

Working Paper # 6
Watershed Modeling of Various Flood Damage Reduction Strategies

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Study Purpose

Temporarily storing runoff from spring snowmelt and summer storms is one of the key strategies to achieving flood damage reduction within the Red River basin. However, there has been no consensus as to the most feasible, practical and environmentally friendly means to achieve a significant amount of flood storage.

The Red River Mediation Working Group requested the Technical and Scientific Advisory Committee (TSAC) to select an actual watershed and to identify and test various flood damage reduction strategies. One of the primary issues is the extent to which a strategy to "store water where it falls" achieves local flood reduction benefits as well as main stem benefits. This exercise looked at hydrologic impacts of localized storage, land use changes, and on- and off-channel impoundments.

This effort was strictly a hydrology study; there was no attempt to assess the feasibility of actually implementing any particular strategy, or quantify other benefits or adverse impacts.

Selected Watershed

A 70 square mile subwatershed of the Wild Rice River basin was used for this exercise. The Wild Rice River basin was selected since a U.S. Army Corps of Engineers' HEC-1 watershed model has already been developed by Houston Engineering under contract to the watershed district. The existing HEC-1 model provided the starting point for this exercise. As directed by the Working Group, the selected subwatershed will not be identified in this paper.

The selected subwatershed is located above the beach ridge. At their confluence, this subwatershed represents 7% of the total drainage area of the Wild Rice River. A preliminary analysis found that the runoff from the selected subwatershed generally peaks two to three days before the Wild Rice River peaks. An important question is whether adding storage within the study watershed, thereby delaying its runoff, could possibly increase peak flood flows along the Wild Rice River.

There are few public ditches within this subwatershed. Grassed swales are the most common drainage conveyance feature in the upper portion of the watershed. Channel gradients generally range from five to fifteen feet per mile. The few existing wetlands are generally found in the very upper reaches of the watershed. Over 80 percent of the study watershed is currently in agricultural production. Forest cover represents the next largest land use category at 10 percent of the study watershed. The wooded acres are primarily found in the lower portion of the watershed along the watercourses. The other land use categories found in the watershed are pasture, prairie, wetlands, and farmsteads.

Watershed Model

The existing Houston Engineering HEC-1 watershed model for the Wild Rice River watershed divided the 70 square mile study watershed into five subbasins, ranging in size from 1 to 34 square miles. The TSAC watershed model further subdivided the watershed into 34 subbasins, ranging in size from 0.5 to 8.6 square miles. This more detailed model allows smaller scale watershed modifications, such as individual wetland restorations, to be analyzed more effectively. Model parameters for each of the new subwatersheds were developed consistent with the methodology used by Houston Engineering. The TSAC model was then calibrated to Houston Engineering model. All subsequent computer simulations used the TSAC model, so that the comparison of the results for existing versus proposed conditions is comparing "apples to apples."

The Houston Engineering HEC-1 model was calibrated to two summer storm events; additional analyses used standard 24-hour and 10-day duration design storms. The same design storms were also used for this modeling exercise.

Wetlands - There has been a significant change to the landscape during past 100 years from a drainage perspective. But the important consideration is not what the change has been, but rather the feasibility and practicality of a wetland restoration strategy. Can a strategy of wetland restoration provide measurable peak flood flow and volume reduction, not only within the immediate subwatershed, but also further downstream along the main stem rivers?

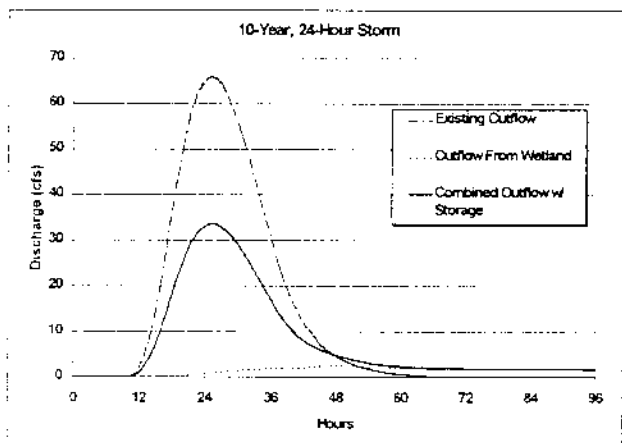
A major objective of this modeling exercise was to assess the hydrologic impact of the wetland restoration guidelines identified in Working Papers 1 and 2. These guidelines call for a maximum bounce of two feet for the 10-year 24-hour storm, and the drainage of the stored water within a 10-day period. To achieve a maximum two-foot bounce, Working Paper 2 indicated that approximately 5% of the tributary area would be required for the impoundment area. Since the average size of the subwatersheds in the TSAC watershed model is 1300 acres, the 5% guideline would suggest that approximately 65 acres of wetlands would be required in each subwatershed.

The best means to assess the hydrologic impact of a restored wetland is to model each wetland as an impoundment. But this is only realistic for a relatively small number of larger wetlands, i.e., larger than 20 acres. It was hoped that the U.S. Geological Survey topographic maps (mostly 10' contour interval), the National Wetlands Inventory and aerial photographs (NAPP - 1992) could be used to identify potential wetland restoration sites. The relatively few obvious wetland restoration sites identified using these sources were primarily located in the upstream portion of the watershed.

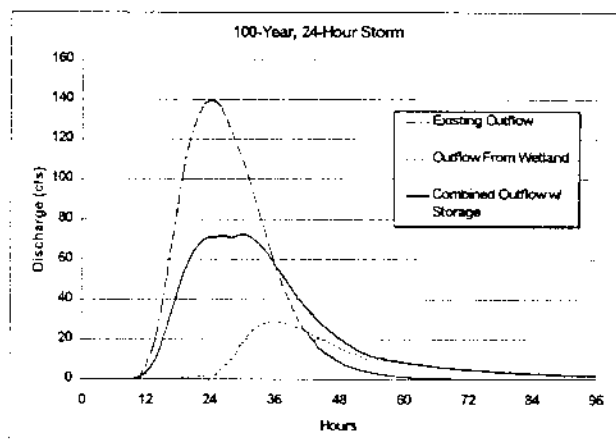
The above data sources did identify numerous smaller depressions, generally less than 5 acres each. Restoration of these small basins would likely involve a simple ditch plug, with no provision for positive outflow of stored water. There is no question that these small wetlands would store runoff; many would essentially eliminate their watershed's runoff contribution to downstream flooding. Working Paper 2 identified possible hydrologic modeling techniques for these small basins. But these techniques were not tried since a consensus was not reached by the TSAC on appropriate assumptions regarding antecedent storage.

The conservative assumption is that the storage in these basins would not be available prior to a flood event without some type of outlet feature to drain off the stored water in a relatively short period of time. The limited available evidence suggests that the storage in these small basins is available prior to spring runoff (see Working Paper #2). Whether this storage would be consistently available prior to a summer flood event, is not as well understood. More data and study are required.

Since a sufficient number of actual restoration sites could not be identified, this modeling exercise was changed to become a test of wetland restoration guidelines contained in Working Papers 1 and 2. Ten of the thirty-four subbasins within the TSAC model were selected to apply these guidelines. All of these subbasins are located within the upper portion of study watershed. Steeper land gradients in the lower portion of the watershed would make wetland restorations less practical. It was assumed that wetlands were restored to the extent that they would control runoff from only one-half of each subbasin. This assumption applied to the selected 10 subbasins resulted in runoff from 15% of the study watershed being controlled by wetland storage. Each wetland was modeled as an impoundment with a 2-foot bounce following the 10-year 24-hour event. The stored runoff was assumed to be slowly released during a 10-day period. The following two graphs illustrate the assumption of controlling runoff from one-half of each subbasin.



Hydrograph Plot #1a



Hydrograph Plot #1b

There are two existing non-gated impoundments within the study watershed. The above exercise added wetland storage within the watershed of one of these impoundments. As a result, the full storage capacity of that impoundment was no longer utilized during the 24-hour flood event. It was assumed that with the wetland storage, outflow from the impoundment could be restricted to restore the full utilization of its storage capacity. The modeling results showing the effect of wetland restoration controlling runoff from 15% of the study watershed, and the minor change to one of the existing impoundments are shown in Hydrograph plots 2 and Table 1.

Off-channel storage - One location within the study watershed was identified as a potential site for an off-channel impoundment. The drainage area above this site is 10.5 square miles or 15% of the study watershed. It was assumed that this off-channel impoundment (640 acres) would store the entire flood hydrograph from its 10.5 square mile watershed, except for a maximum flow rate of 10 cubic feet per second (cfs). Table 1 and hydrograph plots 2 and 3 show the effect of combining both the watershed storage and the off-channel storage. The results are shown at the outlet of the study watershed, and on the Wild Rice River just upstream of the Ada diversion.

On-channel impoundment - The next strategy investigated was an on-channel impoundment near the mouth of the study watershed. For this analysis, it was assumed 2500 acre feet of storage was available with a maximum pool depth of approximately 40 feet. Both an ungated and a gated outlet structure were analyzed using the 24-hour, 100-year design storm, and including all of the wetland and off-channel storage features discussed above.

A simple culvert was assumed as the outlet structure for the ungated impoundment scenario. A trial and error approach was used to select a culvert which would result in the temporary storage of the maximum 2500 acre feet of runoff during the 100-year, 24-hour event. The largest possible culvert was selected which met this criteria so as to minimize the impact of the impoundment for the frequent runoff events. This alternative reduced the peak outflow from study watershed by almost 50%. This ungated impoundment delayed outflow by at most two days, which resulted in an 8% higher peak flow on the Wild Rice River near Ada.

The same impoundment was then analyzed with a gated outlet structure. A gated impoundment would be ideally operated to store that portion of the tributary watershed's runoff contributing to downstream flooding. A trial and error approach was used to find the optimal time to close the impoundment gate to gain the maximum reduction in peak flows on the Wild Rice River near Ada for the 100-year, 24-hour design storm. This approach found that closing the gates at hour 50 of this design flood event resulted in reducing the peak flow at Ada by approximately 2%.

During an actual flood event, the operator of the impoundment will not know the precise time to close the gate to achieve maximum downstream flood reduction. A second analysis was therefore performed to assess the sensitivity of the timing of gate closure. For this second analysis, the impoundment gate was assumed closed at hour 40, which is roughly 7 hours after the beginning of flooding near Ada, but 10 hours earlier than the optimum closure time. As shown in Table 2 and hydrograph plots 5 and 6, timing of the gate closure has little impact on the total volume of runoff during the peak flood period, but it does have an impact on downstream peak flows.

TABLE 2

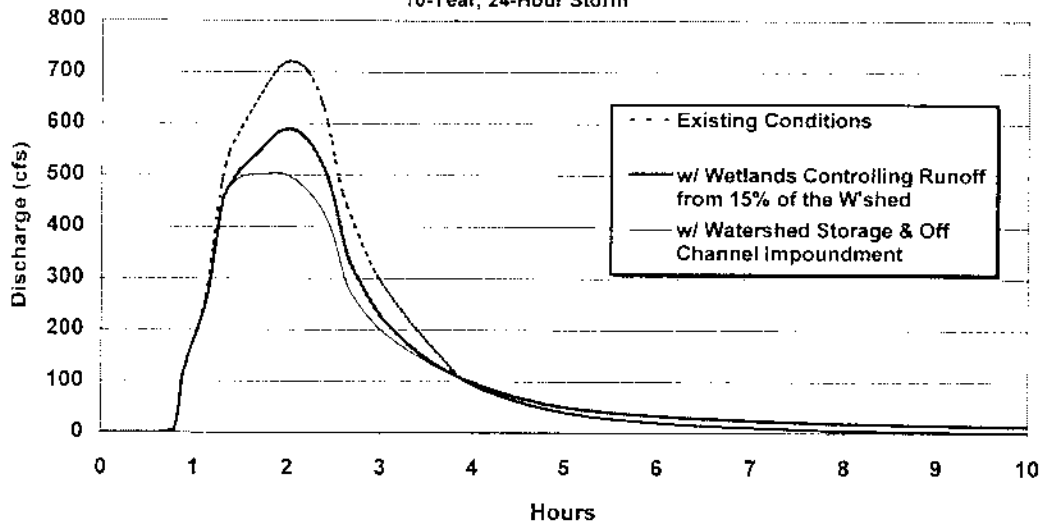
**On-Channel Impoundment Alternatives
(Combined with Wetland Storage and Off-Channel Impoundment)**

	@ Study Watershed Outlet (70 sq. miles)			Wild Rice River nr Ada (1060 sq. miles)		
	Peak Flow (cfs)	Runoff Volume (acre ft.)*		Peak Flow (cfs)	Runoff Volume (acre ft.)*	
		5-day	10-day		5-day	10-day
100-year, 24-hour storm						
- existing conditions	1470	6040	6310	6370	53,300	88,300
- w/ non-gated impoundment	760	5540	5920	6850	52,600	87,700
- percent change	-48.3	-8.3	-6.2	+7.5	-1.3	-0.6
- w/ gated impoundment						
- gate closed @ hour 40	1110	3000	3910	6500	50,100	85,600
- percent change	-24.5	-50.3	-38.0	+2.0	-6.0	-3.1
- gate closed @ hour 50	1220	2990	3910	6280	50,300	85,600
- percent change	-17.0	-50.5	-38.0	-1.4	-5.6	-3.1

* Runoff volumes computed for the highest 5-day total volume (day 1 through day 6), as well as the cumulative 10-day period.

@ Outlet of Study Watershed
(70 Square Miles)

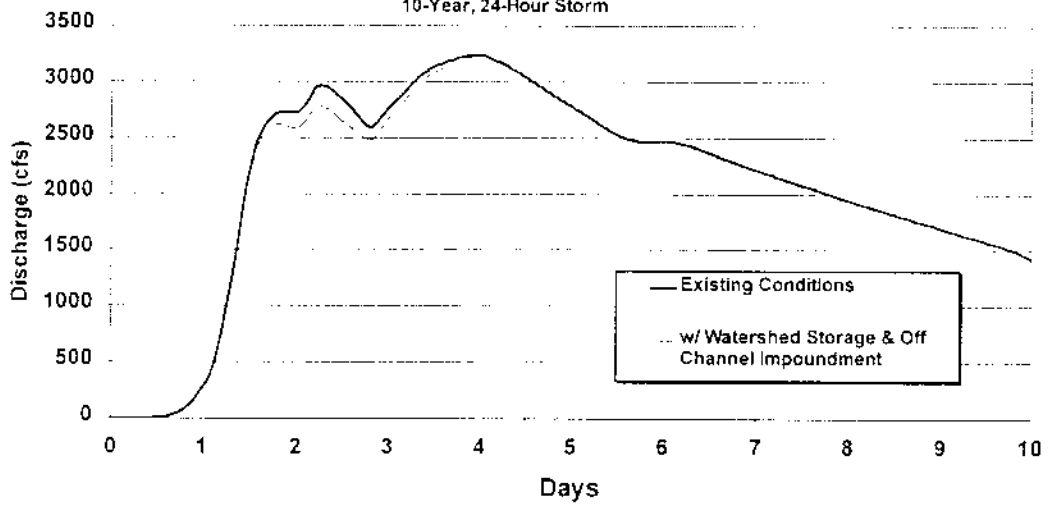
10-Year, 24-Hour Storm



Hydrograph Plot #2

Wild Rice River near Ada
(1060 Square Miles)

10-Year, 24-Hour Storm



Hydrograph Plot #3

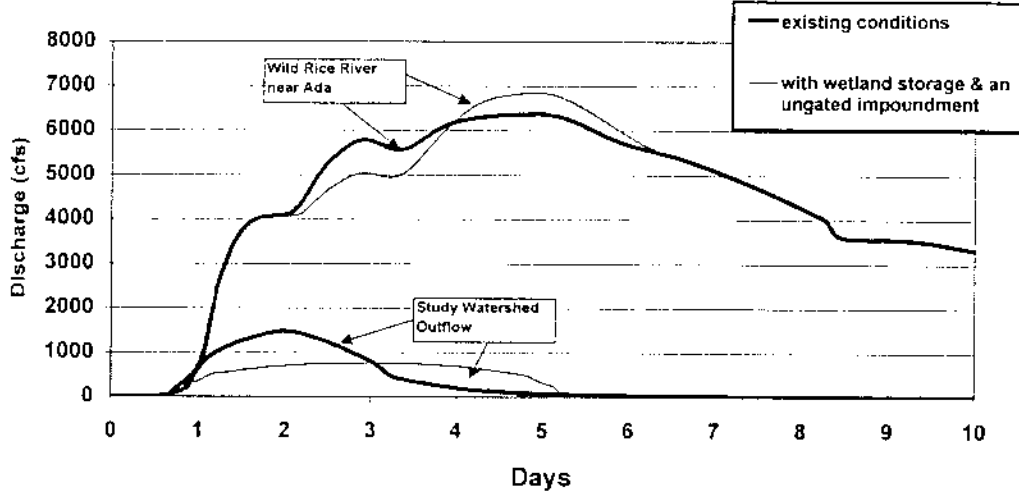
TABLE I
Watershed Storage Alternatives

	@ Study Watershed Outlet (70 sq. miles)			Wild Rice River nr Ada (1060 sq. miles)		
	Peak Flow (cfs)	Runoff Volume (acre ft.)*		Peak Flow (cfs)	Runoff Volume (acre ft.)*	
		4-day	10-day		4-day	10-day
10-year 24-hour storm						
- existing conditions	720	2630	2780	3240	21,600	42,400
- w/ wetland storage	590	2230	2510	---	---	---
- w/ off-channel impoundment	620	2310	2460	---	---	---
- w/ combined wetland storage & off-channel impoundment.	500	2020	2300	3230	21,100	42,000
- percent change	-30.1	-23.2	-17.3	-0.3	-2.3	-0.6
100-year, 24-hour storm						
- existing conditions	1480	5930	6310	6370	41,700	88,300
- w/ wetland storage	1220	5340	5920	---	---	---
- w/ off-channel impoundment	1220	5100	5480	---	---	---
- w/ combined wetland storage & off-channel impoundment	1020	4710	5290	6390	40,700	87,400
- percent reduction	-31.1	-20.6	-16.2	+0.3	-2.4	-1.0

* Runoff volumes computed for the highest 96-hour total volume (day 1 through day 5), as well as the cumulative 10-day period.

Ungated On-Channel Impoundment

100-Year, 24-Hour Storm

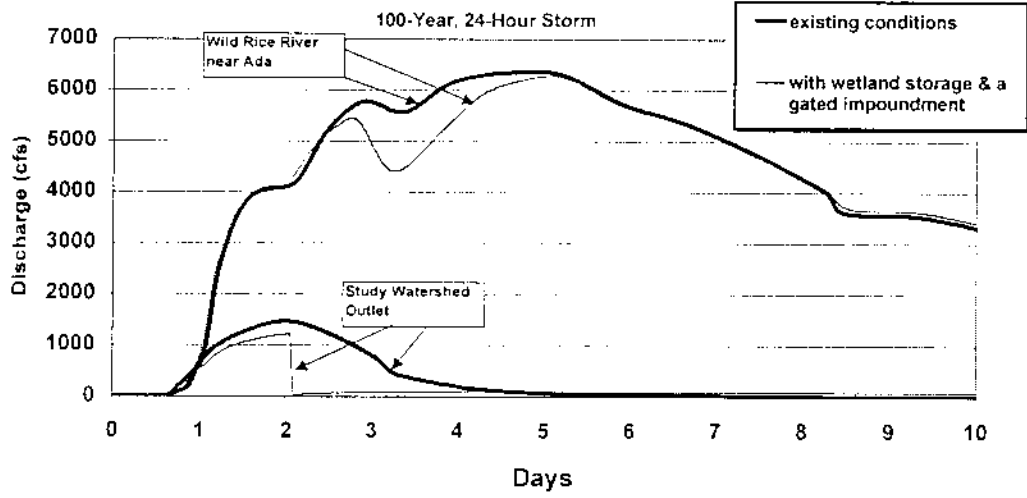


Hydrograph Plot #4

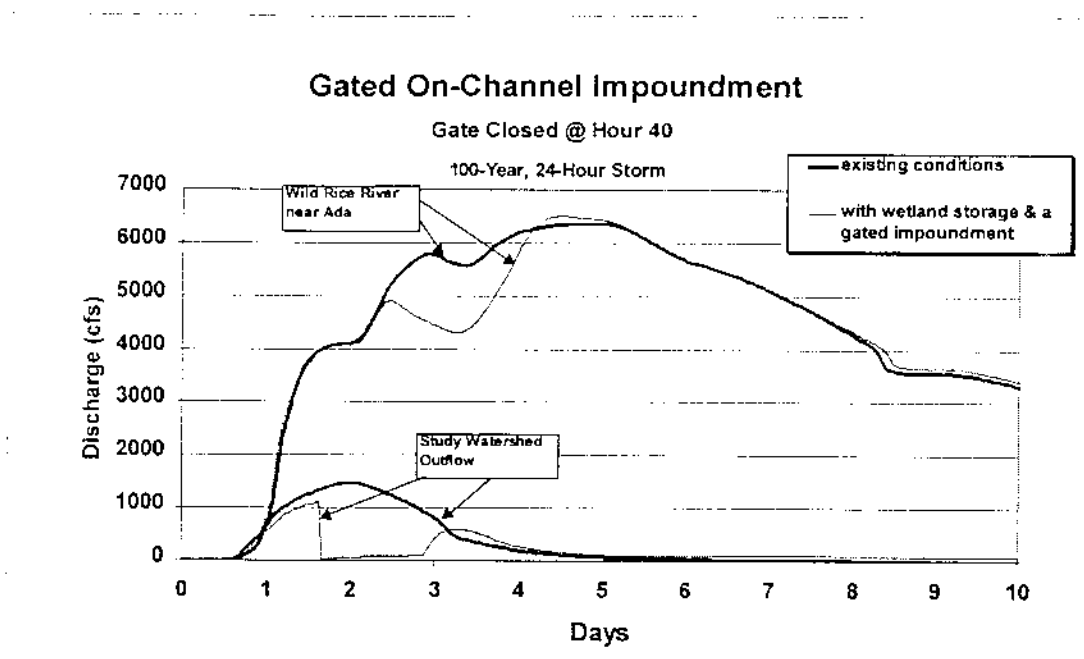
Gated On-Channel Impoundment

Gate Closed @ Hour 50

100-Year, 24-Hour Storm



Hydrograph Plot #5



Hydrograph Plot #6

Land Use Practices - The next modeling exercise looked at the effect of improving the “hydrologic condition” of the watershed. As defined by the Natural Resources Conservation Service, hydrologic condition includes factors such as the amount of year-round cover, amount of grass or close-seeded legumes in rotation, percent residue and degree of surface roughness. The worksheet included in Working Paper 3 indicates that curve numbers can be reduced by two to four percent by assuming “good” rather than “poor” hydrologic conditions. All curve numbers in the TSAC HEC-1 model for existing conditions were reduced by three percent; the results are tabulated below.

@ Study Watershed Outlet

	Peak Flow (cfs)	Runoff Volume (acre feet)	
		4-day	10-day
<u>10-year, 24-hour storm</u>			
- existing conditions	720	2630	2780
- w/ increased crop residue	640	2310	2430
- percent change	-11.1	-12.2	-7.9
<u>100-year, 24-hour storm</u>			
- existing conditions	1480	5930	6310
- w/ increased crop residue	1370	5420	5770
- percent change	-7.6	-8.6	-8.6

Summary

A hydrologic model is an important tool for evaluating various flood reduction strategies. This exercise quantified the impact of various strategies to add flood storage within an actual watershed. The effect of reducing peak flood flows and flood volume was determined within the subwatershed and along downstream river reaches. This modeling exercise should be repeated on other subwatersheds where more time and data exist to identify specific wetland restoration sites and other watershed practices.

The wetland restoration guidelines contained in Working Papers 1 and 2 work! Even though these practices were applied to only 15% of the watershed, there were measurable reductions in peak flows – a 50% reduction immediately downstream of each small subbasin modeled and an 18% reduction at the outlet of the study watershed. A 30% reduction in peak flow was computed at the study watershed outlet with the addition of an off-channel impoundment. Even greater reductions in peak flows and flow volume would be realized with a higher percentage of the watershed controlled wetland storage. The key element of this approach is the design of the outlets of the constructed/restored wetlands to hold runoff for several days or longer. There would be essentially no downstream flood reduction if the runoff were stored for only a few hours.

Since the selected study watershed comprises only 7% of the Wild Rice River watershed, it's not surprising that significant reductions in peak flows along the Wild Rice River were not realized. Adding storage within the selected subwatershed did not reduce the peak flow on Wild Rice River since the small impoundments stored the "early" flow. But even this early flow causes flooding along the Wild Rice River. This suggests that adding storage in the study watershed should still be a component of a comprehensive watershed plan that includes storage in subwatersheds farther upstream.

An ungated on-channel impoundment at the mouth of the study watershed does not appear to be a viable alternative to reducing flooding along the downstream reaches of the Wild Rice River. The gated impoundment at the mouth of the subwatershed proved to be more effective than the ungated impoundment in reducing the total volume of flood flow along the Wild Rice River near Ada. The operation of the gated outlet structure during an actual flood event would be very important in the level of downstream flood reduction actually achieved. The operator will not have the benefit of a "trial and error" approach used in this analysis.

Farming practices, in particular crop residue management, was shown to have the potential to reduce peak flood flows and flow volumes by roughly 10% if employed throughout the subwatershed.

From a hydrologic perspective of maximizing flood damage reduction, the various strategies to add flood storage will work best if used as part of a comprehensive watershed approach. A watershed approach would ensure that solutions for local problems also address downstream flooding concerns.