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Morganza Control Structure Forebay: Numerical Hydraulic Model Investigation

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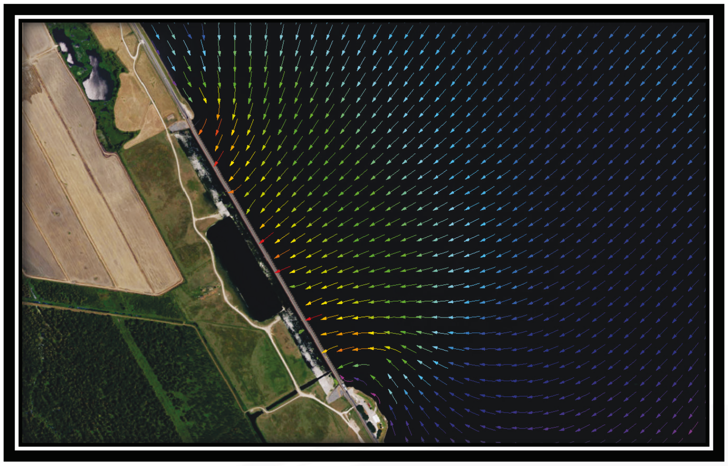

MRG&P

Mississippi River
Geomorphology &
Potamology Program

Report prepared for the
Mississippi River Commission

Mississippi River Geomorphology and
Potamology Program

MRG&P Report No. 23
October 2018

Morganza Control Structure Forebay

Numerical Hydraulic Model Investigation

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Final report

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Under Project 127672, “Morganza Forebay AdH Model”

Abstract

Flows and water levels within and approaching the Morganza Control Structure Forebay were investigated with an Adaptive Hydraulics model. The model was used to evaluate the influence of the potato ridge and lower guide levee grades on energy losses and flow patterns within the forebay. The diversion discharge capacity of the Morganza Control Structure is sensitive to computed water levels in the forebay and to estimated water levels at the entrance to the Morganza Floodway. Computed water levels in the forebay are determined by Mississippi River stages and energy losses across the potato ridge and within the forebay. The model simulated Morganza Control Structure operations and diversion discharge under two soft opening scenarios for a provisional project design flood hydrograph. The model demonstrates the potential impacts of the potato ridge grade on the discharge capacity of the Morganza Control Structure. The Adaptive Hydraulics code was modified to permit computation of individual gate discharges based on available operating head across the structure. Additional code enhancements are needed to simplify specification of structure operating rules. These modifications will support future coupling of this model with the Morganza Floodway model and development of a similar coupled model for the Old River Control Complex.

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Preface

The research documented in this report was conducted as part of the Mississippi River Geomorphology & Potamology (MRG&P) Program, under Project 127672, “Morganza Forebay AdH Model.” The MRG&P is part of the Mississippi River and Tributaries Program and is managed by the U.S. Army Corps of Engineers (USACE), Mississippi Valley Division (MVD), and districts. The MRG&P Technical Director was Dr. Ty V. Wamsley.

The MVD Commander was MG Richard G. Kaiser. The MVD Director of Programs was Mr. James A. Bodron.

Mississippi River engineering direction and policy advice were provided by the Mississippi River Commission. The Commission members were MG Kaiser, USACE; the Honorable Sam E. Angel; the Honorable Norma Jean Mattei, PhD; RDML Shepard Smith, National Oceanic and Atmospheric Administration (NOAA); BG Mark Toy, USACE; and BG Paul Owen, USACE.

The investigation was conducted by a collaboration among the following offices and agencies: MVD, New Orleans District (MVN), and the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). The technical monitor for the New Orleans District was Dr. Tzenge-huey (Jerry) Shih. Insights into the operation and behavior of the Morganza Control Structure provided by Dr. Shih, Dr. Stephen Maynord (CHL, retired), Mr. Russell Beauvais, Ms. Kayla LeBlanc, Mr. William Veatch, and Mr. David Ramirez (MVN) are gratefully acknowledged.

At the time of publication of this report, Mr. Jeffrey Eckstein was the Acting Director of CHL.

The Commander of ERDC was COL Bryan S. Green, and the Director of ERDC was Dr. David W. Pittman.

Unit Conversion Factors

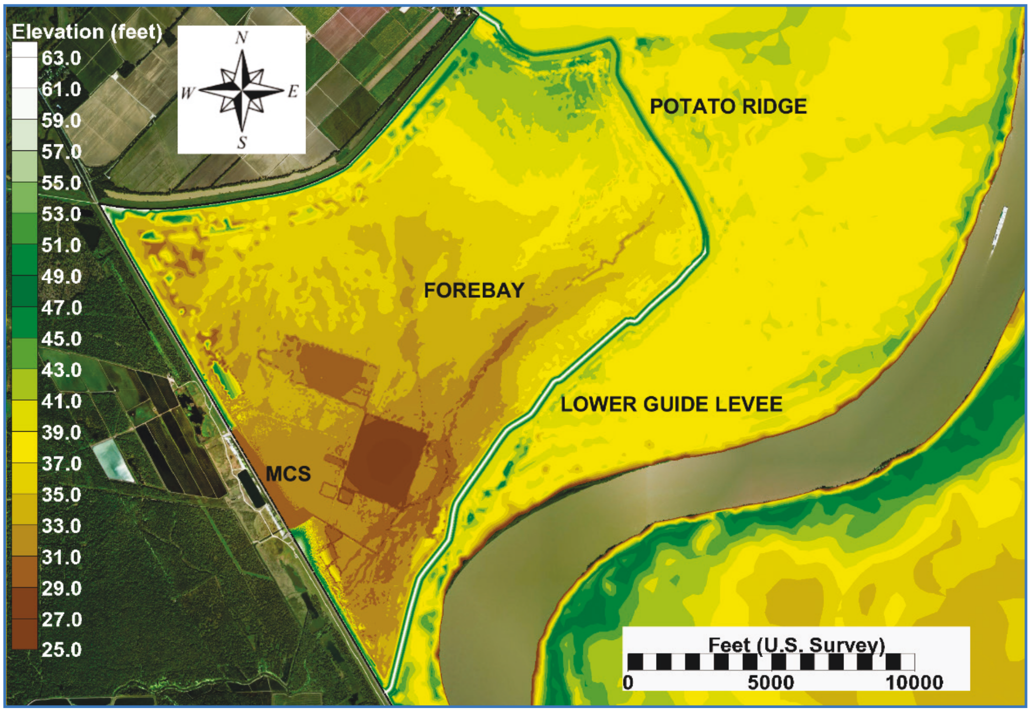
Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1,609.347	meters

1 Introduction

1.1 Background

The Morganza Control Structure (MCS) is a key element of the Mississippi River and Tributaries (MR&T) project. In conjunction with the Old River Control Complex, the MCS limits flow in the Mississippi River downstream of the structure to 1.5 million cubic feet per second (cfs) by diverting up to 600,000 cfs into the Morganza Floodway. The MCS has 125 gates, each 28.25 feet (ft) wide separated by 3 ft wide piers. The MCS Forebay (Figure 1) is a 5,000 acre basin bounded by the MCS and MR&T mainline levees to the southwest and northwest, by the lower guide levee to the southeast, and by the potato ridge to the northeast. The privately maintained potato ridge protects agricultural operations in the forebay from minor flooding. The potato ridge would be overtopped during major floods, and the water control plan calls for degradation of the potato ridge prior to operation of the MCS. The MCS has been operated twice since construction was completed in 1954.

Figure 1. Ground elevations in the Morganza Control Structure Forebay and adjacent Mississippi River floodplain.



In mid-April 1973, failure of a wing wall and scour damage to the foundation of the Old River Control (ORC) Low Sill Structure prompted emergency operation of the MCS to reduce Mississippi River stages at the ORC, thus reducing head across and flows through the Low Sill Structure (Kaufman 1978). The estimated maximum diversion flow at the MCS in 1973 was 194,000 cfs through 42 gates. The observed drawdown between the Mississippi River and the MCS exceeded 2 ft during this operation with an observed forebay stage of approximately 56 ft.

In mid-May 2011, the MCS was operated to limit downstream Mississippi River flows to 1.5 million cfs. The stage in the forebay was 59.3 ft when MCS operations were initiated on 14 May 2011. The estimated maximum diversion flow was 182,000 cfs through 17 gates on 18 May 2011 (Maynord 2014). The observed drawdown through the forebay typically was less than 0.3 ft as determined by the difference in observed stages at gage MFI-4, located along the mainline Mississippi River Levee immediately upstream of the potato ridge, and at gage MD-8, located in the forebay approximately 400 ft south-southeast of the structure.[1]

1.2 Objectives

Flow conditions in and approaching the forebay were investigated with a two-dimensional (2D), hydrostatic, depth-averaged, numerical hydraulic model. In particular, the model was used to evaluate the influence of potato ridge and lower guide levee grades on flows entering and exiting the forebay along with associated energy losses within the system.

1.3 Approach

Four alternatives were proposed by the sponsor to investigate changes in flow patterns and stages that can be anticipated for various levee elevations and operating scenarios.[2] Each alternative was simulated for the rising limb and peak flows of a provisional project design flood (PDF) hydrograph (Figure 2) for two soft opening scenarios.[3] In the first soft opening scenario, MCS operation would begin 3 days before the Tarbert Landing discharge is projected to reach 1.5 million cfs. In the second soft

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[1] MCS gage records provided by William Veatch (MVN) on 26 Aug 2015.

[2] Personal communication with David Ramirez and Tzenge-huey (Jerry) Shih (MVN) from 10 Oct 2015 to 9 Dec 2015.

[3] Personal communication with David Ramirez, William Veatch, and Tzenge-huey (Jerry) Shih (MVN) from 25 April to 19 May 2016.

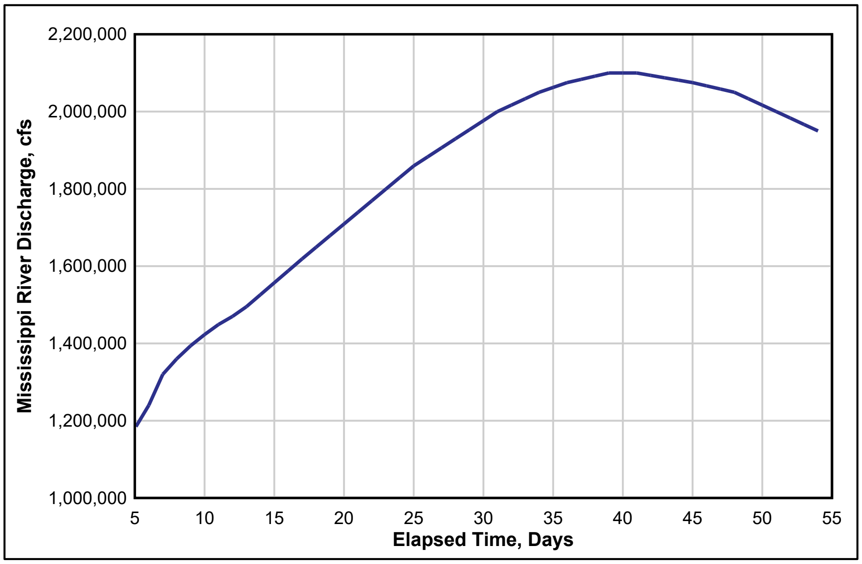
opening scenario, MCS operation would begin 3 days before the stage reaches 57 ft at the MCS (assuming a 1.5 million cfs inflow within 10 days). During the soft opening, a pair of lower leaf gates (or a single set of lower and upper leaf gates) would be opened each day until the Tarbert Landing discharge reached 1.5 million cfs. Afterwards, additional gates would be opened as needed to limit downstream flows in the Mississippi River to 1.5 million cfs.

The geometric alternatives evaluated were the following:

1. Plan 1: Potato ridge grade of 49 ft (currently authorized by the Water Control Manual) and lower guide levee grade of 60 ft (approximate 2011 condition).
2. Plan 2: Potato ridge grade of 49 ft and lower guide levee grade of 62 ft (current condition).
3. Plan 3: Potato ridge grade of 53 ft and lower guide levee grade of 60 ft.
4. Plan 4: Potato ridge grade of 53 ft and lower guide levee grade of 62 ft.

A base condition with the potato ridge grade set to 43 ft, the approximate average natural ground elevation along the ridge, was modeled to provide a baseline for comparison of alternatives and is referred to in this report as a fully degraded condition. Ground elevations in the forebay are generally higher near the upstream end and lower near the downstream end of the potato ridge.

Figure 2. Provisional PDF hydrograph at upstream model boundary.



2 Model Development

2.1 Adaptive Hydraulics (AdH) model

AdH is a multi-physics, finite element, numerical modeling system capable of automatically refining an unstructured computational mesh when necessary to resolve gradients in the flow field (Berger and Stockstill 1999). This numerical, hydraulic model investigation was conducted using the 2D, depth-averaged, shallow water equations describing open channel flow. The 2D model directly computes energy losses associated with changes in flow velocity and distribution within complex topography as exemplified by the lateral diversion of flow from the Mississippi River floodplain into the forebay.

The AdH code was modified for this investigation to permit direct computation of the MCS gate discharge based on computed stages in the forebay, a specified tailwater hydrograph, and a specified gate operation schedule. The modifications are discussed in section 2.3.

2.2 Geometric features

The model extends from St. Francisville, LA, at River Mile (RM) 262 upstream past the Tarbert Landing Discharge Range to RM 309.[1] Model limits are presented in Figure 3. Channel bathymetry was obtained from the 2004 Comprehensive Hydrographic Survey supplemented by river training structure information from the regional scale Mississippi River Hydrodynamic and Delta Management Study AdH model.[2] Floodplain topography, along with pre- and post-2011 levee grades, were obtained from multiple lidar datasets.[3] For compatibility with other nearby AdH models, the horizontal datum was set to Universal Transverse Mercator (UTM) Zone 15, North American Datum (NAD) of 1983 in feet. The vertical datum was set to the North American Vertical Datum (NAVD) of 1988. The finite element mesh contains 267,677 computation nodes assigned to 528,785 elements. The model geometry resolves the entrance to individual gate bays at the MCS allowing outflows to be specified at each gate bay.

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[1] River Miles are referenced to the 1962 mileage along the Lower Mississippi River beginning at Head of Passes.

[2] Brown, Gary L., et al. In preparation. Mississippi River Hydrodynamic and Delta Management Study: Delta Management Modeling.

[3] Acquisition of lidar datasets from 2003, 2007, 2010, and 2013 was coordinated with Dr. Jay Ratcliff (ERDC/CHL) from June 2015 to November 2015.

Figure 3. Model limits (red outline).

2.3 Model operation

Unsteady flow simulations require specification of a Mississippi River discharge hydrograph at the upstream boundary of the model and a stage hydrograph or a stage-discharge rating curve at the downstream boundary. These boundary conditions may be defined using historical records or hypothetical hydrographs. Unsteady flow simulations also require initial water depth and velocity fields that were generated for this investigation by computing a steady flow condition approximating the initial boundary conditions.

Two different options were used to simulate operation of the MCS. To simulate historical operations, a discharge hydrograph was specified for each MCS gate. This first option was used during simulations of the 2011 flood event. While this approach is reasonable and effective for historical operations, the usage of an externally defined gate discharge hydrograph for hypothetical operations can be inconsistent with model computations. For example, the model will enforce a specified gate discharge even if the computed available head at the MCS is too small to produce that discharge.

The gate discharge at any time is dependent on the gate status (closed, lower-leaf gate removed, or both lower- and upper-leaf gates removed), the forebay stage, and the tailwater. To avoid potential inconsistencies between computed and externally estimated forebay stage hydrographs, the AdH code was modified to permit computation of the gate discharge using the gate discharge equations developed during the post 2011-flood physical model study of the MCS (Maynord 2014). For half-opened gates (lower leaf removed), the controlled flow equations were applied to compute individual gate discharges at each time-step. For fully opened gates (both leaf removed), the uncontrolled flow equations were applied. The individual gate discharges were summed to determine the total diversion discharge through the MCS. This second option was used during simulation of the provisional PDF hydrograph and requires specification of an operating schedule for each gate and a tailwater hydrograph. For consistency with the physical model study and reported gage readings within the model domain, computed stages in this report are referenced to the National Geodetic Vertical Datum (NGVD) of 1929.

Tailwater submergence effects begin to reduce the computed gate discharge once the total diversion discharge exceeds approximately 270,000 cfs with a corresponding tailwater of 48 ft. For simulations with the provisional PDF hydrograph, the tailwater hydrograph was estimated from a stage-discharge rating curve developed during the physical model study. While inconsistency between the computed discharge and the estimated tailwater hydrograph remains possible with this option, the total MCS diversion discharge may be reasonably approximated based on the operational requirement to limit downstream Mississippi River flows to 1.5 million cfs. For diversion discharges exceeding approximately 530,000 cfs (with an estimated tailwater of 54 ft), the submergence corrections to the controlled flow gate discharge equations must be extrapolated beyond the range of the measurements made in the physical model.

The primary limitation of the second option is that development of a gate operation schedule requires multiple model simulations to balance the computed forebay stage and the total MCS discharge with the required diversion discharge. Daily gate opening and closing requirements were estimated based on flow diversion requirements for the next 24 hours along with the corresponding maximum tailwater and the estimated minimum forebay stages during that period. Pairs of gates were opened or closed at 15-minute intervals starting at the beginning of an elapsed simulation day (i.e., at 8 a.m. each day). If the computed diversion discharge was insufficient, the computed minimum forebay stages would be used to guide updates to the gate operation schedule, and the process would be repeated. Additional logic, similar to the HEC-RAS Rules Editor for operation of hydraulic structures, would be required in AdH to bypass this limitation (USACE 2016).

For the design diversion discharge of 600,000 cfs and the corresponding estimated tailwater of 55.6 ft, the uncontrolled flow gate discharge equations require a forebay stage of at least 57.3 ft to pass the design flow with all 125 gates fully opened. Under these conditions, submergence effects reduce the discharge by approximately 44%. That reduction is slightly above the upper limit of 40% of the range of submergence conditions evaluated during the physical model experiments. The submergence effects are sensitive to the estimated tailwater. For example, reducing the estimated tailwater by 1 ft would decrease the required forebay stage by 0.8 ft.

The gate discharge equations were developed with a least one adjacent gate closed on both sides of each open gate. This configuration would be expected to result in a larger pier contraction coefficient (i.e., greater head loss in the flow approaching the gate, than configurations where multiple adjacent gates are open). Thus, these equations may underestimate gate discharge for diversion flows approaching the design discharge of 600,000 cfs when multiple adjacent gates are fully or partially open. However, limited physical model tests with adjacent gates open actually showed an increased head loss in the approach flow (Maynord 2014).

2.4 Hydraulic circumstantiation

Model circumstantiation efforts focused on reproduction of observed stages during MCS operations in May of 2011 and for a typical mid-bank, in-channel flow. Hydraulic roughness coefficients were assigned by finite element mesh material type as presented in Table 1. These coefficient values reproduce observed stages at Red River Landing within 0.1 ft.

Observed stages at gages MFI-4 and MA-1 near the upstream entrance to the potato ridge were reproduced to within 0.5 ft.

Very little information on current speed and direction is available within the area of interest. The model does show flow entering the forebay across the upper portion of the potato ridge and exiting back towards the river over the lower portion when the MCS is not in operation and when diversion flows are less than approximately 300,000 cfs. An example is presented in Figure 4. This pattern is consistent with visual observations reported by multiple observers.[1]

Table 1. Hydraulic roughness coefficients.

Classification	Materials	Manning's *n*-value
River channel	1	0.025
Floodplain	2, 7	0.057
Training Structures	3	0.048*
Floodplain Lakes	4	0.02
Levees	5	0.03
Forebay	6	0.03

*Approximate value based on a specified effective roughness height of 4 ft.

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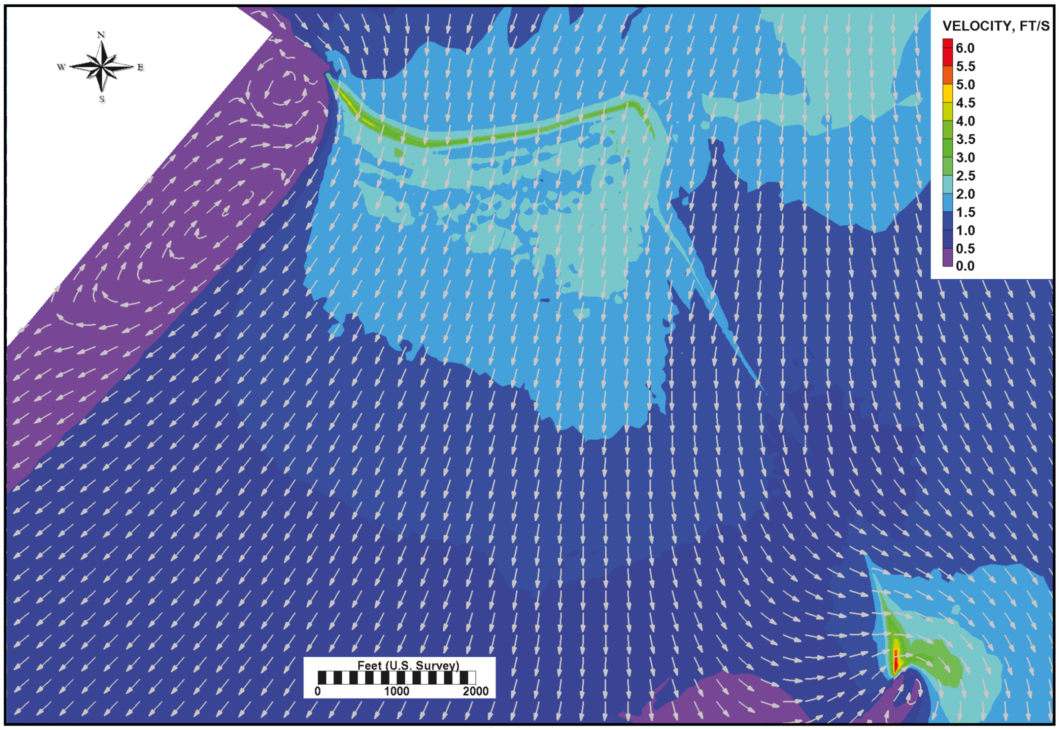
[1] Personal communication with Russell Beauvais and Kayla LeBlanc (MVN), 11 June 2015, and William Butler (ERDC/CHL), 19 January 2016.

Figure 4. Computed velocity pattern over the potato ridge at the entrance to the forebay for existing conditions with an MCS diversion flow of 181,000 cfs.



Confidence in the current adjustment is limited primarily by three factors. First, very little bathymetric data were available for Raccourci Old River, an oxbow lake immediately upstream of the forebay, and thus the conveyance of flow through the lake could be significantly different than model estimates. Second, no data were available at the outset of the study to confirm the computed distribution of flow between the river and the floodplain. Comparisons of computed and observed flow distributions would provide an additional constraint on the range and combinations of hydraulic roughness values that would reproduce observed stages. Finally, there are uncertainties in the estimated inflows into the modeled reach derived from discharge measurements at Tarbert Landing (Oberg et al. 2012).

During model simulations of the 2011 flood, computed discharge in the 10-mile wide, left overbank of the Mississippi River at the latitude of Morganza, LA, approached 1 million cfs, approximately two-thirds of the total flow. Review of the model computations indicated that this result was plausible but would be sensitive to estimated hydraulic roughness in floodplain. During January of 2016, flow measurements were collected throughout the model domain that will provide insights into flow distributions between the channel and adjacent floodplains. The measured flow in the Mississippi River channel near Morganza, LA, was only approximately half of the total flow near the peak of the 2016 flood event indicating that the remainder of the flow is conveyed by the floodplain.[1] This information lends some credibility to the flow distribution computed by the model for the larger 2011 event, but additional model simulations are needed to refine hydraulic roughness estimates.

Model development has progressed to a point that permits application of the model to determine relative impacts of proposed levee grades and operating schemes on stages and current patterns. Additional refinements to the model, particularly incorporation of additional bathymetric data for Raccourci Old River and comparison of observed and computed flow distributions between the river and floodplain, would serve to increase confidence in computed results.

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[1] Personal communication with William Butler and Terry Waller (ERDC/CHL), January 2016.

3 Analysis of Alternatives

For comparison of alternatives, a gate operating schedule was developed for the base condition geometry with the potato ridge grade set to 43 ft over a distance of 10,000 ft. This geometry approximates a fully degraded potato ridge. As previously noted, the development of the selected gate operating schedule required multiple simulations to iteratively adjust the number of gate openings required each day to meet targeted flows. This iterative development process was terminated once peak computed flows in the Mississippi River at St Francisville exceeded the 1.5 million cfs limit by less than 1%.

The selected gate operating schedule is a modified version of Plan A, a proposed operating plan to reduce downstream scour potential (Maynord 2014). For diversion flows in excess of 520,000 cfs, additional gates were opened to compensate for computed forebay stages that were lower than the assumed stage in the original Plan A. The modified version utilized 119 gates with 96 gates fully opened and 23 gates half opened during a 4-day period at the peak of the provisional PDF hydrograph and produced a peak MCS diversion discharge of 597,000 cfs. The selected gate operating schedule was used for the model simulations of the alternatives discussed in this report. As the discharge through the MCS increases, the incremental discharge added by each additional gate opening decreases. Thus, the pace of gate operations tends to quicken with increasing flow. With the selected gate operating schedule, as many as 16 gates per day were transitioned from half to fully open.

Computed stages on either side of the lower guide levee did not exceed 59 ft for any of the alternatives, so the lower guide levee did not overtop during any of the provisional PDF hydrograph simulations. Significant wind waves were observed in the forebay during the 2016 Flood event.[1] Thus, at a grade of 60 ft, the lower guide levee could experience brief periods of overtopping due to wind events.

The following discussion of potato ridge grade impacts is based on simulations of the first soft opening scenario, where MCS operations are

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[1] Personal observations, David P. May (ERDC-CHL), 31 December 2015.

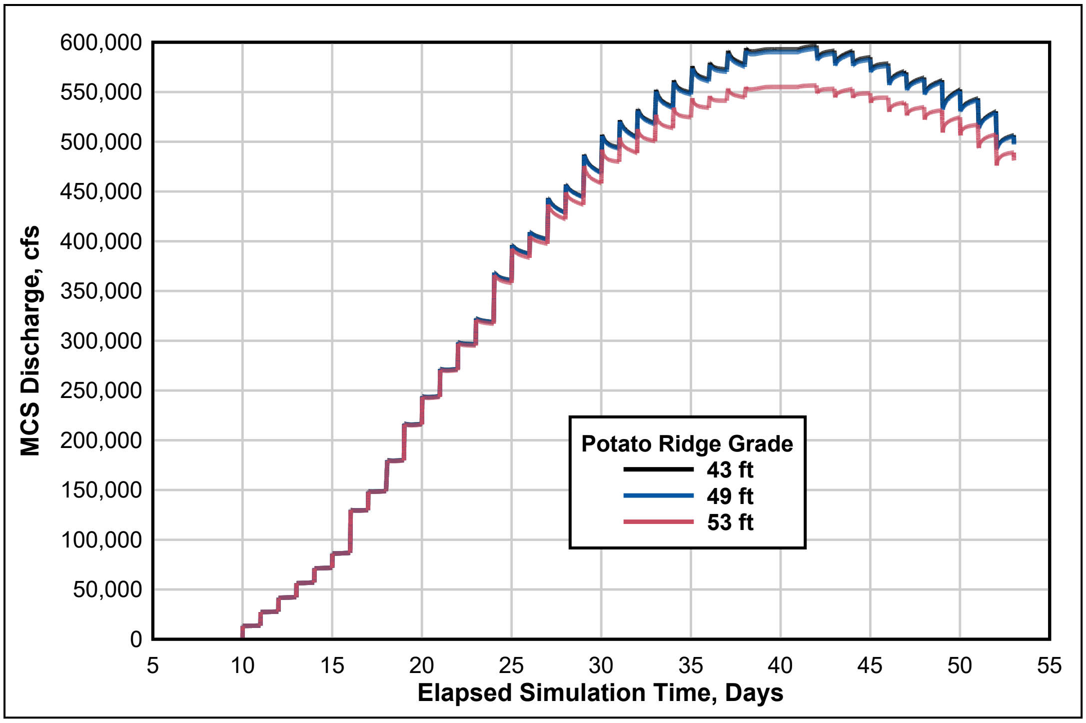
initiated 3 days before the Mississippi River flow reaches 1.5 million cfs. The second soft opening scenario is discussed in section 3.2.

3.1 Potato ridge grade impacts

For the base condition geometry, the computed stage at the peak of the PDF, Plate 1, drops approximately 1.4 ft over the length of the forebay (including energy loss over the potato ridge but excluding localized drawdown due to increased flow velocity immediately upstream of the MCS). The steepest hydraulic gradients occurred at the upstream end of the potato ridge where a non-degraded portion of the transition between the potato ridge and the MR&T levee is overtopped. Note that computed stages at the peak are higher on the Mississippi River side of the lower guide levee than in the forebay. Thus, the lower guide levee serves to increase stages in the forebay and the head available for MCS operation.

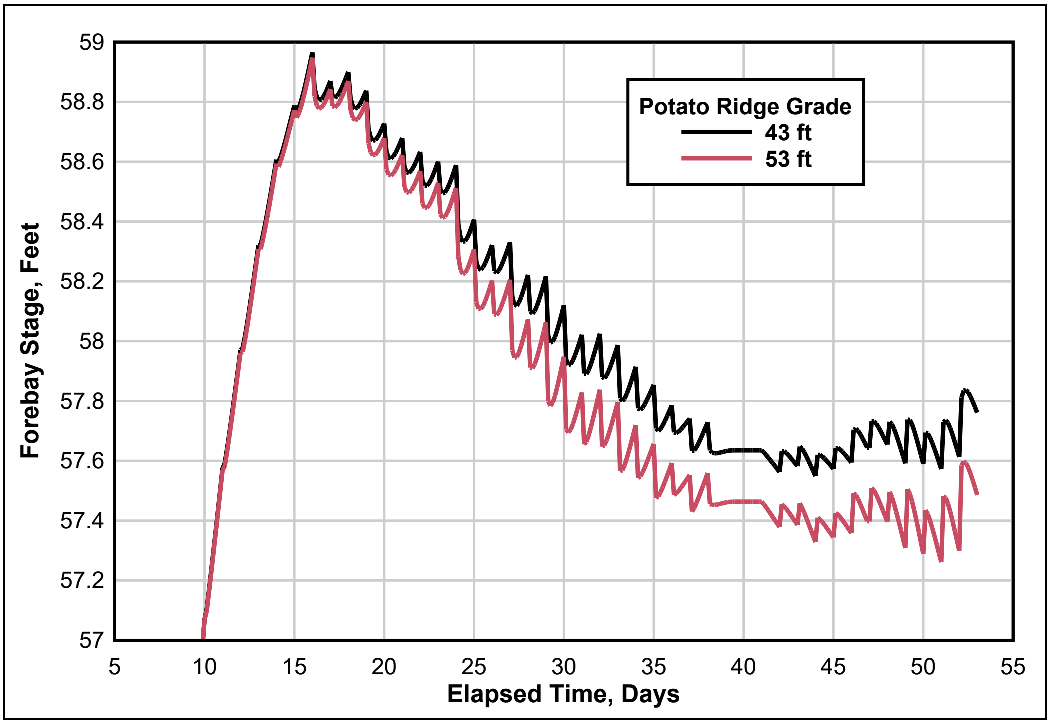
In contrast, computed stage at the peak of the PDF, Plate 2, drops approximately 1.8 ft over the same distance for plans 3 and 4 with the potato ridge grade set to 53 ft. The increase of 0.4 ft as compared to the base condition is roughly split between stage reductions inside the forebay and stage increases outside the levees. The reduction in forebay stages reduced the head available for operation of the MCS; thus, the computed MCS discharge at the peak of the PDF hydrograph was reduced by almost 7% as presented in Figure 5. For plans 1 and 2 with the potato ridge grade set to 49 ft, the corresponding reduction in MCS discharge was less than 1%.

Figure 5. Impact of potato ridge grade on total computed MCS diversion discharge for provisional PDF hydrograph and selected gate operation schedule.



The computed MCS discharge hydrograph, Figure 5, illustrates the impact of daily gate operations on system behavior. The gate operating schedule discussed in this section incorporated the soft opening schedule based on a discharge forecast exceeding 1.5 million cfs. For diversions of less than 250,000 cfs, opening additional gates simply increased the discharge; the tailwater submergence effect is not significant. For diversions over 300,000 cfs, the initial increase in diversion discharge is offset by the combined effects of decreasing forebay stages and increasing tailwater enough to decrease diversion discharge by as much as 17,000 cfs before the next day. The sensitivity of the diversion discharge to forebay stage is illustrated in Figure 6 by the difference in computed stages for potato ridge grades of 43 and 53 ft where a stage reduction of less than 0.2 ft causes the 7% reduction in diversion discharge presented in Figure 5. While the stage-induced discharge reduction at an individual gate was less than 400 cfs, the cumulative reduction through over 100 gates represented a significant loss of diversion discharge capacity for the potato ridge grades of 53 ft. The computed minimum forebay stages occurred after the flood peak and must be considered in the gate closure sequence.

Figure 6. Forebay stage response to the selected gate operating schedule for the provisional PDF hydrograph.



As previously noted in section 2.3, the gate discharge and tailwater rating equations developed during the physical model study may be solved to estimate the minimum forebay stage that will provide the design discharge of 600,000 cfs with all 125 gates fully opened (Maynord 2014). The computed stages at the hydrograph peak for the potato ridge grade of 53 ft were less than 0.15 ft above the minimum required stage of 57.3 ft.

System behavior may also be illustrated by the response of a single gate. Figure 7 presents the discharge hydrograph for gate 61, one of the first pair of gates opened. The lower leaf gate was opened on day 10 while the forebay stage was steadily increasing and tailwater submergence effects were insignificant. The gate discharge increased until day 16 when the forebay stage peaks and begins to fluctuate. The upper leaf gate was opened on day 17, and gate discharge rapidly increased by 30%. Subsequently, the gate discharge began to decrease, initially in response to falling forebay stages and also, after day 20, to increasing tailwater submergence. By the peak of the PDF hydrograph, the gate discharge had decreased 40% from the initial fully open gate discharge. This reduction in individual gate discharge was fully offset by activation of additional gates. The computed Mississippi River discharge hydrograph at the downstream boundary of the model near St. Francisville, LA, is presented in Figure 8.

While a potato ridge grade of 49 ft had no significant impact on flows as compared to the base grade of 43 ft, raising the grade to 53 ft reduced discharge for a fully open gate by as much as 375 cfs. This difference, multiplied by 96 fully open gates, accounted for over 90% of the increased Mississippi River discharge at St Francisville computed for the higher potato ridge grade.

While operating additional gates would permit an increase in MCS diversion discharge with a potato ridge grade of 53 ft, this increase would be accompanied by additional reductions in the forebay stage and corresponding decreases in individual gate discharge. Given an allowable reduction in computed forebay stage of less than 0.15 ft and uncertainties in various model inputs and parameterizations, such as extrapolation of the gate equations and estimates of hydraulic roughness coefficients and tailwater, a model demonstration of this option would most likely be inconclusive.

Figure 7. Computed discharge hydrograph for gate 61. The lower leaf gate is removed on day 10, and the upper leaf gate is removed on day 17.

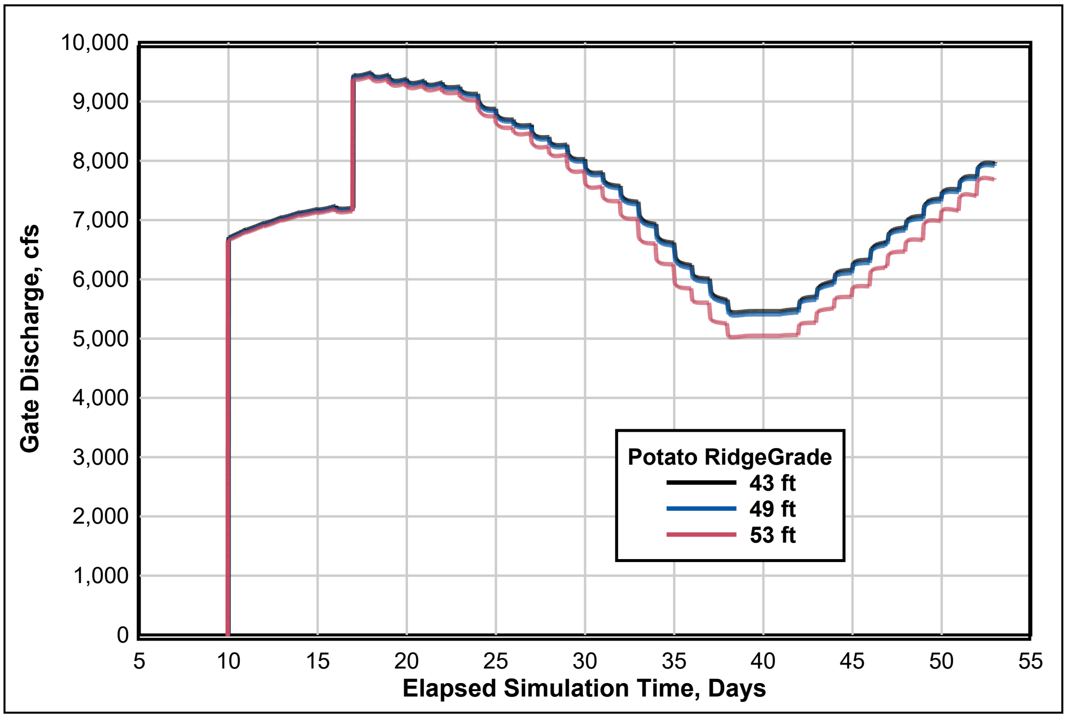
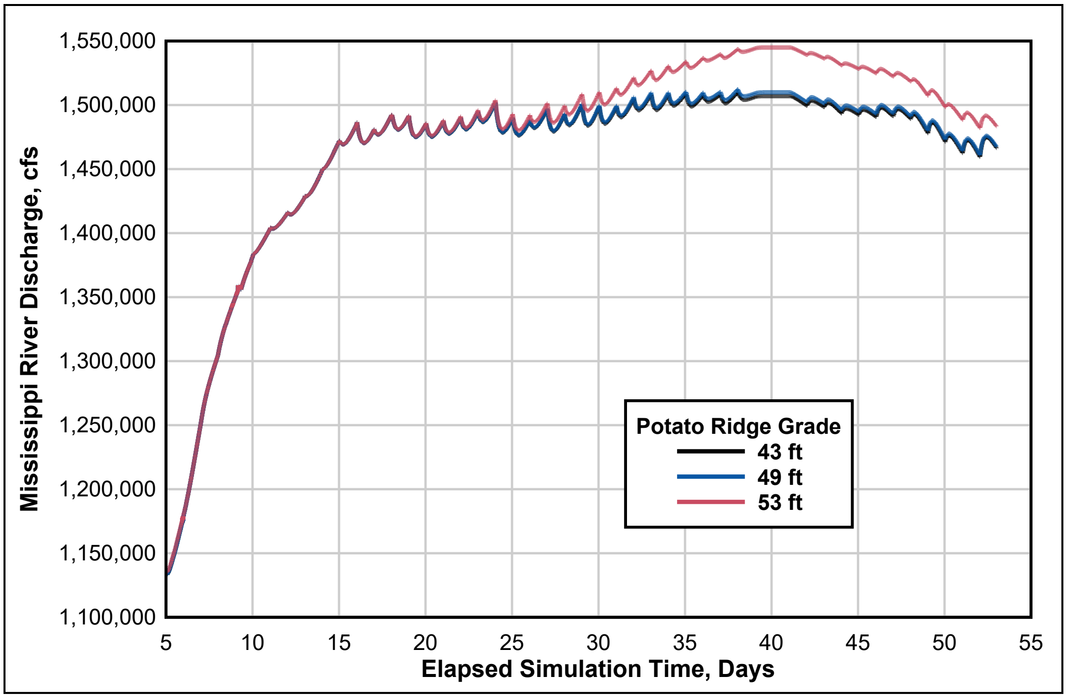


Figure 8. Computed discharge hydrograph at the downstream boundary of the model near St. Francisville, LA.



3.2 Soft opening schedule impacts

Simulations of both soft opening schedules produced no significant changes in computed stages or discharges for Mississippi River flows at Tarbert Landing greater than 1.6 million cfs. For both soft opening scenarios, the lower leaf gates were opened for a pair of gates each day until the Tarbert Landing discharge reached 1.5 million cfs, and subsequent gate openings were scheduled to limit Mississippi River discharges downstream of the MCS. In the first soft opening scenario, one pair of gates per day was opened for the first 6 days with the last pair required to meet the downstream Mississippi River discharge limit of 1.5 million cfs. In the second opening scenario, one pair of gates per day was opened for the first 9 days after. No additional gates were opened until 4 days later when required by increasing Mississippi River discharges.

The second soft opening scenario, based on a 57 ft stage forecast threshold, produced a smaller initial diversion flow, as presented in Figure 9 for gate 61 and as presented in Figure 10 for the entire MCS. Initially, opening gates on day 5 of the simulation instead of day 10 reduced stages in the forebay between days 10 and 17 by less than 0.8 ft. This reduction in stage accounted for the slight reduction in gate discharge. The model simulations presented here were conducted for the base condition, potato ridge grade of 43 ft. The potato ridge grade had no significant effect on model behavior during the soft opening sequences. Increasing the potato ridge grade above 53 ft would delay flooding of the forebay and initiation of the second soft opening scenario.

Figure 9. Comparison of computed discharge hydrographs at gate 61 for soft opening scenarios.

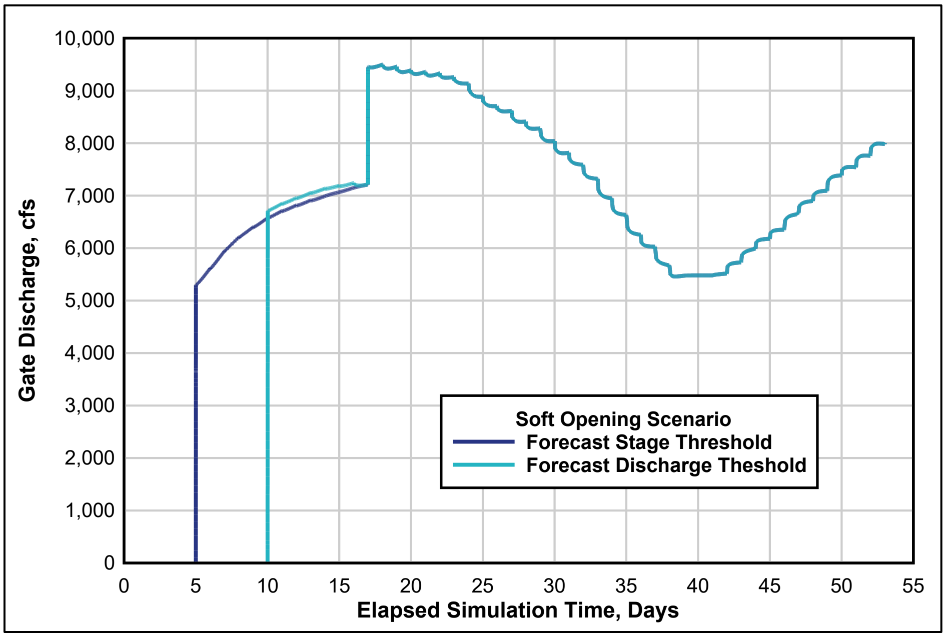
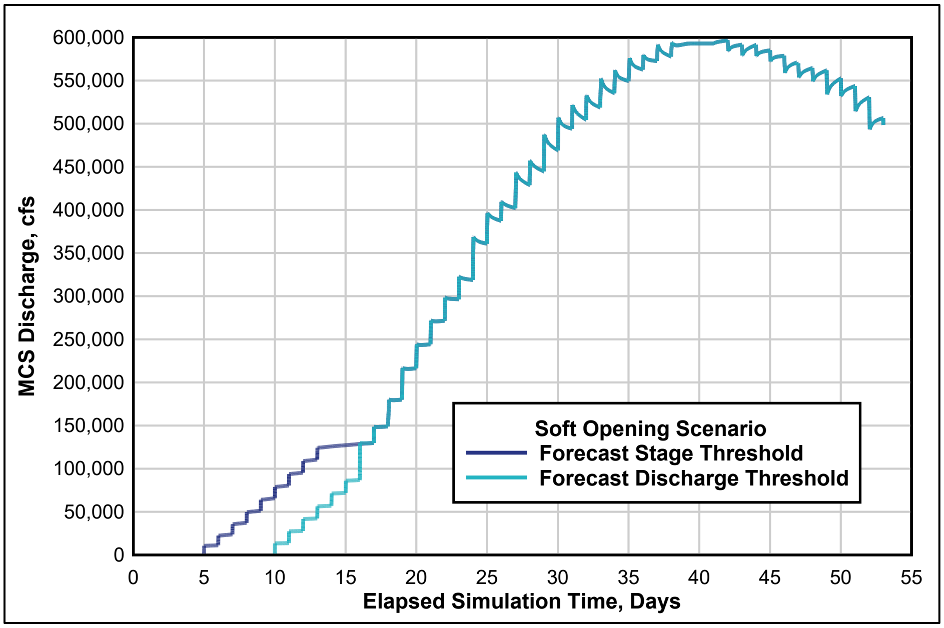


Figure 10. Impact of soft opening scenario on total computed MCS diversion discharge.



3.3 Hydraulic conditions at the potato ridge

Velocity contour maps for the peak of the provisional PDF hydrograph with potato ridge grades of 43, 49, and 53 ft are presented in Plates 3-5. In all cases, the highest computed velocities occurred near both ends of the potato ridge where flow must turn into the forebay and pass over transitions to higher adjacent levees. Computed velocities over the upstream end of the potato ridge ranged from 10 to 16 feet per second (fps), and this area has the greatest potential for local scour. Peak computed velocities were lower at the downstream end of the potato ridge; however, this area may experience a greater duration of high velocities. In general, increasing the height of the potato ridge produced a more uniform distribution of flow into the forebay accompanied by higher velocity and greater local head loss.

As compared to the base condition, the primary difference in the computed velocity field for plans 1 and 2 was a localized increase in velocity as flow passed over the potato ridge. The increase in grade from 43 ft to 49 ft did not significantly redistribute flows entering the forebay. Therefore, the additional head loss associated with the higher grade was relatively small and did not affect the overall performance of the system. In contrast, increasing the potato ridge grade to 53 ft forces a portion of the flow to pass over the ridge farther downstream. The additional head loss over the potato ridge due to this redistribution of flow was sufficient to reduce forebay stages (Figure 6) and the total flow diverted through the MCS (Figure 5).

4 Discussion

This numerical hydraulic model investigation demonstrated that the potato ridge grade can have a significant impact on the overall performance of the Morganza Control Structure. At the design discharge of 600,000 cfs, the system is sensitive to small changes in the available head. In particular, gate discharge becomes increasingly sensitive to stages in the forebay and to tailwater submergence effects as the total MCS discharge approaches the design discharge. The cumulative effect of small changes in gate discharge (the consequence of changes in head) multiplied by over 100 gates is sufficiently large to affect overall performance. Also, the number of gate changes required to effect a given change in MCS discharge increases as the total diversion flow approaches the design flow, a factor that needs to be considered in planning structure operations.

At a grade of 49 ft, the impact of the potato ridge on diversion flows during simulation of the provisional project design flood hydrograph was negligible as compared to the degraded (43 ft) condition specified in the base condition. Increasing the grade to 53 ft reduced computed stages in the forebay by approximately 0.2 ft. That reduction in available head was sufficient to reduce total MCS discharge by 7%. A forebay stage of 57.3 ft is the estimated minimum stage permitting a diversion flow of 600,000 cfs. For a diversion flow of 550,000 cfs and a potato ridge grade of 53 ft, the computed stage was less than 0.15 ft above this threshold.

During the Mississippi River Flood of 2016, simulations were conducted with an earlier version of this model to evaluate the impacts of partially degrading the potato ridge. Those simulations were conducted before AdH was modified to permit internal computation of gate discharge and did not fully resolve the viability of partial degradation as an option for maintaining the diversion discharge capacity of the system. This option may be worth reconsideration in future model studies.

The model computed significant hydraulic gradients at both ends of the potato ridge near the transitions to higher adjacent levees. Computed velocities near the upstream end of the potato ridge at the peak of the project design flood hydrograph ranged from 10 to 16 fps, indicating a significant potential for local scour.

Differences in computed flows at the transition between the lower guide levee and the potato ridge were not significant to overall system performance. Therefore, the grade of the lower guide levee did not affect overall modeled system performance during simulation of the PDF since computed stages did not exceed the lower levee grade specified in plans 1 and 3. Peak computed stages and field observations indicate that the lower guide levee may be susceptible to wind wave overtopping at the lower levee grade. Model simulations imply that the length of the lower guide levee does have a potentially significant impact on available head in the forebay and on upstream Mississippi River stages.

5 Conclusions and Recommendations

This model, like all models, has limitations and uncertainties. Four issues were identified during this model investigation that should be considered in future efforts to model the system.

Analysis and modeling of flow distributions between the channel and floodplain measured during the 2016 flood would improve estimates of hydraulic roughness in the channel and floodplain. Flow distribution between the channel and floodplain is a significant model variable in all hydraulic and sedimentation models. In hydraulic models, incorrect assumptions may limit the reliability of computed stages when model flows are extrapolated beyond historical flows. In sedimentation models, incorrect assumptions may influence computed sedimentation processes throughout the full range of modeled flood flows. In the case of the forebay, small changes in the computed riverside stages along the potato ridge could significantly alter the diversion discharge capacity of the system. Also, during any future operation of the MCS, temporary stage recorders should be deployed within the forebay and on both sides and ends of the potato ridge to provide higher resolution validation data for any future analysis of system behavior.

A single-valued rating curve, developed during the physical model study (Maynord 2014) was used to define a tailwater hydrograph during simulations of the provisional PDF, and the system was modeled as if the tailwater were an independent variable in the system. The tailwater hydrograph is actually interdependent with gate discharges and should be determined as an integral part of a complex unsteady flow system. A logical next step in modeling this system would be to couple this model with an existing model of the Morganza Floodway (Bell et. al. 2017). The modifications to AdH permitting internal computation of gate discharge are a significant first step towards that goal. Additional enhancements to the AdH code, similar to the HEC-RAS Rules Editor for structure operations, would significantly reduce or eliminate the need to iteratively define gate operation schedules. A long-term goal should be to incorporate the Old River Control Complex into the coupled model.

The provisional PDF hydrograph employed in this study was developed by extending the 2011 flood hydrograph to the design flood discharge 1.5 million cfs at Tarbert Landing. Revisions to PDF hydrograph, under development at the time of this study, should be evaluated in the coupled model.

For MCS diversion discharges in excess of 530,000 cfs, the gate discharge equations developed during the physical model study (Maynord 2014) were extrapolated beyond the range of the measured data. Some additional analysis, possibly a comparison with hydraulic design criteria for similar structures, should be conducted to validate or revise the extrapolated curves. Additionally, the coupled AdH model, proposed above, could directly compute the flow through the structure for these higher diversion discharges when the head differential across the MCS is relatively small compared to the water depth. While this approach also has limitations, it would provide insights into the behavior of flows approaching the MCS that could not be fully resolved with the limited spatial extent of the physical model.

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Plates

PLATE 1. Computed stage contours at peak project design flood discharge with potato ridge grade of 43 ft (Base condition).

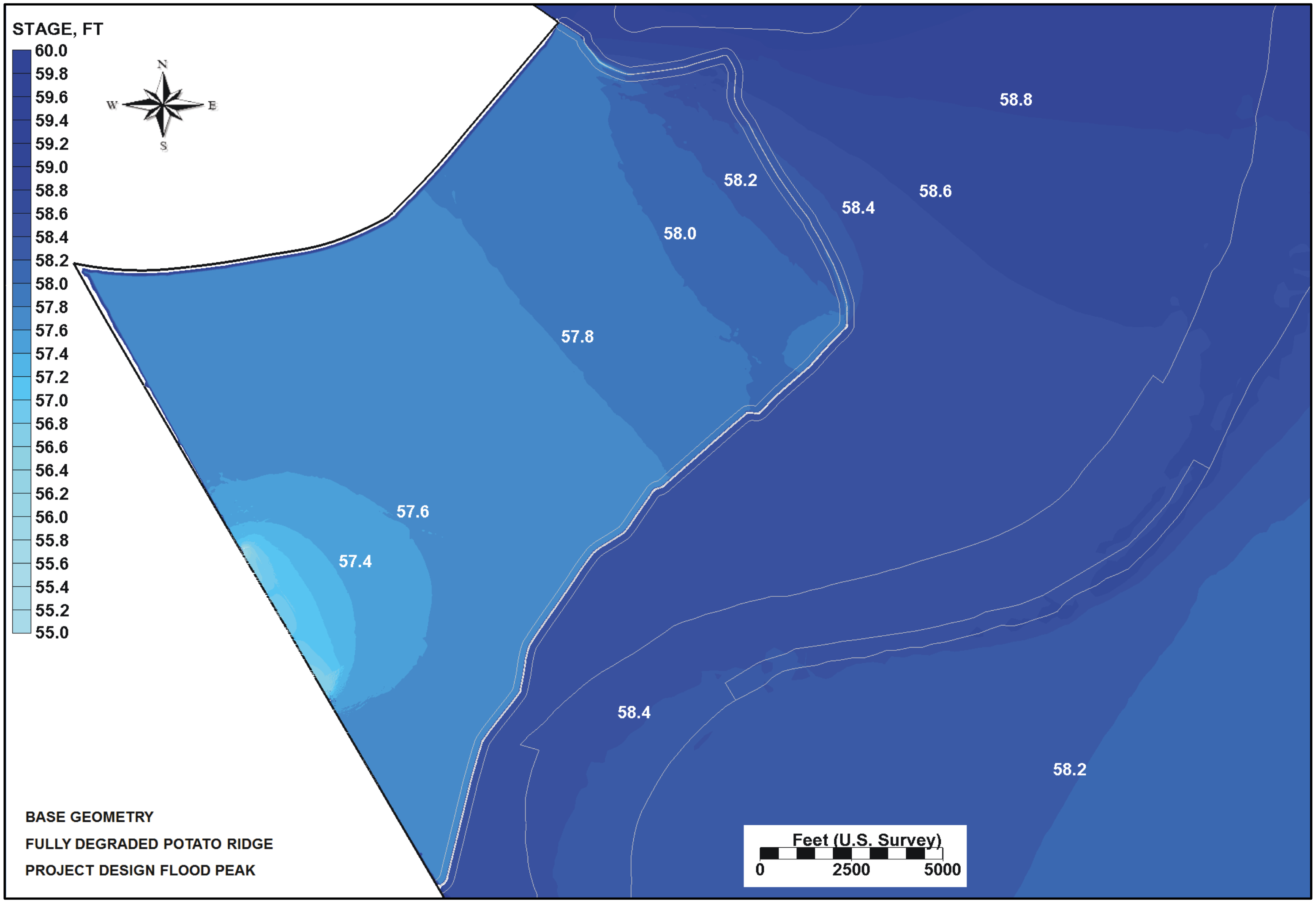


PLATE 2. Computed stage contours at peak project design flood discharge with potato ridge grade of 53 ft (Plan 4).

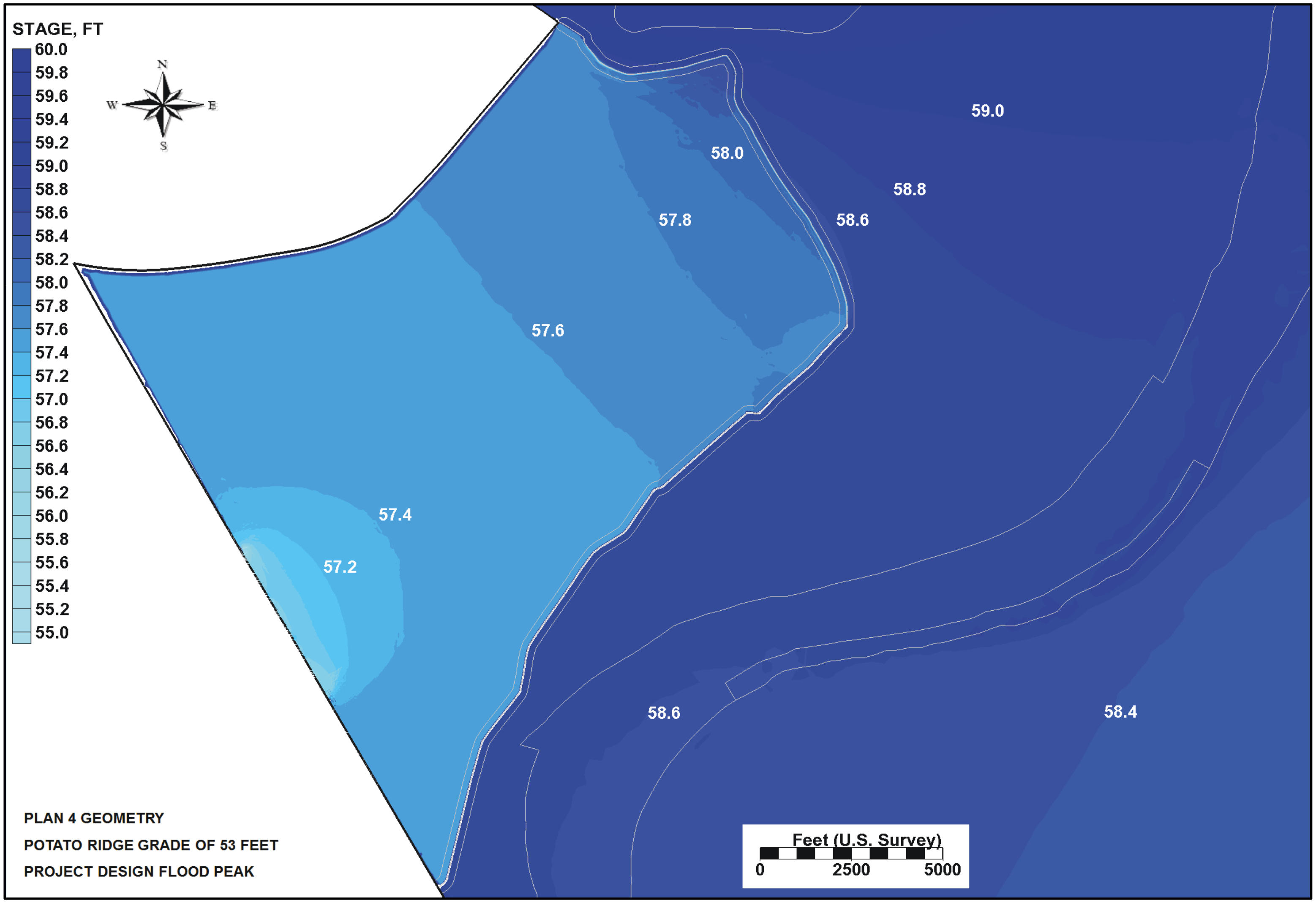


PLATE 3. Computed velocity contours at peak project design flood discharge with potato ridge grade of 43 ft (Base condition).

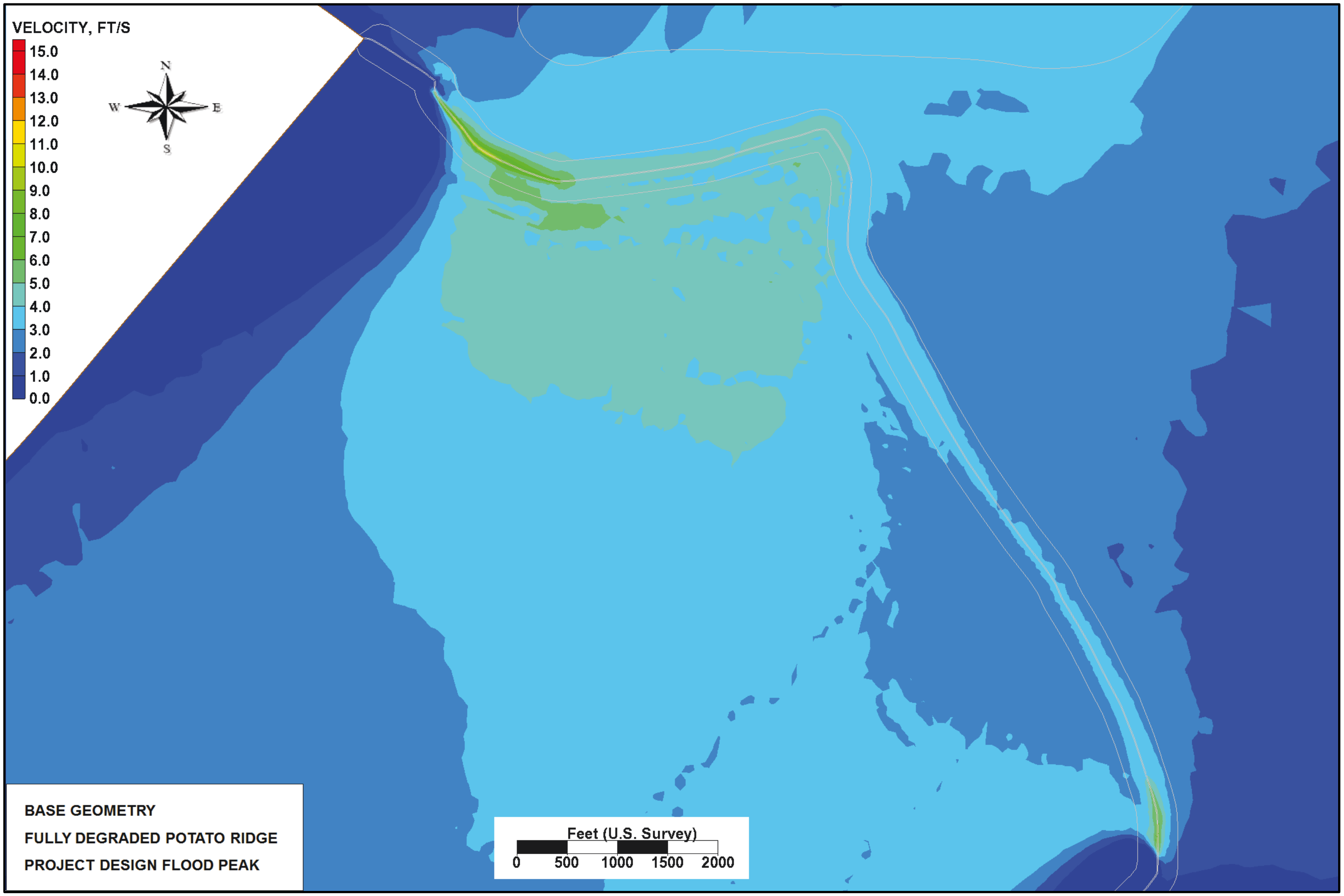


PLATE 4. Computed velocity contours at peak project design flood discharge with potato ridge grade of 49 ft (Plan 2).

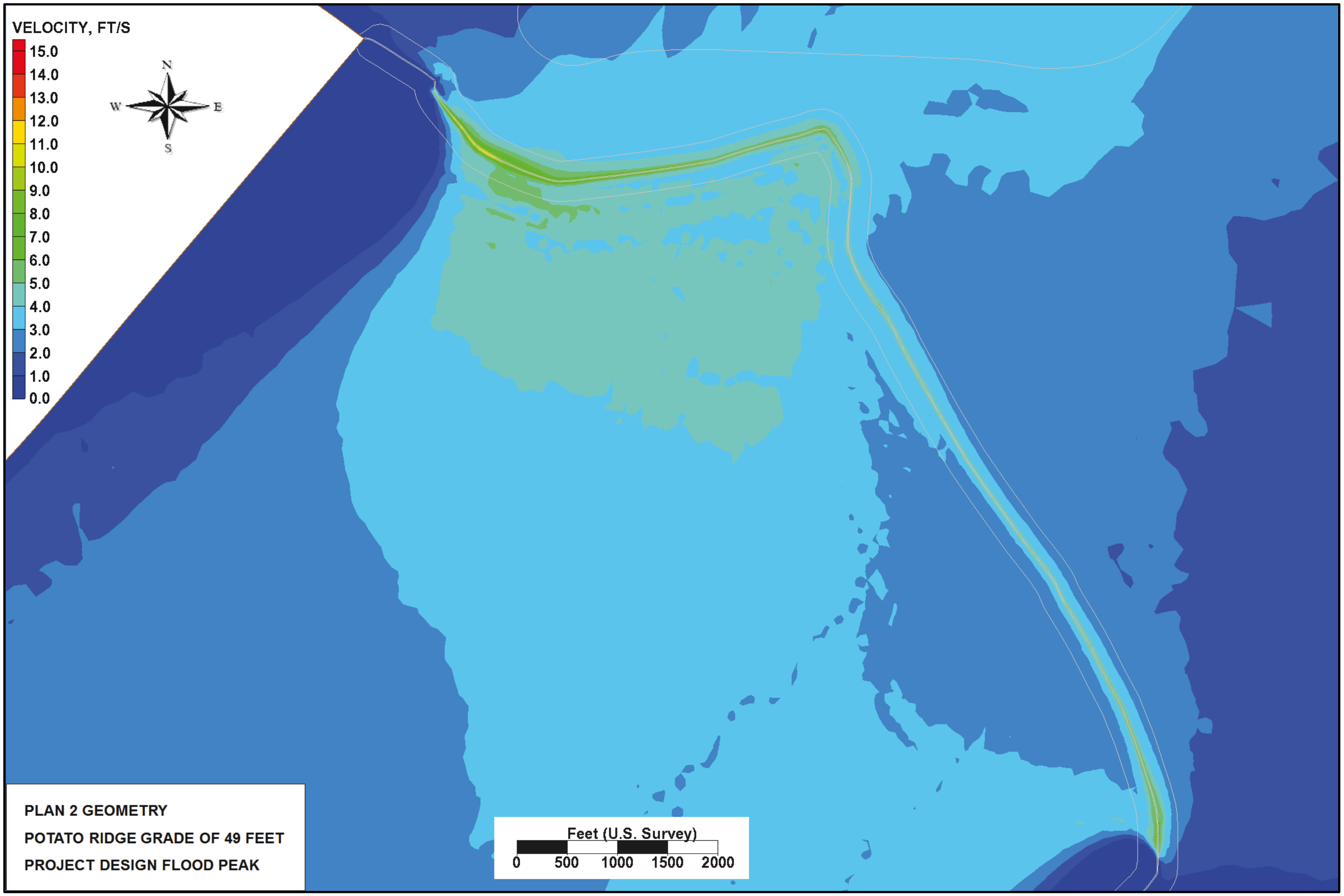
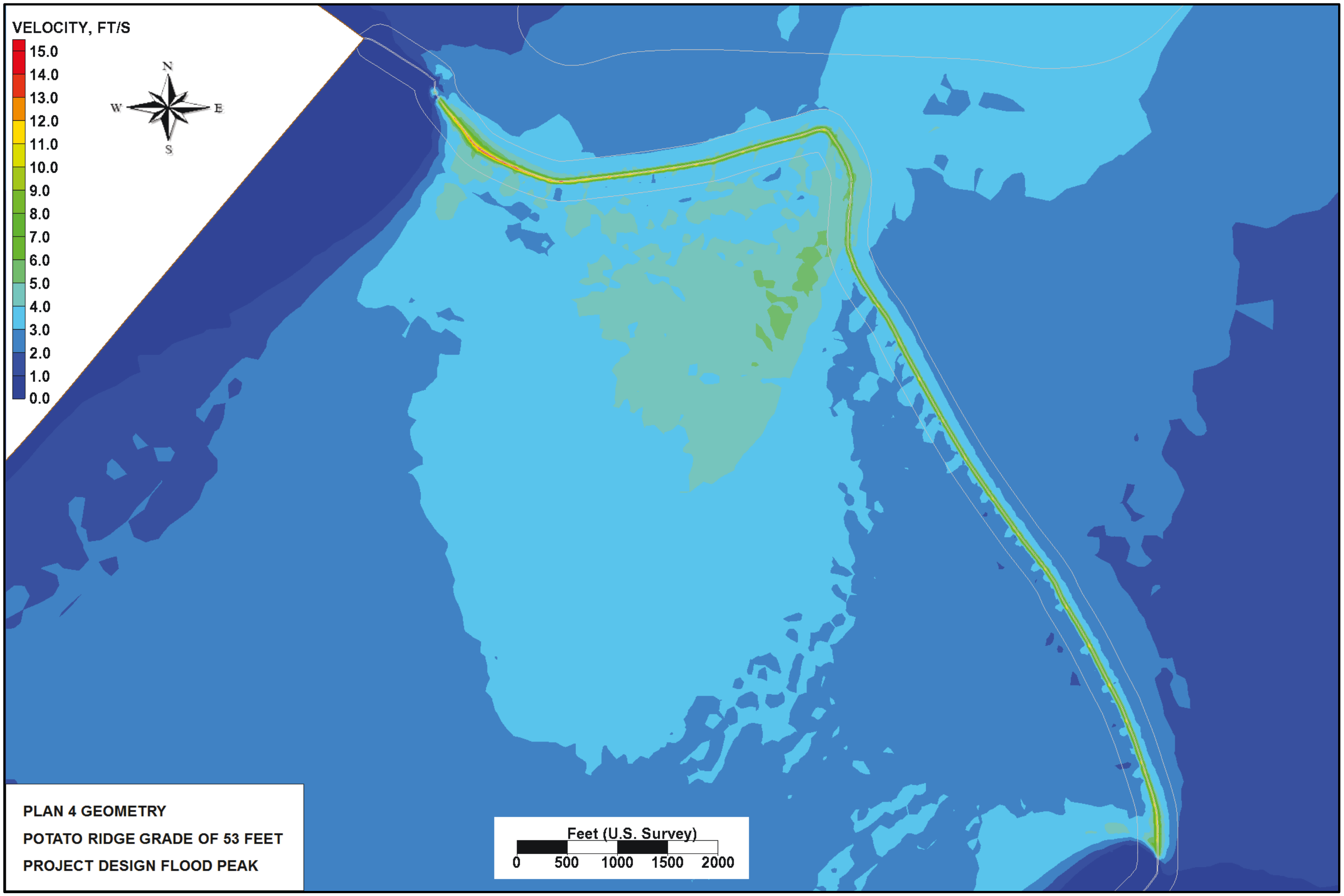


PLATE 5. Computed velocity contours at peak project design flood discharge with potato ridge grade of 53 ft (Plan 4).



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14. ABSTRACT
Flows and water levels within and approaching the Morganza Control Structure Forebay were investigated with an Adaptive Hydraulics model. The model was used to evaluate the influence of the potato ridge and lower guide levee grades on energy losses and flow patterns within the forebay. The diversion discharge capacity of the Morganza Control Structure is sensitive to computed water levels in the forebay and to estimated water levels at the entrance to the Morganza Floodway. Computed water levels in the forebay are determined by Mississippi River stages and energy losses across the potato ridge and within the forebay. The model simulated Morganza Control Structure operations and diversion discharge under two soft opening scenarios for a provisional project design flood hydrograph. The model demonstrates the potential impacts of the potato ridge grade on the discharge capacity of the Morganza Control Structure. The Adaptive Hydraulics code was modified to permit computation of individual gate discharges based on available operating head across the structure. Additional code enhancements are needed to simplify specification of structure operating rules. These modifications will support future coupling of this model with the Morganza Floodway model and development of a similar coupled model for the Old River Control Complex.

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