MODELING OF SPECIAL HIGH-FLOW RELEASES ALONG PLATTE RIVER IN CENTRAL NEBRASKA

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Abstract: The Platte River is a wide and shallow sand-bed river. Reservoirs in the watershed above the Platte River have reduced flows in the downstream river channel and trapped sediments. As a result, the river channel has narrowed and vegetation has encroached into the formerly wide channel. The reduction in channel width has reduced habitat for endangered migratory birds. Special high-flow releases are now being considered from certain local reservoirs to scour seedling vegetation from mechanically cleared areas of the river channel in an attempt to restore some habitat for the endangered migratory birds.

An unsteady flow model has been developed for the Platte River from Overton to Grand Island, Nebraska (from river miles 239.3 to 167.9), to route the special-high flow release along the river channel. The model predicts the magnitude and duration of peak flow and stage as the flow is routed downstream. The model uses the HEC-RAS computer program as a foundation for the unsteady flow modeling. This model was supplemented with a new procedure to simulate the losses to and gains from groundwater and bank storage. The model has been calibrated against measured fluctuating flow hydrographs near Kearney, Nebraska (river mile 215.0) by routing the measured flow hydrographs from the upstream end of the model reach near Overton, Nebraska. In the calibration process, it has been found that a hydraulic model that only considers unsteady flow routing, without losses to and gains from bank storage and groundwater can not replicate the measured flow hydrograph in a natural channel such as Platte River in central Nebraska. A new procedure has been developed to account for these losses and gains in the routing process. In addition, the calibration process has also taken into consideration the roughness in order to accurately match the lag time of the hydrographs. The model is being used to help design a special high-flow release planned for the future.

INTRODUCTION

The Platte River, flowing through the state of Nebraska, provides habitat for endangered migratory birds, including the whooping crane, interior least tern, and piping plover. The habitat of these migratory birds has degraded over the 20th century (National Research Council of the National Academies, 2005). As part of the habitat improvement program, the U.S. Fish and Wild Life Service is planning special high flow release from local upstream reservoirs to scour seedling vegetation from mechanically cleared areas of the Platte River in an attempt to restore the habitats of these endangered species (U.S. Department of the Interior, Bureau of Reclamation and Fish and Wildlife Service, 2003).

An unsteady flow model is being developed by Bureau of Reclamation to route the planned special high-flow release from local upstream reservoirs through the Platte River from Overton to Grand Island, Nebraska (river miles 239.3 to 167.9). The results of this model development and its application to the Platte River are reported in this paper.

MODEL DEVELOPMENT

The HEC-RAS computer program (U.S Army Corps of Engineers, 2002) is used as the foundation for the unsteady flow model. Cross sections of the Platte River, in central Nebraska, have been surveyed during 1989, 1998 and 2002. The cross-section network was initially established and surveyed in 1989. A total of 90 cross sections were surveyed from North Platte to near Grand Island, Nebraska (river miles 310.5 to 157.1) with an average longitudinal spacing of 1.7 miles between two successive cross sections. A cross section was surveyed at each bridge crossing along with cross sections 0.1 mile upstream and 0.1 mile downstream from the bridge. Various subsets of the 1989 cross sections (excluding bridge cross sections) were resurveyed in 1998 and 2002. The bed and banks of the Platte River are composed primarily of sand and there are typically multiple channels separated by vegetated islands. The cross-section surveys include all channels of this sometimes braided, anastomosing, and anabranched river.

Initially, a Manning's *n* roughness coefficient of 0.035 was assigned to the main channel and a coefficient of 0.07 was assigned to the overbank area. The main channel roughness coefficient was revised during the calibration process. The cross sections from near Overton to near Grand Island, Nebraska (river miles 239.3 to 157.1) were used to construct the geometry of the river model. The most recent survey data were used to represent each river cross section. Cross-sections were interpolated every 500 feet in between measured cross sections to route unsteady flows without causing instability in the solution scheme of the HEC-RAS computer program. The upstream boundary condition of the model was the hydrograph near Overton, Nebraska and the downstream boundary condition was the assumption of normal depth at River mile 157.1 with average river slope of 0.00126.

The loss of flow to bank storage during the rising limb of the hydrograph and gain from bank storage during the falling limb of the hydrograph is accounted for by a special program developed by the authors. Also river losses to or gains from the surrounding groundwater table are accounted for by introducing a groundwater flow hydrograph that is separate from the flow to or from bank storage.

MODEL CALIBRATION

Fluctuating flow hydrographs were generated by the hydro-cycling operation from the upstream power plants. The two measured fluctuating flow hydrographs near Overton, Nebraska were used to calibrate the unsteady flow model:

1. March-April flows of 2002 and
2. February-March flows of 2005

First, the model was used to route the 2002 flow hydrograph with the initial Manning's *n* roughness coefficients of 0.035 and 0.07. With these roughness coefficients, the start of flow rise near Grand Island (71 miles downstream from Overton) was predicted to occur 15 hours after the measured start of rise flow (see figure 1). Therefore, the Manning's *n* roughness coefficient was reduced to shorten this 15-hour lag time. Since the flow did not overtop the banks, only the main channel roughness coefficient was varied.

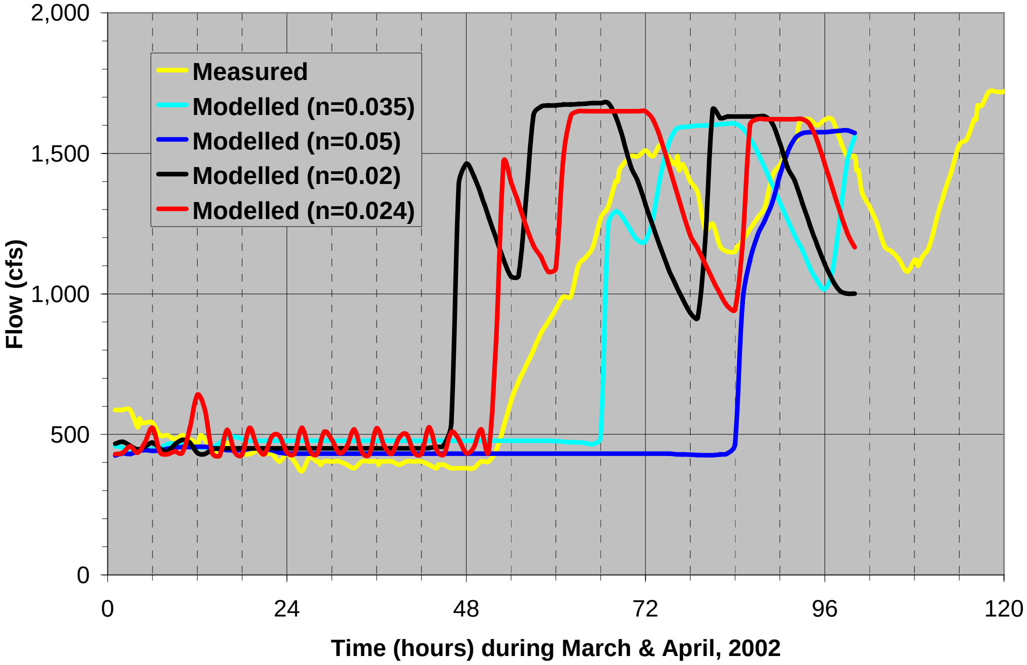

Figure 1 Comparison of measured and modeled hydrographs near Grand Island, Nebraska for various Manning's *n* roughness coefficients applied to the fluctuating flow period during March and April 2002

A regression analysis was then made between the lag time (time difference between predicted and measured start of rise) and main channel *n* values (see figure 2). The calibrated roughness coefficient corresponding to the desired lag time is 0.024. For verification, the predicted and measured start of flow rise was compared for the Platte River near Kearney, Nebraska (see figure 3). However, the peaks and volumes of the four routed discharge waves were over predicted.

Measured and modeled hydrographs near Kearney, Nebraska and the difference in flow between the two were plotted on the same time line (see figure 4, yellow and light-blue lines). A definite trend of losses to and gains from groundwater and bank storage was noticed. The losses to bank storage are associated with the start of rise of the first hydrograph wave, with maximum loss rate occurring just before the peak of each hydrograph wave. The gains from bank storage start after the river flow recedes and reach a maximum rate at about 50 percent of the peak stage above the base flow.

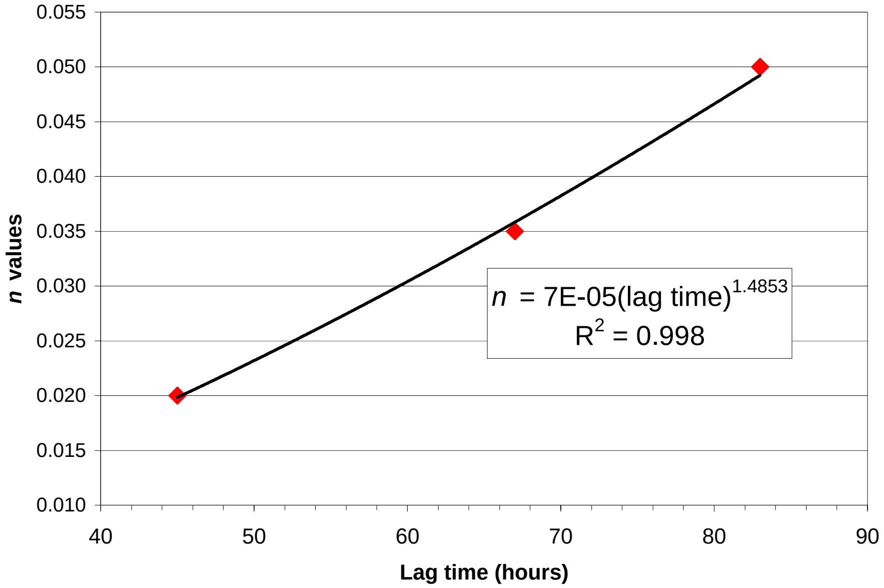

Figure 2 Lag Time near Grand Island, Nebraska versus Manning's *n* value

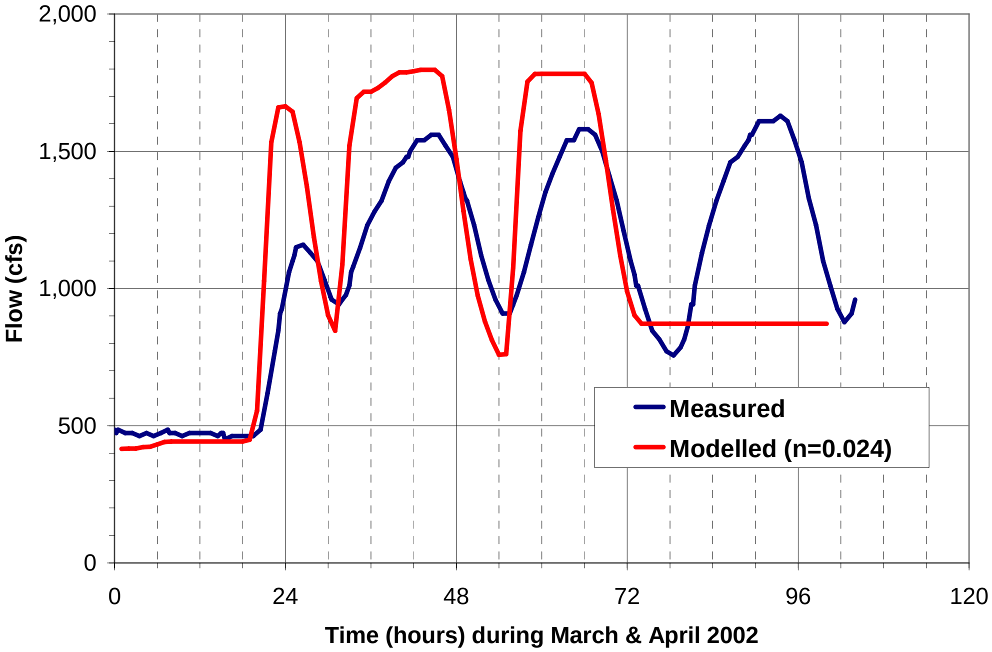

Figure 3 Comparison of measured and modeled hydrographs near Kearney, Nebraska applied to a fluctuating flow period during March and April 2002. The calibrated roughness coefficient of 0.024 was verified because the predicted start of flow rise matches the measured start of flow rise.

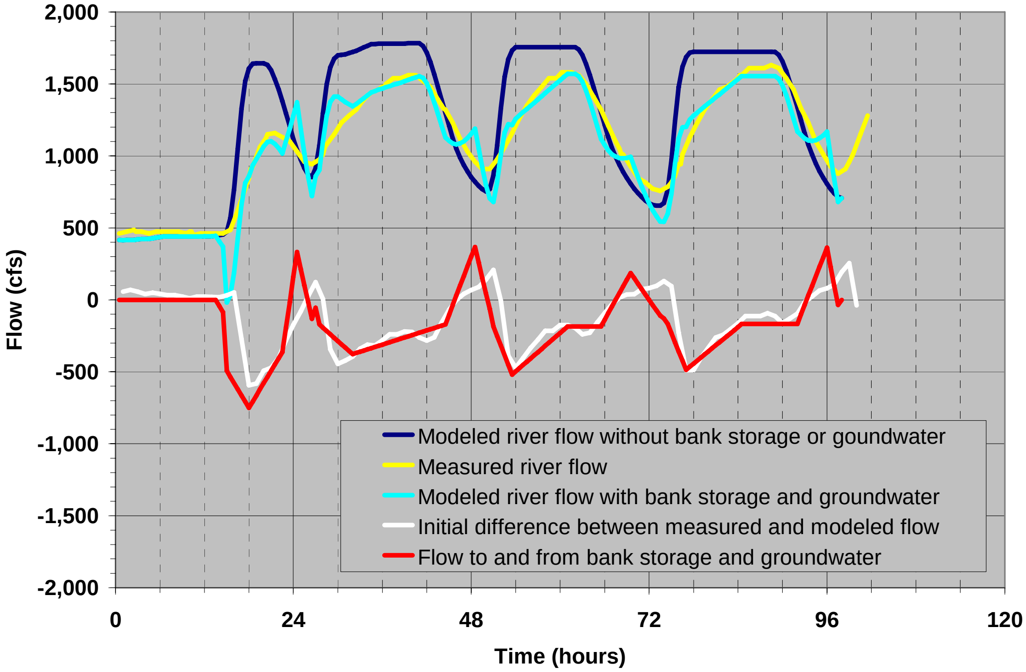

Figure 4 Comparison of measured and predicted unsteady flows on the Platte River near Kearney, Nebraska, March-April 2002

In order to match the modeled hydrograph with the measured hydrograph, two addition hydrographs are employed to simulate flow to and from bank storage and flow to or from groundwater:

1. A triangular hydrograph was to account for losses of river flow to bank storage during the rising limb of the river-flow hydrograph and gains to river flow during the falling limb of the river-flow hydrograph
2. A groundwater inflow or outflow hydrograph was used to account for river flow losses to or gains from the surrounding groundwater, independent from bank storage.

Losses to bank storage during the rising limb of the river-flow hydrograph were assumed to be equal to the gains from bank storage during the falling limb, so there is no net loss or gain in river flow over the period of simulation. When the losses to or gains from groundwater are added to the bank storage, the result is the net flow into and out of the river bank and groundwater.

The model procedure for flow to and from bank storage is presented in figure 5. The flow of river water to bank storage begins at t_0, which is has a lag time (Lag) of 1 or 2 hours after the start of rise in the river flow. The peak rate of flow to bank storage (Q_L) occurs at t_1, which corresponds to 97 percent of the maximum stage increase above the base flow. The end of river flow to bank storage occurs at t_2 ($\Delta t_2 = a\Delta t_1$; $a = 1$ to 3). When the duration of the peak flow is long enough (Δt_3), there is no flow to or from bank storage. Flow return from bank storage begins at some lag time (t_3) after the decrease in river flow. The peak rate of return flow from bank storage (Q_G) occurs at t_4, which corresponds to 45 percent of the maximum stage increase above the base flow. The end of return flow from bank storage occurs at t_5 ($\Delta t_5 = 5\Delta t_4$).

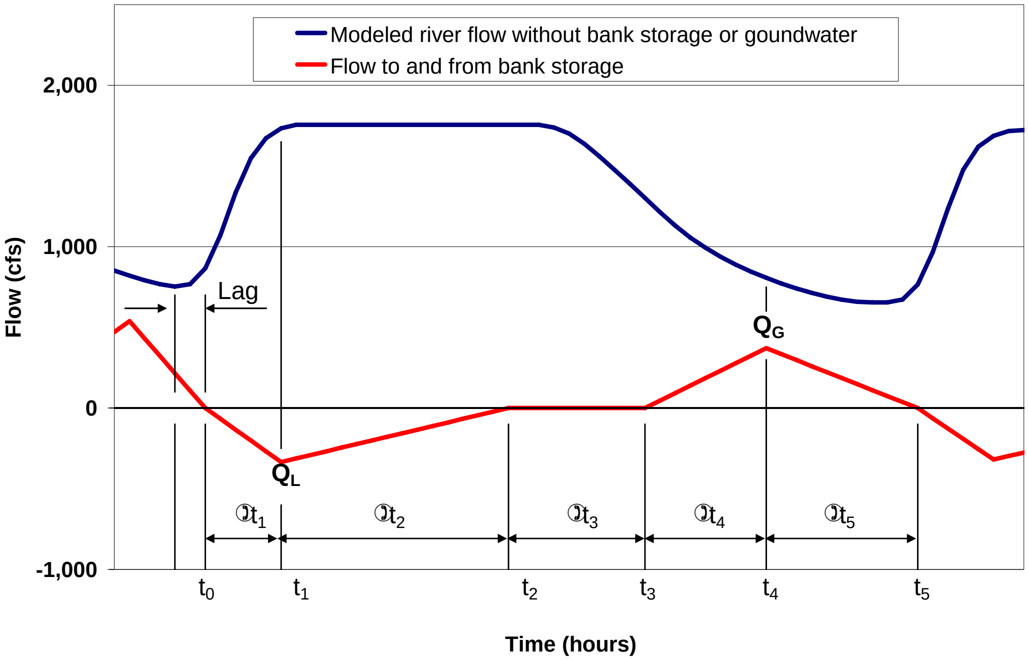

Figure 5. Model procedure of hydrograph flow to and from bank storage.

For the fluctuating flows of 2002, the discharge waves of the measured hydrograph near Kearney, Nebraska have less flow volume than the modeled hydrograph without considering bank storage or groundwater (see figure 4, yellow and blue lines). This volume difference means that there is a net loss to ground water. The actual bank storage volume is not precisely know, but, based on calibration, was found to be approximately equal to 50 percent of the flow volume difference between the measured hydrograph and the modeled hydrograph without bank storage or groundwater (see figure 4, white line). The net change in river flow due to bank storage and groundwater flow was determined (see figure 4, red line) and applied to the HEC-RAS model results to predict the final hydrograph (see figure 4, light blue line). The predicted hydrograph agreed well with the measured hydrograph (see figure 4, yellow line).

For the fluctuating flows of 2005, the discharge waves of the measured hydrograph near Kearney, Nebraska have more flow volume than the modeled hydrograph without considering bank storage or groundwater (see figure 6, yellow and blue lines). This volume difference means that there is a net gain from ground water. The bank storage volume was again modeled as equal to 50 percent of the flow volume difference between the measured hydrograph and the modeled hydrograph without bank storage or groundwater (see figure 6, white line). The net change in river flow due to bank storage and groundwater flow was determined (see figure 6, red line) and applied to the HEC-RAS model results to predict the actual hydrograph (see figure 6, light blue line). These predicted hydrograph results also agreed well with the measured hydrograph (see figure 6, yellow line).

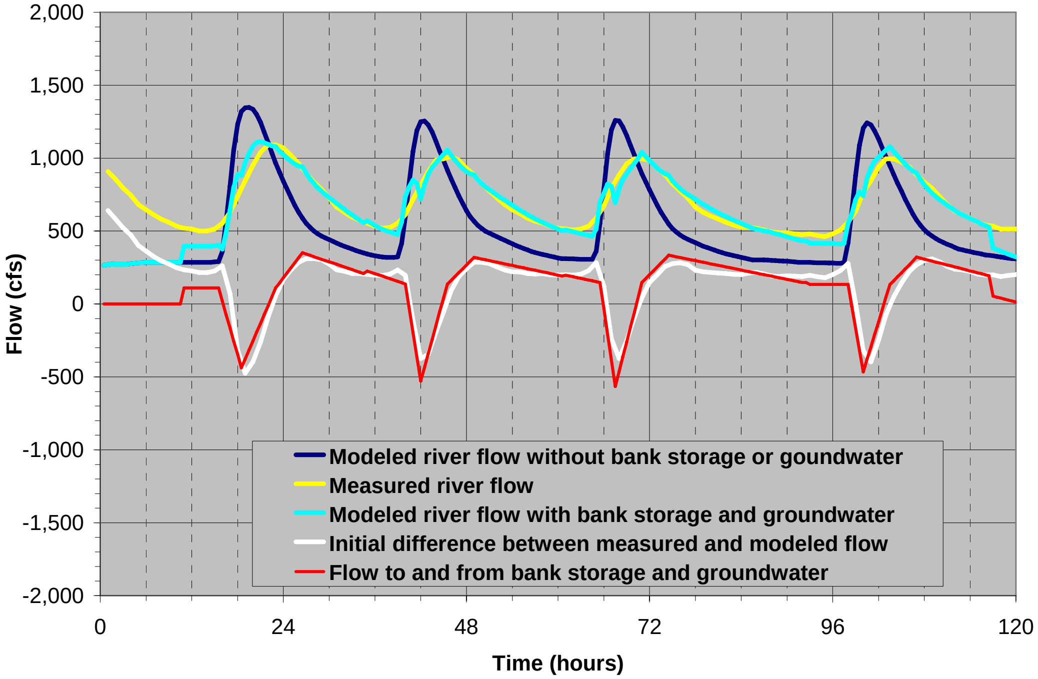

Figure 6 Comparison of measured and predicted unsteady flows on the Platte River near Kearney, Nebraska, February 2005

The model procedure was applied to the design of a preliminary special high-flow release hydrograph for the Platte River. This hydrograph was routed from Overton to Kearney, Nebraska using the HEC-RAS model (see figure 7, medium-blue line). The model procedure was then used to adjust the hydrograph predicted by the HEC-RAS model. A net loss of river flow to groundwater was assumed at a rate of 200 ft^3/s. The bank-storage volume that was calibrated for the 2002 fluctuating flows was increased by a scaling factor to account for the longer duration of the special high flow release.

The hydrographs representing the losses to and gains from bank storage and the resulting net losses to groundwater are also shown in Figure 7 (see green and red lines). The adjusted hydrograph near Kearney has lower peak flows and less volume than the hydrograph modeled without bank storage or groundwater (see figure 7, light-blue line).

CONCLUSIONS

The HEC-RAS model alone was found insufficient to route unsteady flow through a channel with significant bank storage and groundwater flow. For the Platte River in central Nebraska, bank storage and groundwater flow are important processes that need to be considered for unsteady flow modeling of flows less than the bank-full discharge capacity.

The use of a triangular hydrographs to account for the flow to and from bank storage and the specification of a separate hydrograph to account for flow to or from groundwater works well for the Platte River in central Nebraska. The model procedure was successfully calibrated for periods of fluctuating flow in 2002 and 2005 with nearly the same calibration parameters. The model procedure worked well for the two different conditions of a net loss of river flow and a net gain river flow to and from groundwater. Application of the model procedure to the design of a special high-flow release to scour seedling vegetation along the Platte River looks promising. Additional work need to be conducted to extend the model procedure downstream from Kearney to Grand Island, Nebraska.

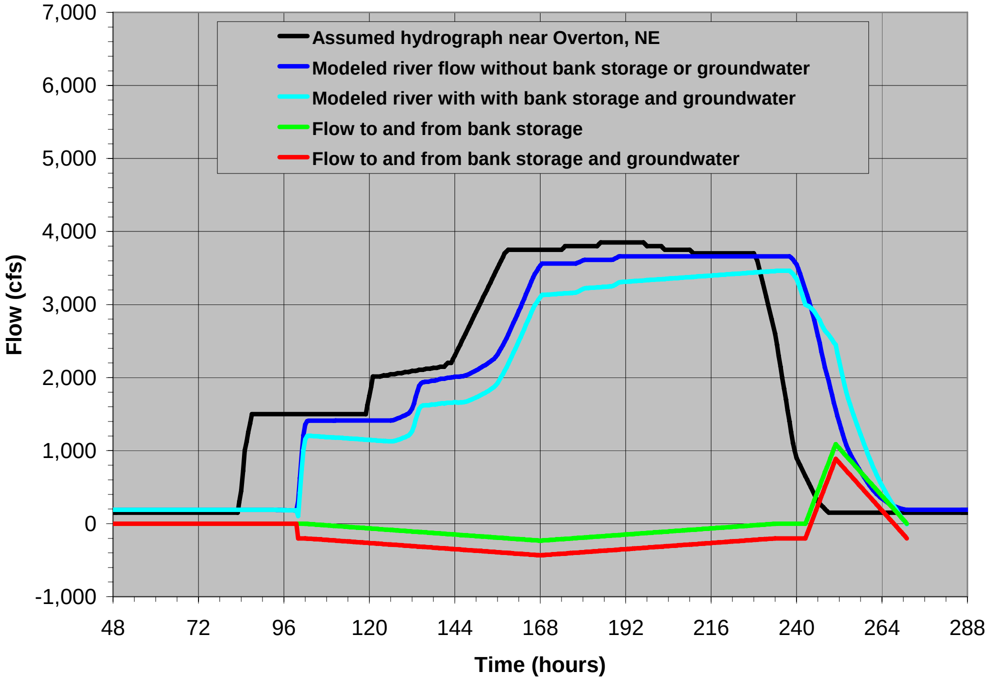

Figure 7 Predicted special-flow hydrograph routed 71 miles from Overton to Kearney, Nebraska.

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