority of soils (73%) classified as type B, characterized as having low to moderate runoff potential. Soils characterized as types C and D (moderate to high runoff potential and high runoff potential, respectively) comprise 15% and 8%, respectively. The distribution of hydrologic soil types within the Maple River subwatersheds can be found in table A-1 in Appendix A.

Wetlands data was obtained from the United States Fish and Wildlife Service (USFWS) National Wetland Inventory (NWI) compiled in the early 1990's at a 1:24,000 scale. GIS coverages on a quadrangle basis were downloaded from the USFWS web page (http://192.189.43.33/download.htm). Seven classes of wetlands were identified. Table 3 shows the distribution of wetland types and their surface areas within the Maple and Wild Rice River watersheds. The Maple River watershed has over 10,000 more wetlands than does the Wild Rice River watershed, but the average wetland size is considerably smaller, particularly in the case of the temporary and drained wetlands. Tables A-3 and A-4 in Appendix A provide more detail on the number, size, and types of all wetlands by subwatershed for both the Maple River and the Wild Rice River watersheds. Tables A-5 and A-6 in Appendix A provide further statistics on the drained wetlands by subwatershed for both watersheds.

Of most interest are the drained wetlands, as the model is to simulate the effect of restoring drained wetlands on peak flood flows in the watershed. The drained wetlands represent about 0.25% of the Maple River watershed by area, but 1.3% in the Wild Rice River watershed. Also, the drained wetlands in the Wild Rice River watershed are about 3 times larger than those for the Maple River watershed. The potential storage volume represented by the drained wetlands in the Wild Rice River watershed is over 5 times greater than that for the Maple River, yet it may still not be sufficient to store a significant amount of a large flood's runoff volume to significantly lower the peak flow and stage.

Figures 6 and 7 show the number of drained wetlands of various sizes for the Maple River and Wild Rice River watersheds. As previously mentioned, the drained wetlands in the Maple River watershed are considerably smaller than those in the Wild Rice River watershed. For instance, there are well over 200 drained wetlands in the Wild Rice watershed with surface areas exceeding 50 acres, while there are only three exceeding 40 acres in the Maple watershed.

ARCINFO line coverages of watershed boundaries at the 1:24,000 scale were obtained from the USGS. Subwatersheds are included in this coverage.

Table 3. Comparison of wetlands in the Maple River and Wild Rice River watersheds.

Maple River watershed

	No. of wetlands	Wetland surface area, acres	Wetland area by % of total watershed area
Drained wetlands	2187	2757	0.27
Other	37496	41514	4.01
Total	39683	44271	4.28

Wild Rice River watershed

	No. of wetlands	Wetland surface area, acres	Wetland area by % of total watershed area
Drained wetlands	4065	15217	1.46
Other	25129	87692	8.41
Total	29194	102909	9.87

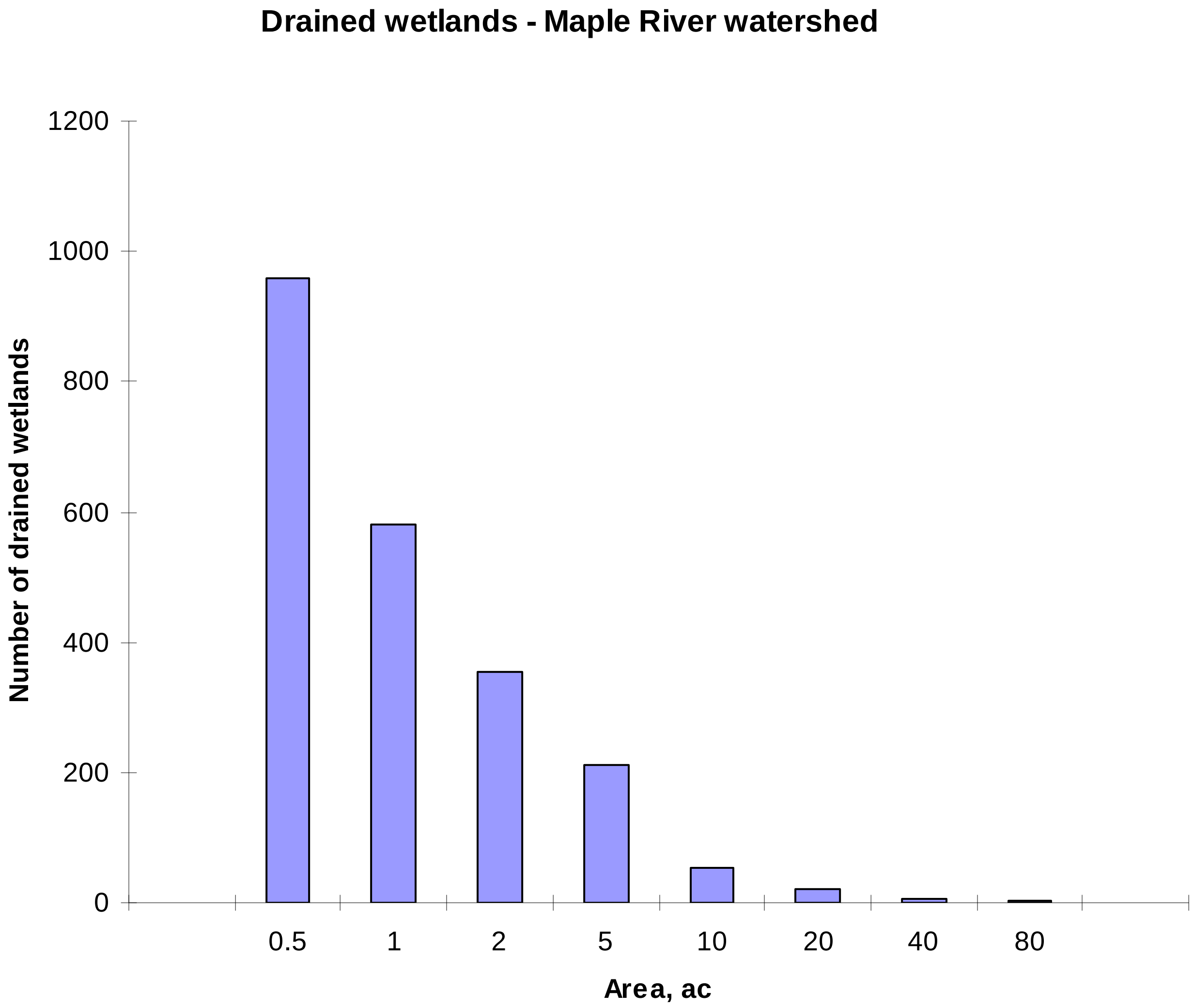


Figure 6. Distribution of drained wetland sizes in the Maple River watershed.

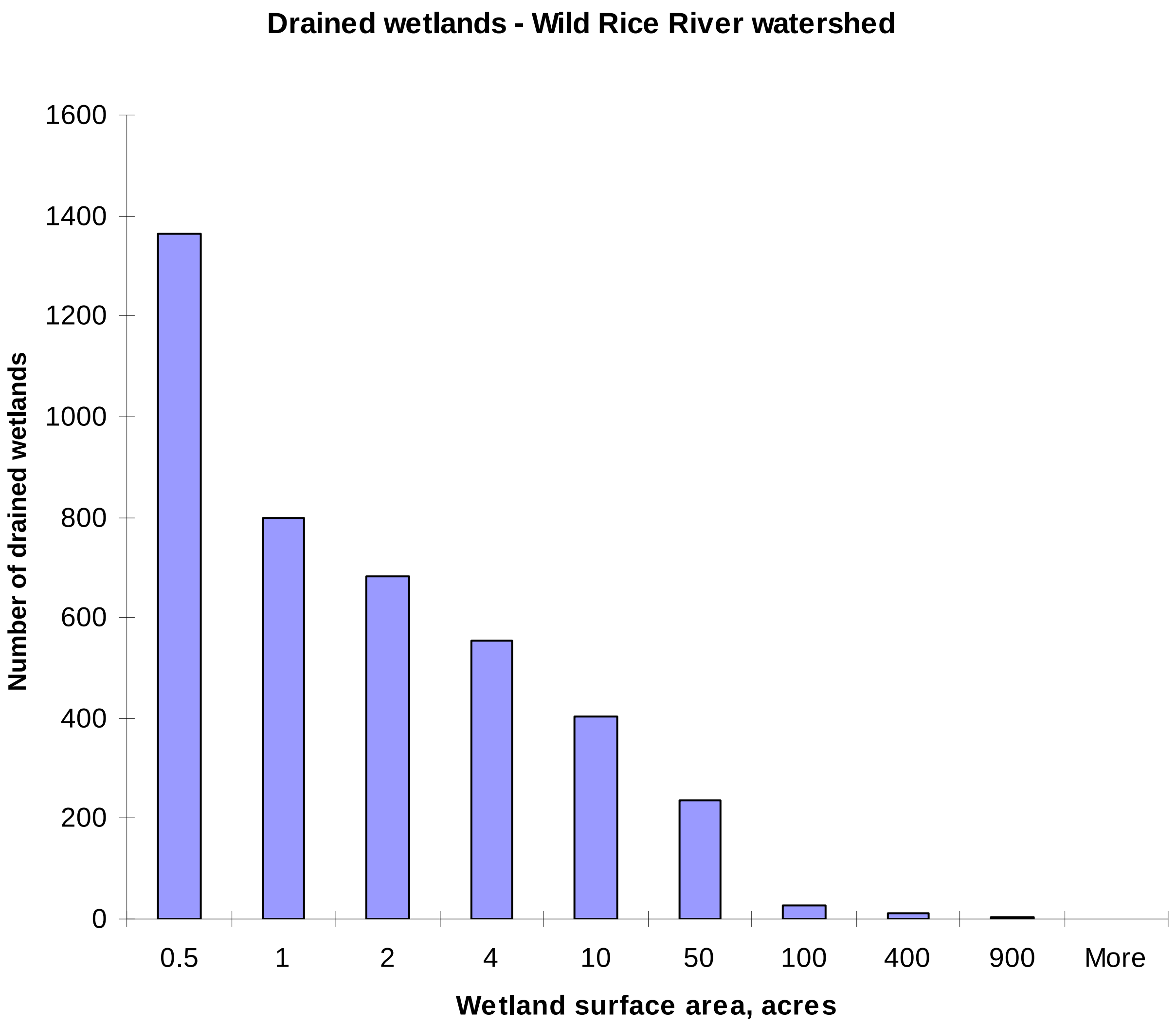


Figure 7. Distribution of drained wetland sizes for the Wild Rice River watershed.

The subwatershed delineation was quite detailed for the Wild Rice River Watershed with 160 subwatersheds. This many subwatersheds are excessive for a basin-scale model, and some were combined for a total of 80 subwatersheds. This is still a large number of subwatersheds, which may not be justified for this scale of modeling. The Maple River coverage included only a few subwatersheds, which did not appear to be correctly delineated. Therefore more detailed subwatershed boundaries were obtained from Moore Engineering (Volk, 1998), and some were combined, while others were subdivided to obtain 48 subwatersheds with areas of the same order of magnitude when feasible. The main reason for using this number of subwatersheds is to reflect the spatial distribution of the wetlands as accurately as possible given the necessity to lump wetland storage on a subwatershed basis.

Major river reaches for the Maple River were obtained from a 1:24,000 scale USGS coverage via the ND GIS repository. Minor rivers and streams (including major drainage ditches) were obtained from the USFW NWI database at the same scale. For the Wild Rice River, the major river coverage was obtained from the Department of Natural Resources (DNR). These coverages included left and right banks, and many closed loops that made them unsuitable for importing into WMS for further analysis. The coverage required extensive editing before it could be imported into WMS. The necessary editing procedures will be discussed in the Model Development section of this report.

Once the watershed boundary and subwatershed boundaries were determined, the areas and perimeters of the subwatersheds were determined. Other GIS coverages such as the soil types, land uses, and wetlands could then be analyzed and aggregated on a subwatershed basis and used to determine input parameters for the HEC-1 watershed model.

Subwatershed areas for the Maple River and Wild Rice River can be found in table A-1 and table A-2 respectively in Appendix A.

MODEL DEVELOPMENT

This section will discuss the development of the HEC-1 model used to simulate the Maple River watershed, including the parameters describing the streamflow diversions used to model the wetland storage, precipitation, initial abstraction of precipitation, overland flow, and streamflow routing.

Figure 8 shows the subwatersheds delineated for the Maple River watershed. Subwatersheds 18, 20-22, 26-27, 29, 31-33, and 36 lie mainly in the lake plain and beach regions. These subwatersheds represent about 29% of the watershed surface area. The other 37 subwatersheds lie mainly in the upland or lake-washed till plain.

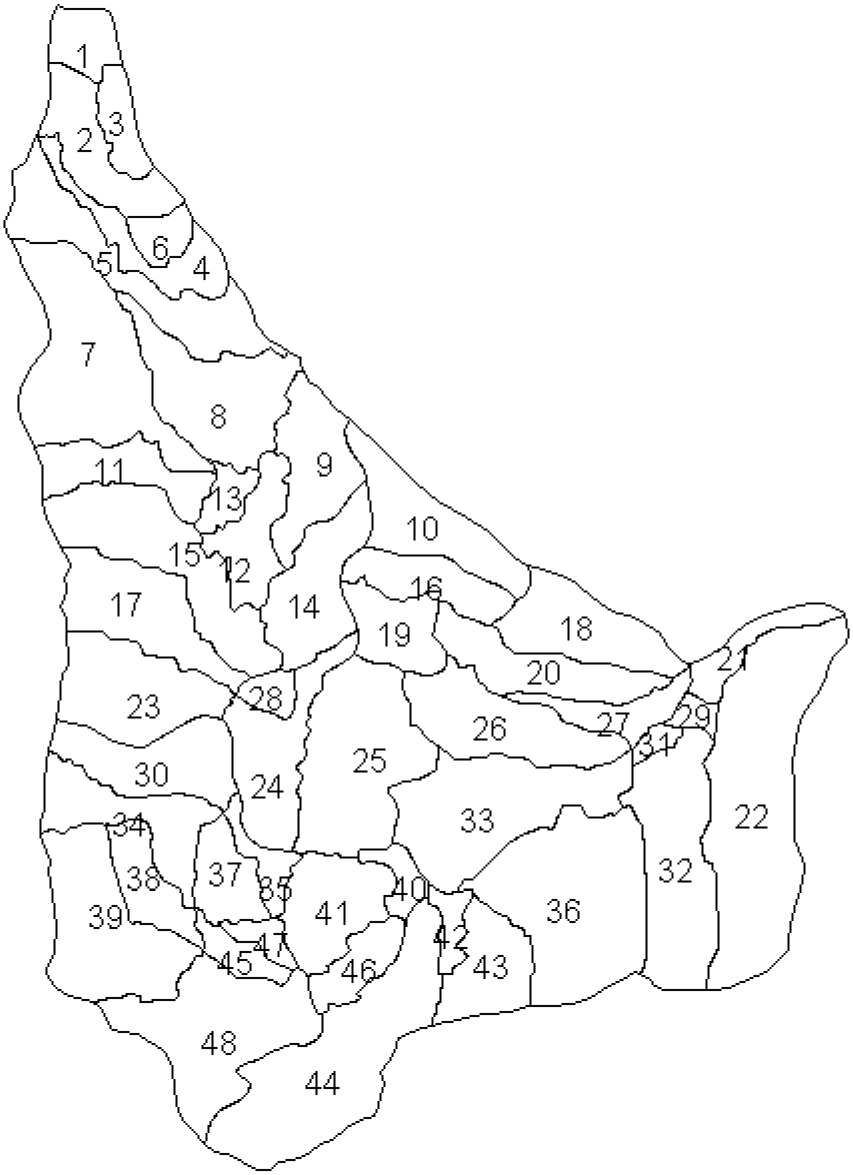


Figure 8. Subwatersheds in the Maple River watershed.

Representation of wetland storage as flow diversions

Table 4 presents a summary of wetlands in the Maple River watershed analyzed by region. The Lake Plain/Beach regions are combined as the beach area is fairly small compared to the other regions, and some subwatersheds lie in both regions. The majority of the wetlands (greater than 95%) occur in the upper or lake-washed till region of the watershed and occupy about 0.6% of the surface area. The majority of drained wetlands (greater than 96%) also were located in the upper region of the watershed and occupied about 0.3% of the surface area compared with 0.05% in the Lake Plain/Beach region. By area, only about 8% of the drained wetland area was located in the Lake Plain/Beach region.

Table 4. Summary of wetlands in the Maple River watershed by region.

Lake Plain/Beach (approximately 29% of watershed area)

Type of wetland	Number of wetlands	Total area, acres	% wetlands by area
Drained	81	228	0.05
Other	1817	2055	0.53

Upland or Lake-Washed Till (approximately 71% of watershed area)

Type of wetland	Number of wetlands	Total area, acres	% wetlands by area
Drained	2106	2530	0.30
Other	35679	39461	4.84

Since the ultimate purpose of this project is to investigate the effect that restoring drained wetlands may have on peak flood flows on a watershed scale, only the potential storage capacity represented by the drained wetlands is explicitly modeled. The effect of other wetlands is implicitly represented by the overland flow parameters for each subwatershed. Thus the possible storage represented by the other wetlands cannot be specified (wetlands empty, partly full, full.) Since the effect of restoring the drained wetlands is of interest, explicitly modeling the other wetlands is not necessary.

Initially the drained wetlands were to be represented as storage reservoirs at the mouth of each subwatershed. The potential storage capacity of all the drained wetlands in each subwatershed would be combined into a single reservoir. This would have required that stage-volume relationships be developed for each subwatershed, and probably that a weir equation be applied to each wetland with the resulting stages and discharges summed to develop an overall stage-discharge relationship for the combined wetlands.

As discussed earlier in the Modeling Strategy section of this report, the reservoir approach has some shortcomings. All the flow from a subwatershed must pass through the reservoir before being routed downstream. For subwatersheds with small numbers of drained wetlands, the resulting small reservoir will quickly be filled. Basically, this approach assumes that all the flow in a subwatershed will be intercepted by a restored wetland before ultimately reaching the mouth. This is unrealistic due to the small percentage of drained wetlands. Even in subwatersheds with a larger percentage of drained wetlands, it is unlikely that all the flow in a subwatershed will be intercepted by a restored wetland. With the reservoir approach, all the storage capacity must be filled before any flow exits the reservoir and is routed downstream. Since it is likely that some of the overland flow won't be intercepted by the restored wetlands, this will cause a lag in the time that the flow reaches the mouth of the subwatershed. Also, determining the stage-discharge relationship for a wetland is more difficult than obtaining such a relationship for a man-made impoundment. Choice of a spillway length and other coefficients may not accurately reflect the overflow characteristics of a wetland.

Using the flow diversion capabilities of HEC-1 allows the modeler to set the rate of diversions as a reasonable percentage of total watershed flow. When modeling the effect of larger numbers of restored drained wetlands, which would likely intercept more overland flow, the diversion rate can be increased. Also, the timing of the diversions can be controlled to study the effect on the flood hydrograph, by setting the minimum flow at which the diversions begin to a greater percentage of peak flow.

The only parameters required for flow diversions are the rate and total volume of the diversion. A diversion can be a fixed flowrate, or may be specified by providing an outflow hydrograph representing variable rates of diversion depending on a specified inflow hydrograph representing the flow reaching the subwatershed outlet where the diversion is located. In either case, the diversions will not start until the flow reaching the outlet is equal to or exceeds the rate of diversion.

The diversion rates will be set based on the results of modeling the watershed without storage represented by restoring the drained wetlands. The total volume of the diversion is based on estimating the volume of the drained wetlands. The GIS database supplied by the NWI only specifies the wetland area. The depths and thus the volumes of the wetlands are not available. Estimates of wetland storage volume were obtained using two different methods.

The first method used data obtained in a study of water storage capacity of natural wetland depressions in the Devils Lake Basin of North Dakota (Ludden, Frink, and Johnson, 1983.) In their study, a selected sample area of the Devils Lake basin was mapped photogrammetrically and 1-foot contour maps of the selected wetlands were developed. Ludden et al computed the wetland depression volume using the formula:

$$V = \sum \left(\frac{h}{3} \right) \left(a_u + a_1 + \sqrt{a_u a_1} \right)$$

where v is the volume, h is the vertical distance between contours (1 foot or 0.3 meters), a_u is the area at the upper contour, a_1 is the area at the lower contour, and the summation is over all increments of elevation. The computed volumes of the Devils Lake basin wetlands were plotted against their surface area and a regression analysis was performed on the data. Figure 9 shows the plotted data and the fitted line, resulting in the following linear equation with a correlation coefficient of $r^2 = 0.95$:

Volume (in ac-ft) = 0.915 x surface area (in acres)

Using this equation, the volume of storage represented by the drained wetlands in the Maple River watershed is about 2524 ac-ft, with a depth of 0.915 feet per acre.

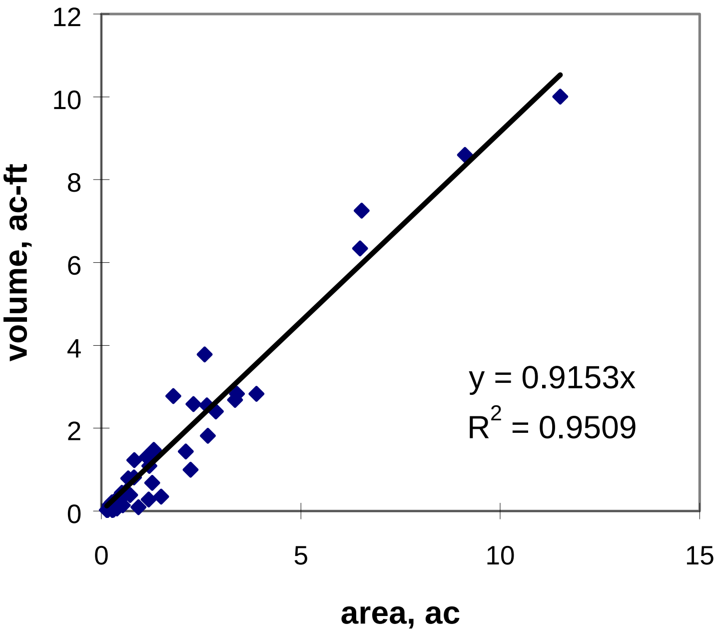


Figure 9. Regression analysis of the Ludden et al (1983) calculated wetland volumes.

Another project on estimating the water storage capacity of drained wetlands in the Devils Lake basin was recently completed by the U.S. Bureau of Reclamation in February of 1999 (USBR, 1999.) This study mapped drained wetlands in the St. Joe-Calio Coulee subbasin. Some of the wetlands were mapped with 1:12,000 scale color infrared (CIR) photography, with a randomly selected sample analyzed from 1:4000 scale black and white aerial photography. High accuracy elevation data was generated for this smaller sample and used to calculate drained wetland volumes. Two equations were developed relating volume to surface area. The simpler of the two equations was used, which related volume only to surface area. The other equation included another variable incorporating the maximum and minimum pixel value in for various numbers of pixels, with the best results obtained from 11x11 pixels. However, this only increased the r^2 value from 0.92 to 0.95, and the simpler equation was used since the data for this pixel relief variable was not readily available. The equation used was:

$$V^{0.333} = -2.0874 + 0.403604(A^{0.4})$$

where V is the volume (m^3) and A is the surface area (m^2). Figure 10 shows a plot of the estimated wetland volumes using data from the Ludden et al study overlain by a line representing the USBR equation, which also appears to be a reasonable fit to the data.

Using the USBR equation and converting the volumes from m^3 to acre-feet, the total storage represented by the drained wetlands was estimated to be 3033 ac-ft, which is about 20% higher than that estimated by the equation derived from the Ludden et al data.

The USBR model is based on measurements of drained wetlands only, with an average depth of 8.6 inches, compared to the Ludden et al average depth of 19.5 inches. The difference was partially attributed to the fact that the Ludden et al study included undrained wetlands in their analysis, which may be deeper on the average than drained wetlands because shallower wetlands are easier to drain and years of cultivation in drained wetlands have probably reduced their depth. The average depth of wetlands in the Maple River watershed was 1.1 feet.

It was decided to use the volumes as estimated by the USBR model since the study was performed on drained wetlands rather than both drained and undrained wetlands. As will be discussed in the next section of this report, these volumes are used as base values, and simulations are run with multiples of these base volumes to investigate the effect on the flood hydrograph of constructing more wetland storage than that represented by the existing drained wetlands.

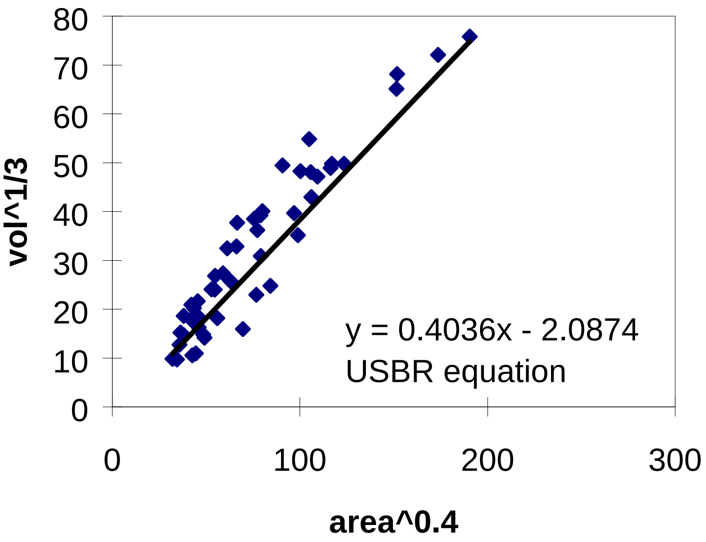


Figure 10. Wetland volumes (Ludden et al, 1983) plotted against the USBR equation for estimating wetland volumes.

Subwatershed parameters

The parameters describing the subwatersheds include the surface area and base flow parameters. The surface area was initially obtained by from a GIS coverage with the delineated subwatershed boundaries. The WMS program was used to make some minor adjustments to a few of the subwatershed boundaries and the areas of the revised subwatersheds were recomputed within WMS. Table A-7 in Appendix A lists subwatershed parameters such as surface area.

Base flow parameters include the starting base flow value that is the flow in the stream just before the hydrograph begins to rise. Other parameters set the exponential decay rate at which flow recedes after a specified threshold flow rate is reached on the recession limb of the hydrograph. A value of 0.98 was used for all subwatersheds. The threshold flow rate is generally set as a ratio of peak flow. The ratio was set as 0.10 for the subwatersheds.

Precipitation events

Unless it is desired to simulate a historic event, statistically based design storms are typically used in hydrologic modeling. Storms with different durations and frequencies or return periods can be specified based on historic data. The storm duration should exceed the time of concentration for the watershed. For a watershed the size of the Maple River (greater than 1600 mi^2), the duration of the design storm should be at least 10 days. Having storms which are uniformly distributed over the watershed and a duration as long as the time of concentration should produce the highest peak flows available in the watershed, since all of the watershed will be contributing runoff simultaneously.

Storms with return periods of 10, 25, 50 and 100 years and 10 day duration were used to investigate the effects of wetland storage on lower-frequency events. It must be emphasized that a 10-year storm will not necessarily produce a 10-year flood event, since there are other variables besides rainfall depth that influence the amount of runoff and the peak flow during a flood event such as antecedent moisture conditions, or backwater effects due to ice jams or debris.

The depth of precipitation was determined using the U.S. Weather Bureau Technical Paper 49 or TP-49 (U.S. Department of Commerce, 1964). The temporal distribution of the precipitation was determined using the second quartile distribution and 90 percent probability curve developed by Huff (1967), which results in the most temporally uniform distribution. This was chosen because Huff observed that storms occurring over large watersheds (greater than 400 mi^2) experienced more temporally uniform rainfall distribution. Table A-8 in Appendix A shows the precipitation distribution for each storm.

In HEC-1, the design storm is described by specifying the total basin averaged precipitation and then specifying the time series that describes the temporal distribution for each subwatershed. WMS provides a menu that facilitates entering this data as once the time series is entered for the first subwatershed, it can be chosen for each subwatershed in turn.

Precipitation losses

Precipitation losses consist of interception and depression storage, which are surface storage of water, and infiltration into the subsurface. After these are accounted for, the remainder is precipitation excess which is routed overland to the nearest stream. In most single-event models such as HEC-1, precipitation losses are unavailable once they are subtracted from the precipitation. The soil moisture content is not modeled. In water-balance models such as HSPF these losses are routed into the subsurface or evaporated or transpired by plants. Soil moisture changes as precipitation events occur or between such events.

There are several choices to calculate precipitation losses in HEC-1. All are empirical equations. The Green-Ampt equation, the Holtan loss equation, and the SCS curve number method are all related to soil properties and land use. The exponential loss rate relates loss rate to rainfall intensity and accumulated losses , which are representative of the changing soil moisture storage available.

The initial and uniform loss method allows the user to set an initial loss that must be satisfied before any excess precipitation occurs, and an continuous uniform rate of loss.

The initial and uniform loss method was used in this study. There are guidelines to estimate these loss rates based on soil type and storm frequency. These guidelines only estimate the loss due to infiltration. Surface storage in depressions or interception storage must be added to the initial loss. Examining hydrographs of historic flood events and the precipitation hyetographs can help determine the amount of initial loss. For instance, a rainfall event may occur that lasts for two days. The hydrograph may not start to rise until 18 hours have passed. The initial loss may be estimated as the amount of rainfall that occurred over the first 18 hours. The continuous uniform loss rate can be estimated based on the soil type and land use if no other data is available.

The duration of design storms simulated in this study were ten days. After investigating some historical flood events, it was determined that the lag between the start of precipitation and the rise in the flood hydrograph was 4-5 days. Therefore the initial loss was determined as the sum of the first five days of precipitation during the 10-day event.

Overland runoff routing

After losses are extracted from the precipitation, the rainfall excess is transformed into surface runoff. There are two basic types of approaches available in HEC-1. One is a hydraulic routing method that uses the kinematic wave equation, while the other type is hydrologic routing based on developing a unit hydrograph. There are several unit hydrograph methods available in HEC-1, including the Clark, Snyder, and SCS unit hydrographs.

Both the Clark and Snyder unit hydrograph methods require two parameters that define the shape of the hydrograph. The SCS method requires one parameter, since the method assumes that the rising limb of the hydrograph accounts for 35.7 percent of runoff, thus fixing the relative shape of the hydrograph. Using the Clark or Snyder methods allows more flexibility in determining the shape of the hydrograph, but the parameters are more difficult to estimate. WMS has built-in capabilities to help determine these parameters, but a DEM of adequate resolution is required. The DEMs available for the Maple River watershed were not of high enough resolution to allow making use of WMS’s full capabilities in this way.

The SCS method was developed on rural watersheds. The only parameter the user must determine is the lag time from the center of rainfall excess to the time of peak flow. This lag can be estimated from the time of concentration T_c by multiplying T_c by 0.6. Data from gaged watersheds can be used to determine lags or time of concentration. For the case of ungaged watersheds, as is the case for most of the subwatersheds in the Maple River watershed, the lag can be estimated using the SCS equation:

$$T_L = L^{0.8}\left[\frac{(S+1)^{0.7}}{1900\sqrt{Y}}\right]$$

where:
T_L = time from center of rainfall excess to hydrograph peak (hours)
L = hydraulic length of watershed (feet)
S = maximum retention in the watershed (inches)
Y = watershed slope (percent)

S is directly related to the SCS curve number (CN) and is computed using:

$$S = \frac{1000}{CN} - 10$$

The SCS unit hydrograph method was used in this study to route overland flow. The SCS curve numbers were determined based on the land use and hydrologic soil types in each subwatershed. The hydraulic lengths and slopes for each subwatershed were estimated using DEMs and the GIS subwatershed boundary and stream coverages in WMS. As discussed earlier, the features in WMS that allow automatic estimation of such parameters were not available, but the program could be used to interactively estimate the hydraulic length and slope for each subwatershed. Where available, 7-1/2 minute DEMs were used, and for those areas of the watershed where they were not available, 1:250,000 scale DEMs were used. Considering the size of the subwatersheds, the 1:250,000 scale DEMs were adequate to estimate average subwatershed slopes.

The procedure for estimating hydraulic length and slope for each subwatershed consisted of importing the GIS subwatershed boundary and stream coverages into WMS. Then the USGS DEMs were imported, and a time computation coverage was created in WMS. The time computation coverage allows the user to draw arcs representing the flow paths that runoff would take in a subwatershed. The length and slope of these arcs is computed by WMS. Where overland flow enters a stream, the hydraulic length of the subwatershed can be determined by finding the length of the arc up to the point where it intercepts the stream, and then the stream length to the subwatershed outlet. Other arcs were drawn to estimate the average subwatershed slope.

Table A-7 in Appendix A provides the estimated lags for each subwatershed.

Streamflow routing

Once excess precipitation has been transformed into overland runoff and routed to the outlet of a subwatershed, it enters the stream at that point and is added to streamflow routed from upstream. The resulting combined flow is then routed downstream to the next subwatershed outlet where overland runoff from that subwatershed is combined with streamflow, and the process continues until the flow reaches the watershed outlet.

There are several methods available in HEC-1 to route streamflow. Several are hydrologic methods, most of which employ the continuity equation (a mass balance approach) and an empirical relationship between storage and discharge of water within a stream reach. Hydrologic methods generally use parameters derived from hydrograph analysis in a stream reach and do not directly use actual channel characteristics such as slope, cross-section shape, and channel roughness. For ungaged stream reaches, these parameters are difficult to determine. Hydraulic routing methods are physically based and involve solving the differential equations of unsteady flow in open channels and differ in their underlying assumptions and boundary conditions. Parameters are determined from channel characteristics such as cross-section geometry and slopes. Since they use actual channel properties, hydraulic methods are more desirable to use if the stream reach data are available.

The Muskingum-Cunge (MC) method was chosen for streamflow routing. The MC method is developed from the full unsteady flow equation and compares well with solutions of this equation over a wide range of conditions. It begins to diverge from the unsteady flow equation for very rapidly rising hydrographs routed through channels with slopes less than 1 foot per mile.

Data required for each reach in the MC method includes 1) representative channel cross section; 2) reach length L; 3) Manning’s roughness coefficient n; and 4) channel bed slope. Channel cross sections were obtained from a flood hazard analysis performed on the Maple River watershed by the United States Department of Agriculture Soil Conservation Service (SCS, 1981). Manning’s n values were estimated based on photographs of various reaches published in the flood hazard analysis report (SCS, 1981) and consideration of the land uses. Reach lengths were determined from the GIS stream and subwatershed coverages, and the channel bed slopes from USGS 7.5 minute quadrangle maps. Table A-7 in Appendix A provides the reach lengths and slopes in each subwatershed.

Developing the HEC-1 tree model

WMS can automatically generate a HEC-1 tree model with subbasins, junctions, reaches, reservoirs, and diversions if the watershed, subwatersheds, streams, and outlets are generated from a DEM. WMS can also create a tree model from imported GIS subwatershed and stream coverages. The third option is for the user to create the tree model by dragging and dropping model elements in WMS's graphic interface. This last method is similar to the way a HEC-1 model can be created in HEC-HMS. The advantage of these methods is the ease in establishing the links between upstream and downstream subwatersheds, stream reaches, and junctions.

The HEC-1 tree model was created using the drag and drop method in WMS. Once the various model elements are created and linked, data can be entered by double-clicking on each element in turn and entering the required data via menus. For data such as precipitation for design storms, the storm hyetographs can be entered for each return period storm for the first subwatershed, then the appropriate storm hyetograph selected for the particular simulation. When the next subwatershed is selected, the same storm hyetographs are available for selection. Once the data for a simulation is entered, the file can be copied and used to create the simulation for a storm with a different return period by selecting the appropriate hyetrograph. This saves considerable time when entering data. There are other ways in which data entry is facilitated through WMS's graphical interface.

Hydrographs for the diversions representing wetland storage could be entered similarly to the hyetographs for precipitation. However, there are only 6 design storms compared to 32 diversion hydrographs for each design storm (a total of 192 hydrographs.) In this case, it is easiest to enter a hydrograph for a particular design storm in each subwatershed and copy these files for the other design storms. Once diversion hydrographs and storm hyetographs are specified for a given return period, the files can be copied for various wetland storage scenarios. For each storage scenario only the amount of storage available in each subwatershed need be changed.

Another aid when entering data such as a diversion hydrograph is that the hydrograph is plotted as the user enters data. Errors in data entry are easily seen. The same aid is available for hyetographs and stream cross-sections. Although the graphical interface is easier to use than a line editor for entering data, data entry is still a major task.

Figure 11 shows the HEC-1 tree model for the case with no wetland storage (no diversions.) Figure 12 shows the HEC-1 model with wetland storage represented by diversions. These models were created in HEC-HMS as the graphic elements are larger scale and clearer than the graphic elements in WMS. Only the model elements were created in HEC-HMS; no data was entered and no simulations were run within HEC-HMS. The graphic was obtained by capturing the image from the screen using Paint Shop Pro 5.0 and pasting it into a MS Word document. Printing out the tree model from within HEC-HMS was not satisfactory.

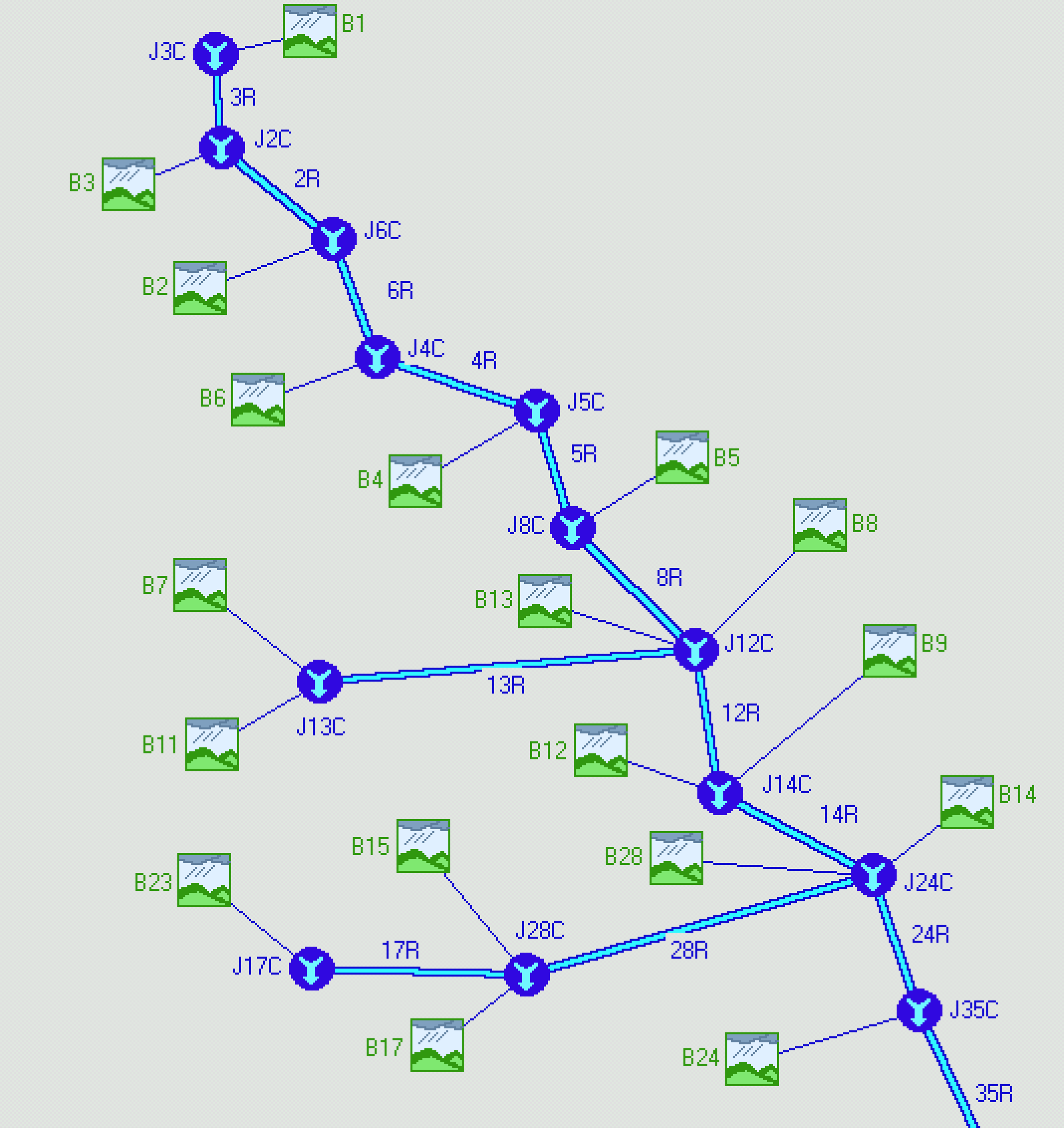


Figure 11. Tree diagram of the Maple River HEC-1 model with no wetland storage (no diversions) – Part 1 of 2.

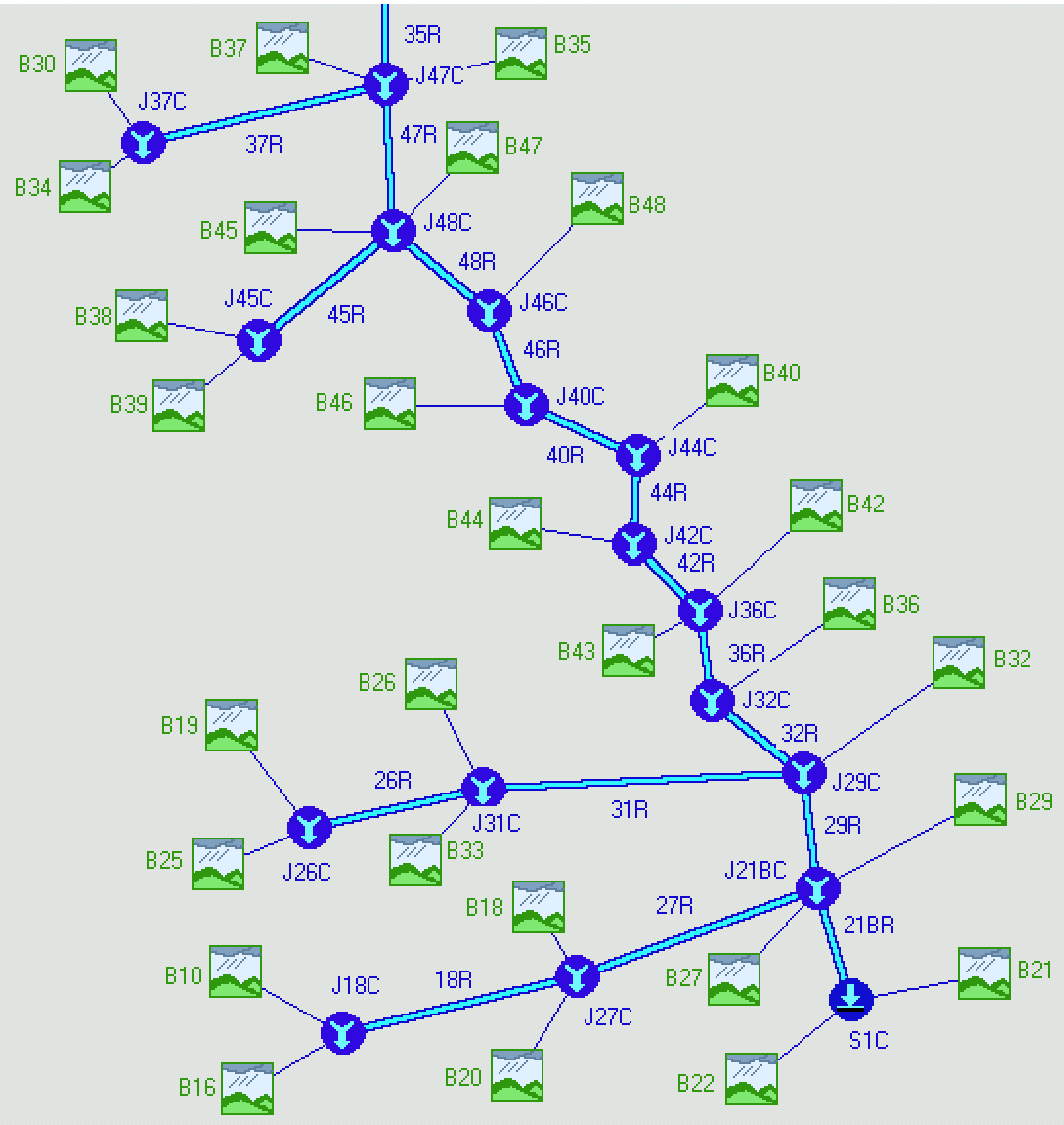


Figure 11 continued. Tree diagram of the Maple River HEC-1 model with no wetland storage (no diversions) – Part 2 of 2.

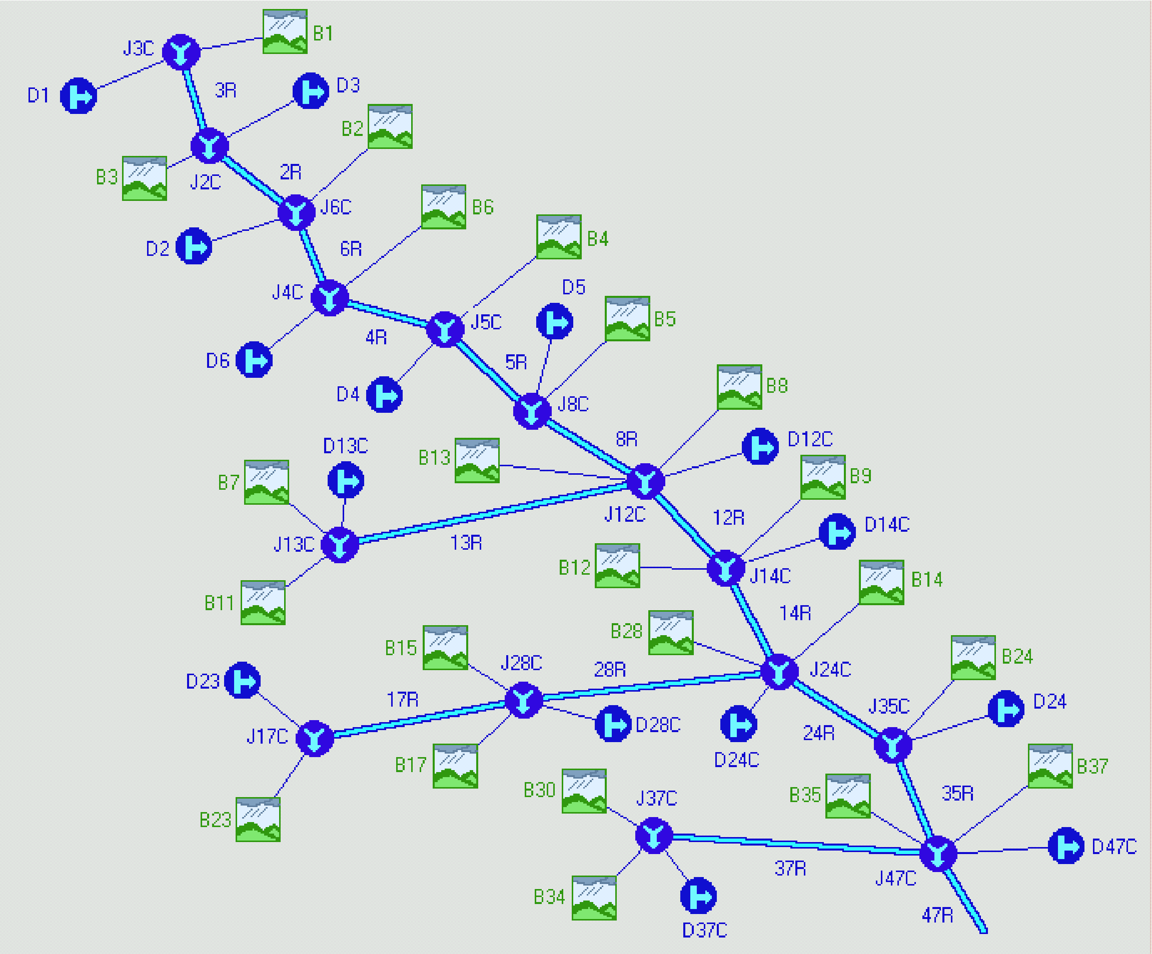


Figure 12. Tree diagram of the Maple River HEC-1 model with wetland storage (flow diversions) – Part 1 of 2.

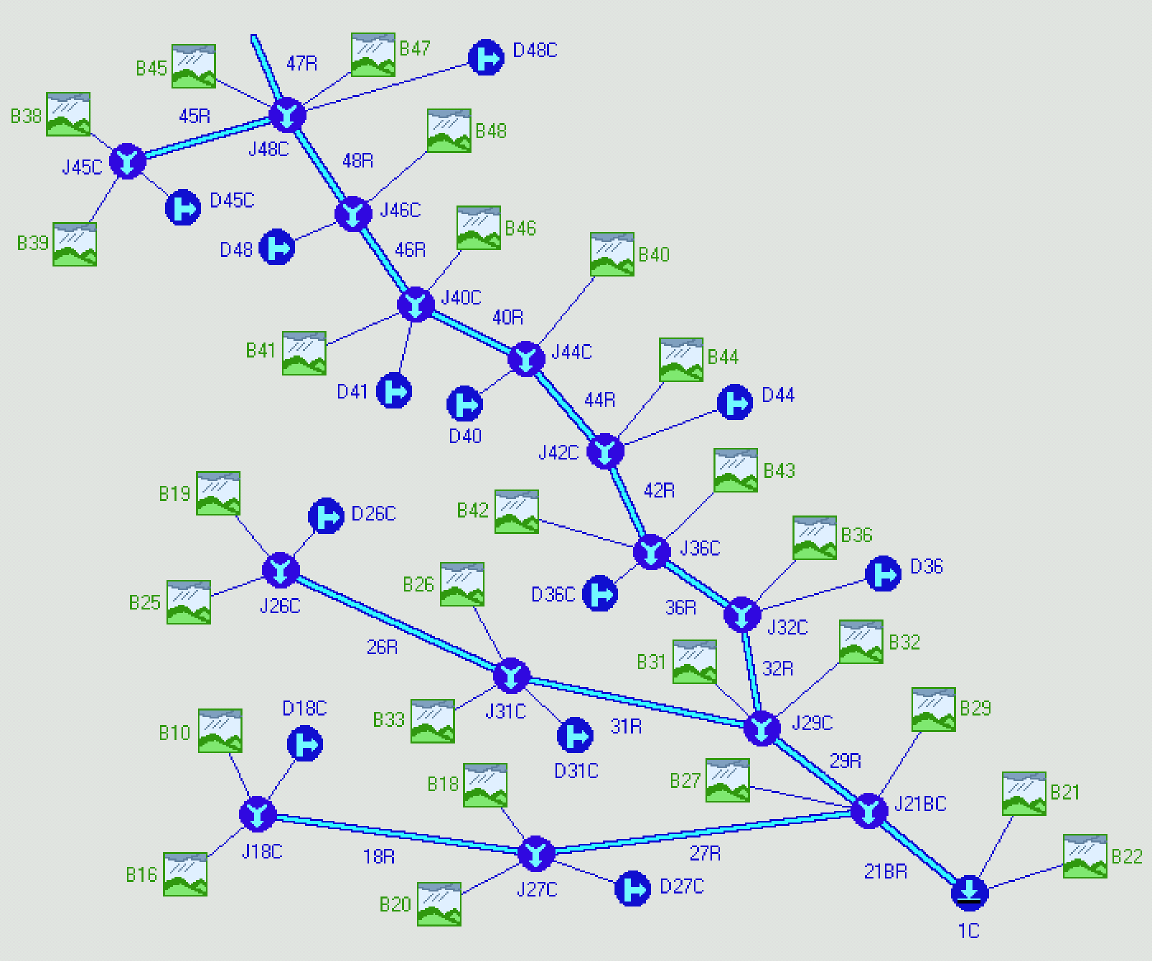


Figure 12 continued. Tree diagram of the Maple River HEC-1 model with wetland storage (flow diversions) – Part 2 of 2.

SIMULATION SCENARIOS

Calibration event

To determine if the model parameters reasonably simulate the hydrologic response of the Maple River watershed, a May 1998 flood event was chosen. The flood event consisted of a 10-day sequence of precipitation occurring over the entire Maple River Basin.

It is difficult to calibrate a hydrologic model, especially on a large watershed. There are only three USGS streamflow gage stations in the Maple River watershed, with the station near Hope, ND located so high in the watershed that it has only a 20 mi^2. drainage area. The sparsity of gage stations means that the individual subwatersheds cannot be calibrated using HEC-1's calibration routine. Snowmelt events are difficult to model as point measurements of snowfall at weather stations give an incomplete picture of the snow depth and its water content over the entire watershed. Gamma ray measurements from flights over the watershed, or satellite images can help if the data is available. Ice jams, blocked ditches, and backwater effects can significantly affect the water surface elevations in the river. Complete knowledge of antecedent conditions such as soil moisture content and the level of water in wetlands, for instance, is not possible. Calibrating on a major flood event does not guarantee that the model will accurately simulate another flood event even when they are the same magnitude and both caused by snow melt or rainfall.

Rather than calibrate on a snowmelt event, it was decided to calibrate on a rainfall event. Actually, the largest flood event in the Maple River watershed occurred in June and July of 1975 due to several large rain storms in the watershed. This event resulted in a peak flow of 11,300 cfs, nearly twice as high as the peak flow of 6,620 cfs in the spring of 1997. Finding a recent rainfall-caused flood event proved to be difficult for two reasons. First, the event needed to occur over most or all of the watershed in order to model the response of the entire watershed. Second, there were missing streamflow records for the USGS gage station near Mapleton. This gage station measures flow drained from more than 1400 mi^2 of the watershed, but the gage was not in operation from October 1975 to December 1995 . It is preferable to find a recent flood event as changes in the watershed and the river itself have occurred over time. The above-mentioned rainfall occurring from May 7 to May 17 was chosen as the best event available for calibration. Table 5 lists the USGS gaging stations located in the Maple River watershed and the URL where daily streamflow records can be downloaded.

Table 5. USGS Streamflow gaging stations in the Maple River Watershed.

Station Name	Station Number	Latitude and Longitude	County	Drainage area mi^2
Maple River near Hope, ND	05059600	47°19'30" N 97°47'25" W	Steele	20.2
Maple River near Enderlin, ND	05059700	46°37'18" N 97°34'25" W	Ransom	843
Maple River near Mapleton, ND	05060000	46°51'40" N 97°06'10" W	Cass	1450

Web page address for USGS water resources data:
http://water.usgs.gov/public/data.html

Table 6 shows the location of the weather stations in and around the Maple River Watershed. The Cavalier, Colgate, and Enderlin stations measure daily precipitation. The Bald Hill Dam station measures hourly precipitation, and may be used to determine the time sequence of rainfall. Figure 13 shows a Thiessen polygon used to determine which station's rainfall hyetograph to use for each subwatershed.

Table 6. Weather Stations in and near the Maple River Watershed.

Station Name	**Cooperative ID**	**Location**	**Data Type**
Bald Hill Dam	320450	47° 02' N, 98° 05' W	Hourly
Chaffee	321477	46° 48' N, 97° 16' W	Daily
Colgate	321686	47° 15' N, 97° 39' W	Daily
Enderlin 2W	322695	46° 37' N, 97° 38' W	Daily

Web page address for National Climactic Data Center:	http://www.ncdc.noaa.gov/ol/ncdc.html

The model was run with these rainfall sequences, with the first 5 days of precipitation initially abstracted. Five days were chosen because the hydrograph at Mapleton showed an initial rise five days after the beginning of the rainfall. The initial abstraction includes infiltration losses, losses due to leaf and vegetation storage, and small depression storage. The effect of existing wetlands is lumped in the response of the watershed along with the effect of land use, soil type, and subwatershed slope in the SCS curve number and the lag in each subwatershed.

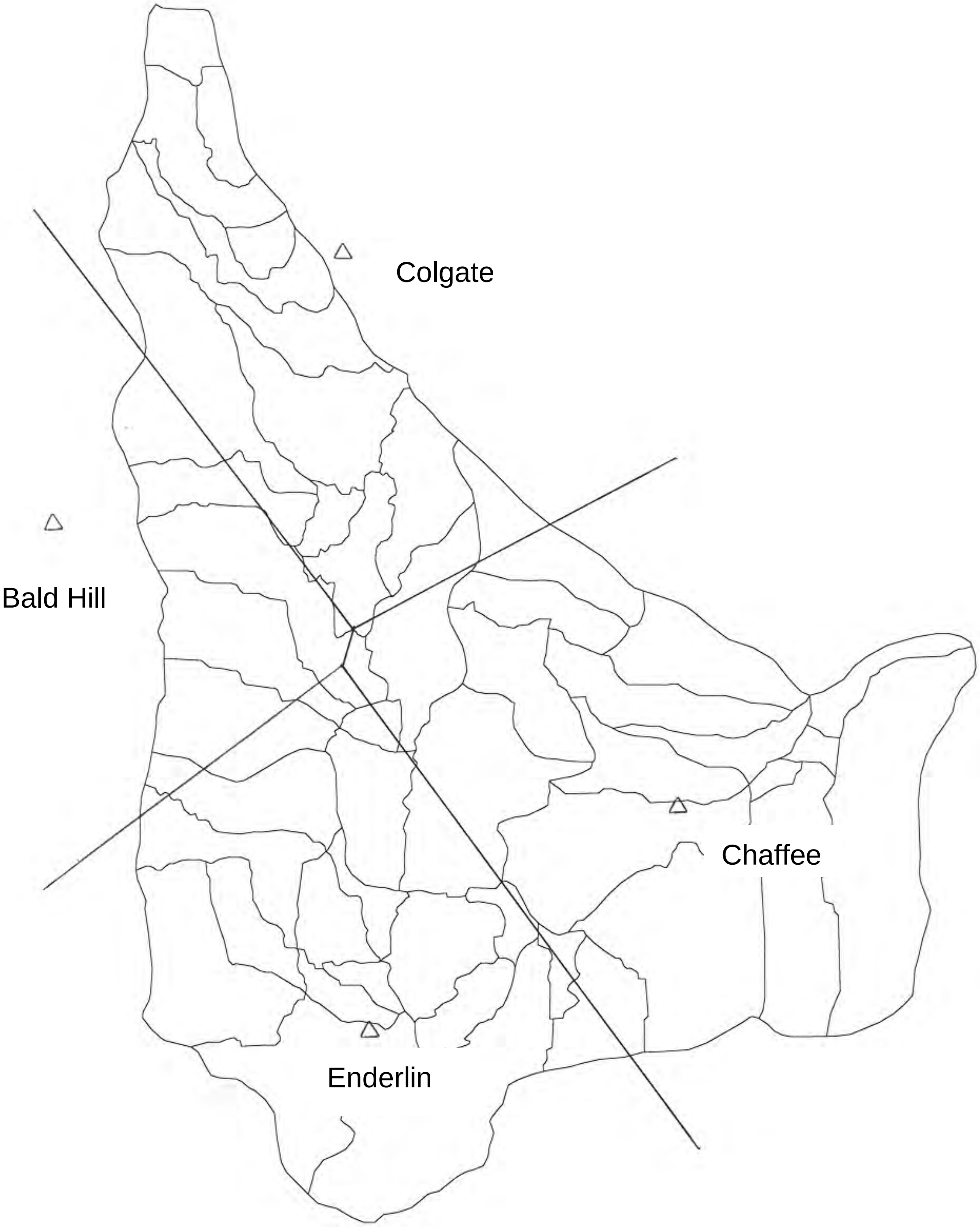


Figure 13. Thiessen polygon with NWS weather stations in the Maple River watershed.

It was necessary to adjust the estimated SCS curve numbers slightly. The curve numbers for the subwatersheds in the upper watershed were lowered by 2, while the curve numbers in the lower watershed (beach and lake plain) were raised by 2. The resulting curve numbers were still within the suggested ranges for the land use and hydrologic soil types.

Figure 14 shows the results of the calibration run compared to the actual flood hydrograph at the Mapleton gage station. The model output is in two-hour increments. These flows were averaged on a daily basis as the actual flood hydrograph is based on daily average flows. The simulated peak daily flow was 1686 cfs, which is 8.8% higher than the actual daily peak flow of 1550 cfs. The simulated volume of flow was 14700 ac-ft compared to the actual volume of 15200 ac-ft, which is within 3.3%. The simulated daily peak flow occurred a day after the actual daily peak flow, but the peak 2-hourly flow simulated in the model actually occurred the day before the simulation's average daily peak flow, better matching the actual peak. The rising limb of the simulation's hydrograph lags behind that of the actual hydrograph.

The base scenarios: no restored wetland volume

The first simulations were performed assuming no restored wetland volume available for storage of runoff. Using the parameters from the calibration run, and 10-day duration design storms from 10-year, 25-year,50-year, and 100-year events, four base flood hydrographs were derived. These hydrographs provided a basis for comparison when simulations were run with varying amounts of storage available from the restored wetlands. Table 7 lists the conditions of storage volumes, diversion rates, and design storms for each base simulation

Diversion Hydrographs

The flow hydrographs from the base simulation runs were used to determine the diversion hydrographs for each diversion which represented the restored wetlands storage volume. The peak runoff from each subwatershed was used to determine the peak diversion rate. For simulations utilizing the original number and distribution of drained wetlands, the maximum diversion rate was set as 25% of the subwatershed's runoff. This assumes that 25% of the watershed area contributes flow to the wetlands. Since the drained wetlands identified represent about 0.25% of the watershed area, this assumption should be reasonably generous. For the simulations utilizing larger wetland storage volumes, diversions are set to 50% of runoff. Since the actual area drained by each wetland is not possible to determine, these rates of diversion were set mainly to assure that all wetland volume would be utilized.

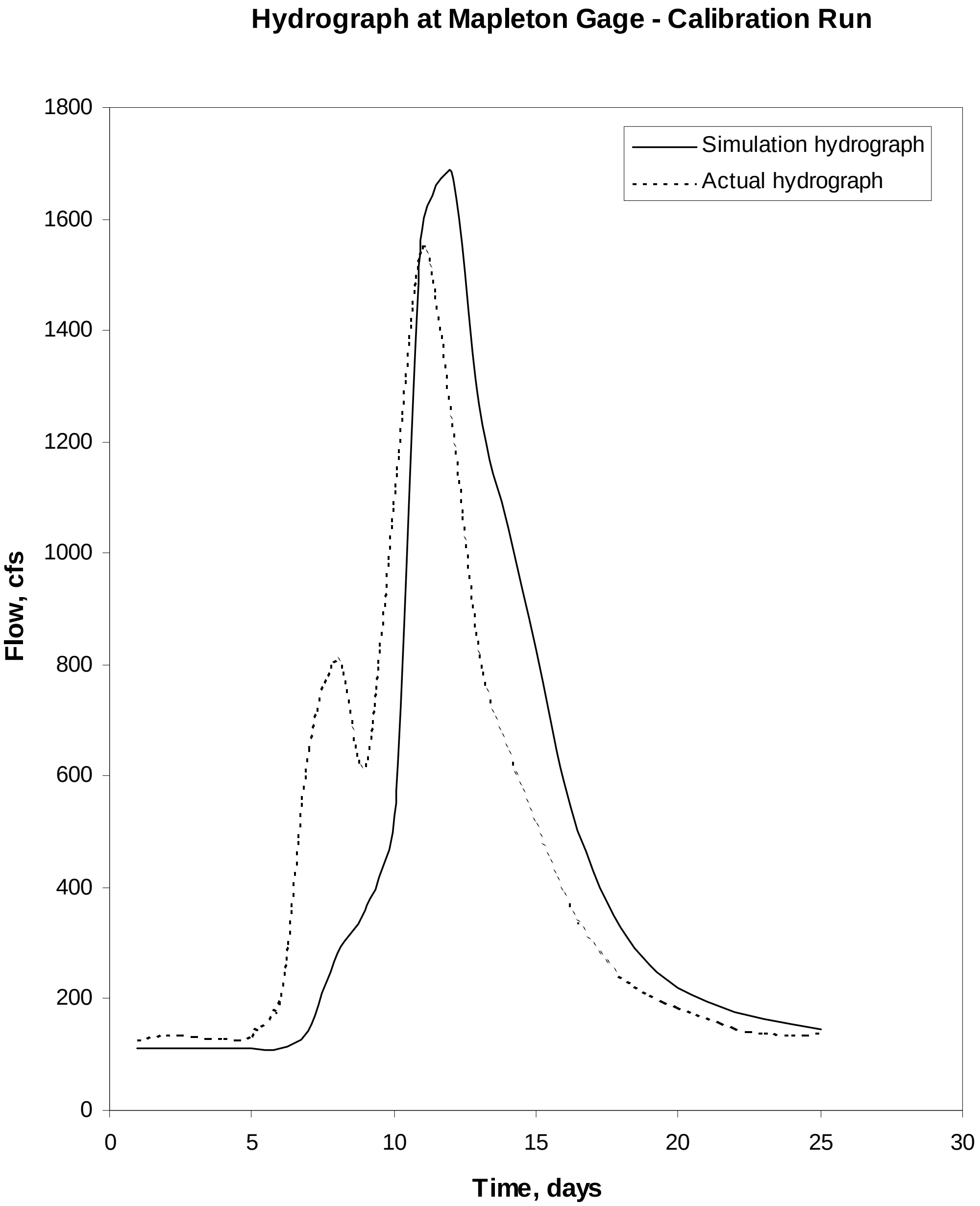


Figure 14. Calibration run hydrograph at Mapleton gage station.

Restored wetland scenarios

The first 16 scenarios assumed that the drained wetlands identified in the USFWS NWI would be restored in their original locations. The wetland storage volumes were estimated under three assumptions:

- 1 foot of bounce (the depth of the original wetlands)
- 2 feet of bounce (additional volume added through excavation)
- 4 feet of bounce (additional volume added through excavation with a control structure to control outflow)

The assumption of 1 foot of bounce resulted in 2700 ac-ft of storage; the 2 feet of bounce resulted in 5400 ac-ft; and four feet of bounce results in 10800 ac-feet of storage. This is approximately 0.25%, 0.5%, and 1.0% restored wetlands by surface area of the entire watershed.

Simulations were run for each assumption of storage volume and the four design storms, resulting in 16 simulations. Table 7 lists the conditions of storage volumes, diversion rates, and design storms for each simulation. The first 12 simulations set the diversion rate at 25% of runoff, with diversion flow beginning as soon as runoff reaches the subwatershed outlet. However, note that the last four simulations use the 4 feet of bounce storage volume assumption, but sets the diversion rates to 50% of runoff. This was necessary to ensure that all wetland volume would be utilized. At 25% diversion rates under the 10,800 ac-ft storage volume scenarios, the wetland volume was not fully utilized even under the 10-year precipitation event.

The next set of simulations use the same volumes of wetland storage as the first 16 simulations, but the diversion hydrographs are changed so that diversion flows do not begin until the runoff reaches a value of 50% of peak runoff. This was done to investigate the effect of the timing of the diversions on the hydrograph peak. Table 8 shows the conditions of storage volumes, diversion rates and timing, and design storms for these simulations.

The final 12 simulations distribute the restored wetland volume by area, rather than as originally distributed. The volumes of storage simulated vary from 11,400 ac-ft, 28,500 ac-ft, and 57,000 ac-ft, which is 1%, 2.5% and 5% by area assuming a 1.1 foot bounce. These volumes are 3.8 times, 9.4, times, and 18.8 times more wetland storage than that represented by the drained wetlands identified in the Maple River watershed. It is desired to increase the wetland storage beyond that available from the existing drained wetlands to investigate the effect on the flood hydrograph. Diversion flows are set to occur at a rate of 50% of runoff to assure that all wetland storage will be utilized. Table 9 shows the conditions of storage volumes, diversion rates, and design storms for these simulations.

Table 7. Restored wetlands distributed as originally located.

Wetland volume, ac-ft	Diversion timing	% of flow diverted	Design Storm return period, years
0	No diversions	0	10
			25
			50
			100
2700 (1 ft bounce)	As flow arrives	25	10
			25
			50
			100
5400 (2 ft bounce)	As flow arrives	25	10
			25
			50
			100
10800 (4 ft bounce)	As flow arrives	25	10
			25
			50
			100
10800 (4 ft bounce)	As flow arrives	50	10
			25
			50
			100

Table 8. Restored wetlands distributed as originally located with diversions lagged to begin when flow = 50% of peak flow.

Wetland volume, ac-ft	Diversion timing	% of flow diverted	Design Storm return period, years
2700 (1 ft bounce)	Flow = 50% of peak rate	25	10
			25
			50
			100
5400 (2 ft bounce)	Flow = 50% of peak rate	25	10
			25
			50
			100
10800 (4 ft bounce)	Flow = 50% of peak rate	25	10
			25
			50
			100

Table 9. Restored wetlands uniformly distributed by subwatershed area. (assuming 1.1 foot bounce)

Wetland volume, ac-ft	Diversion timing	% of flow diverted	Design Storm return period, years
11400	As flow arrives	50	10
			25
			50
			100
28500	As flow arrives	50	10
			25
			50
			100
57000	As flow arrives	50	10
			25
			50
			100

These simulations distribute the restored wetlands uniformly among the subwatersheds. When simulating a uniform distribution of precipitation over the watershed, and when simulating the effect of larger storage volumes than are possibly available from the actual drained wetlands, having the storage uniformly distributed should assure that most if not all of the storage will be utilized. As originally distributed, the percentage of drained wetlands by area in each subwatershed ranges from 0 to 1.43%. Increasing this storage on the basis of the original distribution of drained wetlands will result in storage not being utilized in some of the subwatersheds containing the larger percentages of drained wetlands.

SIMULATION RESULTS

Results of the simulations will be presented in the form of hydrographs as measured at the outlet of subwatershed 21, which is very near the location of the USGS gaging station below Mapleton, ND. This includes 90% of the drainage area of the Maple River. The stage-discharge curve for the Mapleton gage can be used to estimate the water surface elevation of the river for various peak flow rates. The stage values for the various wetland storage volume scenarios will be compared to the stages determined from the base simulations with no wetland storage considered.

Figure 15 shows the stage-discharge curve for the Maple River below Mapleton. Note the break in the curve above the elevation of 21 feet. This indicates that the flood plain widens considerably above this elevation, accounting for the fact that a larger change in flow results in a smaller change in stage. For instance, assume an initial peak flow of 4000 cfs, corresponding to a stage of 21.98 feet. A 10% reduction in peak flow results in a flow of 3600 cfs and a stage of 21.68 feet. The reduction in stage is 0.3 feet. Compare this result to an initial flow of 2000 cfs with a stage of 19.16 feet. A reduction of 400 cfs results in a peak flow of 1600 cfs and a stage of 17.84. The reduction in stage is 1.32 feet. Therefore simply comparing the change in peak flowrate will be misleading. It is more meaningful to compare changes in stage due to reductions in peak flow.

However, it must be realized that these stages may not occur at these flowrates during a flood event. Ice jams, debris clogs, or backwater may all affect the stage-discharge curve. Therefore these values of stage derived from the simulation results should only be used for comparison purposes and not as absolute values.

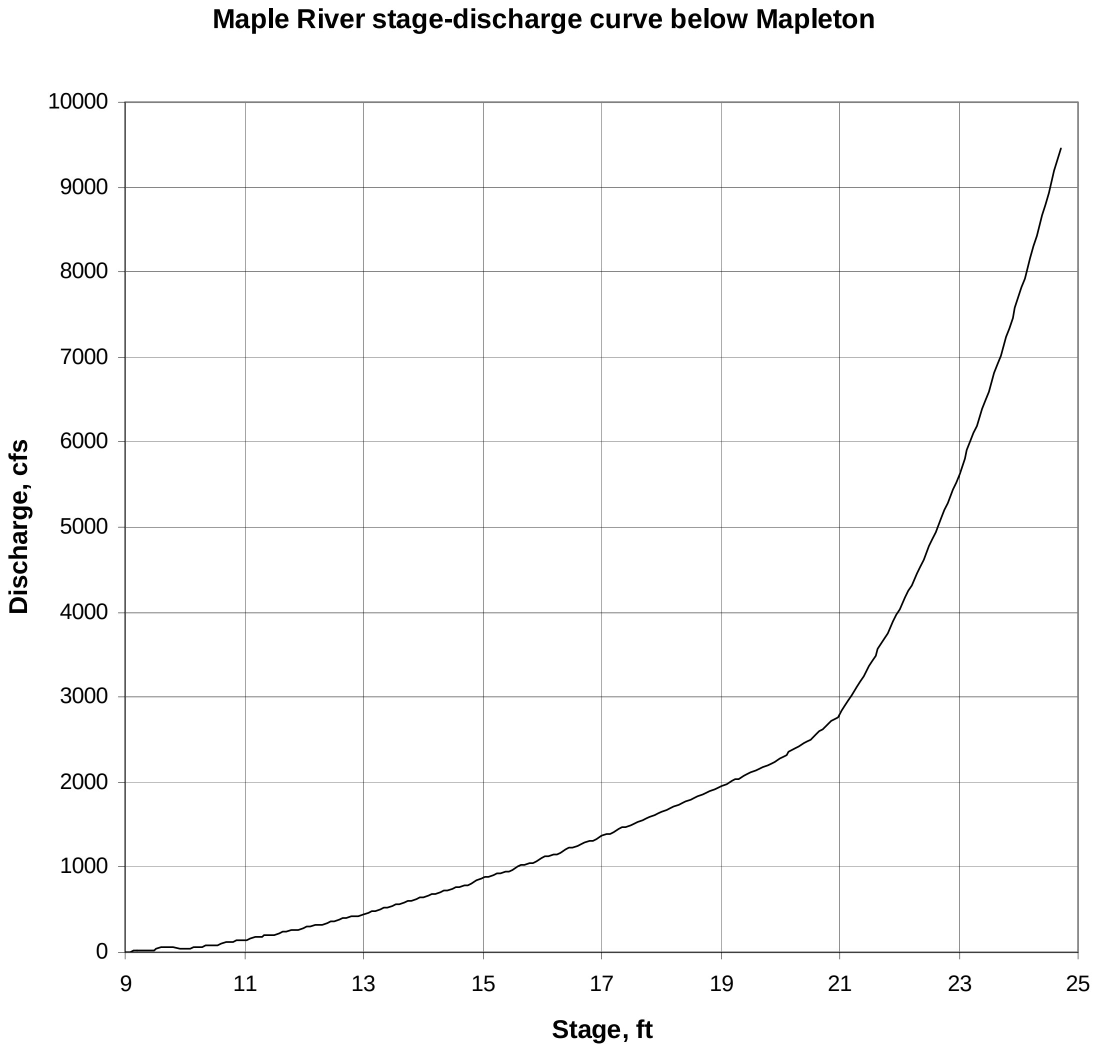


Figure 15. Stage-discharge curve for the Maple River below Mapleton, ND.

The base scenarios: no restored wetland volume

Table 10 shows the peak flow and stages for the scenarios simulated with no additional wetland storage volume. As discussed earlier, the peak flows for a 10-year design storm do not exactly correspond to a 10-year flood, but are still useful for comparison purposes. Peak flows ranged from 2385 cfs for the 10-year storm to 9359 cfs for the 100-year storm. The peak flow of 6796 cfs for the 50-year storm is similar in magnitude to the daily peak flow of 6620 cfs experienced during the 1997 flood. Stages range from 20.22 feet to 24.66 feet.

Restored wetland scenarios: original distribution

Table 10 also shows the peak flow and stages for the first 16 scenarios in which the storage volume represented by restoring the original drained wetlands are simulated. The 2700 ac-ft represents 1 foot of bounce, 5400 represents 2 feet of bounce, and 10800 represents 4 feet of bounce. It was assumed that no more than 25% of the runoff would be intercepted by the wetlands, based on the fact that the drained wetlands occupy about 0.26% of the watershed by area. The actual drainage area for these drained wetlands is not known,

The reduction in stage is calculated by finding the percent difference between the stages for the base scenarios with no storage and the stages for the scenarios including wetland storage distributed as originally located. For the scenario with 1 foot of bounce or available storage, the reductions ranged from 2.9% for the 10-year event to 0.4% for the 100-year storm. Assuming 2 feet of bounce results in reductions ranging from 4.1% for the 10-year storm to 0.73% for the 100-year storm.

When assuming 4 feet of bounce and flow diverted at the rate of 25% of outflow into wetland storage, the reduction in stage ranged from 6.6% for the 10-year storm to 0.85% for the 100-year storm. However, not all the wetland storage was utilized. The simulations were run again assuming flow diverted at the rate of 50% of outflow into wetland storage. All wetland storage volume was utilized, and the reduction in stage ranged from 9.9% for the 10-year storm to 1.26% for the 100-year storm.

Figure 16 shows the hydrographs for the 10-year storm with each storage scenario plotted on a different curve. The hydrographs for the other storm events are shown on figures 17 -19. Note that most of the reduction of flow volume occurs on the rising limb of the hydrographs, with an accompanying reduction in peak flow. As excess precipitation results in runoff, some of the overland flow will be intercepted by the wetlands. If runoff is sufficient to fill a wetland, then it will overflow and may move overland and ultimately exit the subwatershed. Wetland storage will begin to be utilized as soon as excess runoff reaches the wetland, so a reduction of runoff volume should begin on the rising limb. Depending on the drainage area of each wetland, the wetland may fill before

Table 10. Results of Scenarios 1-16.

No restored wetlands 10-day duration design storm

	10-year	25-year	50-year	100-year
Flow, cfs	2385	4906	6796	9359
Stage, ft	20.22	22.58	23.59	24.66

Restored wetlands distributed as originally located
2700 ac-ft storage 25% diversions

	10-year	25-year	50-year	100-year
Flow, cfs	2151	4674	6593	9113
Stage, ft	19.64	22.44	23.50	24.57
Reduction in stage	2.9%	0.62%	0.38%	0.36%

Restored Wetlands distributed as originally located
5400 ac-ft storage 25% diversions

	10-year	25-year	50-year	100-year
Flow, cfs	2075	4561	6436	8887
Stage, ft	19.4	22.36	23.42	24.48
Reduction in stage	4.1%	0.97%	0.72%	0.73%

Restored Wetlands distributed as originally located
10800 ac-ft storage 25% diversions

	10-year	25-year	50-year	100-year
Flow, cfs	1914	4429	6309	8804
Stage, ft	18.89	22.28	23.36	24.45
Reduction in stage	6.6%	1.3%	0.97%	0.85%

Restored Wetlands distributed as originally located 50% diversions
10800 ac-ft storage 50% diversions

	10-year	25-year	50-year	100-year
Flow, cfs	1707	4345	6127	8544
Stage, ft	18.21	22.22	23.26	24.35
Reduction in stage	9.9%	1.6%	1.4%	1.26%

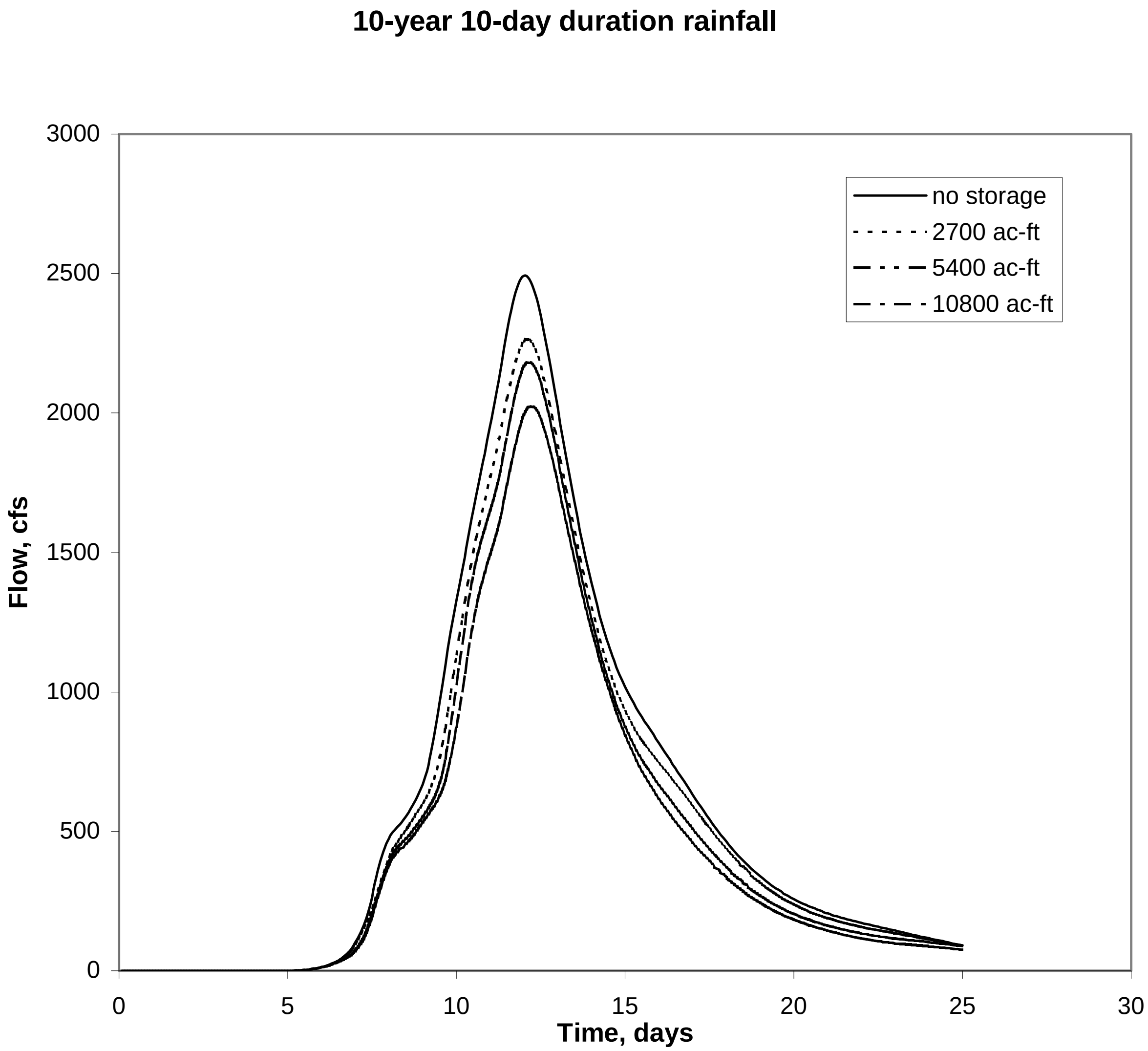


Figure 16. 10-year 10-day storm event hydrograph. Restored wetlands located as originally distributed.

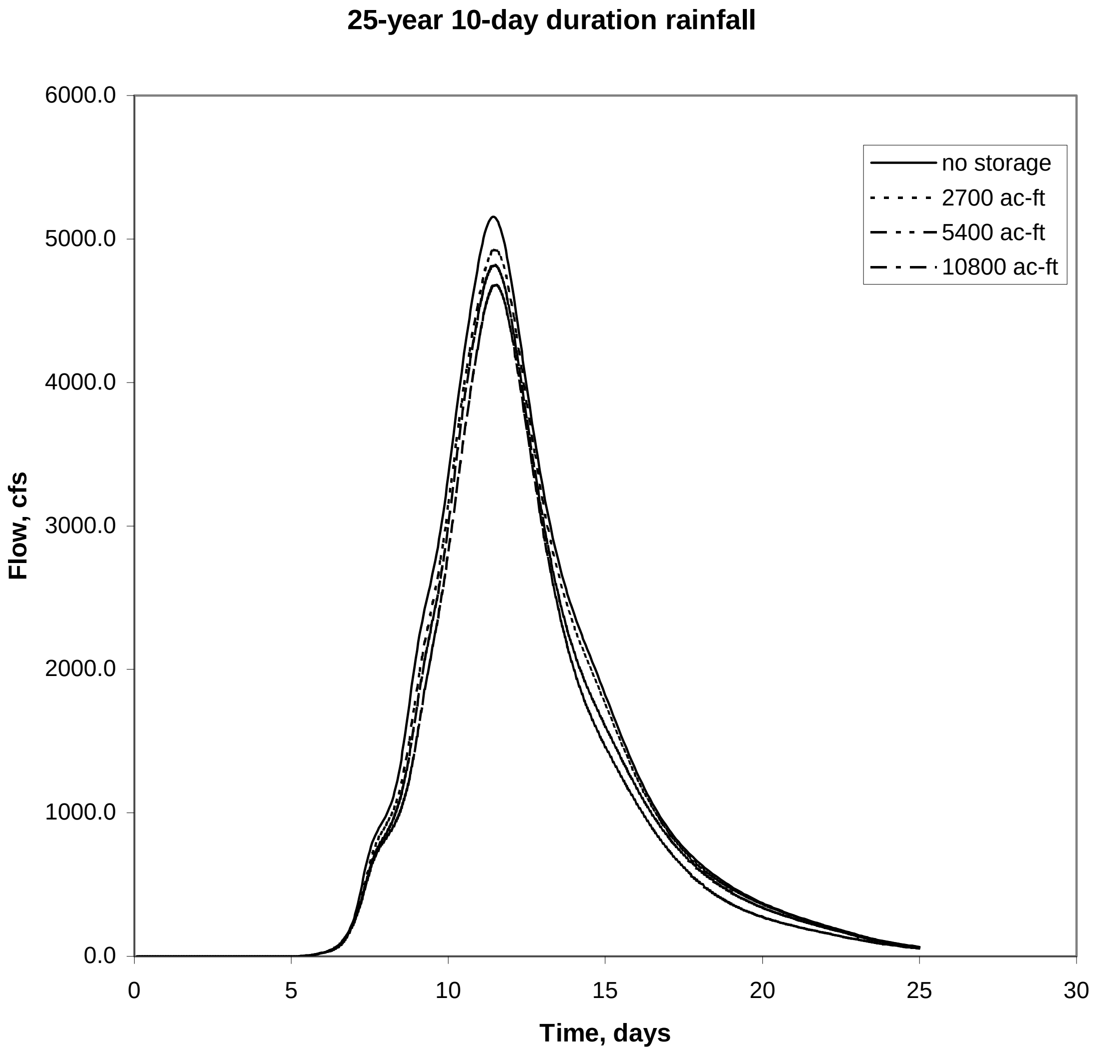


Figure 17. 25-year 10-day storm event hydrograph. Restored wetlands located as originally distributed.

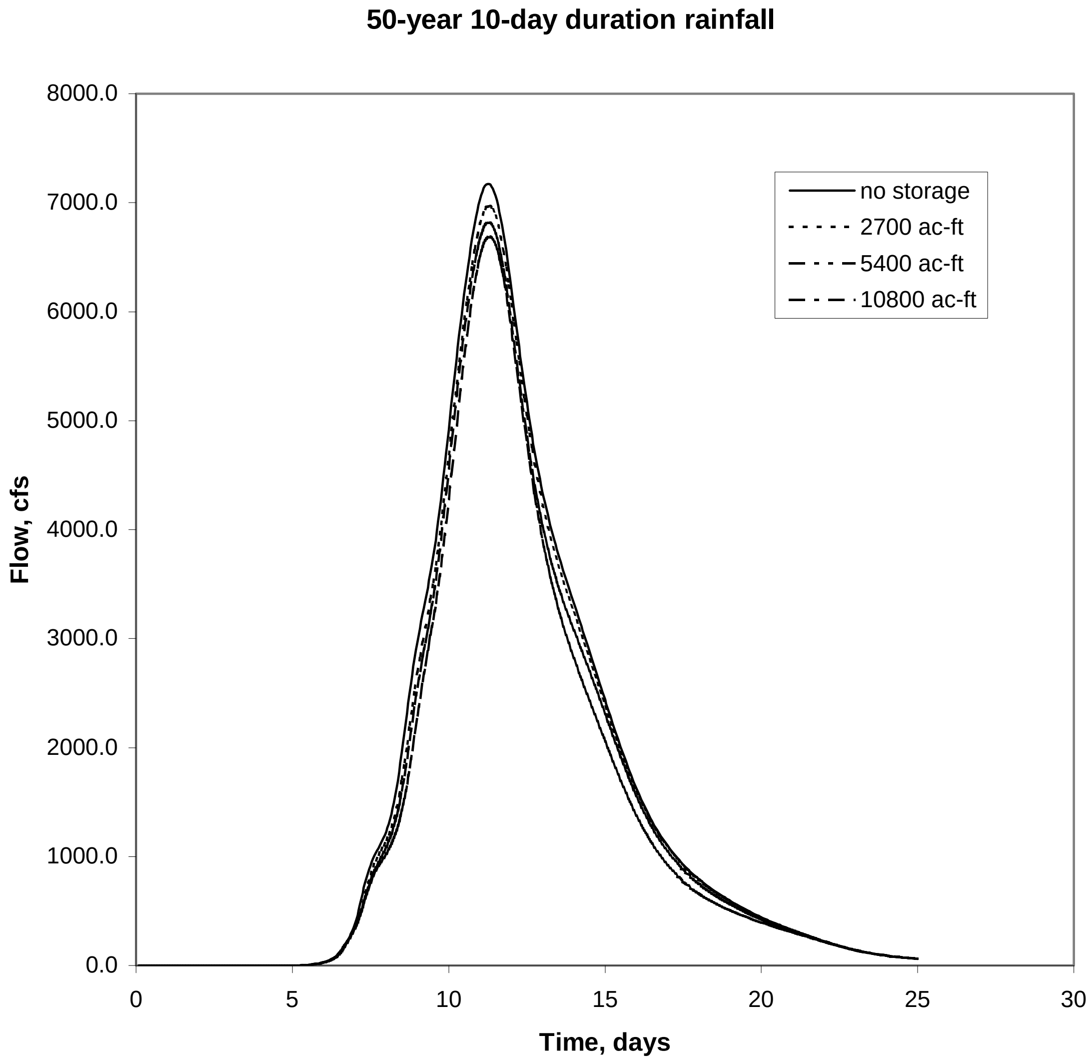


Figure 18. 50-year 10-day storm event hydrograph. Restored wetlands located as originally distributed.

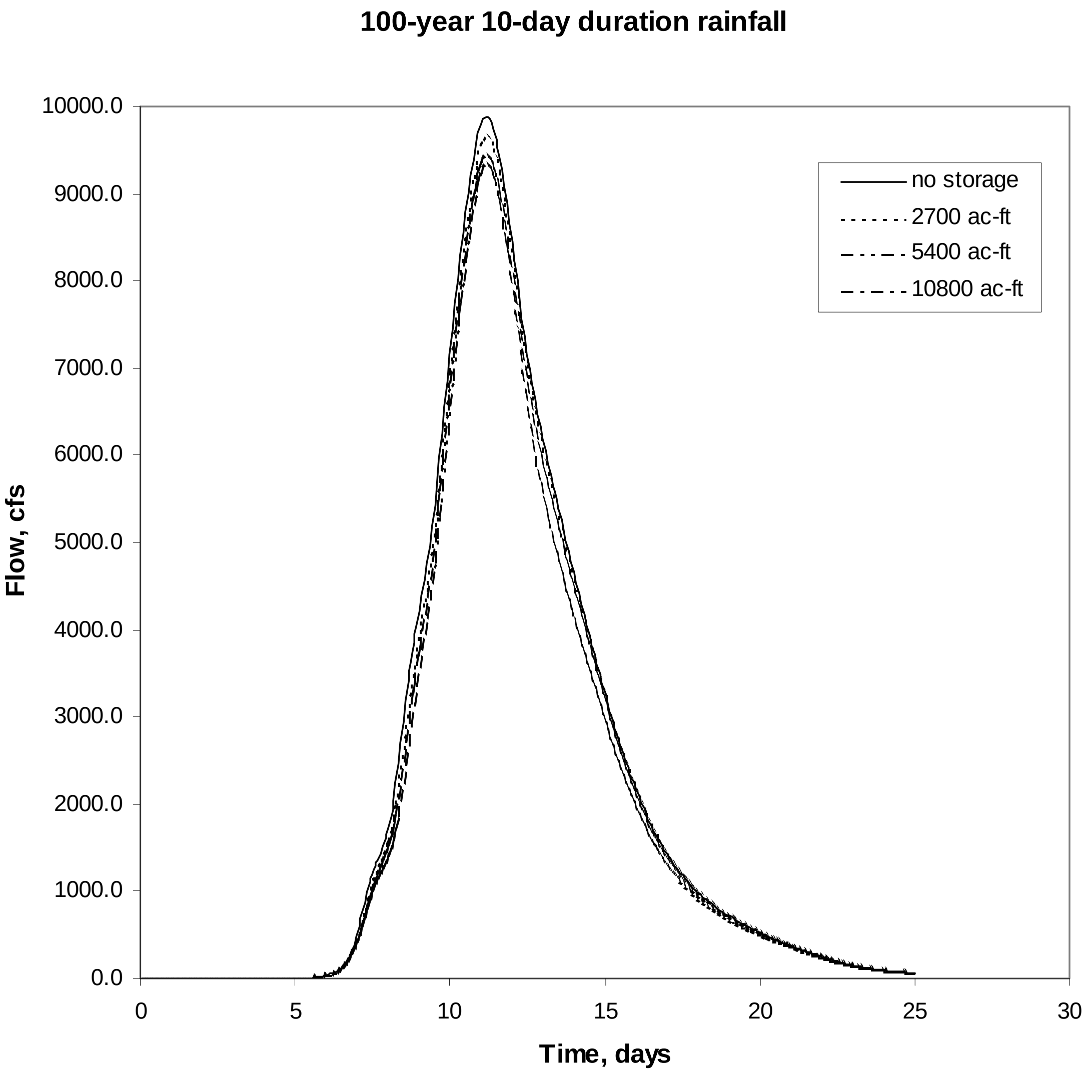


Figure 19. 100-year 10-day storm event hydrograph. Restored wetlands located as originally distributed.

peak flow occurs on the watershed. If the wetland drains a relatively small area, it may not fill completely for some of the higher-frequency storm events. For these simulations, diversion rates were set at percentages that ensured all storage would be utilized.

These simulations were run again after changing the diversion flow hydrographs so that flow would not be diverted until runoff reached 50% of peak runoff. Since the drainage area for each drained wetland is not known, and thus the travel time overland to the wetland, the timing of when the overland flow may be intercepted by a wetland may occur earlier or later in the storm event. Table 11 shows the results of the simulations run with the diversions lagged. The percent reductions in stage vary the most for the 10-year storm events, with almost no difference for the 50-year and 100-year events. Figures 20 and 21 show hydrographs for the scenarios with 4 feet of bounce with a 10-year storm event and a 100-year storm event. Note that the hydrographs are nearly identical for the 100-year event, while there is some difference (of less than 1% reduction in stage) for the 10-year storm event. Changing the timing of diversion flows was not significant for the lower-frequency events.

Restored wetlands distributed uniformly

Another series of scenarios was simulated to determine the effect of increasing available wetland storage beyond the original 0.26% of the watershed by area. These wetlands were assumed to be distributed uniformly over the upland portion of the watershed, which contains the majority of existing and drained wetlands and the majority of drainage area. The uniform distribution of wetlands better ensures that all wetland storage volume will be utilized. Wetland storage volumes were simulated at 1%, 2.5%, and 5% of the watershed by area assuming a depth of 1.1 feet, which was the average estimated depth of the existing drained wetlands. The wetland storage volumes simulated were 11400, 28500, and 57000 ac-ft. These volumes represent 3.8, 9.4, and 18.8 times the storage volume estimated for the existing drained wetlands.

Flow was diverted to wetland storage at a rate of 50% of runoff. This essentially means that half the surface area of the watershed generates runoff that is intercepted by a restored wetland. This may not be possible to achieve, but it ensures that most if not all of the wetland storage volume is utilized.

Table 12 shows the results of the simulations. For 1% restored wetlands by area, the percent reduction in stage ranges from 18.8 for the 10-year storm event to 0.85 for the 100-year event. For the greatest storage volume, 5% restored wetlands by area, the percent reduction in stage ranges from 34.0% for the 10-year storm event to 8.4% for the 100-year event. Increasing the wetland storage available by 1900 percent resulted in a stage reduction of less than 9%.

Table 11. Results of Scenarios 17-28.

No restored wetlands 10-day duration design storm

	10-year	25-year	50-year	100-year
Flow, cfs	2385	4906	6796	9359
Stage, ft	20.22	22.58	23.59	24.66

Restored wetlands distributed as originally located
2700 ac-ft storage diversions lagged to start at 50% of peak flow

	10-year	25-year	50-year	100-year
Flow, cfs	2103	4686	6585	9104
Stage, ft	19.49	22.44	23.49	24.57
Reduction in stage				
With lag	3.6%	0.62%	0.42%	0.36%
No lag	(2.9%)	(0.62%)	(0.38%)	(0.36%)

Restored Wetlands distributed as originally located
5400 ac-ft storage diversions lagged to start at 50% of peak flow

	10-year	25-year	50-year	100-year
Flow, cfs	2030	4499	6383	8951
Stage, ft	19.26	22.32	23.39	24.51
Reduction in stage				
With lag	4.7%	1.15%	0.85%	0.61%
No lag	(4.1%)	(0.97%)	(0.72%)	(0.73%)

Restored Wetlands distributed as originally located
10800 ac-ft storage diversions lagged to start at 50% of peak flow

	10-year	25-year	50-year	100-year
Flow, cfs	1856	4453	6348	8803
Stage, ft	18.70	22.29	23.38	24.45
Reduction in stage				
With lag	7.5%	1.28%	0.89%	0.85%
No lag	(6.6%)	(1.3%)	(0.97%)	(0.85%)

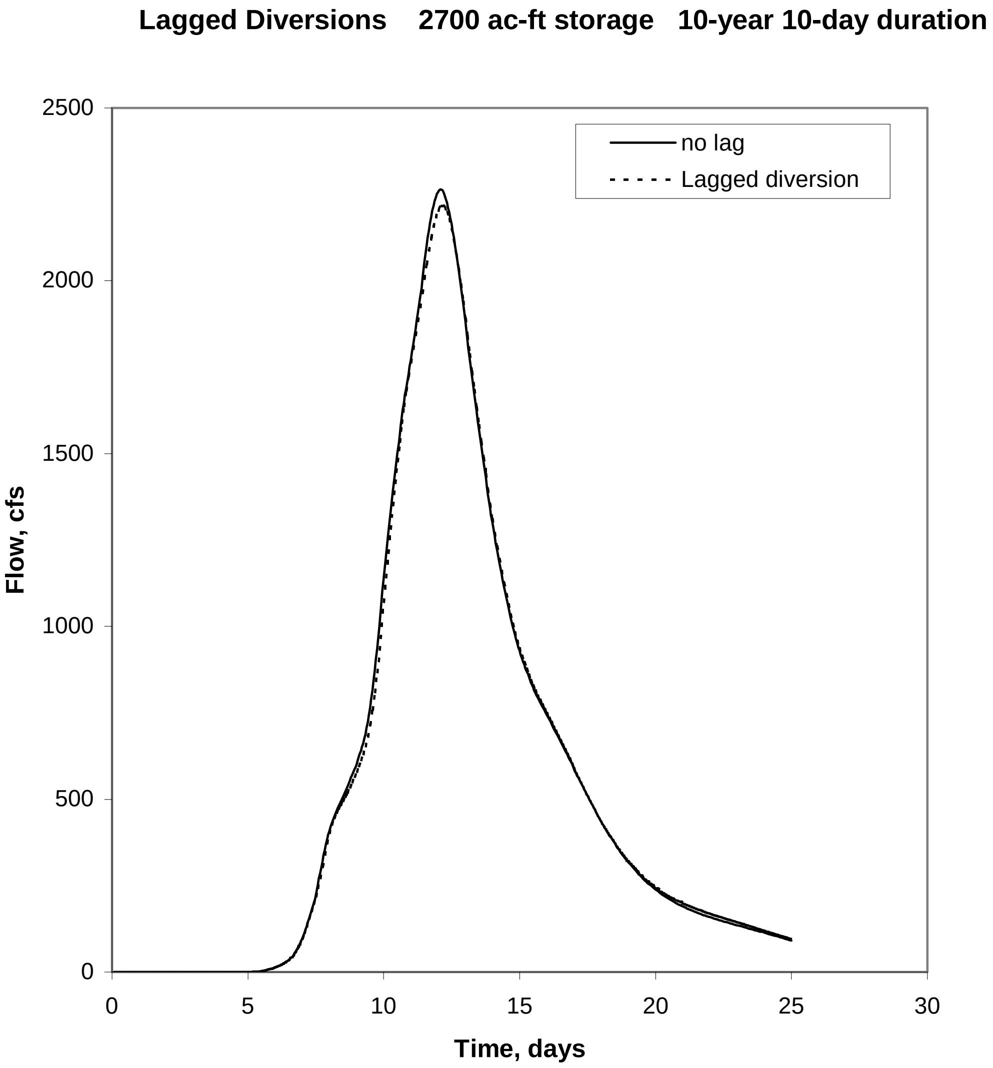


Figure 20. 10-year 10-day storm event hydrograph. Restored wetlands located as originally distributed. Diversions lagged to occur after outflow reaches 50% of peak outflow.

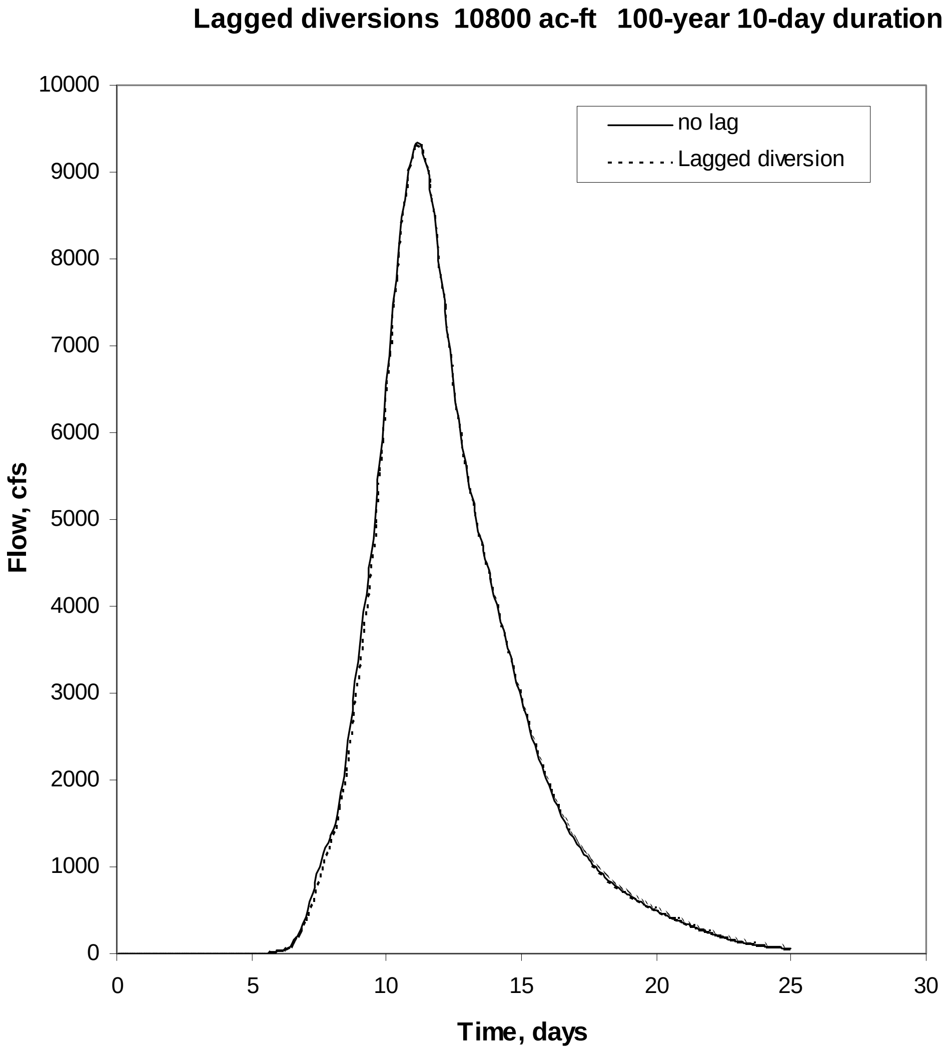


Figure 21. 100-year 10-day storm event hydrograph. Restored wetlands located as originally distributed. Diversions lagged to occur after outflow reaches 50% of peak outflow.

Table 12. Results of Scenarios 29-40.

No restored wetlands 10-day duration design storm

	10-year	25-year	50-year	100-year
Flow, cfs	2385	4906	6796	9359
Stage, ft	20.22	22.58	23.59	24.66

Restored wetlands distributed by subwatershed area
11400 ac-ft storage 50% diversions

	10-year	25-year	50-year	100-year
Flow, cfs	1208	4024	6126	8809
Stage, ft	16.42	22.00	23.26	24.45
Reduction in stage				
	18.8%	2.6%	1.4%	0.85%

Restored wetlands distributed by subwatershed area
28500 ac-ft storage 50% diversions

	10-year	25-year	50-year	100-year
Flow, cfs	645	2371	4186	7212
Stage, ft	14.01	20.20	22.11	23.79
Reduction in stage				
	30.7%	10.5%	6.3%	3.5%

Restored Wetlands distributed as originally located
57000 ac-ft storage 50% diversions

	10-year	25-year	50-year	100-year
Flow, cfs	514	1567	2857	4929
Stage, ft	13.35	17.73	21.05	22.60
Reduction in stage				
	34.0%	21.5%	10.8%	8.4%

Figures 22 – 25 show the hydrographs for each storm event and each volume of storage. The most significant reduction in peak flow occurs for the higher-frequency 10-year storm event.

SUMMARY AND CONCLUSIONS

The Maple River watershed was modeled using HEC-1 to determine the effect of restoring drained wetlands on peak flood flows. Design storms of 10, 25, 50 and 100 year recurrence intervals were modeled. The watershed was first modeled with no restoration of drained wetlands, then with storage representing the drained wetlands at their original location assuming 1 foot, 2 feet, and 4 feet of bounce depending on how the drains for these wetlands would simply be plugged or whether they would be deepened and a control structure used. Since the drained wetlands represented only about 0.25% of the watershed by area, the effect of adding significantly more wetlands was also studied. Wetland storage of 1%, 2.5%, and 5% by area was modeled. These wetlands were distributed uniformly throughout the watershed.

Wetland storage was represented by flow diversions within HEC-1. This allows flexibility in the timing and amount of flow diverted to storage. The percent of flow diverted can be adjusted to reflect the amount of wetland storage available and the surface area drained by the wetlands. Considering the drained wetlands only occupy about 0.26% of the watershed, it is highly unlikely that all the overland flow will be intercepted by these wetlands if restored. Therefore the diversion rate was set at 25% of the outflow at the mouth of each subwatershed. For higher volumes of wetlands, such as in the 4-foot of bounce case, or in the 1%, 2.5% and 5% case, the diversion rate was set at 50% of outflow. Using these rates assured that all wetland storage would be utilized. In reality, this may not occur, especially for the higher-frequency events. The contributing area for some of the wetlands may not be great enough to provide sufficient runoff to fill these wetlands during the more frequent events.

The storage volume available in the restored wetlands was estimated using an equation developed from a study performed by the USBR (USBR 1999) on drained wetlands in the Devils Lake basin. The average bounce or depth of the wetlands was about 1.1 feet. In this study it is assumed that all this volume is available at the beginning of the simulated flood event. This is a generous assumption. For spring snowmelt floods, all the storage may not be available. If the preceding fall has a significant rainfall, there will likely be water in the wetlands, since evapo-transpiration is the main mechanism by which these wetlands lose moisture. In the summer, when most of the precipitation falls, some of the storage may be unavailable depending on how recently rain has fallen.

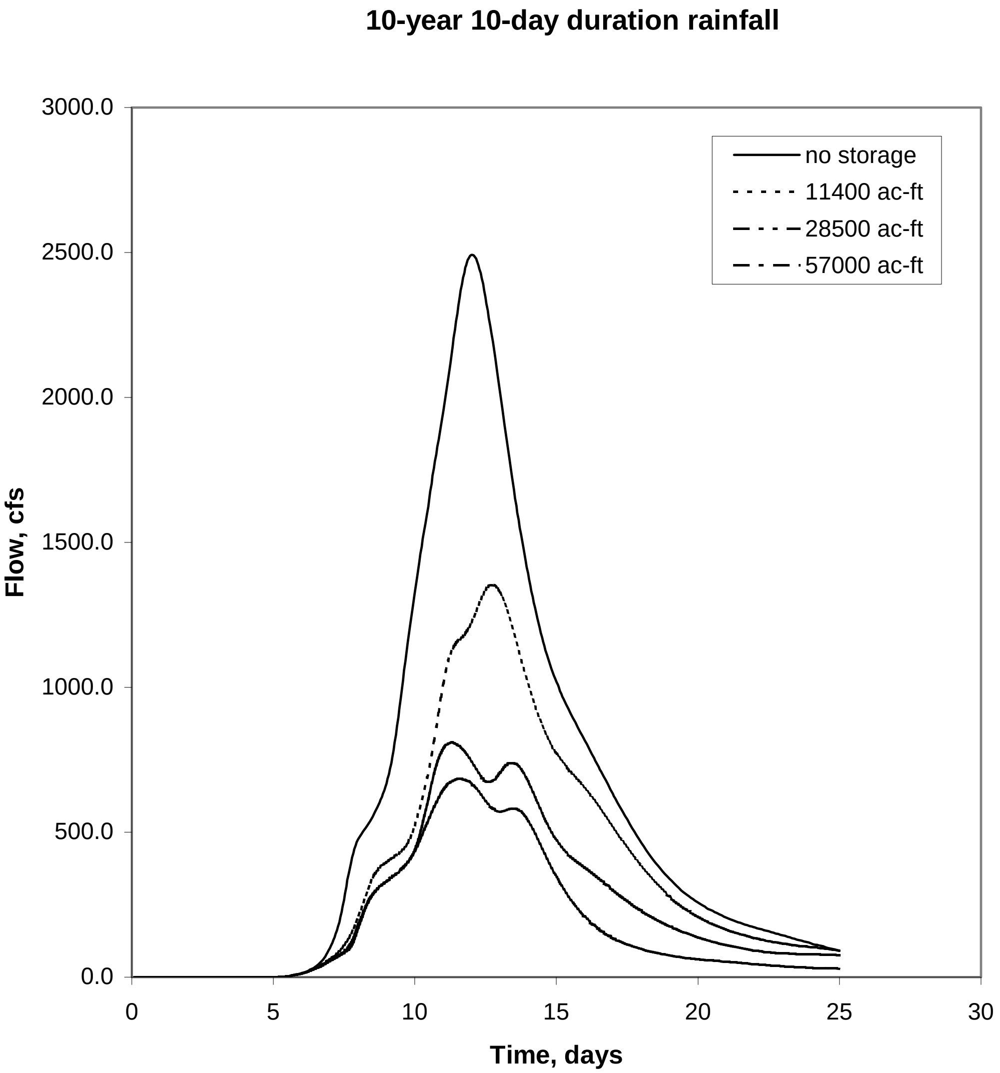


Figure 22. 10-year 10-day storm event hydrograph. Restored wetlands distributed uniformly by subwatershed area.

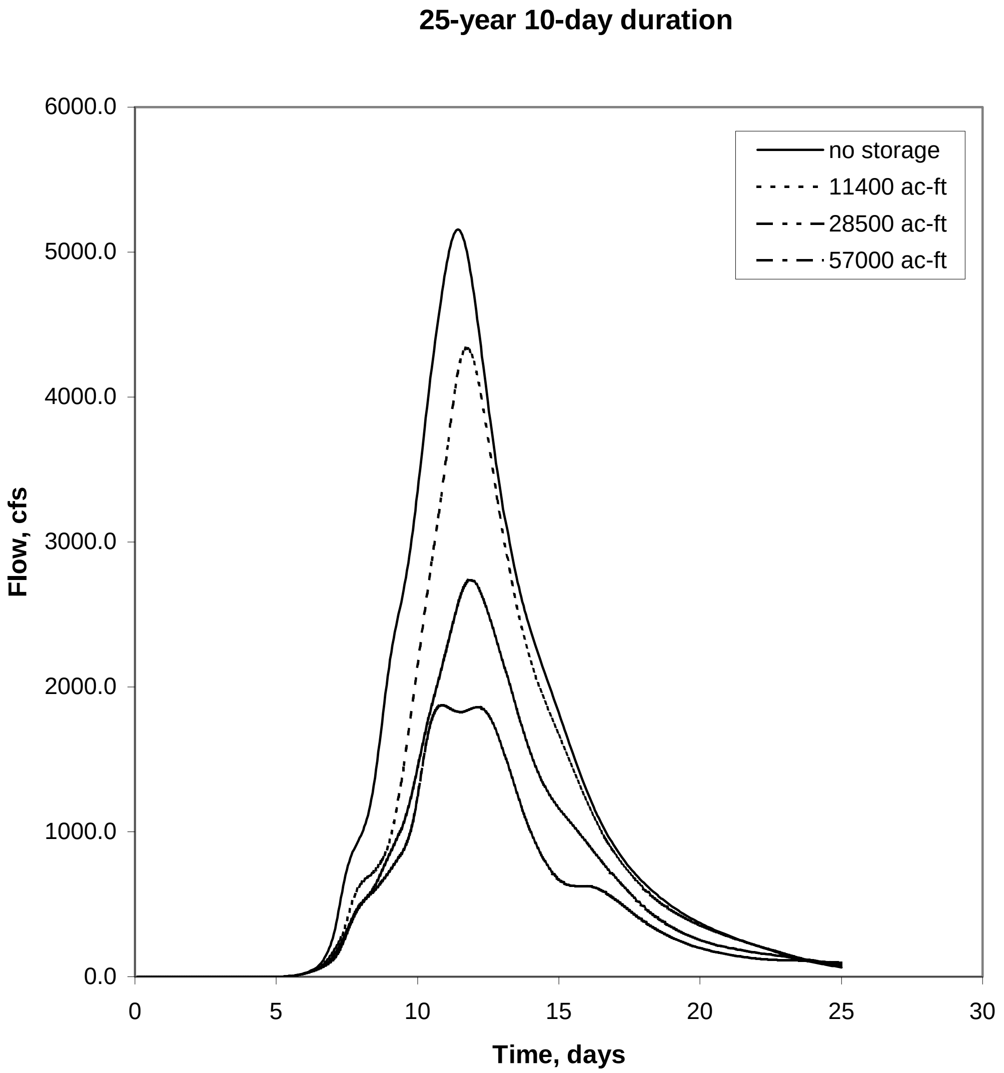


Figure 23. 25-year 10-day storm event hydrograph. Restored wetlands distributed uniformly by subwatershed area.

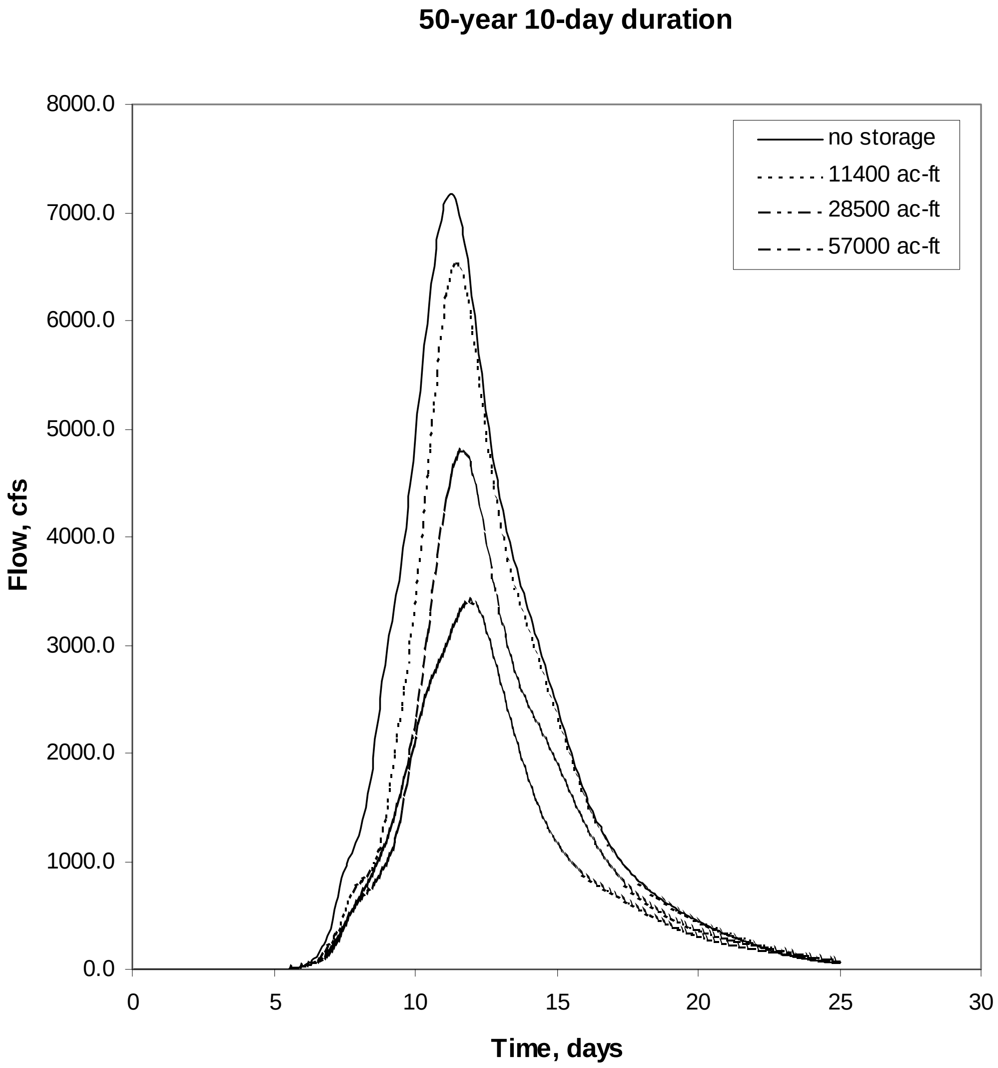


Figure 24. 50-year 10-day storm event hydrograph. Restored wetlands distributed uniformly by subwatershed area.

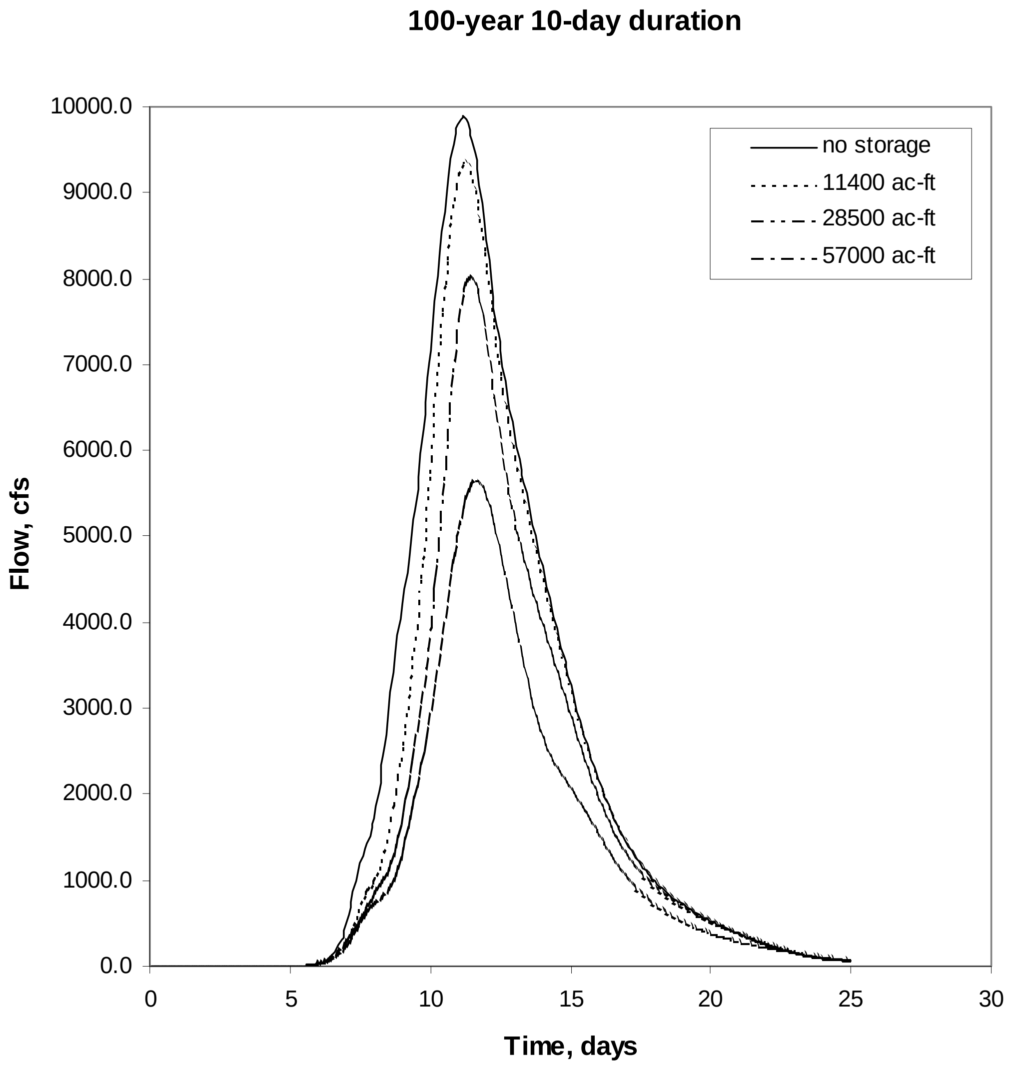


Figure 25. 10-year storm event hydrograph. Restored wetlands distributed uniformly by subwatershed area.

The results of modeling the effect of restoring the drained wetlands in their original locations showed that for a 1 foot bounce the maximum reduction in flood stage was about 3% for a 10-year storm. For a 100-year event, the reduction was less than 0.4%. For a 4 foot bounce, the flood stage was reduced about 10% for the 10-year event, but only 1.26% for the 100-year event. Changing the timing of diversions did not significantly affect the results.

To investigate the effect of much greater wetland storage, the model was run with 1%, 2.5% and 5% restored wetlands. These wetlands were distributed uniformly over the watershed to maximize their effect on flood stage. The best results were for the higher-frequency events. With 1% restored wetlands by area, the flood stage was reduced by nearly 19%. With 5% wetlands, flood stage was reduced by 34%. For a low-frequency event such as the 100 year storm, storage from 1% restored wetlands reduced the flood stage by less than 0.9%. For 5% restored wetland, flood stage was reduced by 8.4%. This case represents nearly 20 times the existing drained wetlands by area.

Recently a study was performed to determine the hydrologic effects of wetland drainage and land use change in the Little Cobb River watershed which is tributary to the Minnesota River (Miller, 1999.) This 130 mi^2 watershed had undergone extensive drainage. Miller modeled the watershed with the Hydrologic Simulation Program-FORTRAN (HSPF), a continuous water-balance model, for a period of 43 years. He assumed 10% and 40% wetlands by area. Flow duration curves were developed for the daily flows from the simulations. These flood frequency curves converged for the large magnitude, low-frequency events even with 40% wetlands.

Based on the results of this study restoring drained wetlands could not have significantly effected the flood stage for a flood on the order of the 1997 Red River Valley Flood in the Maple River watershed. Even increasing the additional wetland storage represented by restoring drained wetlands by 4 times did not result in a significant reduction in flood stage. Also, wetlands were assumed empty at the time of the flood event, which may not be the case. The findings from the Miller study (Miller, 1999) support these results. For flows on the order of magnitude of a 100-year event, even 40% wetlands by area did not have a significant effect. Restoring drained wetlands is highly unlikely to significantly affect the low-frequency flood events such as the Red River Valley flood of 1997.

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APPENDIX A

Table A-1
Maple River watershed data

		Hydrologic soil types				Land Use Types					
Subwatershed ID	Area sq mi	Soil A %	Soil B %	Soil C % %	Soil D % %	Developed Land %	Crop/Pasture %	Rangeland %	Forest %	Water %	Wetlands %
1	13.9	0.0	100.0	0.0	0.0	0.0	96.7	1.9	0.0	0.0	1.4
2	30.2	0.0	100.0	0.0	0.0	0.0	94.9	4.2	0.0	0.0	0.9
3	12.9	0.0	100.0	0.0	0.0	1.5	96.8	1.8	0.0	0.0	0.0
4	22.0	0.0	99.5	0.5	0.0	0.0	95.8	4.0	0.0	0.0	0.2
5	48.1	0.0	86.0	14.0	0.0	0.0	97.5	0.6	0.0	0.7	1.2
6	9.2	0.0	100.0	0.0	0.0	1.7	92.8	5.5	0.0	0.0	0.0
7	74.6	0.0	60.0	40.0	0.0	0.2	94.3	3.2	0.0	0.3	2.0
8	50.1	0.0	75.0	25.0	0.0	0.2	98.8	0.2	0.0	0.1	0.8
9	34.1	0.0	95.0	5.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
10	37.3	0.0	100.0	0.0	0.0	0.3	99.5	0.2	0.0	0.0	0.0
11	25.7	0.0	100.0	0.0	0.0	0.0	95.6	3.6	0.0	0.0	0.8
12	23.1	0.0	68.0	32.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
13	9.0	0.0	97.0	3.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
14	36.8	0.0	77.0	23.0	0.0	0.5	99.2	0.0	0.0	0.0	0.2
15	55.7	0.0	96.0	4.0	0.0	1.1	96.7	2.2	0.0	0.0	0.0
16	22.9	0.0	100.0	0.0	0.0	0.1	99.9	0.0	0.0	0.0	0.0
17	41.4	0.0	83.0	17.0	0.0	1.4	97.3	0.0	0.0	0.7	0.6
18	36.6	0.0	30.0	58.0	12.0	1.6	98.4	0.0	0.0	0.0	0.0
19	22.7	0.0	100.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
20	32.6	0.0	30.0	46.0	24.0	2.7	97.3	0.0	0.0	0.0	0.0
21	13.9	0.0	48.0	6.0	46.0	1.6	98.3	0.0	0.0	0.0	0.0
22	103.3	7.0	7.0	79.0	7.0	1.3	98.2	0.3	0.2	0.0	0.0
23	44.4	0.0	96.0	4.0	0.0	0.4	0.0	99.2	0.0	0.3	0.0
24	38.0	0.0	63.0	37.0	0.0	0.3	98.8	0.0	0.0	0.7	0.3
25	67.3	0.0	99.6	0.4	0.0	0.7	96.2	0.0	0.0	1.1	2.1
26	43.8	0.0	57.0	16.0	27.0	0.9	99.1	0.0	0.0	0.0	0.0
27	16.3	0.0	6.0	41.0	53.0	0.4	99.6	0.0	0.0	0.0	0.0
28	7.0	0.0	52.0	48.0	0.0	1.9	98.1	0.0	0.0	0.0	0.0
29	4.6	0.0	51.0	49.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
30	36.8	0.0	91.0	9.0	0.0	0.0	97.7	0.0	0.0	2.0	0.3
31	3.8	0.0	70.0	0.0	30.0	0.0	100.0	0.0	0.0	0.0	0.0
32	59.7	9.0	13.0	15.0	63.0	0.0	98.7	0.9	0.4	0.0	0.0
33	65.2	0.0	52.0	12.0	34.0	0.1	99.6	0.0	0.0	0.0	0.3
34	33.2	0.0	87.0	13.0	0.0	0.1	96.1	0.0	0.0	0.9	2.9
35	9.9	0.0	59.0	41.0	0.0	0.0	99.4	0.0	0.0	0.6	0.0
36	82.6	21.0	28.0	8.0	43.0	0.2	99.3	0.0	0.2	0.0	0.3
37	18.9	0.0	91.0	9.0	0.0	0.0	99.5	0.0	0.0	0.3	0.3
38	19.1	0.0	55.0	45.0	0.0	0.5	98.5	0.0	0.0	0.7	0.2
39	56.0	0.0	67.0	33.0	0.0	0.1	95.7	0.0	0.0	3.8	0.5
40	8.3	0.0	100.0	0.0	0.0	0.0	98.9	0.0	0.0	1.1	0.0
41	32.7	0.0	99.0	1.0	0.0	0.0	93.8	0.0	0.0	6.2	0.0
42	7.6	33.0	67.0	0.0	0.0	0.0	96.8	0.0	2.4	0.0	0.8
43	27.5	64.0	36.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
44	84.1	0.0	100.0	0.0	0.0	0.2	97.3	0.0	0.0	1.6	1.0
45	9.5	0.0	89.0	11.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
46	15.7	0.0	100.0	0.0	0.0	1.0	96.9	0.0	2.1	0.0	0.0
47	6.4	0.0	45.0	55.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
48	64.1	0.0	98.0	2.0	0.0	0.6	97.7	0.0	0.0	1.1	0.6

Table A-2
Wild Rice River watershed data

		Land Use Types					
Subwatershed ID	Area sq mi	Developed Land %	Crop/Pasture %	Rangeland %	Forest %	Water %	Wetlands %
1	26.2	1.1	70.3	14.7	3.1	2.5	8.2
2	43.5	0.6	54.0	9.7	18.2	6.6	10.9
3	29.5	1.0	84.9	4.5	8.6	0.1	1.0
4	29.6	1.0	82.2	8.5	1.8	2.3	4.2
5	13.6	1.2	19.3	17.2	43.7	9.0	9.7
6	33.0	2.3	29.8	0.0	49.3	1.8	16.8
7	9.6	0.5	21.0	17.3	47.5	3.4	10.2
8	32.5	1.2	87.2	3.9	6.7	0.1	0.9
9	19.8	0.8	88.1	5.6	3.3	0.0	2.1
10	13.6	1.0	19.2	0.0	45.1	3.1	31.5
11	21.2	0.5	19.6	21.2	48.1	3.1	7.6
12	11.3	2.6	20.0	0.6	63.5	1.0	12.4
13	38.6	0.9	82.2	9.2	2.9	1.2	3.7
14	1.0	0.3	31.6	2.5	57.4	3.2	4.9
15	11.9	2.7	76.8	13.6	6.2	0.2	0.6
16	14.8	0.3	7.9	16.4	61.7	3.5	10.2
17	9.0	4.0	22.7	0.0	49.6	1.4	22.3
18	15.9	1.4	11.1	0.0	43.9	21.9	21.7
19	7.8	1.3	17.5	0.0	56.5	0.1	24.6
20	16.1	0.2	10.8	11.4	67.0	3.6	7.1
21	28.6	0.3	2.5	0.0	68.1	13.6	15.5
22	41.2	1.9	68.8	8.8	12.7	4.2	3.6
23	11.1	1.6	69.3	6.0	22.5	0.1	0.5
24	14.7	0.8	75.8	3.7	18.9	0.1	0.6
25	17.6	1.2	5.9	0.0	75.1	2.3	15.5
26	7.5	0.8	86.2	7.2	4.3	0.1	1.4
27	18.0	2.5	8.2	0.0	72.7	3.1	13.5
28	35.7	0.7	97.5	1.0	0.9	0.0	0.0
29	5.1	1.9	79.8	4.6	11.8	1.8	0.1
30	22.1	0.3	13.8	8.0	63.2	6.2	8.6
31	10.8	1.4	86.1	6.6	2.8	1.4	1.7
32	28.5	1.1	74.3	9.9	12.0	1.6	1.0
33	7.7	2.1	4.6	4.1	69.0	15.4	4.8
34	23.7	0.9	97.0	0.6	1.5	0.0	0.0
35	29.3	3.5	79.1	4.3	10.0	1.6	1.5
36	9.0	0.5	19.0	10.8	66.1	0.3	3.3
37	9.7	3.9	55.5	7.1	30.1	2.7	0.6
38	2.4	0.0	0.0	0.0	46.1	0.8	53.1
39	28.9	1.0	45.2	12.7	29.9	5.7	5.4
40	18.0	1.0	65.9	8.4	17.9	1.7	5.1
41	15.9	0.1	0.2	0.0	79.2	6.5	13.9
42	0.3	9.5	75.9	1.6	11.8	1.2	0.0
43	18.3	1.7	88.9	1.0	7.0	1.3	0.0
44	39.4	0.9	0.3	2.4	75.5	14.4	6.5
45	3.9	7.4	80.4	6.3	5.5	0.0	0.4
46	21.9	1.3	84.1	9.6	3.2	0.6	1.3
47	7.1	1.7	66.3	7.9	22.6	0.8	0.8
48	2.7	5.2	40.7	5.3	46.1	2.7	0.0
49	12.2	0.9	74.3	16.8	3.7	0.2	4.2
50	21.8	2.0	83.3	10.6	3.1	0.3	0.7
51	39.7	0.9	47.7	16.6	24.1	5.0	5.7
52	7.8	0.7	90.8	1.3	5.8	1.2	0.1
53	23.8	0.6	91.7	6.1	1.5	0.1	0.0
54	12.9	0.2	0.1	0.0	75.2	5.1	19.4
55	6.0	0.7	73.9	13.1	7.8	2.5	2.0
56	12.1	1.0	91.5	3.6	2.5	0.6	0.9
57	12.8	0.9	90.9	0.6	6.1	1.3	0.3
58	35.8	1.6	67.8	17.7	6.7	1.6	4.6
59	12.9	0.5	95.3	1.3	1.9	0.8	0.2

Table A-2 continued
Wild Rice River watershed data

Subwatershed ID	Area sq mi	Land Use Types Developed Land %	Crop/Pasture %	Rangeland %	Forest %	Water %	Wetlands %
60	24.0	0.2	0.1	3.1	81.7	9.1	5.9
61	42.5	1.0	92.8	3.9	1.7	0.1	0.4
62	24.4	1.2	53.8	5.4	37.7	0.4	1.5
63	8.0	1.4	75.7	12.1	8.2	1.1	1.6
64	24.7	0.4	75.4	12.5	0.5	1.5	9.6
65	10.7	0.6	1.9	4.0	77.9	7.7	8.0
66	14.3	0.7	0.0	3.9	80.1	10.1	5.2
67	41.9	1.7	68.9	17.4	2.2	4.0	5.8
68	20.1	0.8	7.8	6.6	50.9	25.8	8.2
69	21.4	0.0	0.0	0.0	0.0	0.0	0.0
70	37.3	0.5	4.5	3.5	71.0	14.3	6.2
71	16.6	1.3	92.6	3.4	2.7	0.0	0.0
72	38.4	0.3	98.5	0.0	1.1	0.0	0.0
73	8.2	1.2	73.8	14.8	8.4	0.1	1.7
74	20.3	0.4	48.0	46.4	2.0	0.4	2.9
75	68.7	0.6	83.0	6.1	7.8	0.3	2.2
76	9.8	0.0	0.0	0.0	0.0	0.0	0.0
77	51.1	0.0	0.0	0.0	0.0	0.0	0.0
78	41.2	0.3	33.0	1.1	63.9	1.0	0.8
79	19.7	0.9	92.9	4.0	2.2	0.0	0.0
80	10.8	0.2	20.9	1.2	76.5	0.5	0.6

Table A-3
Maple River watershed wetlands by subwatershed

Upper watershed

Subwatershed	Subwatershed	Semi-permanent wetlands			Seasonal wetlands			Temporary wetlands			Drained wetlands			Impounded wetlands		
ID	area, sq mi	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area
1	13.9	33	99.3	1.12	126	258.0	2.90	225	200.1	2.25	24	21.6	0.243			
2	30.2	52	164.6	0.85	338	359.2	1.86	622	368.7	1.90	49	109.9	0.568	3	8.0	0.041
3	12.9	14	18.0	0.22	94	120.0	1.45	297	135.1	1.63	18	11.3	0.136			
4	22.0	8	12.8	0.09	142	227.1	1.61	598	345.3	2.45	83	83.1	0.590			
5	48.1	101	361.6	1.18	369	568.4	1.85	1122	820.9	2.67	292	375.6	1.221	2	7.2	0.023
6	9.2	28	42.8	0.73	103	181.0	3.07	393	234.1	3.97	2	1.3	0.022	1	8.7	0.148
7	74.6	137	1084.5	2.27	740	995.5	2.09	1345	682.2	1.43	149	191.4	0.401	9	12.7	0.027
8	50.1	46	121.0	0.38	324	708.2	2.21	1487	1153.8	3.60	316	457.6	1.426			
9	34.1	5	6.2	0.03	58	143.1	0.66	285	252.3	1.16	118	165.3	0.758			
10	37.3	10	20.0	0.08	43	25.5	0.11	260	228.8	0.96	49	53.8	0.225	9	52.5	0.220
11	25.7	51	174.5	1.06	298	333.4	2.03	406	264.6	1.61	63	88.5	0.538	4	5.7	0.034
12	23.1	12	24.7	0.17	161	256.8	1.74	488	360.5	2.44	97	109.1	0.738			
13	9.0	1	1.0	0.02	62	92.9	1.62	217	129.8	2.26	30	22.8	0.397			
14	36.8	11	6.7	0.03	99	193.9	0.82	430	241.9	1.03	77	59.0	0.250			
15	55.7	104	192.4	0.54	540	602.3	1.69	1238	711.0	1.99	71	61.7	0.173	7	19.5	0.055
16	22.9	6	13.3	0.09	18	26.5	0.18	200	131.2	0.89	43	44.9	0.306	1	1.6	0.011
17	41.4	124	272.9	1.03	244	232.8	0.88	499	263.7	1.00	41	45.9	0.173	13	104.6	0.395
19	22.7	27	32.3	0.22	66	64.1	0.44	324	161.4	1.11	60	37.0	0.255	4	20.0	0.138
23	44.4	109	320.6	1.13	356	406.9	1.43	692	282.2	0.99	31	20.3	0.071	4	9.2	0.032
24	38.0	84	207.2	0.85	686	1042.0	4.29	933	399.2	1.64	26	27.5	0.113			
25	67.3	99	1677.9	3.89	467	831.4	1.93	1364	635.8	1.48	48	46.8	0.108	4	73.3	0.170
28	7.0	15	18.7	0.42	95	164.9	3.68	250	107.7	2.40	11	7.3	0.164			
30	36.8	96	379.9	1.61	491	711.5	3.02	840	396.9	1.69	26	84.5	0.359	1	34.7	0.148
34	33.2	107	825.7	3.89	425	569.8	2.68	698	307.6	1.45	20	22.0	0.103			
35	9.9	17	77.7	1.23	124	120.6	1.91	181	78.9	1.25	2	6.3	0.100			
37	18.9	44	102.3	0.85	304	403.7	3.34	665	300.6	2.48	17	8.1	0.067			
38	19.1	31	106.8	0.87	200	268.9	2.20	451	288.4	2.36	16	14.2	0.116	1	3.3	0.0271114
39	56.0	189	1326.2	3.70	706	1318.4	3.68	925	560.1	1.56	79	93.3	0.261	4	14.3	0.0399149
40	8.3	3	17.3	0.33	16	33.3	0.63	41	37.8	0.71	5	7.0	0.133			
41	32.7	68	377.6	1.81	296	416.7	1.99	886	481.2	2.30	9	19.6	0.094			
42	7.6	11	45.7	0.94	17	24.5	0.51	41	68.4	1.41	2	1.1	0.022			
43	27.5	34	117.0	0.67	105	271.5	1.55	358	404.4	2.30	44	44.0	0.250			
44	84.1	231	1340.6	2.49	1450	2067.1	3.84	1471	766.1	1.42	44	46.1	0.086			
45	9.5	13	13.5	0.22	193	212.8	3.49	202	109.9	1.80	14	28.8	0.473			
46	15.7	25	29.5	0.29	62	45.4	0.45	125	106.1	1.06						
47	6.4	3	3.0	0.07	106	85.0	2.08	194	95.6	2.34	2	0.9	0.021			
48	64.1	213	798.9	1.95	1455	1608.8	3.92	1317	545.2	1.33	128	112.0	0.273	1	0.2	0.001
sum	1156	2162	10435		11379	15992		22070	12657		2106	2529		68	375	
average	31.2	58	282.0	1.0	308	432.2	2.0	596	342.1	1.8	59	70.3	0.3	4	23.5	0.1
maximum	84.1	231	1677.9	3.9	1455	2067.1	4.3	1487	1153.8	4.0	316	457.6	1.4	13	104.6	0.4
minimum	6.4	1	1.0	0.0	16	24.5	0.1	41	37.8	0.7	2	0.9	0.0	1	0.2	0.0

Table A-3

Maple River watershed wetlands by subwatershed

Lake Plain/Beach

Subwatershed ID	Subwatershed area, sq mi	Semi-permanent wetlands			Seasonal wetlands			Temporary wetlands			Drained wetlands			Impounded wetlands		
		number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area
18	36.6	6	4.0	0.02	8	9.9	0.04	56	31.1	0.13	3	0.8	0.004	1	1.9	0.008
20	32.6	1	0.3	0.00	9	4.2	0.02	105	55.4	0.27	7	8.1	0.039			
21	13.9	8	11.4	0.13				10	5.6	0.06				1	2.1	0.023
22	103.3	18	42.4	0.06	61	122.2	0.18	117	134.7	0.20	15	39.8	0.060			
26	43.8	23	43.1	0.15	28	23.1	0.08	134	101.5	0.36	5	5.9	0.021			
27	16.3	3	0.6	0.01	1	0.6	0.01	19	17.7	0.17	1	0.1	0.001			
29	4.6				15	3.8	0.13	4	5.7	0.19	2	1.7	0.057			
31	3.8							9	11.1	0.46	1	0.3	0.014			
32	59.7	19	11.9	0.03	25	14.5	0.04	77	46.9	0.12	3	3.8	0.010	5	4.8	0.012
33	65.2	16	92.9	0.22	45	90.2	0.22	302	222.0	0.53	17	24.4	0.058			
36	82.6	48	107.3	0.20	160	305.7	0.58	478	519.9	0.98	27	142.9	0.270	5	5.8	0.011
sum	462	142	314		352	574		1311	1152		81	228		12	15	
average	42.0	16	34.9	0.1	39	63.8	0.1	119	104.7	0.3	8	22.8	0.1	3	3.6	0.0
maximum	103.3	48	107.3	0.2	160	305.7	0.6	478	519.9	1.0	27	142.9	0.3	5	5.8	0.0
minimum	3.8	1	0.3	0.0	1	0.6	0.0	4	5.6	0.1	1	0.1	0.0	1	1.9	0.0

Table A-4

Wild Rice River watershed wetlands by subwatershed

Upper Watershed

Subwatershed	Subwatershed	Permanent wetlands			Semi-permanent wetlands			Seasonal wetlands			Temporary wetlands			Drained wetlands			Impounded wetlands		
ID	area, sq mi	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area	number	area, acres	% by area
1	26.2	1	5.7	0.03	80	666.5	3.98	330	744.6	4.45	100	261.8	1.56	195	1187.6	7.09	1	3.2	0.02
2	43.5	56	330.0	1.19	253	1806.0	6.49	947	1877.8	6.75	181	434.7	1.56	398	1730.8	6.22	0		
3	29.5	2	2.0	0.01	33	64.5	0.34	196	411.6	2.18	112	146.0	0.77	103	283.3	1.50	0		
4	29.6	3	17.0	0.09	72	443.4	2.34	298	687.3	3.63	174	164.2	0.87	209	741.1	3.91	0		
5	13.6	19	60.5	0.69	51	214.2	2.46	297	845.2	9.71	82	387.6	4.45	61	211.4	2.43	4	5.4	0.06
6	33.0	7	25.5	0.12	23	94.0	0.44	803	1577.3	7.46	118	1740.6	8.23	108	487.8	2.31	0		
7	9.6	2	13.9	0.23	15	110.5	1.80	160	358.2	5.84	24	1131.1	18.44	6	15.6	0.25	0		
8	32.5	4	11.6	0.06	13	108.0	0.52	160	354.4	1.70	62	69.9	0.34	91	273.1	1.31	6	13.1	0.06
9	19.8	0			29	172.0	1.36	116	154.9	1.22	50	139.5	1.10	60	68.5	0.54	0		
10	13.6	1	0.6	0.01	2	145.7	1.68	117	173.8	2.00	63	1890.1	21.72	39	945.6	10.87	0		
11	21.2	17	66.1	0.49	33	51.6	0.38	350	1321.3	9.72	171	1868.2	13.74	45	96.9	0.71	1	11.4	0.08
12	11.3	3	4.2	0.06	7	6.6	0.09	187	515.3	7.11	32	216.2	2.98	38	85.6	1.18	0		
13	38.6	5	13.1	0.05	116	410.3	1.66	350	637.8	2.58	127	272.0	1.10	167	352.2	1.43	0		
14	1.0	0			0			11	35.5	5.34	1	0.4	0.06	4	1.8	0.27	0		
15	11.9	0			9	28.2	0.37	125	323.1	4.25	44	81.0	1.07	36	78.5	1.03	0		
16	14.8	6	24.8	0.26	7	61.9	0.65	122	556.0	5.88	84	1632.7	17.27	4	29.9	0.32	0		
17	9.0	10	36.5	0.63	21	31.3	0.54	84	139.7	2.42	42	479.4	8.31	18	27.3	0.47	1	0.6	0.01
18	15.9	5	178.4	1.75	22	434.0	4.26	188	341.5	3.35	89	1126.2	11.05	19	37.5	0.37	0		
19	7.8	1	0.9	0.02	0			83	394.4	7.90	15	137.0	2.74	7	89.0	1.78	1	0.9	0.02
20	16.1	21	47.1	0.46	21	89.7	0.87	213	291.9	2.83	292	993.4	9.63	31	120.4	1.17	10	10.6	0.10
21	28.6	16	90.5	0.49	19	42.0	0.23	162	302.2	1.65	191	2698.4	14.74	1	1.9	0.01	0		
22	41.2	33	176.2	0.67	172	449.1	1.70	578	972.4	3.69	135	174.6	0.66	248	583.9	2.22	0		
23	11.1	0			2	5.7	0.08	74	101.9	1.44	31	16.8	0.24	19	51.7	0.73	0		
24	14.7	0			1	0.2	0.00	74	194.7	2.06	49	232.2	2.46	44	63.3	0.67	0		
25	17.6	4	20.7	0.18	10	42.7	0.38	376	673.2	5.97	119	741.6	6.58	13	85.4	0.76	0		
27	18.0	2	7.2	0.06	21	50.7	0.44	233	362.2	3.14	105	1074.2	9.30	25	91.4	0.79	1	3.6	0.03
30	22.1	25	147.4	1.04	79	244.7	1.73	335	778.3	5.50	205	1126.3	7.96	73	238.5	1.69	0		
31	10.8	1	3.6	0.05	12	68.5	0.99	113	308.1	4.47	36	72.5	1.05	77	163.1	2.37	0		
33	7.7	6	30.2	0.62	9	46.5	0.95	68	60.8	1.24	43	460.2	9.39	0			0		
35	29.3	5	19.9	0.11	66	263.7	1.41	218	244.9	1.31	146	448.0	2.39	148	293.0	1.56	0		
36	9.0	2	14.2	0.25	8	19.6	0.34	98	285.1	4.93	39	240.1	4.15	3	2.2	0.04	0		
37	9.7	6	2.9	0.05	7	31.1	0.50	47	53.0	0.86	27	76.0	1.23	15	30.9	0.50	0		
38	2.4	0			0			9	28.7	1.90	12	193.1	12.83	0			0		
39	28.9	33	162.7	0.88	121	530.2	2.87	553	1086.0	5.88	121	548.9	2.97	129	249.4	1.35	0		
40	18.0	15	63.3	0.55	46	142.8	1.24	136	282.7	2.45	64	495.8	4.29	35	65.2	0.56	3	4.7	0.04
41	15.9	43	155.6	1.53	33	79.0	0.77	168	227.9	2.23	161	567.2	5.56	0			0		
42	0.3	0			0			0			0			0			0		
45	3.9	0			0			10	47.2	1.91	9	13.5	0.55	6	34.9	1.41	0		
46	21.9	6	31.8	0.23	63	154.1	1.10	148	403.9	2.89	104	89.6	0.64	81	200.2	1.43	0		
47	7.1	2	5.2	0.12	5	11.5	0.25	28	30.7	0.68	5	21.8	0.48	2	0.8	0.02	3	8.9	0.20
48	2.7	0			2	1.2	0.07	15	12.0	0.70	3	11.8	0.69	0			0		
49	12.2	1	0.5	0.01	21	120.5	1.54	111	406.8	5.21	53	557.8	7.15	27	293.5	3.76	0		
50	21.8	2	0.4	0.00	22	41.8	0.30	69	123.4	0.88	52	407.6	2.92	36	80.4	0.58	2	4.8	0.03
51	39.7	39	224.2	0.88	261	837.2	3.30	641	2314.6	9.12	148	907.8	3.58	144	812.6	3.20	0		
54	12.9	25	114.9	1.39	8	31.3	0.38	234	277.1	3.35	92	556.5	6.72	3	10.2	0.12	1	15.6	0.19
55	6.0	3	13.7	0.36	15	90.9	2.37	28	125.6	3.28	4	63.8	1.66	1	9.6	0.25	1	1.1	0.03
56	12.1	8	31.2	0.40	26	58.9	0.76	40	56.8	0.73	32	47.3	0.61	22	35.3	0.45	1	0.5	0.01
58	35.8	43	158.7	0.69	228	892.0	3.89	488	1025.1	4.47	75	764.9	3.33	181	1311.0	5.71	0		
60	24.0	30	140.3	0.91	46	155.2	1.01	318	537.7	3.50	247	1330.5	8.66	0			5	49.1	0.32
62	24.4	12	53.3	0.34	54	189.8	1.22	117	317.0	2.03	101	149.3	0.96	102	176.9	1.13	5	15.8	0.10
63	8.0	4	30.1	0.59	10	26.9	0.53	37	100.4	1.97	18	71.3	1.40	13	21.1	0.41	0		
64	24.7	6	30.4	0.19	138	1195.4	7.55	180	359.6	2.27	144	228.4	1.44	152	437.7	2.76	0		
65	10.7	9	28.3	0.41	26	112.8	1.65	144	207.9	3.04	99	856.5	12.51	1	0.3	0.00	0		
66	14.3	16	46.2	0.50	40	98.2	1.07	184	221.1	2.41	151	887.0	9.67	0			9	18.2	0.20
67	41.9	41	174.7	0.65	273	864.8	3.23	569	1875.6	7.00	73	435.8	1.63	235	1129.7	4.22	2	4.8	0.02
68	20.1	34	128.3	1.00	124	367.9	2.86	340	635.6	4.95	166	720.4	5.61	20	50.6	0.39	1	5.2	0.04

Table A-4 continued
Wild Rice River watershed wetlands by subwatershed

Upper Watershed

Subwatershed ID	Subwatershed area, sq mi	Permanent wetlands number	Permanent wetlands area, acres	Permanent wetlands % by area	Semi-permanent wetlands number	Semi-permanent wetlands area, acres	Semi-permanent wetlands % by area	Seasonal wetlands number	Seasonal wetlands area, acres	Seasonal wetlands % by area	Temporary wetlands number	Temporary wetlands area, acres	Temporary wetlands % by area	Drained wetlands number	Drained wetlands area, acres	Drained wetlands % by area	Impounded wetlands number	Impounded wetlands area, acres	Impounded wetlands % by area
70	37.3	38	145.8	0.61	133	443.9	1.86	370	539.8	2.26	197	1171.5	4.91	2	9.5	0.04	1	32.4	0.14
73	8.2	0			6	32.0	0.61	25	52.8	1.01	23	23.7	0.45	17	8.6	0.16	0		
75	68.7	5	19.7	0.04	159	528.4	1.20	276	772.7	1.76	224	214.9	0.49	208	262.6	0.60	0		
76	9.8	9	31.7	0.50	25	77.6	1.23	82	118.1	1.88	61	131.1	2.09	3	8.1	0.13	0		
78	41.2	15	17.7	0.07	51	333.5	1.26	188	406.3	1.54	101	134.0	0.51	87	228.4	0.87	0		
79	19.7	3	2.1	0.02	48	104.0	0.83	68	135.3	1.07	71	693.0	5.50	25	36.8	0.29	0		
80	10.8	3	28.4	0.41	4	33.8	0.49	37	66.9	0.97	39	20.3	0.29	21	18.8	0.27	0		
sum	1223.6	708	3189.6		3201	13758.6		13126	28873.7		5639	32848.1		3858	13961.0		59	209.9	
average	19.4	11	60.2	0.43	51	237.2	1.46	208	465.7	3.48	90	529.8	4.79	61	249.3	1.55	1	10.5	0.08
max	68.7	56	330.0	1.75	273	1806.0	7.55	947	2314.6	9.72	292	2698.4	21.72	398	1730.8	10.87	10	49.1	0.32
min	0.3	0	0.4	0.00	0	0.2	0.00	0	12.0	0.68	0	0.4	0.06	0	0.3	0.00	0	0.5	0.01

Lake Plain and Beach

Subwatershed ID	Subwatershed area, sq mi	Permanent wetlands number	Permanent wetlands area, acres	Permanent wetlands % by area	Semi-permanent wetlands number	Semi-permanent wetlands area, acres	Semi-permanent wetlands % by area	Seasonal wetlands number	Seasonal wetlands area, acres	Seasonal wetlands % by area	Temporary wetlands number	Temporary wetlands area, acres	Temporary wetlands % by area	Drained wetlands number	Drained wetlands area, acres	Drained wetlands % by area	Impounded wetlands number	Impounded wetlands area, acres	Impounded wetlands % by area
26	7.5	0			4	42.4	0.89	57	232.0	4.85	30	69.4	1.45	15	71.1	1.49	0		
28	35.7	0			1	1.1	0.00	7	11.2	0.05	28	11.2	0.05	25	10.9	0.05	0		
29	5.1	0			6	12.7	0.39	7	61.5	1.87	4	0.9	0.03	5	3.1	0.09	0		
32	28.5	12	16.5	0.09	58	165.9	0.91	155	276.8	1.52	47	524.6	2.87	25	43.8	0.24	2	1.8	0.01
34	23.7	0			0			7	2.2	0.01	10	8.7	0.06	12	7.5	0.05	0		
43	18.3	0			0			2	1.2	0.01	1	0.2	0.00	0			0		
44	39.4	52	280.1	1.11	44	129.2	0.51	449	507.8	2.02	370	1662.9	6.60	6	20.5	0.08	0		
52	7.8	5	8.2	0.17	2	0.8	0.02	7	6.8	0.14	5	3.1	0.06	2	2.0	0.04	0		
53	23.8	1	0.4	0.00	5	2.4	0.02	24	30.7	0.20	23	54.9	0.36	10	12.9	0.08	1	0.4	0.00
57	12.8	3	2.9	0.04	1	3.7	0.04	5	3.4	0.04	5	2.5	0.03	2	1.0	0.01	0		
59	12.9	8	8.5	0.10	0			5	4.8	0.06	10	6.2	0.07	4	1.1	0.01	0		
61	42.5	1	2.9	0.01	8	10.6	0.04	46	112.8	0.41	42	126.9	0.47	22	62.0	0.23	1	2.9	0.01
69	21.4	4	19.9	0.15	6	8.0	0.06	25	96.5	0.70	40	513.0	3.74	3	1.9	0.01	0		
71	16.6	0			0			7	54.0	0.51	8	4.6	0.04	7	50.0	0.47	0		
72	38.4	0			2	3.0	0.01	15	23.7	0.10	27	592.7	2.41	7	7.0	0.03	0		
74	20.3	6	8.0	0.06	9	28.0	0.21	82	244.4	1.88	45	462.7	3.56	12	65.0	0.50	3	5.4	0.04
77	51.1	19	35.3	0.11	95	354.6	1.09	188	392.8	1.20	244	1481.3	4.53	50	896.4	2.74	10	67.0	0.21
sum	405.8	111	382.9		241	762.3		1088	2062.5		939	5525.7		207	1256.1		17	77.6	
average	23.9	7	38.3	0.18	14	58.6	0.32	64	121.3	0.92	55	325.0	1.55	12	78.5	0.38	1	15.5	0.05
max	51.1	52	280.1	1.11	95	354.6	1.09	449	507.8	4.85	370	1662.9	6.60	50	896.4	2.74	10	67.0	0.21
min	5.1	0	0.4	0.00	0	0.8	0.00	2	1.2	0.01	1	0.2	0.00	0	1.0	0.01	0	0.4	0.00

Table A-5
Maple River watershed drained wetlands

Subwatersheds		Drained wetlands						
Number	Area sq mi	Number	Total area ac	Average area, ac	Maximum area, ac	Minimum area, ac	Median area, ac	% by area
1	13.9	24	21.64	0.90	7.86	0.11	0.38	0.243
2	30.2	49	109.87	2.24	16.14	0.18	0.96	0.568
3	12.9	18	11.25	0.63	1.71	0.15	0.46	0.136
4	22.0	83	83.06	1.00	6.58	0.14	0.49	0.590
5	48.1	292	375.58	1.29	75.47	0.05	0.58	1.221
6	9.2	2	1.30	0.65	0.99	0.31	0.65	0.022
7	74.5	149	191.37	1.28	18.87	0.10	0.62	0.401
8	50.1	316	457.57	1.45	25.62	0.08	0.55	1.426
9	34.1	118	165.26	1.40	9.38	0.11	0.78	0.758
10	37.3	49	53.83	1.10	14.02	0.11	0.44	0.225
11	25.7	63	88.52	1.41	18.26	0.10	0.67	0.538
12	23.1	97	109.10	1.12	11.53	0.09	0.51	0.738
13	9.0	30	22.79	0.76	2.41	0.20	0.52	0.397
14	36.8	77	58.96	0.77	3.48	0.08	0.52	0.250
15	55.7	71	61.70	0.87	10.96	0.12	0.42	0.173
16	22.9	43	44.93	1.04	5.45	0.13	0.70	0.306
17	41.4	41	45.94	1.12	11.54	0.08	0.52	0.173
18	36.6	3	0.85	0.28	0.41	0.14	0.30	0.004
19	22.7	60	36.97	0.62	2.62	0.10	0.32	0.255
20	32.6	7	8.13	1.16	3.90	0.14	0.63	0.039
21	13.9	0						0.000
22	103.3	15	39.84	2.66	22.17	0.24	1.42	0.060
23	44.4	31	20.25	0.65	2.18	0.07	0.45	0.071
24	38.0	26	27.47	1.06	3.38	0.07	0.77	0.113
25	67.3	48	46.76	0.97	7.55	0.04	0.56	0.108
26	43.8	5	5.90	1.18	1.69	0.98	1.00	0.021
27	16.3	1	0.15	0.15	0.15	0.15	0.15	0.001
28	7.0	11	7.35	0.67	3.06	0.15	0.42	0.164
29	4.6	2	1.67	0.84	1.05	0.62	0.84	0.057
30	36.8	26	84.53	3.25	36.43	0.09	0.43	0.359
31	3.8	1	0.33	0.33	0.33	0.33	0.33	0.014
32	59.7	3	3.77	1.26	3.45	0.11	0.21	0.010
33	65.2	17	24.40	1.44	4.44	0.19	0.94	0.058
34	33.2	20	21.95	1.10	4.17	0.08	0.89	0.103
35	9.9	2	6.28	3.14	5.50	0.78	3.14	0.100
36	82.5	27	142.88	5.29	77.83	0.17	0.85	0.270
37	18.9	17	8.06	0.47	2.05	0.19	0.31	0.067
38	19.1	16	14.18	0.89	4.26	0.16	0.56	0.116
39	55.9	79	93.28	1.18	7.56	0.13	0.63	0.261
40	8.3	5	7.03	1.41	2.71	0.59	0.69	0.133
41	32.7	9	19.62	2.18	13.23	0.34	0.82	0.094
42	7.6	2	1.08	0.54	0.85	0.23	0.54	0.022
43	27.5	44	43.98	1.00	5.12	0.12	0.62	0.250
44	84.1	44	46.08	1.05	4.07	0.11	0.73	0.086
45	9.5	14	28.81	2.06	9.55	0.29	1.62	0.473
46	15.7	0						
47	6.4	2	0.86	0.43	0.64	0.22	0.43	0.021
48	64.1	128	112.02	0.88	7.61	0.10	0.47	0.273

Table A-6
Wild Rice River watershed drained wetlands

Subwatersheds		Drained wetlands						
Number	Area sq mi	Number	Total area ac	Average area, ac	Maximum area, ac	Minimum area, ac	Median area, ac	% by area
1	26.2	195	1187.5	6.09	154.64	0.09	0.84	7.09
2	43.5	398	1730.7	4.35	109.77	0.09	1.07	6.22
3	29.5	103	283.3	2.75	31.23	0.14	0.91	1.50
4	29.6	209	741.0	3.55	99.59	0.09	0.74	3.91
5	13.6	61	211.4	3.47	52.30	0.14	0.86	2.43
6	33.0	108	487.8	4.52	64.85	0.10	0.95	2.31
7	9.6	6	15.6	2.59	9.23	0.21	1.35	0.25
8	32.5	91	273.0	3.00	79.46	0.10	1.12	1.31
9	19.8	60	68.5	1.14	6.43	0.10	0.58	0.54
10	13.6	39	945.5	24.24	822.89	0.11	0.67	10.87
11	21.2	45	96.9	2.15	18.74	0.19	1.10	0.71
12	11.3	38	85.6	2.25	17.25	0.14	0.87	1.18
13	38.6	167	352.2	2.11	24.80	0.09	0.78	1.43
14	1.0	4	1.8	0.45	1.03	0.13	0.33	0.27
15	11.9	36	78.5	2.18	10.61	0.10	1.14	1.03
16	14.8	4	29.9	7.47	27.69	0.22	0.99	0.32
17	9.0	18	27.3	1.52	9.55	0.18	0.70	0.47
18	15.9	19	32.6	1.71	7.13	0.14	0.75	0.32
19	7.8	7	89.0	12.71	24.61	1.55	12.44	1.78
20	16.1	31	120.4	3.88	28.76	0.19	1.81	1.17
21	28.6	1	1.9	1.87	1.87	1.87	1.87	0.01
22	41.2	248	583.8	2.35	30.74	0.10	1.08	2.21
23	11.1	19	51.6	2.72	28.68	0.09	0.59	0.73
24	14.7	44	63.3	1.44	7.98	0.09	0.58	0.67
25	17.6	13	85.4	6.57	34.05	0.14	1.65	0.76
26	7.5	15	71.1	4.74	41.70	0.12	1.35	1.49
27	18.0	25	91.4	3.65	21.73	0.26	1.28	0.79
28	35.7	25	10.9	0.44	1.68	0.12	0.28	0.05
29	5.1	3	3.1	0.61	2.13	0.18	0.22	0.09
30	22.1	73	238.4	3.27	23.19	0.20	1.87	1.69
31	10.8	77	163.0	2.12	14.84	0.08	0.90	2.37
32	28.5	25	43.8	1.75	9.29	0.20	0.99	0.24
33	7.7	1	3.4	3.41	3.41	3.41	3.41	0.07
34	23.7	12	7.5	0.62	2.37	0.11	0.28	0.05
35	29.3	148	293.0	1.98	46.80	0.10	0.73	1.56
36	9.0	3	2.2	0.73	1.17	0.30	0.70	0.04
37	9.7	15	30.9	2.06	12.79	0.10	0.39	0.50
38	2.4	1	0.2	0.22	0.22	0.22	0.22	0.01
39	28.9	129	249.4	1.93	9.52	0.09	1.08	1.35
40	18.0	35	65.2	1.86	16.98	0.13	0.81	0.56
41	15.9	1	0.4	0.42	0.42	0.42	0.42	0.00
42	0.3	1	0.2	0.20	0.20	0.20	0.20	0.10
43	18.3	1	0.2	0.20	0.20	0.20	0.20	0.00
44	39.4	6	20.5	3.42	7.59	0.13	2.82	0.08
45	3.9	81	200.1	2.47	19.95	0.21	1.23	8.09
46	21.9	81	200.1	2.47	19.95	0.21	1.23	1.43

Table A-6 continued
Wild Rice River watershed drained wetlands

Subwatersheds		Drained wetlands						
Number	Area sq mi	Number	Total area ac	Average area, ac	Maximum area, ac	Minimum area, ac	Median area, ac	% by area
47	7.1	2	0.8	0.38	0.42	0.33	0.38	0.02
48	2.7	1	4.9	4.91	4.91	4.91	4.91	0.29
49	12.2	27	293.5	10.87	109.18	0.11	1.14	3.76
50	21.8	36	80.4	2.23	12.90	0.09	0.79	0.58
51	39.7	144	812.5	5.64	203.32	0.09	1.35	3.20
52	7.8	2	2.0	0.99	1.11	0.86	0.99	0.04
53	23.8	10	12.9	1.29	5.00	0.49	0.84	0.08
54	12.9	3	10.2	3.39	7.10	0.33	2.74	0.12
55	6.0	1	9.6	9.58	9.58	9.58	9.58	0.25
56	12.1	22	35.3	1.60	5.05	0.09	0.96	0.45
57	12.8	2	1.0	0.52	0.83	0.22	0.52	0.01
58	35.8	181	1310.9	7.24	427.61	0.09	1.20	5.71
59	12.9	4	1.1	0.26	0.61	0.09	0.18	0.01
60	24.0	0						
61	42.5	22	62.0	2.82	27.77	0.17	0.78	0.23
62	24.4	102	176.9	1.73	15.93	0.09	0.67	1.13
63	8.0	13	21.1	1.62	3.73	0.15	1.26	0.41
64	24.7	152	437.7	2.88	166.28	0.09	0.58	2.76
65	10.7	1	19.0	19.00	19.00	19.00	19.00	0.28
66	14.3	0						
67	41.9	235	1129.5	4.81	117.55	0.10	1.12	4.21
68	20.1	20	50.6	2.53	27.33	0.19	0.92	0.39
69	21.4	3	1.8	0.90	0.92	0.89	0.90	0.01
70	37.3	2	1.8	0.90	0.92	0.89	0.90	0.01
71	16.6	7	49.9	7.14	20.31	0.12	0.63	0.47
72	38.4	7	7.0	1.01	2.83	0.18	0.37	0.03
73	8.2	17	8.6	0.51	2.16	0.10	0.31	0.16
74	20.3	12	64.9	5.41	17.44	0.36	2.92	0.50
75	68.7	208	262.6	1.26	17.60	0.08	0.63	0.60
76	9.8	3	8.1	2.70	4.41	0.21	3.49	0.13
77	51.1	50	896.3	17.93	274.00	0.10	1.43	2.74
78	41.2	87	228.4	2.62	41.29	0.09	0.80	0.87
79	19.7	25	36.8	1.47	12.79	0.11	0.22	0.29
80	10.8	21	18.8	0.89	8.19	0.11	0.42	0.27

Table A-7
HEC-1 model parameters for Maple River watershed

Subwatershed data					Stream reach data	
Subwatershed ID	Area sq mi	SCS Curve number	Subwatershed slope, ft/mi	Lag hrs	Length ft	Slope ft/mi
1	13.9	68	42.2	9.1	23810	8.1
2	30.3	68	31.7	19.5	48792	8.7
3	12.9	68	23.8	15.7	39599	4.0
4	22.0	68	29.0	25.3	29489	2.7
5	48.1	69	35.4	26.1	23565	6.3
6	9.2	68	30.1	9.1	107961	8.0
7	74.6	71	37.0	25.0	39705	0.7
8	50.1	70	14.3	30.0	62716	2.4
9	34.1	68	17.4	24.8		
10	37.3	72	19.5	28.5	56305	29.2
11	25.7	68	31.7	16.6	42777	1.0
12	23.1	71	6.3	26.5	29649	3.7
13	9.0	68	21.1	12.1	76622	1.0
14	36.8	70	23.8	26.8		
15	55.7	68	24.3	35.4		
16	22.9	72	21.1	21.6	18581	5.7
17	41.4	69	35.9	24.5	71303	5.4
18	36.6	78	7.9	29.4		
19	22.7	72	22.2	21.3		
20	32.6	78	11.1	28.0	100752	0.7
21	13.9	78	1.6	83.4		
22	103.3	79	3.2	72.1		
23	44.4	67	28.5	21.8	92914	1.1
24	38.0	71	18.0	30.2		
25	67.3	72	19.5	27.5	108671	2.6
26	43.8	76	7.9	45.3	9439	2.8
27	16.3	81	6.3	25.1	31127	2.5
28	7.0	72	12.7	14.5	45356	0.6
29	4.6	76	3.2	32.9		
30	36.8	69	19.5	22.6	20559	3.3
31	3.8	75	1.6	30.7	44911	1.2
32	59.7	79	5.8	34.7		
33	65.2	75	6.3	40.7		
34	33.2	69	23.2	18.3	31158	1.9
35	9.9	71	12.7	21.8	201158	1.5
36	82.5	76	13.2	55.1	50514	6.6
37	18.9	69	18.0	18.9		
38	19.1	72	29.0	12.9		
39	55.9	71	25.9	16.7	12458	3.0
40	8.3	72	6.3	16.7		
41	32.7	72	22.2	12.6	31462	2.4
42	7.6	69	10.6	21.4		
43	27.5	67	2.6	47.2	20460	2.3
44	84.1	72	12.7	33.7	61591	9.5
45	9.5	69	25.3	19.8	79705	4.3
46	15.7	68	30.1	20.1	21494	4.7
47	6.4	72	26.4	10.4	8668	4.9
48	64.1	68	20.1	22.1	6548	6.5

Table A-8
Design storm precipitation temporal distributions

		Design storm precipitation per interval, inches					
Time, hrs	% of precip	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
6	0.03	0.001	0.001	0.001	0.002	0.002	0.002
12	0.03	0.001	0.001	0.001	0.002	0.002	0.002
18	0.05	0.002	0.002	0.003	0.003	0.004	0.004
24	0.20	0.007	0.009	0.011	0.014	0.015	0.017
30	0.20	0.007	0.009	0.011	0.014	0.015	0.017
36	0.50	0.016	0.023	0.028	0.034	0.038	0.043
42	0.50	0.016	0.023	0.028	0.034	0.038	0.043
48	0.50	0.016	0.023	0.028	0.034	0.038	0.043
54	1.00	0.033	0.046	0.057	0.068	0.076	0.085
60	4.00	0.131	0.184	0.227	0.272	0.306	0.340
66	1.00	0.033	0.046	0.057	0.068	0.076	0.085
72	3.00	0.098	0.138	0.170	0.204	0.229	0.255
78	4.00	0.131	0.184	0.227	0.272	0.306	0.340
84	6.00	0.197	0.275	0.341	0.407	0.459	0.511
90	4.00	0.131	0.184	0.227	0.272	0.306	0.340
96	5.50	0.180	0.252	0.312	0.373	0.421	0.468
102	7.50	0.246	0.344	0.426	0.509	0.574	0.638
108	7.00	0.230	0.321	0.398	0.475	0.535	0.596
114	4.00	0.131	0.184	0.227	0.272	0.306	0.340
120	5.00	0.164	0.229	0.284	0.339	0.382	0.425
126	5.00	0.164	0.229	0.284	0.339	0.382	0.425
132	2.00	0.066	0.092	0.114	0.136	0.153	0.170
138	2.00	0.066	0.092	0.114	0.136	0.153	0.170
144	2.00	0.066	0.092	0.114	0.136	0.153	0.170
150	1.00	0.033	0.046	0.057	0.068	0.076	0.085
156	0.50	0.016	0.023	0.028	0.034	0.038	0.043
162	0.50	0.016	0.023	0.028	0.034	0.038	0.043
168	3.00	0.098	0.138	0.170	0.204	0.229	0.255
174	3.00	0.098	0.138	0.170	0.204	0.229	0.255
180	3.00	0.098	0.138	0.170	0.204	0.229	0.255
186	2.00	0.066	0.092	0.114	0.136	0.153	0.170
192	2.00	0.066	0.092	0.114	0.136	0.153	0.170
198	3.00	0.098	0.138	0.170	0.204	0.229	0.255
204	3.00	0.098	0.138	0.170	0.204	0.229	0.255
210	5.00	0.164	0.229	0.284	0.339	0.382	0.425
216	2.00	0.066	0.092	0.114	0.136	0.153	0.170
222	2.00	0.066	0.092	0.114	0.136	0.153	0.170
228	1.00	0.033	0.046	0.057	0.068	0.076	0.085
234	2.00	0.066	0.092	0.114	0.136	0.153	0.170
240	2.00	0.066	0.092	0.114	0.136	0.153	0.170
Total	100.00	3.28	4.59	5.68	6.79	7.65	8.51