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Impacts of Wetlands on Floods Boone River Basin

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14. ABSTRACT

This report documents a study that was conducted by the Hydrologic Engineering Center in response to a request from the Scientific Assessment and Strategy Team (SAST) of the US Geological Survey. This request was for assistance in determining the potential benefits of alternative flood control measures in the upper Midwest. In particular, it was asked that the study look at depressional pothole storage, on-stream wetlands, and alternative land management practices for the Boone River basin in northern Iowa. The goal was to evaluate these items effects on flood peaks and flooding in the basin. The results of the study are only representative of the Boone River basin; the level of rigor was not enough to draw specific conclusions. However, the results may be useful as a basis for more thorough work in the future.

15. SUBJECT TERMS
wetlands, floods, Boone River basin, benefits, alternative, flood control measures, depressional pothole storage, on-stream wetlands, land management, flood peaks, potholes, surface connections, direct runoff, storage capacity, peak flow, storm, duration, channel, agriculture, conveyance, flood reduction

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1. Introduction

This study is in response to a request from the Scientific Assessment and Strategy Team (SAST) for assistance in determining the potential benefits of alternative flood control measures in the upper Midwest. The SAST was formed by the White House through the U.S. Geological Survey EROS Data Center to investigate the Great Mississippi River Flood of '93. In particular, it was asked that the study look at depressional pothole storage, on-stream wetlands, and alternative land management practices for the Boone River Basin in Northern Iowa. In each of these cases, the goal was to evaluate their effect on flood peaks and flooding in the basin.

The potholes in the Boone River Basin are drained with surface connections such that they do not impede direct runoff. A model was desired to show the impact of removing their surface connections. It was expected that this increase in the storage capacity in the basin would reduce both the total volume for a given flood as well as the peak flow. This proved to be the case for the Boone but with diminishing significance as the storm size and duration increased.

The on-stream wetland status in the Boone River was less defined than for the potholes. Ideally, some sites should have been identified which involved wetlands along the channel that had been leveed and drained for agriculture. The impact of returning the wetlands storage and conveyance benefits to flood reduction could then be analyzed. With literally no more information than that provided by 7.5 quad maps, some hypothetical on-stream wetlands were modeled to get an order of magnitude indication of their potential impact on flood reduction.

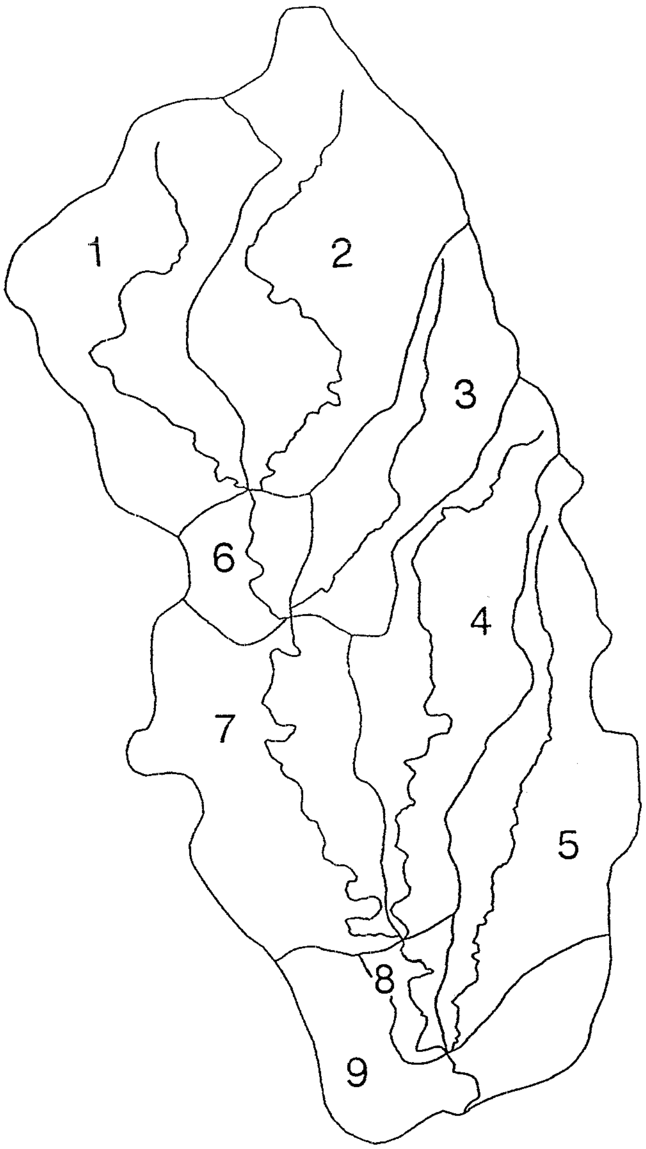
Information for performing an analysis of land management practices was provided by the SAST. Reductions in curve numbers, CN, for Conservation Reserve Program (CRP) and Food and Security Act (FSA) conditions were provided for each county by the U.S. Soil Conservation Service.

The results of the study are only representative of the Boone River Basin; the level of rigor was not great enough to draw specific conclusions. However, the results may be useful as a basis for more thorough work in the future.

This study was performed by Troy R. Nicolini, John C. Peters, and Arlen D. Feldman.

2. Existing-Conditions Model Development

The Boone River Basin was subdivided into nine subbasins for this analysis; these included four local and five headwater subbasins. The locations of subbasin boundaries were chosen to disaggregate the basin to the extent that wetlands could be located at various locations. The subbasin delineation is shown in Figure 1.



Subbasins

1 - Prairie Creek

2 - Upper Boone

3 - Otter Creek

4 - Eagle Creek

5 - White Fox Creek

6 - Local 1

7 - Local 2

8 - Local 3

9 - Local 4

Figure 1.
Boone River above Webster City

Unit hydrograph parameters were estimated for the subbasins based on three sources: (1) Rock Island District provided parameters for the entire basin; (2) calibration of the subdivided basin using the storms of 1979 and 1981; and (3) TR-55 methods of determining time of concentration.

The Rock Island District provided an HEC-1F model of the Boone River above Webster City. In this model, Snyder's unit hydrograph method was used with TP= 56 hours and Cp= .34. These were converted into Clark's TC and R to facilitate comparison with calibration results for the subdivided basin.

TC values for the subbasins were estimated by TR-55 methods, and then adjusted slightly to match the computed and observed hydrographs at Webster City. The TC values used are shown in Table 1. They agree well with those used in the Rock Island District HEC-1F model for the entire basin (accounting for routing and connectivity).

R values were based on calibration using the 1979 and 1981 events, with a slight adjustment to reflect the Rock Island District value for CP. The R values are also shown in Table 1.

Table 1
TC and R Values for the Subbasins of the Boone River

Basin	TC (hours) From calibration and TR-55 methods	R (hours) From Calibration
Upper Boone	36	33
Prairie Creek	46	30
Otter Creek	34	26
Local areas	45	28
Eagle Creek	48	27
White Fox Creek	30	60

Loss rates for the subbasins were represented using the SCS curve number method. An existing-condition value of 76 was provided by the SAST. This value represents antecedent moisture conditions II.

Muskingum-Cunge routing reaches were developed using 7.5 minute quad maps to measure slope and length of reaches. There were no Manning's n values available from the Rock Island District; therefore, estimates were made based on the slope and general stream characteristics of the area.

Because parameters were estimated using several different sources of information, with good agreement amongst the sources, a fair amount of confidence is placed in the existing-conditions model.

3. On-Stream Wetland Modeling

Three areas along the Boone River were identified, using 7.5 minute quads, as candidates for placement of on-stream wetlands. Unfortunately, the Rock Island District has performed no studies of the Boone River that would result in more specific information than can be obtained from 7.5 minute quads. Therefore, the location and representation of the on-stream wetlands provide only an order-of-magnitude answer on impacts that might be expected for a river like the Boone.

The Muskingum-Cunge hydrologic routing method was used to represent the on-stream wetlands. An eight point cross section was used to represent the channel, along with roughness, slope, and length to solve a simplified version of the diffusion wave equation for one-dimension, steady state flow. The Muskingum-Cunge method was chosen because it accounts for storage in overbank areas, and allows for an overbank Manning's n which is different from the main channel.

The lengths and eight point cross sections of the wetlands were estimated from the 7.5 minute quad maps. Their slopes were assumed to be equal to that of the channel. The Manning's n values for the wetlands were increased significantly above those for the channel and normal overbanks to a value of 0.15. The wetlands were placed in the model by splitting up the river reaches at the appropriate point and adding a reach which described the wetland. The dimensions and other characteristics of the three wetlands can be seen in the HEC-1 input file in Appendix 2. The boundary effects of going from the contained channel to the wide expansive wetland reach and back again to the contained channel were ignored. They were deemed to be negligible for this level of study.

The impacts of the on-stream wetlands can be seen in Figures 2 through 5, for 1-, 5-, 25-, and 100-year events. The impact is small for these four storm sizes. These results were anticipated based on examination of the 7.5 minute quad maps. The Boone River has overflow banks which are bounded relatively close to the main channel. There are no expansive floodplains that have been leveed off from the main channel. The largest conceivable wetlands along the stream do not appear to provide enough storage to impact the peak or volume of flow significantly. Therefore, the Boone River Basin is not a good candidate for on-stream wetland development, and this study of the Boone fails to indicate the extent to which other rivers in the mid-west might derive flood control benefits from on-stream wetlands. It does illustrate that candidate rivers for on-stream wetlands investigation should have identifiably large amounts of recoverable floodplain storage to expect significant impacts on large floods.

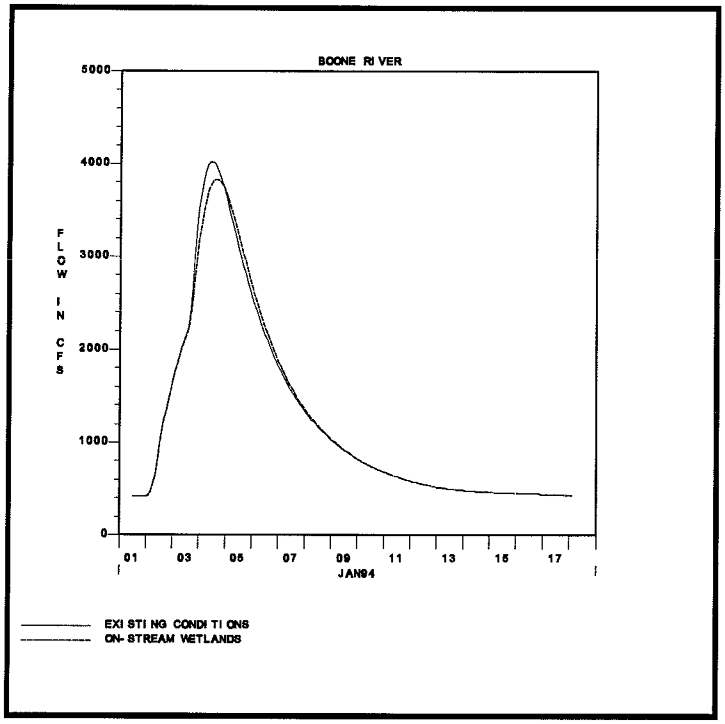


Figure 2: On-Stream Wetland for 1-Year, 1-Day Hypothetical Event

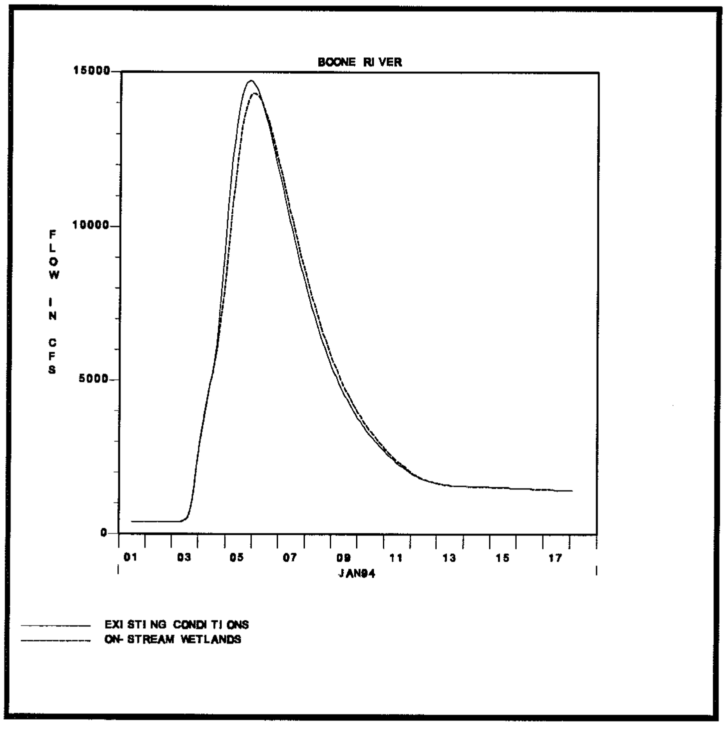


Figure 3: On-Stream Wetland for 5-Year, 4-Day Hypothetical Event

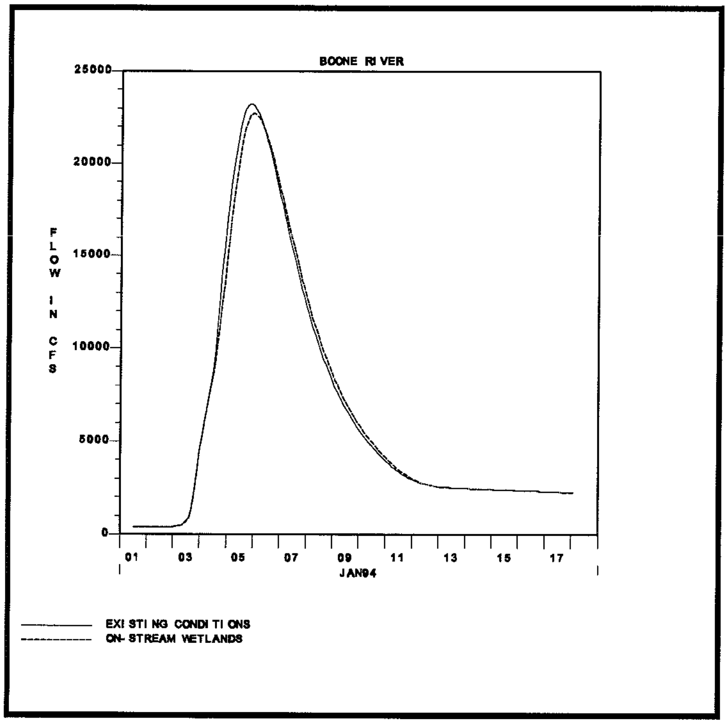


Figure 4: On-Stream Wetland for 25-Year, 4-Day Hypothetical Event

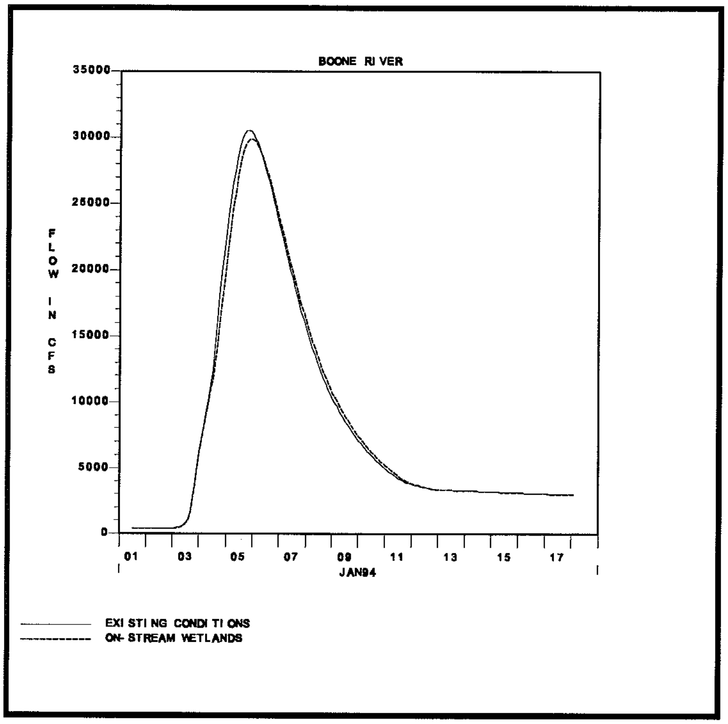


Figure 5: On-Stream Wetland for 100-Year, 4-Day Hypothetical Event

4. Pothole Modeling

The Boone River Basin has many depressional potholes capable of retaining runoff. It has been assumed during the course of this brief study that the potholes are currently contributing to direct runoff; they have surface connections so that they pass overland flow along to the stream system. What was not known was the delay imparted to this overland flow by the drained potholes. For the purpose of this study, it was assumed that the parameters estimated from calibration and basin measurement account for any such delays for existing conditions.

Modifications were made to the existing conditions model to reflect the condition where the potholes are non-contributing; that is, their surface connections are removed. Two approaches were attempted, with varying degrees of success. Before describing these approaches, it's worth describing how the physical processes were understood to occur when the potholes are not drained.

Consider the onset of a rainfall event: each pothole has a surrounding contributing area upon which rainfall will result in overland flow which ends up in the pothole. Simultaneously, there are areas for which rainfall produces direct runoff to the stream network. Therefore, as long as the potholes are not full, flow at the outlet will be composed solely of runoff from areas that do not contribute to potholes. During this phase, the important physical characteristics are the percentage of the basin which contributes to potholes and the location of these non contributing areas. As the rainfall continues, the potholes fill up, and become contributing areas which produce direct runoff to the stream network. The important factor initiating and affecting this phase is the storage capacity of the potholes relative to the storm size and duration.

Determining the percentage of the basin contributing to potholes proved to be difficult. Even with 7.5 minute quad maps with five foot contours, it was not possible to accurately determine the contributing area. At this scale, the first contour above a typical pothole covers a great deal of area distant from the potholes. Some of this area between the pothole contour and the next highest contour contributes to the pothole. A rough estimate was made that ten percent of each basin contributes to potholes. Therefore, until the potholes are full, ten percent of each basin is considered to be non-contributing. Based on the 7.5 minute quad maps, they were assumed to be uniformly distributed throughout the basin.

To determine the storage of the potholes, the total area of all pot holes was summed using digitization and Arc/Info for one subbasin, the White Fox Creek subbasin. For the White Fox subbasin, the total pothole area equaled approximately 1.2 square miles, about one per cent of the subbasin area of 118 square miles. An average depth of three feet was assumed. Again, this was hard to estimate from the maps. With five foot contours, it is reasonable to assume that the pothole depths are not greater than five feet. It was assumed that the 3-feet depth is an overestimate rather than underestimate. These approximations resulted in a total pothole storage of 2304 acre-feet for the White Fox subbasin. These estimations were assumed to be valid for the other subbasins in the Boone; for each, 1 percent of basin area was used for pothole area, and

10 percent of basin area was used as pothole contributing area.

4.1 Representing Pothole Storage Using Initial Loss Rate Parameters

For this approach, loss rate parameters were used to represent the flow lost to the potholes. For example, for the White Fox subbasin, the estimated amount of pothole storage was 2304 acre-feet. Spread out over the 10 percent of the basin assumed to contribute to potholes, this volume results in 3.6 inches. Therefore, in this representation, the pothole contributing area for the White Fox subbasin was modeled using an initial loss of 3.6 inches. The remaining 90 percent of the basin was modeled with existing conditions parameters, then the two hydrographs were combined.

This method accounted reasonably well for flood volume, but there was no control of the temporal distribution of the impact. Therefore, the impact on the peak flow was not controllable.

4.2 Representing Pothole Storage Using Storage Routing

Storage routing was used in an attempt to describe through time the impact of pothole storage on the basin outflow hydrograph. With this approach, a more detailed view of the processes was possible. The hydrologic response of potholes was broken up into: overland flow into the pothole, storage routing through the pothole, and channel routing from the outlet of the pothole to the outlet of the subbasin.

For overland flow into the pothole, there is some travel time between when rain falls within a pothole contributing area and when the resultant overland flow reaches the pothole. This was described by roughly prorating the unit hydrograph parameters from the entire subbasin. Since the pothole contributing area was taken to be ten percent of the subbasin area, ten percent of the TC value and twenty percent of the R value were used. A larger R was used because the interface between the pothole contributing areas and the actual pothole is not well defined. The attenuating properties of the potholes were assumed to impact the runoff into the potholes.

For the storage effect of the potholes, simple storage routing was used. Storage-discharge relationships were developed for each subbasin which indicated no flow from the potholes until they were full. Because it was recognized that the potholes would not instantaneously go from storing to not storing, a transitional phase was included in the storage-outflow curve. Once the potholes are completely full, outflow is equal to inflow.

Since the potholes are distributed throughout the subbasins, it was assumed that the pothole outflow would travel through the subbasin to reach the outlet. A simple Muskingum routing was used to represent this. The travel time was estimated to be two thirds of TC for the entire subbasin.

The hydrograph from the pothole contributing area was combined with the hydrograph from the remaining 90 percent of the basin. The composite effect of this is the distribution of flow lost to potholes over the life of the event in a physically reasonable way. Figure 6 is a schematic illustration of runoff components and associated hydrographs (for the White Fox subbasin).

The impact of the pothole storage is shown in Figures 7 through 10 for the 1-, 5-, 25-, and 100-year events. These events were of four-day durations, except the 1-year event, which was a 1-day event. Additional simulations were performed using ten-day events for the 5-, 25-, and 100-year events. The results were similar, with an across-the-board smaller impact on the peak flows. Therefore, the large storm with long duration shows little impact from the pothole storage, whereas the short or small storm shows greater impact. The pothole storage is consumed early in the long storm and is not able to provide attenuation benefits at the time of peak flow conditions.

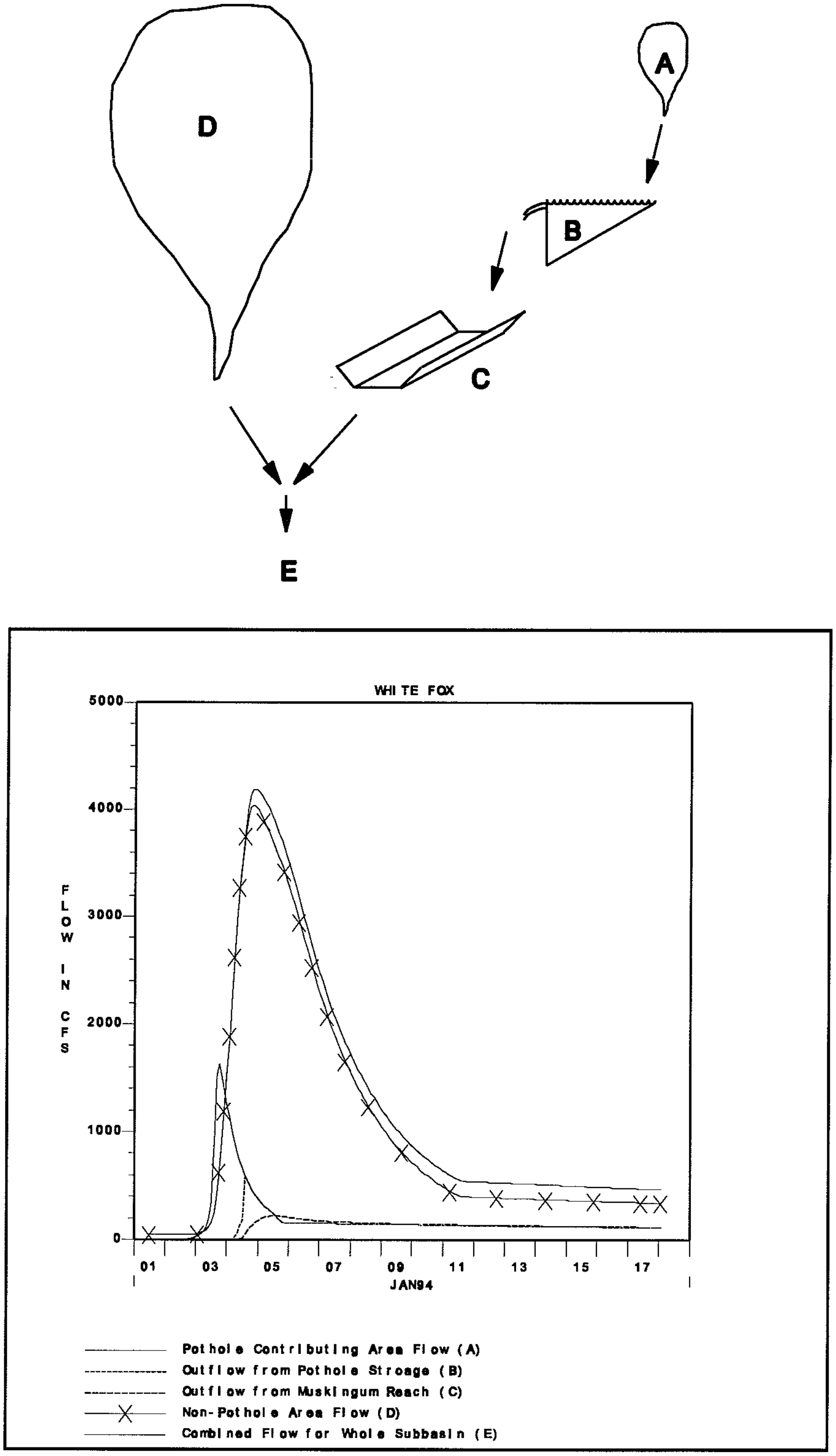


Figure 6: Schematic of Pothole Representation and Respective Hydrograph Components

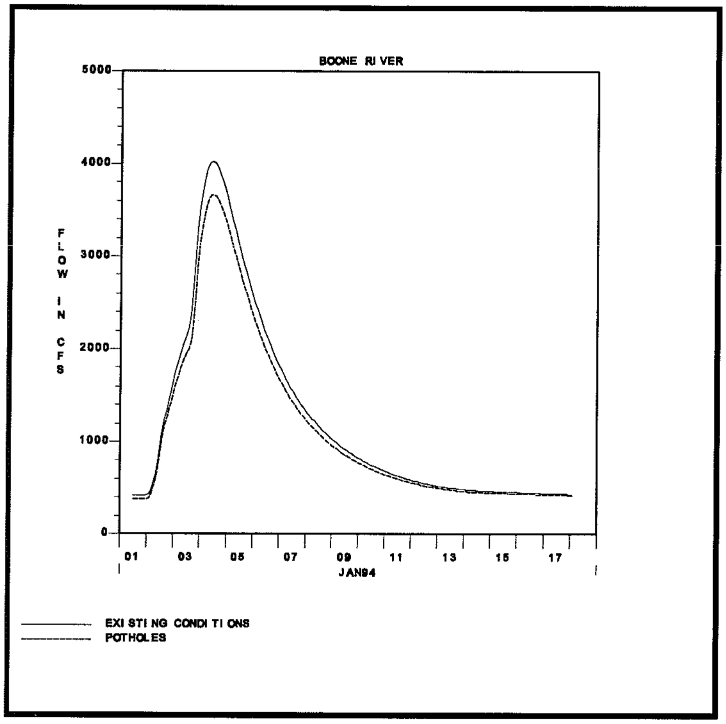


Figure 7: Pothole Storage for 1-Year, 1-Day Hypothetical Event

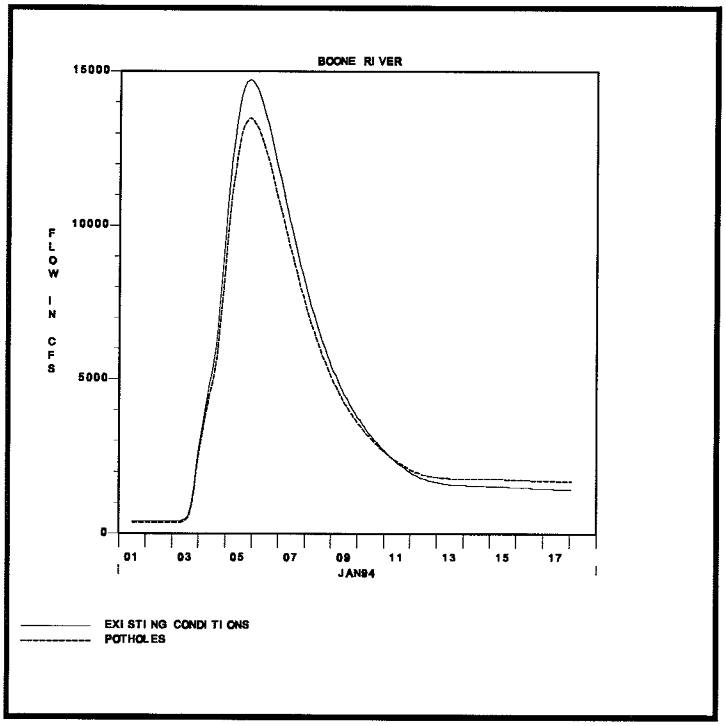


Figure 8: Pothole Storage for 5-Year, 4-Day Hypothetical Event

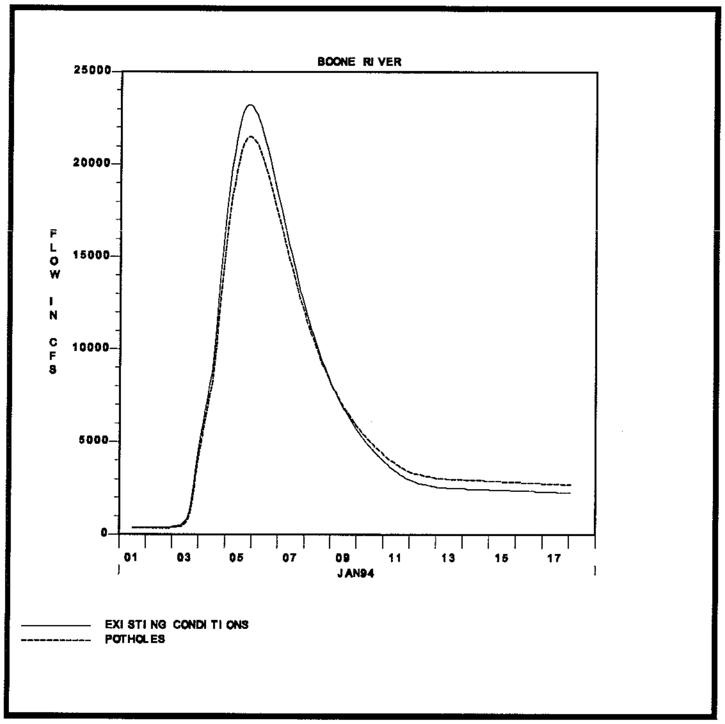


Figure 9: Pothole Storage for 25-Year, 4-Day Hypothetical Event

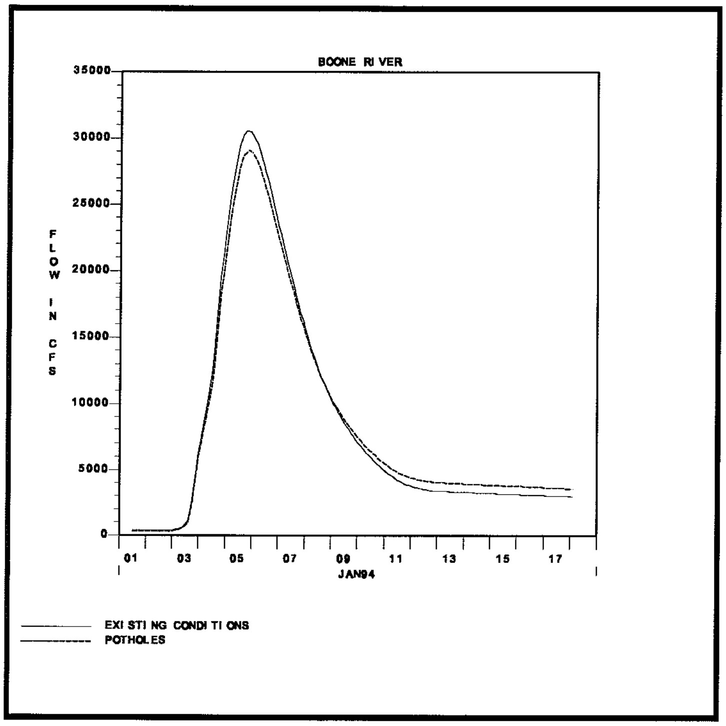


Figure 10: Pothole Storage for 100-Year, 4-Day Hypothetical Event

5. Sensitivity Analysis on Land Management Practices

The SCS curve number used to reflect existing conditions was provided by the SAST. They also provided reductions in curve numbers for CRP and FSA conditions for counties throughout the Boone River area. These were used to produce new curve numbers for each of the subbasins, shown in Table 2. The resultant hydrographs are shown in Figures 11 through 14.

Table 2
SCS Curve Numbers for CRP and FSA Conditions
(Provided by SAST)

	CRP	FSA
Prairie Creek	75.7	74.9
Upper Boone	75.4	74.6
Otter Creek	75.5	75.1
Eagle Creek	75.5	75.4
White Fox	75.5	75.4
Local 1	75.7	75.3
Local 2	75.7	75.3
Local 3	75.5	75.4

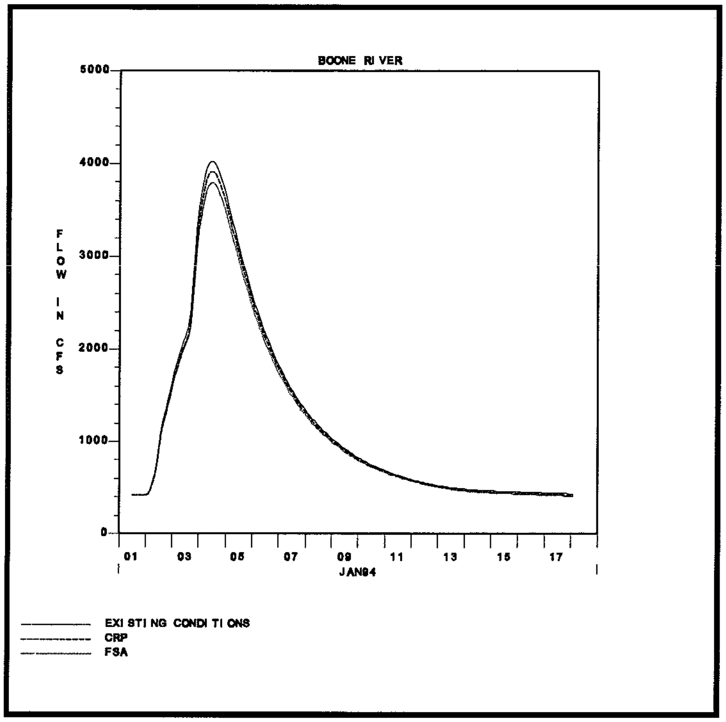


Figure 11: Adjusted for FSA for 1-Year, 1-Day Hypothetical Event

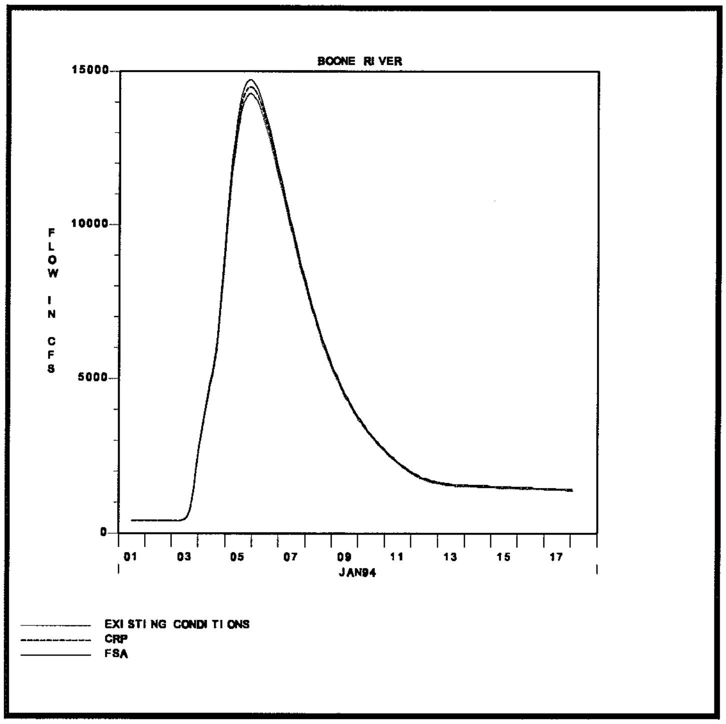


Figure 12: Adjusted for FSA for 5-Year, 4-Day Hypothetical Event

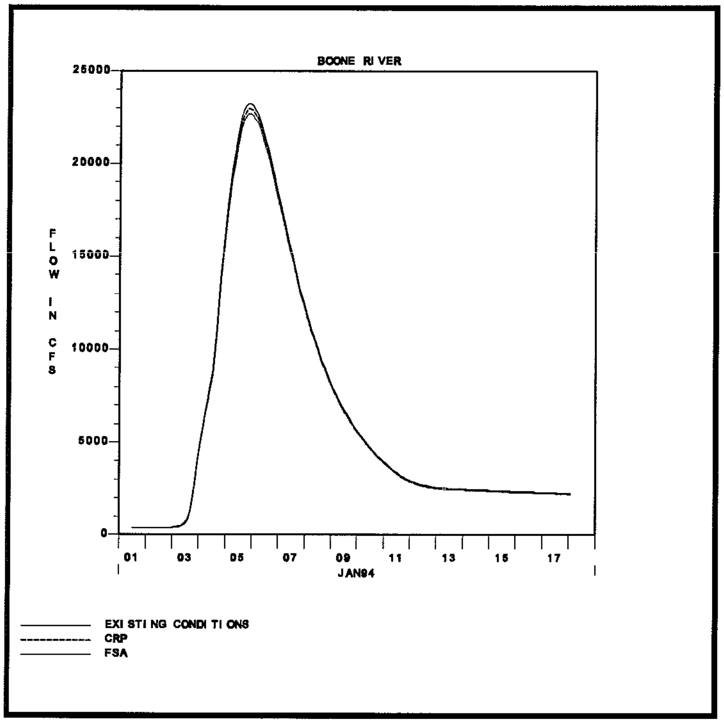


Figure 13: Adjusted for FSA for 25-Year, 4-Day Hypothetical Event

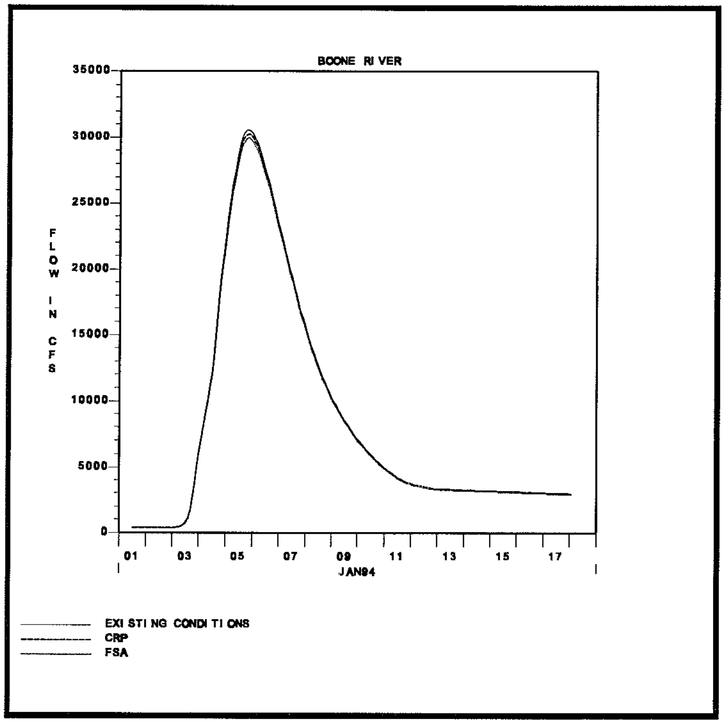


Figure 14: Adjusted for FSA for 100-Year, 4-Day Hypothetical Event

6. Combining On-Stream Wetlands, Potholes, and Land Management Practices.

Simulations were performed to evaluate the combined impact of on-stream wetlands, potholes, and land management practices on flood peaks. The resultant hydrographs are shown in Figures 15 through 18. Table 3 summarizes the percent change in peak flow at the gage near Webster City.

Table 3
Results for Four Storm Frequencies and Six Proposed Plans

Note: All storms are 4 day duration	1 Year		5 Year		25 Year		100 Year	
	Flow (cfs)	Reduction in peak Q	Flow (cfs)	Reduction in peak Q	Flow (cfs)	Reduction in peak Q	Flow (cfs)	Reduction in peak Q
EXISTING CONDITIONS	4026	-	14748	-	23265	-	30603	-
ON-STREAM WETLANDS	3842	5%	14343	3 %	22758	2 %	29980	2 %
POTHOLES	3670	9 %	13503	8 %	21535	7 %	29100	5 %
CRP	3915	3 %	14525	1 %	22990	1 %	30306	1 %
FSA	3798	6 %	14301	3 %	22715	2 %	29992	2 %
All measures	3300	18 %	12672	14 %	20503	12 %	27827	9 %

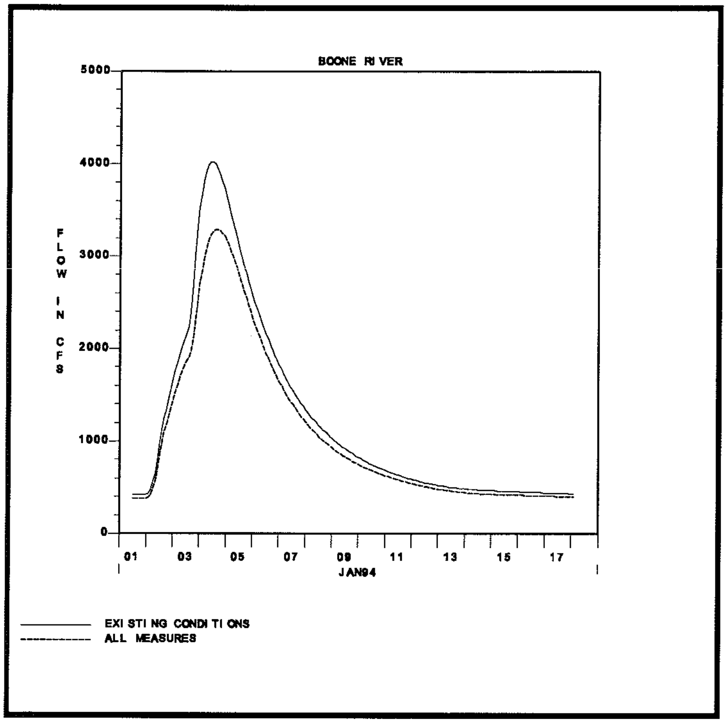


Figure 15: Hydrographs for 1-Year, 1-Day Hypothetical Event

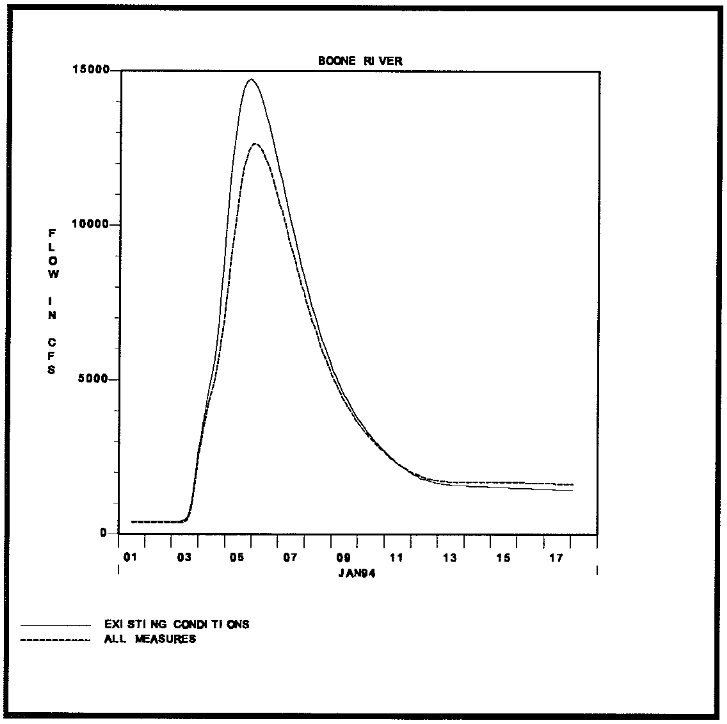


Figure 16: Hydrographs for 5-Year, 4-Day Hypothetical Event

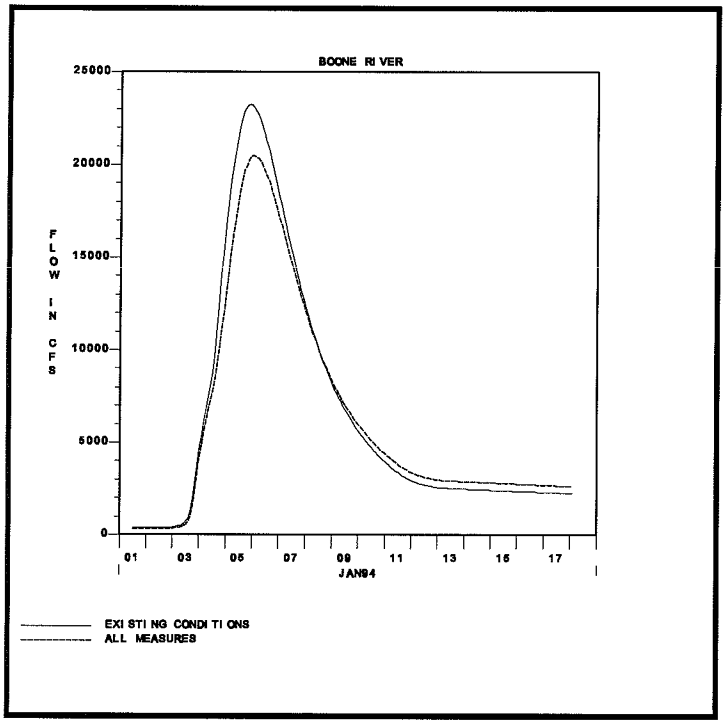


Figure 17: Hydrographs for 25-Year, 4-Day Hypothetical Event

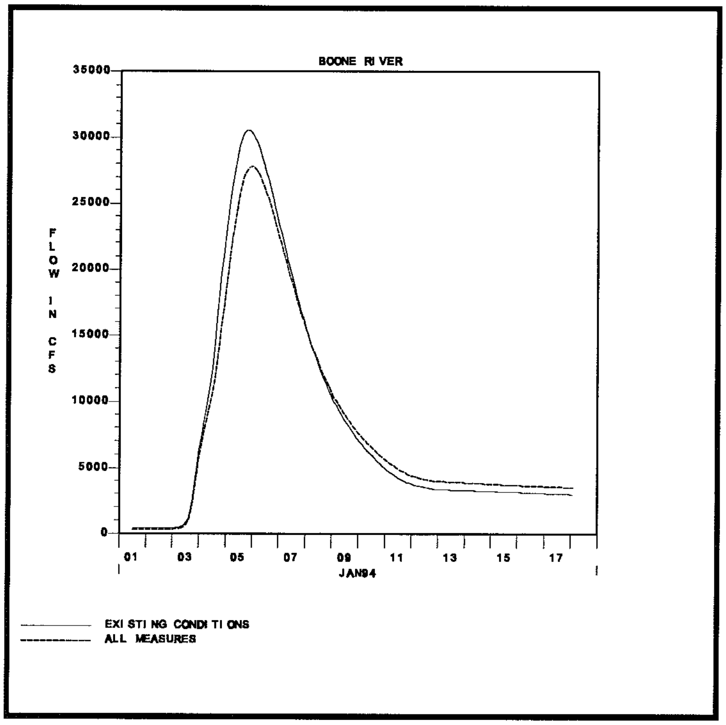


Figure 18: Hydrographs for 100-Year, 4-Day Hypothetical Event

7. Conclusions

(1) This brief study of the Boone River Basin contains the liability that many simplifying assumptions were made because of time constraints. Therefore, the goal of accurately determining the impact wetlands would have on the Boone River Basin was not realistic. In lieu of this, the goal was to derive a first estimate of the potential beneficial impact of wetlands on floods. Consequently, in each case that assumptions were made, there was a conscious effort to err in the direction causing larger beneficial impact. This means that the reader should not take the results as that which are to be expected, but as the maximum possible to be expected

(2) The impact of all the measures together was relatively high because their impacts coincided. In other words, their reductions in flow overlapped in a way that affected the peak flow versus only affecting the rising or falling limb. Therefore, the true impact could be smaller if this study contains errors in some of the timing parameters for the pothole and on-stream wetlands simulation. In future work, the timing of the impacts from several measures should be more thoroughly examined.

(3) The method used to model pothole storage has potential for describing pothole storage impact on flooding. With good data available to calibrate the parameters used, reasonable results could be expected. Unfortunately, data is required for before and after pothole drainage conditions so that their effects can be isolated in the respective parameters.

(4) Digital terrain modeling may hold benefits for solving some of the problems encountered during this study. However, the detail to which these systems are able to describe the basin will be extremely important for studies of depressional areas. For topography like that of the Boone, the potholes are small, numerous, and exist amongst very mild relief. Therefore, some scales used in digital terrain modeling will not be able to describe the potholes well enough. However, with increased detail capture in this technology, the problems of determining pothole storage and contributing area could be solved.

(5) Current, well supported models exist for analysis of both on-stream wetlands and land management practice alternatives. They may be data and effort intensive, but good results are obtainable. However, there are no comparable models available which directly address the effect of depressional pothole storage on floods. The three existing hydrologic models which account for potholes are: the Iowa State Model (C.T. Haan and H.P. Johnson, 1968), the Minnesota Model (I.D. Moore and C.L. Larson, 1979), and DRAIMOD (R.W. Skaggs, 1977). Only DRAIMOD has been kept up to date, and none are extensively supported. Unfortunately, time constraints prohibited acquiring proficiency in, and use, of these models. Future efforts in the area of pothole modeling should incorporate the methods of these models into a well supported package such as HEC-1.

9. References

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Appendix 1
HEC Report Review

Study 1. "Comparison of Modeling Techniques for Wetland Areas," for St. Paul District, US Army Corps of Engineers, HEC Project Report 38-4, Sept. 1988. This study overviews problems, issues and methods associated with analysis of the flood runoff response from wetlands; provides results of a literature review; and summarizes characteristics of three models for relatively detailed analysis of watersheds containing depressional storage: Iowa State Model, Minnesota Model, and DRAIMOD (North Carolina State University).

Study 2. "Red River of the North Unit Hydrograph Analysis," for St. Paul District, US Army Corps of Engineers, HEC, May 1990. This study evaluates use of regression analysis to develop regional relationships for estimating values for unit hydrograph parameters for ungaged basins containing wetlands and drainage systems. The surface area of depression storage was the wetland-related variable with greatest statistical significance.

Study 3. "The Effects of Wetlands on Flood Intensities, Rock River Basin, Wisconsin," for Rock Island District, US Army Corps of Engineers, HEC, Sept. 1981. This study analyzes runoff response characteristics of small, gaged wetland areas that are at the mouths of four drainages having effective areas of 10 to 44 sq. mi. Two key indices related to peak-discharge reduction due to the wetlands are (a) the duration of overbank flooding, and (b) the storage capacity of the wetlands defined in terms of the slope of a storage-outflow function between bankfull discharge and a discharge equal to the 10-year peak inflow.

Appendix 2
HEC-1 Input File

```
ID Boone River Near Webster City
ID Existing conditions, 100 yr, 4 day rainfall
IT   120 01JAN94    1200     200
IO     5       0
JP     6
*DIAGRAM
* **************************************************************
KK BOONP
KM  Compute Runoff for area contributing to potholes
BA 16.37
* *** 100 YR RAIN
PH           852    0.85    1.82    3.45     3.8     4.2    4.75    5.75     6.5
PH   7.5     8.8
BF   -.5     -.1   1.001
LS            76
UC    36      50
KP     3
UC   3.6      10
KP     4
LS          75.4
UC    36      50
KP     5
LS          74.6
KP     6
UC   3.6      10
LS          74.6
KK BOONS
KM  Route pothole contributing area flow through storage
RN
KP     2
RN
KP     3
RS     1    STOR       0
SV     0    2304    2765    3072    3072
SQ     0      10      50     200    5000
KP     4
RN
KP     5
RN
KP     6
RS     1    STOR       0
SV     0    2304    2765    3072    3072
SQ     0      10      50     200    5000
KK BOONR
KM  Route the storage outflow through muskingum reach to delay
RN
KP     2
RN
KP     3
RM     1    32.4       0
KP     4
RN
KP     5
RN
KP     6
RM     1    32.4       0
KK  BOON
KM  Compute Headwater Runoff for Upper Boone
BA 147.3
BF   -.5     -.1   1.001
LS            76
UC    36      50
KP     4
```

```
 LS          75.4
 KP     5
 LS          74.6
 KP     6
 LS          74.6
 KK  BOON
 KM  Combine
 HC     2
 KK  BOON
 RN
 ZW A=BOONE RIVER  C=FLOW F=PLAN1
 KP     2
 RN
 ZW A=BOONE RIVER  C=FLOW F=PLAN2
 KP     3
 RN
 ZW A=BOONE RIVER  C=FLOW F=PLAN3
 KP     4
 RN
 ZW A=BOONE RIVER  C=FLOW F=PLAN4
 KP     5
 RN
 ZW A=BOONE RIVER  C=FLOW F=PLAN5
 KP     6
 RN
 ZW A=BOONE RIVER  C=FLOW F=PLAN6
 KKPRAIRP
 KM Compute runoff from area contributing to prairie creek potholes.
 BA    13
 * *** 100 YR RAIN
 BF   -.5      -.1   1.001
 LS             76
 UC    46       50
 KP     3
 UC   4.6       10
 KP     4
 LS           75.7
 UC    46       50
 KP     5
 LS           74.9
 KP     6
 UC   4.6       10
 LS           74.9
 KKPRAIRS
 KM  Route pothole contributing area flow through storage
 RN
 KP     2
 RN
 KP     3
 RS     1     STOR       0
 SV     0     1872    2246    2496    2496
 SQ     0       10      50     200    5000
 KP     4
 RN
 KP     5
 RN
 KP     6
 RS     1     STOR       0
 SV     0     1872    2246    2496    2496
 SQ     0       10      50     200    5000
 KKPRAIRR
 KM  Route the storage outflow through muskingum reach to delay
 RN
 KP     2
 RN
 KP     3
 RM     1     41.4       0
 KP     4
```

```
RN
KP      5
RN
KP      6
RM      1    41.4       0
KK PRAIR
KM  Compute Headwater Runoff for Prairie Creek
BA 120.4
BF   -.5     -.1   1.001
LS            76
UC    46      50
KP     4
LS          75.7
KP     5
LS          74.9
KP     6
LS          74.9
KK PRAIR
KM  Combine
HC     2
KK PRAIR
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN1
KP     2
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN2
KP     3
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN3
KP     4
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN4
KP     5
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN5
KP     6
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN6
* ***********
KK    C1
KM Combine hydrographs from Prairie Creek and Upper Boone
HC     2
* ***********
KK C2.C1
KM Route Upper Boone and Prairie from confluence No. 1 to No. 2
RD
RC  0.06   0.035    0.06   43824 0.00023
RX      0     300     325     325     425     425     450     550
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
KP     2
RN
KP     3
RD
RC  0.06   0.035    0.06   43824 0.00023
RX      0     300     325     325     425     425     450     550
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
KP     4
RD
RC  0.06   0.035    0.06   43824 0.00023
RX      0     300     325     325     425     425     450     550
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
KP     5
RD
RC  0.06   0.035    0.06   43824 0.00023
RX      0     300     325     325     425     425     450     550
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
KP     6
RN
```

```
* ***********
KK C2.C1
KM Route Upper Boone and Prairie from confluence No. 1 to wetland
KP      1
RN
KP      2
RD
RC  0.06   0.035    0.06   17596 0.00023
RX     0     300     325     325     425     425     450     550
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
KP      3
RN
KP      4
RN
KP      5
RN
KP      6
RD
RC  0.06   0.035    0.06   17596 0.00023
RX     0     300     325     325     425     425     450     550
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
KK C2.C1
KM Route Upper Boone through wetland
KP      1
RN
KP      2
RD
RC  0.15   0.035    0.15   11620 0.00023
RX     0     300     325     325     425     425     950    1050
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
KP      3
RN
KP      4
RN
KP      5
RN
KP      6
RD
RC  0.15   0.035    0.15   11620 0.00023
RX     0     300     325     325     425     425     950    1050
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
* *******
KK C2.C1
KM Route Upper Boone and Prairie from wetland to confluence No. 2
KP      1
RN
KP      2
RD
RC  0.06   0.035    0.06   14608 0.00023
RX     0     300     325     325     425     425     450     550
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
KP      3
RN
KP      4
RN
KP      5
RN
KP      6
RD
RC  0.06   0.035    0.06   14608 0.00023
RX     0     300     325     325     425     425     450     550
RY  21.9     6.9     1.9       0       0     1.9     6.9    21.9
* ***********
KKOTTERP
KM   Compute pothole contributing area runoff for Otter Creek
BA   8.2
BF   -.5     -.1   1.001
LS            76
```

```
UC    34      50
KP     3
UC   3.4      10
KP     4
LS          75.5
UC    34      50
KP     5
LS          75.1
KP     6
UC   3.4      10
LS          75.1
KKOTTERS
KM  Route pothole contributing area flow though storage
RN
KP     2
RN
KP     3
RS     1    STOR       0
SV     0    1152    1382    1536    1536
SQ     0      10      50     200    5000
KP     4
RN
KP     5
RN
KP     6
RS     1    STOR       0
SV     0    1152    1382    1536    1536
SQ     0      10      50     200    5000
KKOTTERR
KM  Route the storage outflow through muskingum reach to delay
RN
KP     2
RN
KP     3
RM     1    30.6       0
KP     4
RN
KP     5
RN
KP     6
RM     1    30.6       0
KK OTTER
KM  Compute Headwater Runoff for Otter Creek
BA  73.4
BF   -.5     -.1   1.001
LS            76
UC    34      50
KP     4
LS          75.5
KP     5
LS          75.1
KP     6
LS          75.1
KK OTTER
KM  Combine
HC     2
KK OTTER
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN1
KP     2
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN2
KP     3
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN3
KP     4
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN4
```

```
KP     5
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN5
KP     6
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN6
* ***********
KK   C2L
KM Compute local above confluence No. 2
BA  28.2
BF   -.5     -.1   1.001
LS            76
UC    12      35
KP     4
LS          75.7
KP     5
LS          75.3
KP     6
LS          75.3
* ***********
KK    C2
KM  Combine routed Prairie & Boone and local above confl. 2 and Otter Creek
HC     3
* ***********
KK  C3.C
KP     1
KM  Route everything at confluence No. 2 to confluence No. 3, first half
RD
RC  0.06   0.035    0.06   85008 0.00029
RX     0     200     250     250     400     400     450     500
RY  22.1    12.1     2.1       0       0     2.1    12.1    22.1
KK  C.C2
KM Second half of routing from confl. No. 2 to confl. No. 3: skip wetland
KP     1
RD
RC  0.06   0.035    0.06   68112 0.00029
RX     0     450     600     600     750     750     775     825
RY  22.2     7.2     2.2       0       0     2.2     7.2    22.2
KP     2
RN
KP     3
RD
RC  0.06   0.035    0.06   68112 0.00029
RX     0     450     600     600     750     750     775     825
RY  22.2     7.2     2.2       0       0     2.2     7.2    22.2
KP     4
RD
RC  0.06   0.035    0.06   68112 0.00029
RX     0     450     600     600     750     750     775     825
RY  22.2     7.2     2.2       0       0     2.2     7.2    22.2
KP     5
RD
RC  0.06   0.035    0.06   68112 0.00029
RX     0     450     600     600     750     750     775     825
RY  22.2     7.2     2.2       0       0     2.2     7.2    22.2
KP     6
RN
KK  C.C2
KM Second half of routing from confl. No. 2 to confl. No. 3: to wetland
KP     1
RN
KP     2
RD
RC  0.06   0.035    0.06   14982 0.00029
RX     0     450     600     600     750     750     775     825
RY  22.2     7.2     2.2       0       0     2.2     7.2    22.2
KP     3
RN
```

```
KP     4
RN
KP     5
RN
KP     6
RD
RC  0.06    0.035     0.06    14982 0.00029
RX     0      450      600      600     750      750      775      825
RY  22.2      7.2      2.2        0       0      2.2      7.2     22.2
KK  C.C2
KM Part two of above routing, through wetland
KP     1
RN
KP     2
RD
RC  0.15    0.035     0.15    10560 0.00029
RX     0       50      100      100     250      250     1450     1650
RY  22.2      7.2      2.2        0       0      2.2      7.2     22.2
KP     3
RN
KP     4
RN
KP     5
RN
KP     6
RD
RC  0.15    0.035     0.15    10560 0.00029
RX     0       50      100      100     250      250     1450     1650
RY  22.2      7.2      2.2        0       0      2.2      7.2     22.2
KK  C.C2
KM Part two of above routing, from wetland to confluence No. 3
KP     1
RN
KP     2
RD
RC  0.06    0.035     0.06    42570 0.00029
RX     0      450      600      600     750      750      775      825
RY  22.2      7.2      2.2        0       0      2.2      7.2     22.2
KP     3
RN
KP     4
RN
KP     5
RN
KP     6
RD
RC  0.06    0.035     0.06    42570 0.00029
RX     0      450      600      600     750      750      775      825
RY  22.2      7.2      2.2        0       0      2.2      7.2     22.2
* ***********
KKEAGLEP
KM  Compute headwater runoff from Eagle Creek
BA    11
BF   -.5       -.1    1.001
LS              76
UC    48        65
KP     3
UC   4.8        13
KP     4
LS            75.5
UC    48        65
KP     5
LS            75.4
KP     6
UC   4.8        13
LS            75.4
KKEAGLES
KM  Route pothole contributing area flow though storage
```

```
RN
KP      2
RN
KP      3
RS      1    STOR       0
SV      0    1728    2074    2304    2304
SQ      0      10      50     200    5000
KP      4
RN
KP      5
RN
KP      6
RS      1    STOR       0
SV      0    1728    2074    2304    2304
SQ      0      10      50     200    5000
KKEAGLER
KM  Route the storage outflow through muskingum reach to delay
RN
KP      2
RN
KP      3
RM      1    43.2       0
KP      4
RN
KP      5
RN
KP      6
RM      1    43.2       0
KK EAGLE
KM  Compute Headwater Runoff for Eagle Creek
BA 104.3
BF    -.5     -.1   1.001
LS              76
UC     48      65
KP      4
LS            75.5
KP      5
LS            75.4
KP      6
LS            75.4
KK EAGLE
KM  Combine
HC      2
KK EAGLE
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN1
KP      2
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN2
KP      3
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN3
KP      4
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN4
KP      5
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN5
KP      6
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN6
* ***********
KK  C3LP
KM  Compute pothole contributing area flow for local above confl. No. 3
BA 12.97
BF    -.5     -.1   1.001
LS              76
UC     45      65
```

```
KP     3
UC   4.5      13
KP     4
LS            75.7
UC    45      65
KP     5
LS            75.3
KP     6
UC   4.5      13
LS            75.3
KK  C3LS
KM  Route pothole contributing area flow though storage
RN
KP     2
RN
KP     3
RS     1    STOR       0
SV     0    1872    2246    2496    2496
SQ     0      10      50     200    5000
KP     4
RN
KP     5
RN
KP     6
RS     1    STOR       0
SV     0    1872    2246    2496    2496
SQ     0      10      50     200    5000
KK  C3LR
KM  Route the storage outflow through muskingum reach to delay
RN
KP     2
RN
KP     3
RM     1    41.5       0
KP     4
RN
KP     5
RN
KP     6
RM     1    41.5       0
KK   C3L
KM  Compute Headwater Runoff for C3L
BA 116.7
BF   -.5     -.1   1.001
LS              76
UC    45      65
KP     4
LS            75.7
KP     5
LS            75.3
KP     6
LS            75.3
KK   C3L
KM  Combine
HC     2
KK   C3L
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN1
KP     2
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN2
KP     3
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN3
KP     4
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN4
KP     5
```

```
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN5
KP     6
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN6
* ***********
KK    C3
KM  Combine Boone flow above confluence No. 3 with flow from Eagle Creek & local
HC     3
* ***********
KK C4.C3
KP     1
KM  Route Boone flow from confluence No. 3 to No. 4
RD
RC  0.06   0.035    0.06   60719 0.00044
RX     0     100     150     150     310     310     410     710
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KP     2
RN
KP     3
RD
RC  0.06   0.035    0.06   60719 0.00044
RX     0     100     150     150     310     310     410     710
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KP     4
RD
RC  0.06   0.035    0.06   60719 0.00044
RX     0     100     150     150     310     310     410     710
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KP     5
RD
RC  0.06   0.035    0.06   60719 0.00044
RX     0     100     150     150     310     310     410     710
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KP     6
RN
KK C4.C3
KM  Route Boone flow from confluence No. 3 to wetland
KP     1
RN
KP     2
RD
RC  0.06   0.035    0.06   27128 0.00044
RX     0     100     150     150     310     310     410     710
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KP     3
RN
KP     4
RN
KP     5
RN
KP     6
RD
RC  0.06   0.035    0.06   27128 0.00044
RX     0     100     150     150     310     310     410     710
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KK C4.C3
KM  Route Boone flow through wetland
KP     1
RN
KP     2
RD
RC  0.15   0.035    0.15   10560 0.00044
RX     0     100     500     500     660     660    1060    1160
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KP     3
RN
KP     4
```

```
RN
KP     5
RN
KP     6
RD
RC  0.15   0.035    0.15   10560 0.00044
RX     0     100     500     500     660     660    1060    1160
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KK C4.C3
KM  Route Boone flow from wetland to confluence No. 4
KP     1
RN
KP     2
RD
RC  0.06   0.035    0.06   23031 0.00044
RX     0     100     150     150     310     310     410     710
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
KP     3
RN
KP     4
RN
KP     5
RN
KP     6
RD
RC  0.06   0.035    0.06   23031 0.00044
RX     0     100     150     150     310     310     410     710
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
* ***********
KK WFOXP
KM  Compute pothole contributing area flow for White Fox
BA  11.7
BF   -.5     -.1   1.001
LS            76
UC    30      60
KP     3
UC     3      12
KP     4
LS          75.5
UC    30      60
KP     5
LS          75.4
KP     6
UC     3      12
LS          75.4
KK WFOXS
KM  Route pothole contributing area flow though storage
RN
KP     2
RN
KP     3
RS     1    STOR       0
SV     0    1728    2074    2304    2304
SQ     0      10      50     200    5000
KP     4
RN
KP     5
RN
KP     6
RS     1    STOR       0
SV     0    1728    2074    2304    2304
SQ     0      10      50     200    5000
KK WFOXR
KM  Route the storage outflow through muskingum reach to delay
RN
KP     2
RN
KP     3
```

```
RM       1      27       0
KP       4
RN
KP       5
RN
KP       6
RM       1      27       0
KK  WFOX
KM  Compute Headwater Runoff for White Fox
BA 106.2
BF   -.5      -.1   1.001
LS              76
UC     30       60
KP      4
LS            75.5
KP      5
LS            75.4
KP      6
LS            75.4
KK  WFOX
KM  Combine
HC      2
KK  WFOX
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN1
KP      2
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN2
KP      3
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN3
KP      4
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN4
KP      5
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN5
KP      6
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN6
* ***********
KK   C4L
KM  Compute local above confluence No. 4
BA  15.0
BF   -.5      -.1   1.001
LS              76
UC     11       30
KP      4
LS            75.5
KP      5
LS            75.4
KP      6
LS            75.4
* ***********
KK    C4
KM  Combine Boone flow above confluence No. 4 and White Fox Creek and local
HC      3
* ***********
KK GA.C4
KM Route Boone flow above confluence No. 4 to gage
RD
RC  0.06   0.035    0.06   26400 0.00064
RX     0     400     500     500     690     690     790    1190
RY  22.5    12.5     2.5       0       0     2.5    12.5    22.5
* ***********
KK GAGEL
KM Compute local above gage
BA  66.7
```

```
BF   -.5     -.1   1.001
LS            76
UC    15      40
KP     4
LS           75.5
KP     5
LS           75.4
KP     6
LS           74.4
* ***********
KK  GAGE
KM Combine mainstem Boone flow at gage with local above gage
HC     2
KK  GAGE
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN1
KP     2
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN2
KP     3
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN3
KP     4
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN4
KP     5
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN5
KP     6
RN
ZW A=BOONE RIVER  C=FLOW F=PLAN6
ZZ
```