Prepared in cooperation with U. S. Fish and Wildlife Service

Simulated Flooding Effects of Proposed Water-Control Structures for Lake Tecumseh and Adjacent Wetlands in Virginia Beach, Virginia

By Jefferson N. Keaton

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Velocity	
foot per second (ft/s)	0.3048	meter per second (m/s)
	Flow Rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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Abstract

The U.S. Geological Survey, in cooperation with the U.S. Fish and Wildlife Service, modified an existing Storm Water Management Model (SWMM) to evaluate the flood-reduction potential of utilizing water-control structures as part of a management plan for Lake Tecumseh and adjacent wetlands in the City of Virginia Beach, Va. Two different management strategies for six design storms and two initial water-surface elevations were evaluated. The management strategies included (1) installing a set of parallel flap gates in a dredged channel, Canal 1, downstream of the lake and wetlands to keep wind-driven tides out of the system; and (2) installing weirs on the outlets of the lake to stabilize water levels in the lake. A series of model scenarios was developed to evaluate how each strategy would affect flooding in the city's storm-drainage system for the 2-, 10-, 25-, 50-, 100-, and 500-year design storms during a median and maximum, wind-driven tide water-surface elevation measured in the drainage system. Results of the model simulations indicate that the proposed structures would not contribute to upstream flooding in the drainage basin known as Watershed 9, although at a few locations upstream, water-surface elevations were higher than existing conditions as a result of the structures. Results of simulations of the tide-gate strategy during times of high, wind-driven tides indicate that, at some locations, upstream water-surface elevations were lower as a result of the gates. For a few locations, the tide gates reduced flooding during times of high tide. Simulations of the second possible strategy, installing weirs at the lake outlets, showed minimal effects on upstream water-surface elevations for either initial condition for any design storm. Flooding in the city's drainage system is largely alleviated by ample storage space in Lake Tecumseh.

Introduction

The ecological structure and function of Lake Tecumseh, the Back Bay Estuary, and surrounding wetlands near the City of Virginia Beach, Va., have been altered, partially because of sedimentation and changes in hydrology caused by development and canal-dredging activities. One of the foremost causes of these alterations is a dredged channel (Canal 1) that runs from Old Dam Neck Road northeast of Lake Tecumseh to the North Bay portion of the estuary (fig. 1) that allows wind-driven tides to regularly flow into the lake and surrounding wetlands. The following effects have been attributed to the routine flooding of the lake and wetlands:

- Decrease in the stormwater storage capacity of Lake Tecumseh.
- Transformation of portions of the adjacent wetlands from forested to emergent.
- Decrease in submerged aquatic vegetation in the lake from resuspension of fine sediments and the related increase in turbidity.

The U.S. Fish and Wildlife Service (USFWS) received a grant under the North American Waterfowl Conservation Act to acquire and restore Lake Tecumseh and adjacent wetlands. Two possible management strategies are under consideration. The first possible strategy is to install a parallel set of unidirectional hydraulic flap gates at a single location in Canal 1 to keep wind-driven tides from entering the lake and wetlands while allowing stormwater runoff to flow downstream. The second possible strategy is to install weirs at the outlets of the lake into Canal 1. The weirs would not protect the adjacent wetlands from tidal flooding but would help stabilize water levels in the lake to benefit fisheries. Before going forward with either the design of the proposed tide gates or weirs, the USFWS wants to understand the potential effects of these structures on upstream water levels. For either option to be considered, it must not increase flooding in the city's stormwater drainage system. The weirs would potentially reduce flooding in some of the developed portions of the basin. The U.S. Geological Survey (USGS), in cooperation with the USFWS, has developed an hydraulic model to assess the effect of the proposed tide gates and weirs on upstream flooding in the drainage system.

Purpose and Scope

This report describes the simulated hydrologic effects of proposed flood-control structures on upstream water levels in a drainage basin known as Watershed 9 in Virginia Beach, Va. Modifications to an existing Storm Water Management Model (SWMM) to include tide gates in

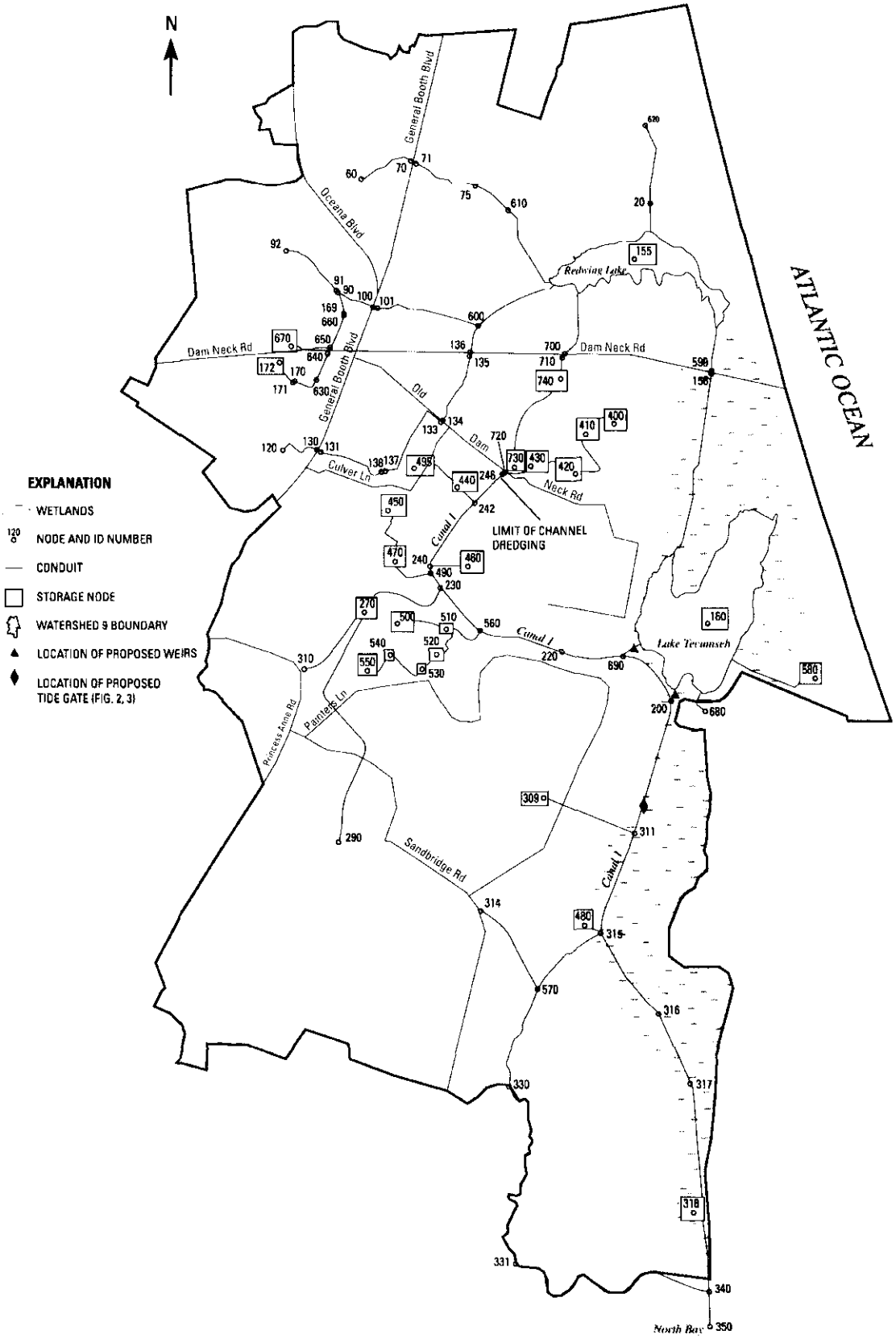

Figure 1. Drainage network for SWMM model for Watershed 9 and Canal 1 and locations of proposed structures near Virginia Beach, Va. (Modified from URS Corporation, 2003b)

Canal 1 or weirs at the outlets of Lake Tecumseh into the canal are described. Simulated water levels are reported at selected model nodes for (1) existing conditions, (2) tide gates only, and (3) weirs only. Simulations were conducted for design storms with recurrence intervals of 2, 10, 25, 50, 100, and 500 years for each of two initial water-surface elevations corresponding to median and maximum elevations measured during 2001 through 2003.

Description of Study Area

The drainage basin described as Watershed 9 (Camp, Dresser, and McKee, 1990; URS Corporation, 2003a, 2003b) is an area along the Atlantic Coast that encompasses a portion of the City of Virginia Beach, Va. The 19.1-mi^2 basin is bordered on the east by the Atlantic Ocean and on the south by North Bay, the northern portion of a large embayment that includes Back Bay and the Back Bay National Wildlife Refuge (fig. 1). It is drained by a dredged channel (Canal 1) that empties into North Bay (fig. 1). The topography of the basin is flat and low-lying, with elevations generally less than 20 ft above sea level. Drainage is tidally influenced. Soils in the area are mostly unconsolidated clays and sands. Precipitation averages approximately 45 in. per year (W. F. Smith, USFWS, written commun., 2003).

The basin is entirely within the City of Virginia Beach and includes large tracts of suburban development, a portion of Naval Air Station Oceana and the Dam Neck Fleet Combat Training Center. The basin is 34.1 percent impervious (URS Corporation, 2003a). The study area has experienced dramatic growth recently, including a substantial increase in single-family residences and subdivisions, although agricultural and forested areas remain within the basin. Open water bodies in the study area include Lake Tecumseh, Redwing Lake, and several smaller lakes, ponds, and marshes. Canal 1 was dredged through low marsh areas and creeks from the north end of North Bay north to Lake Tecumseh where the canal curves, runs adjacent to the lake, and then continues northward to Old Dam Neck Road. There are two outlets from Lake Tecumseh into Canal 1 and at least two other outlets that discharge into the adjacent wetlands. Multiple stormwater management ponds within the basin drain to Canal 1. Wetland resources within the basin include forested, lowland wetlands along both sides of Canal 1 and adjacent to Lake Tecumseh. These wetlands are influenced by wind-driven tidal surges that flow up the canal and spill out into the wetlands and into Lake Tecumseh.

Previous Studies

In the mid-to late 1980's a Stormwater Management Plan was developed for the City of Virginia Beach by Camp, Dresser, and McKee (CDM), which included a report on Watershed 9 and Canal 1 (Camp Dresser and McKee, 1990). This plan describes a U.S. Environmental Protection Agency (USEPA) Stormwater Management Model (SWMM) for assessing the drainage system performance and predicting flooding for the basin. SWMM is a dynamic rainfall-runoff model used to model runoff quantity and quality, primarily for urban areas. Two SWMM modules were used in the current study. RUNOFF was used to simulate the generation of runoff from land surfaces and EXTRAN was used to simulate unsteady flow routing through the drainage network. The 1990 CDM report documents the development of the model, including the hydrologic and hydraulic features represented in the basin. The design storms used in CDM's modeling effort were the 10-year, 25-year, 50-year, and 100-year Soil Conservation Service (SCS) Type II rainfall distributions. The 50-year design storm was used primarily to evaluate the performance of the existing hydraulic system and the effects of proposed upgrades for improved stormwater drainage. The hydraulic system modeled included channels and culverts and various storage nodes, including Redwing Lake, Lake Tecumseh, and multiple detention ponds. The CDM study made recommendations for improving conveyance in specific areas of the basin. The study also included the following major conclusions:

- Redwing Lake flood stage had not increased because of recent development in that portion of the basin but future development might cause more severe flooding in this area.
- Conveyance of Canal 1 south of Lake Tecumseh should not be restricted by development within the flood plain, which would also damage existing wetlands.

In 1993, a Flood Insurance Study (FIS) was completed by the U.S. Army Corps of Engineers (USACE), Norfolk District, in cooperation with the City of Virginia Beach for the Federal Emergency Management Agency (FEMA) (W. F. Smith, USFWS, written commun., 2003). This study included updates to the representation of areas inundated by the 100-year flood on a Flood Insurance Rate Map. The study, the most recent in a series of updates to the original FIS, was conducted to provide information to the city for updating flood-plain regulations and to assist in land-use decisions and flood-plain development. Flood water-surface profiles for the 10-, 50-, 100-, and 500-year design storms were simulated for Canal 1.

The Watershed 9 SWMM model originally developed by CDM (Camp, Dresser, and McKee, 1990) was refined by URS Corporation (2003a). The model was updated because the basin had gone through significant land-use and drainage changes since the original model was developed. PCSWMM software (Computational Hydraulics International, 2002) was used to update the model. Revisions to the model included:

- Rainfall information was revised.
- Subbasins were redelineated.
- Land use and imperviousness were updated.
- Many conduits and storage nodes were added.
- Roughness values for existing conduits were updated.

The URS study was conducted to develop an updated stormwater model that can be used to model the effects of future development or infrastructure improvements within the basin. The model for this basin is included with models for other basins in the city's Storm Water Information Program.

The primary focus of a related study by URS Corporation (2002) was to evaluate flooding in the Pine Meadows Subdivision and to provide recommendations for alleviating flooding in this area caused by a 10-year design storm event. Runoff from this subdivision discharges to Redwing Lake through a detention pond, a series of culverts, and an open channel. Detention pond overflow flows to Canal 1 through a network of storm detention ponds. These ponds do not provide adequate storage capacity during peak storm runoff. A node was added to the Watershed 9 SWMM model representing the Pine Meadows Subdivision. The results of the study showed that the 10-year and 100-year design storms caused street flooding but did not cause structural flooding in the subdivision. In addition, it was determined that during the 10-year storm, the majority of the runoff volume from Pine Meadows discharges to the detention ponds that drain to Canal 1, and that the drainage culvert for the ponds is insufficient to handle storm flows. A further conclusion was that Lake Tecumseh has ample storage capacity that is not fully utilized.

Modeling Approach

The existing SWMM models for Watershed 9 were evaluated for use in this study. The original CDM model developed in 1990 had been previously updated to version 4.31 and the city provided this version of the model for evaluation. In addition, the PCSWMM 2002 model developed by URS Corporation was acquired and compared to the CDM version 4.31 model.

Because the 2002 URS model had been updated, this more recent application was used to simulate baseline conditions for the current study.

Rainfall, runoff, and hydraulic function in Watershed 9 were modeled with PCSWMM 2003 (Computational Hydraulics International, 2003) using USEPA SWMM version 4.4h. The 2002 URS model was imported into PCSWMM 2003 and proposed changes to the drainage system were added for specific scenarios. Three modules of SWMM were used. The RAIN module was used to read precipitation data sets and generate a precipitation interface file. The interface file was used as the input for the RUNOFF module, which was used to simulate the quantity of runoff and route the flows to the hydraulic system. The quality of the runoff was not modeled for this study. The EXTRAN module was used to simulate hydraulic flow routing through open channels, closed conduits, and storage nodes. For the purposes of this study, the simulation length was 25 hours, which is the length of the design storm plus one hour. Because a previously developed model was used, no calibration was done for this study.

Model Development

The development of a PCSWMM model requires that each module be prepared separately. The following sections describe the development of the three modules used in this study- RAIN, RUNOFF, and EXTRAN. The existing PCSWMM 2002 modules developed by URS were converted to PCSWMM 2003 and modified.

RAIN Module

The RAIN module reads in the rainfall hyetograph for a design storm. For this study, SCS Type II 24-hour design storms were modeled for the 2-, 10-, 25-, 50-, 100-, and 500-year storms. The rainfall totals for all design storms except the 500-year storm were cited by URS (2003a). The hyetograph for the 500-year design storm was based on probabilistic extreme rainfall for Savannah, Ga., by the U.S. Department of Energy (Weber and others, 2004). Total rainfall amounts for the 2-, 10-, 25-, 50-, 100-, and 500-year storms were 3.9, 5.98, 7.16, 9.00, 9.61, and 10.28 in., respectively.

RUNOFF Module

The RUNOFF module simulates the physical characteristics of the basin and computes runoff hydrographs for each sub-basin. The RUNOFF module developed by URS Corporation was not altered for this study. Information on model parameters such as subbasin delineation, slope, percent imperviousness, and infiltration can be found in the watershed management plan for Watershed 9 by URS Corporation (2003a).

EXTRAN Module

The EXTRAN module is the hydraulic portion of SWMM that routes the runoff hydrographs generated by the RUNOFF module through open channel and closed conduit networks. It is a complex module that allows for modeling a variety of hydraulic conditions including free-surface and pressure flow, hydraulic structures, tidal conditions, and storage. In this study, the EXTRAN module developed by URS Corporation was modified to include structures proposed by USFWS described in the Model Scenarios section of this report. The results of the EXTRAN runs for the modified input files were compared to the baseline scenario (unmodified input file) for each design storm for each of two initial water-surface elevations.

Model Scenarios

EXTRAN input files for various different scenarios were developed for this study. Models representing two alternative structures to be added to the drainage system proposed by USFWS were compared to the baseline model. The first proposed structure consists of a set of 20 parallel, unidirectional hydraulic flap gates that keep high tides from propagating upstream in Canal 1 and into Lake Tecumseh and adjacent wetlands. EXTRAN files were developed to evaluate the fully open tide gate condition and the fully closed tide gate condition. The tide gates are proposed to be installed on Canal 1 south of the lake, between model nodes 200 and 311 (fig. 1). The second proposed structure is a pair of weirs at the outlets of Lake Tecumseh into Canal 1, between nodes 160 and 200 and 160 and 690 in the model (fig. 1).

For each simulation, two possible initial water surfaces were modeled. These water-surface elevations were chosen to represent a median level (2.2 ft) and a high, wind-driven tide level (3.2 ft). These values correspond respectively to the median and maximum water-surface elevations measured in the canal by USFWS between February 2001 and September 2003. However, the

initial water-surface elevation in the existing URS model was 2.0 ft and this value was used as the median water-surface elevation for the simulations because it allows for better comparison of new scenarios with existing model conditions.

Each of the proposed sets of structures was modeled with the two initial water-surface elevations and with each of the design storms to simulate flooding as a result of rainfall of different magnitudes for the two water-level conditions. These sets of conditions result in 36 simulations for the various combinations of structures, initial water-surface elevations, and design storms. For reporting purposes, these were divided into three scenarios: (1) baseline, (2) tide gates, and (3) Lake Tecumseh weirs.

Scenario 1: Baseline Model with (A) Median and (B) Maximum Initial Water-Surface Elevations

The baseline scenario consisted of the unmodified EXTRAN input files developed by URS Corporation. This simulation was run with the median initial water-surface elevation (2.0 ft) and maximum water-surface elevation (3.2 ft) for each of the six design storms to establish flooding conditions for comparison with the other scenarios.

Scenario 2: Tide Gate with (A) Median and (B) Maximum Initial Water-Surface Elevations

A scenario was developed to analyze the hydraulic effects of the tide gates in Canal 1 during runoff events with the median (2.0 ft) and maximum (3.2 ft) initial water-surface elevations. The proposed tide-gate structure consists of 20 parallel unidirectional flap gates installed across the canal approximately 3,500 ft downstream of the outlet from Lake Tecumseh between nodes 200 and 311 (fig. 1). The flap gates are proposed to be installed on the downstream side of 20 box culverts 4-ft wide and 2-ft high. The invert of the culverts was set in the model to 2.2 ft to correspond to the median water-surface elevation in the canal measured by USFWS. Thus, for initial median water-surface simulations, the gates were modeled as fully open, allowing runoff from the canal into the bay throughout the storm.

SWMM version 4.4h only allows for 15 conduits to be modeled from a single junction. For this reason, the structure that was added to the existing model to represent the 20 box culverts and tide gates was split into 2 identical flow paths (fig. 2). Each of the flow paths consists of an initial 30-ft-long open channel, a node for the junction between the open channel and the upstream end of the culverts, 10 box culverts, a node for the downstream end of the box culverts, and a 35-ft-long

section of open channel downstream of the culverts. Each flow path also includes an overflow channel at an elevation of 6.2 ft to allow high water to flow over the tide gates. The length and slope of conduits 9035 and 9037 (channels upstream and downstream of the tide gates, fig. 2) were adjusted to maintain the original length and slope of Canal 1.

In the case of the maximum initial water-surface elevation, it was assumed that once the water in the channel rises above 2.2 ft, the gates close completely and will not let any runoff pass through. To evaluate this scenario, the culverts and closed gates were represented in the model as a 200-ft-wide weir across Canal 1 (fig. 3). The invert elevation of the weir was set to 6.2 ft, which is the same elevation as the top of the open tide-gate structures. The closed tide-gate structures were added to the model in the same location as the open tide-gate structures.

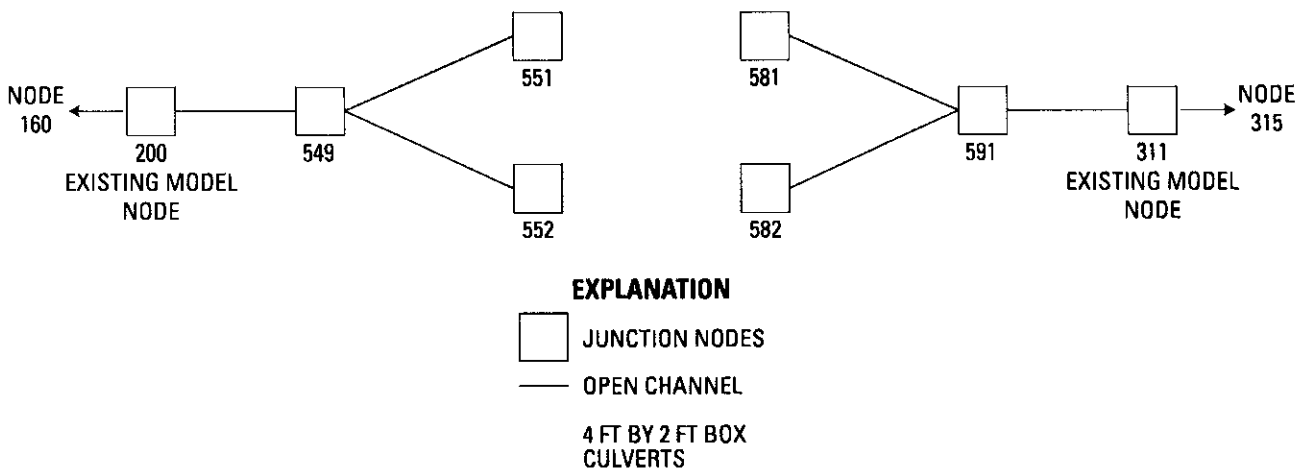

Figure 2. Open tide gate model schematic for proposed tide gates in Canal 1.

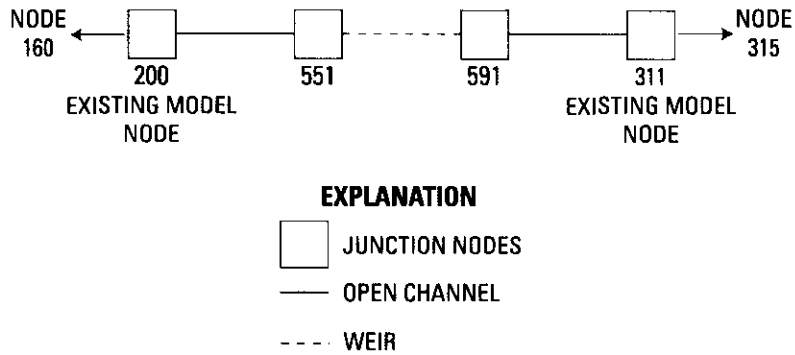

Figure 3. Closed tide gate model schematic for proposed tide gates in Canal 1.

Head Loss Coefficients for Open Tide Gates (Scenario 2A)

The open tide gates will allow runoff to flow downstream but will cause additional head loss. This additional head loss was a potentially important element of this scenario and consideration was given to the best way to model the effect of the tide gates. In PCSWMM 2003, culvert entrance losses, exit losses, and other losses can be specified in the model input file by adjusting loss-coefficient values. These coefficients are collectively represented by the K_L term in the following equation as explained in the Federal Highway Administration manual Hydraulic Design of Highway Culverts (U.S. Department of Transportation, 2001):

$$H_L = K_L * V^2/2g \qquad (1)$$

where H_L is entrance, exit, or other head loss,
V is the velocity through the culvert, and
g is gravitational acceleration.

The head loss is equal to the coefficient times the velocity head. Lower coefficients result in more efficient hydraulic function.

The coefficients are not specified in the existing model, and therefore are assumed to be equal to 1.0. This is the most conservative assumption. The default for exit and other losses is commonly set equal to 1.0, as illustrated in Computational Hydraulics International's User's Guide to SWMM (James and others, 2003) and on the SWMM user's Web site

(*http://www.computationalhydraulics.com/Training/SWMMQ&A/swmmqabrowse.asp*, accessed June 8, 2004).

Originally, two different options for calculating discharge coefficients for the tide gates were considered (app. A). However, to be consistent with the conservative K_L values used in the existing model, head loss coefficients of 1.0 were assumed for the tide gates. Analysis indicates that coefficients of 1.0 produced nearly identical head at nodes 551 and 552 just upstream of the tide gates as less conservative calculated values of K_L (table A1 in app. A).

Scenario 3: Lake Tecumseh Weirs with (A) Median and (B) Maximum Water-Surface Elevation

A transverse horizontal weir was simulated at each outlet from Lake Tecumseh into Canal 1. The invert elevation of the weirs was set at 2.2 ft. In this scenario, outlets of the lake that discharge to the adjacent wetlands to the east were not blocked with weirs to allow stormwater to discharge out of the lake into the wetlands for additional storage.

Simulation Results

The results of scenarios 2 and 3 were compared to the results of the baseline model (scenario 1) to evaluate how the proposed structures would affect upstream flooding. The simulated peak water-surface elevation for each baseline model node was compared to the simulated peak water-surface elevations for each node for the six design storms and for each of the initial water-surface elevations in scenarios 2 and 3. Most of the differences in peak water-surface elevations between the baseline model and scenarios 2 and 3 are minor, that is, within 0.2 ft, as shown in fig. 4. The computed peak water-surface elevation of each node for each of the 36 simulations for the various combinations of structures, initial water-surface elevations, and design storms are provided in tables in appendixes B and C.

Scenario 2A: Tide Gates with Median Initial Water-Surface Elevation

Examination of the simulated peak water-surface elevations for the median initial water-surface condition (app. B) indicates that the open tide gates cause few changes in upstream flooding. The differences in the peak water-surface elevations at the nodes for this scenario and the baseline scenario averaged less than +/- 0.1 ft for all design storms. For the 2- and 10-year storms,

all nodes were within +/- 0.01 ft of the baseline scenario (fig. 4). The maximum difference in simulated peak water-surface elevations (1.3 ft) is at node 169, which is at the downstream end of a culvert several thousand feet upstream of Redwing Lake west of General Booth Boulevard. The simulation indicates that flooding occurs at this node during the 25-year storm in the tide-gate scenario but not for the 25-year storm for the baseline scenario. Water-surface profile plots through the section between nodes 169 and 100 (at General Booth Boulevard) show signs of numerical instability in the baseline and other scenarios in the area, indicated by oscillations in the water-surface profile during the storm. Therefore, this result is not considered reliable. The only other increase in water-surface elevation greater than 0.1 ft in the open tide-gate model occurs at node 100 and is 0.3 ft (app. B).

Scenario 2B: Tide Gate with Maximum Initial Water-Surface Elevation

A similar comparison for the maximum water-surface elevation (3.2 ft) shows that the closed tide gates would have slightly more impact on water-surface elevations in the system (fig. 4, app. C). At some nodes, the water-surface elevation is higher in the tide-gate model than the baseline model; at other nodes it is lower. The most significant reductions in water-surface elevation occur in this scenario for the 2-, 10-, and 25-year design storms (fig. 4) with the largest reductions occurring at nodes 90 (west of General Booth Boulevard), 169, 100, 135 (at Dam Neck Road southwest of Redwing Lake), 400 (detention pond south of Dam Neck Road), 410 (detention pond south of Dam Neck Road), and 650 (at Dam Neck Road west of General Booth Boulevard) (app. C). All of these nodes have a decrease in water-surface elevation for one or more design storms of at least 0.5 ft (app. C). At other nodes, the closed tide gates caused increases in water-surface elevation (app. C). Increases of at least 0.4 ft occur at nodes 495 (detention pond near Culver Lane), 200 (outlet of Lake Tecumseh into Canal 1), 560 (Canal 1 west of Lake Tecumseh), and 650 for one or more design storms (appendix C). At a few nodes, model results indicate that flooding would not occur with the closed tide gates but would occur in the baseline scenario for a particular design storm (app. C). The tide gates alleviate flooding at nodes 91 (west of the intersection of Ocean Boulevard and General Booth Boulevard) for the 25-year storm, 100 for the 10- and 25-year storm, 133 (at Old Dam Neck Road) for the 25-year storm, 135 for the 25-year storm, 520 (detention pond discharging to Canal 1 west of Lake Tecumseh) for the 10-year storm, 550 (detention pond near Painters Lane) for the 10-year storm, 650 for the 10-year storm, and 700 (at Dam Neck Road) for the 100-year storm.

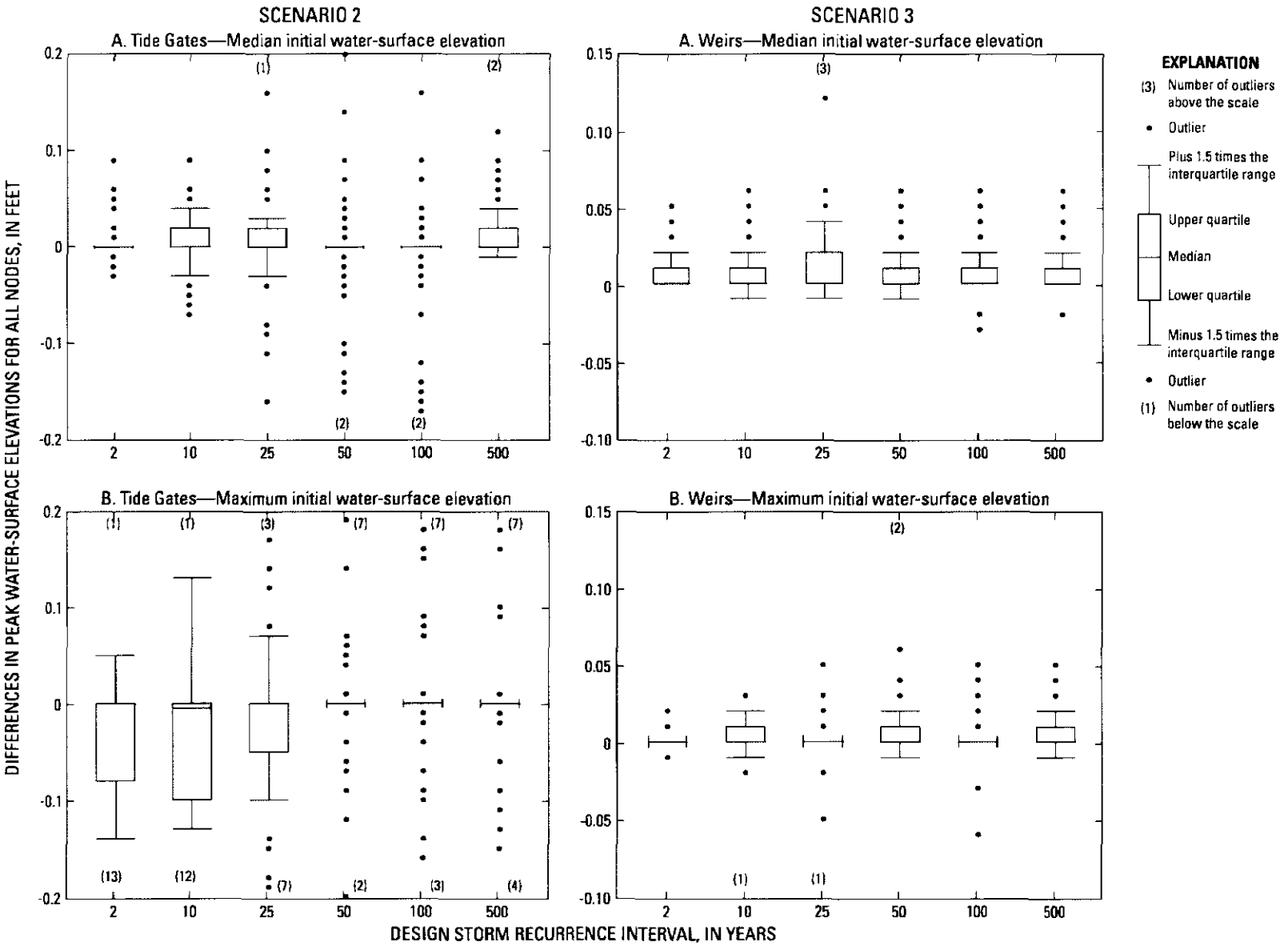

Figure 4. Differences in peak water-surface elevations between baseline model (Scenario 1) and tide gate simulations (Scenario 2) and between baseline model and weir simulations (Scenario 3) for median (2.0 feet) and maximum (3.2 feet) initial water-surface elevations for all nodes for different design storms in Watershed 9, Virginia Beach, Va.

Scenario 3A: Lake Tecumseh Weirs with Median Initial Water-Surface Elevation

The model results indicate virtually no change in upstream water-surface elevation when the outlets of Lake Tecumseh to Canal 1 are blocked with weirs (fig. 4, app. B). Most of the differences in water-surface elevation between this scenario and the baseline scenario are less than 0.1 ft (fig. 4). The only nodes with differences greater than 0.1 ft are 169 and 100, where, for the 25-year storm, the water-surface elevation increases 1.26 and 0.30 ft, respectively (app. B). Both of these nodes are in an area of the model where there is numerical instability, as described above. Therefore, these results are not considered to be reliable.

Scenario 3B: Lake Tecumseh Weirs with Maximum Initial Water-Surface Elevation

The results of the Lake Tecumseh weir scenario with maximum water-surface elevation (app. C) also indicate that the weirs have very little effect on upstream flooding. Most of the differences in water-surface elevation between this scenario and the baseline scenario are less than 0.1 ft (fig. 4). The only area where water-surface elevation is increased or decreased is between nodes 169 and 100 and at node 650 (app. C). Because of numerical instability in this area of the model, however, these results are not considered to be reliable.

Effect of Lake Tecumseh System on Flooding

Lake Tecumseh (node 160), an adjacent pond (node 580), and the adjacent wetlands (node 680) play a prominent role in the functioning of the SWMM model for Watershed 9. Water drains into the lake from upstream (through node 156) throughout runoff events. In addition, under each model scenario, water flows from Canal 1 into Lake Tecumseh (through nodes 200 and 690) during times of peak runoff. Water is then discharged to storage node 580 and out of the model through outfall node 680. Node 680 represents wetlands on the southeast side of the lake that likely drain to Black Gut Reservoir and then to Canal 1 near its outlet through another unnamed canal to North Bay. There is a weir between nodes 160 (Lake Tecumseh) and 680 with its crest set at 2.4 ft. Therefore, when water in the lake exceeds a depth of 2.4 ft, it will flow out of node 680 and is lost from the system.

The model indicates, however, that Lake Tecumseh and the adjacent pond have enough storage capacity to hold stormwater runoff for large storms. To test the effect of the available storage, a high weir was simulated in the model to block water from discharging to node 680. The

100-year storm was then routed through the model to see if flooding would occur without this outfall. The water surface rose in Lake Tecumseh and the adjacent pond by 0.99 ft and 0.68 ft, respectively, but flooding did not increase anywhere in the model. Therefore, model results indicate that Lake Tecumseh has enough available storage to hold much of the water for a 100-year storm. In the simulation, once the storm peaks have passed, water flows back into Canal 1 from Lake Tecumseh. The effect of the lake, pond, and wetlands is to store water during the runoff event, thereby preventing flooding that would likely occur without this storage capacity.

Numerical Instability in the Model

Numerical instability at some locations in the model, primarily between nodes 169 and 100, is indicated by rapidly fluctuating water-surface elevations and discharges over time at certain locations. At these locations, the model is incapable of mathematically describing the hydraulics. The cause of the instability is not readily apparent and restructuring the model was beyond the scope of the project. In this model, the instabilities usually occur near the peak of the runoff and only for limited periods of time. Although the instabilities potentially cause short-term errors in water-surface elevations and discharges at certain points in the model, as indicated above, the problems do not affect the continuity of the overall model.

Summary and Conclusions

The U.S. Geological Survey, in cooperation with the U.S. Fish and Wildlife Service, modified an existing Storm Water Management Model (SWMM) to evaluate the flood-reduction potential of utilizing water-control structures as part of a management plan for Lake Tecumseh and adjacent wetlands in the City of Virginia Beach, Va. A SWMM model has been developed for this area, known as Watershed 9, by Camp, Dresser, and McKee and by URS Corporation. Modifications were made to the URS model because it represents the most up-to-date hydrologic characteristics of the basin. Two different management strategies for six design storms and two initial water-surface elevations were evaluated. The two strategies included (1) installing a set of flap gates in Canal 1 downstream of the lake and wetlands to keep wind-driven tides out of the system, and (2) installing weirs on the outlets of the lake to protect it from high tide water. A series of model scenarios was developed to evaluate how each strategy would affect flooding in the

system for the 2-, 10-, 25-, 50-, 100-, and 500-year design storms during a period of maximum wind-driven tide and for the median water-surface elevation in the drainage system.

Model simulations for these scenarios were conducted and the results were compared to the baseline (existing conditions) model. The results of the simulations indicated that the proposed structures had little effect on flooding. The proposed structures did not cause increases in water-surface elevations in most locations in the system. However, in a few instances, upstream water-surface elevations were slightly higher, especially in the tide-gate scenarios. Results of the tide-gate scenario with the maximum wind-driven tide initial condition indicate that, at some locations, upstream water-surface elevations were lower than those of the same locations in the baseline model. For a few locations, the closed tide gate (the high tide water is assumed to cause the gates to fully close) reduced flooding. The largest difference in peak water-surface elevation with and without the tide gates is believed to be caused by numerical instability in the model. The weirs at the Lake Tecumseh outlets had virtually no effect on upstream flooding for either initial water-surface condition for any of the six design storms.

The proposed structures have little effect on modeled water-surface elevations because Lake Tecumseh, an adjacent pond, and the wetlands on the southeast side of the lake provide sufficient storage for runoff. During runoff events, water flows into the lake from Canal 1 and from the system upstream of the lake. When the water level in the lake is high enough, the lake discharges into the pond and the wetlands, which keeps the water from backing up throughout much of the system. Storage in the lake, pond, and wetlands mitigates flooding throughout the system.

The U.S. Fish and Wildlife Service is interested in the results of this modeling effort to evaluate which, if either, of the management strategies to pursue. This model is intended to be a preliminary evaluation of the hydraulics of the system and the effects that the proposed structures would have on flooding in the basin. Based on these model results, the proposed structures do not appear to increase flooding in the system but also do not appear to have a significant flood-reduction benefit.

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Appendixes

Appendix A. Options for Calculating Tide Gate Head-Loss Coefficients

Option 1

Reviewing the manufacturer's specifications on the performance of the open gates (fig. A1) indicates that the gates cause very little head loss. The first option was to add this additional head loss to the culvert losses. An iterative solution was generated for the K_L term in equation 1. This was done by rerunning the model with increasing K_L values back-calculated from equation 1. In these calculations, the H_L term was set equal to the manufacturer-specified head loss for the previous run's model-generated flow, and the V term was set equal to previous run's model-generated velocity. The first Q and V terms were from the model run with unmodified K_L. The iteratively calculated H_L values increased as modeled flows and velocities decreased. When the K_L values stabilized, a conservative assumption for the term was generated. The K_L value for the gate losses was 0.146. Adding this to the 0.5 for the culvert entrance, the K_L value for entrance losses becomes 0.646, with the values for exit losses and other losses set at the conservative default value of 1.0.

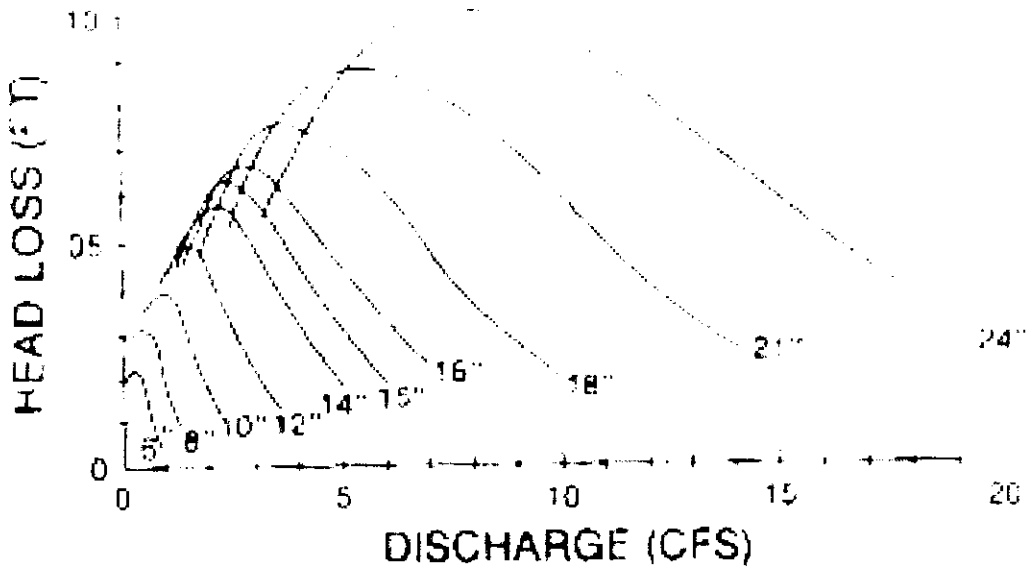
Option 2

A second option was to model the gates as orifices. The orifice equation is:

$$Q = C*A*SQRT(2g*h) \qquad (2)$$

where C is a coefficient of discharge representing the hydraulic efficiency of the orifice, with 1.0 being the most efficient, and
h is head on the orifice,
A is cross-sectional area, and
g is gravitational acceleration.

To simulate the effect of the gates, a head-loss term can be added to the equation. Adding h_g, the head loss due to the gate, to the original equation results in



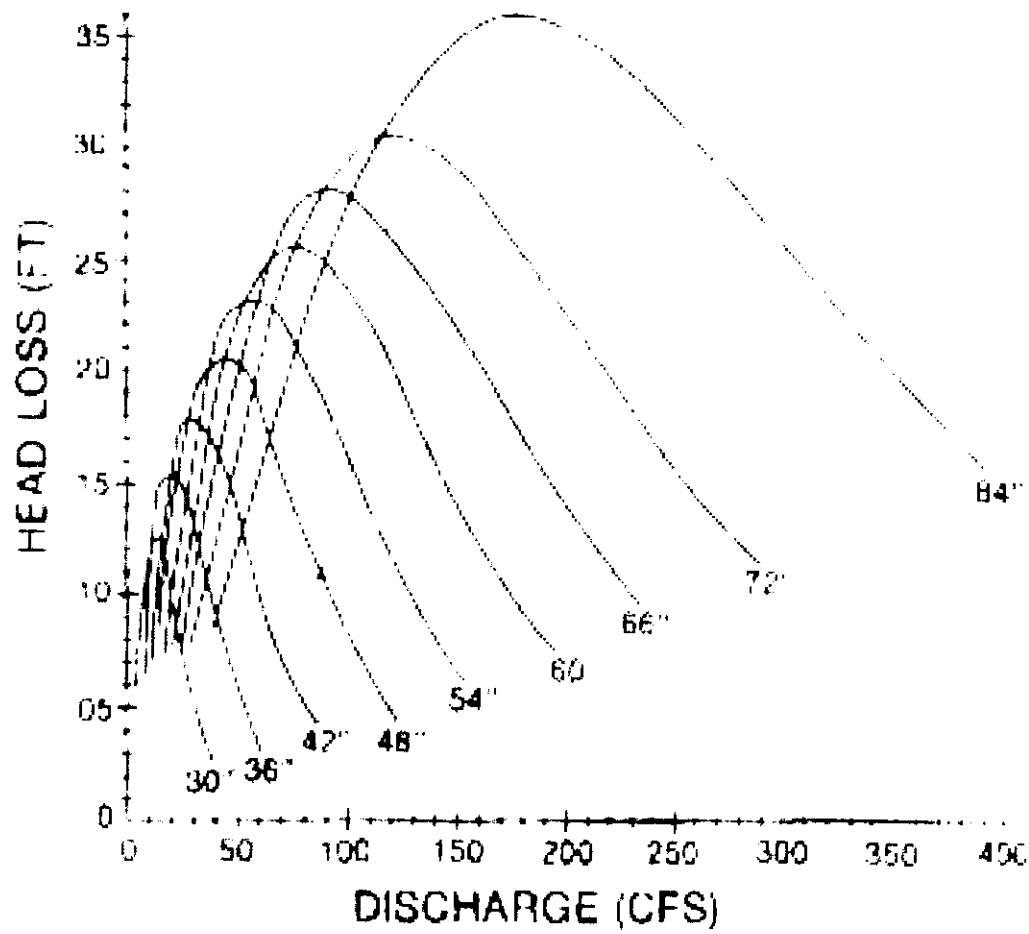


Figure A1. Performance chart for proposed tide gates. (Modified from Waterman Industries, Inc., 2003)

$$Q = C_o*A*SQRT(2g*h-h_g) \quad (3)$$

Where C_o is the original C value, and

h_g is the head loss due to the gate.

Other head losses are represented by the C coefficient. With no head loss represented in this equation other than h_g, C_o is equal to 1.0. For equal discharges the following is true:

$$C_o*A*SQRT(2g*h-h_g) = C_n*A*SQRT(2g*h) \quad (4)$$

where C_n is the new C coefficient that includes the head loss caused by the gate, h_g.

This equation reduces to:

$$C_o/C_n = SQRT(h)/SQRT(h-h_g) \quad (5)$$

C_o/C_n was plotted for the full range of possible discharges through the tide gates (fig. A2). The head losses from the gate used to calculate these values were taken from the manufacturer's chart of head loss vs. discharge. This chart (fig. A1) indicates that the head loss increases with discharge to a point and then decreases. The plot in fig. A2 follows this pattern with the maximum point at 1.173. The plot is theoretically asymptotic to 1.0 on both ends because the head loss at very low or very large discharges approaches 0, which causes C_n to approach 1. The C_n corresponding to the maximum C_o/C_n is 0.853. This would be the conservative assumption for C_n representing the tide gate modeled as an orifice.

Option 1 and option 2 results were compared on test runs with the option of setting K_L for entrance losses to 1.0 along with the exit and other losses and leaving the K_L for entrance losses at 0.5. There is little difference in the results of the different runs (table A1). For this reason, the most simple and conservative choice was to set all K_L values to 1 and not to include orifices at the gate locations.

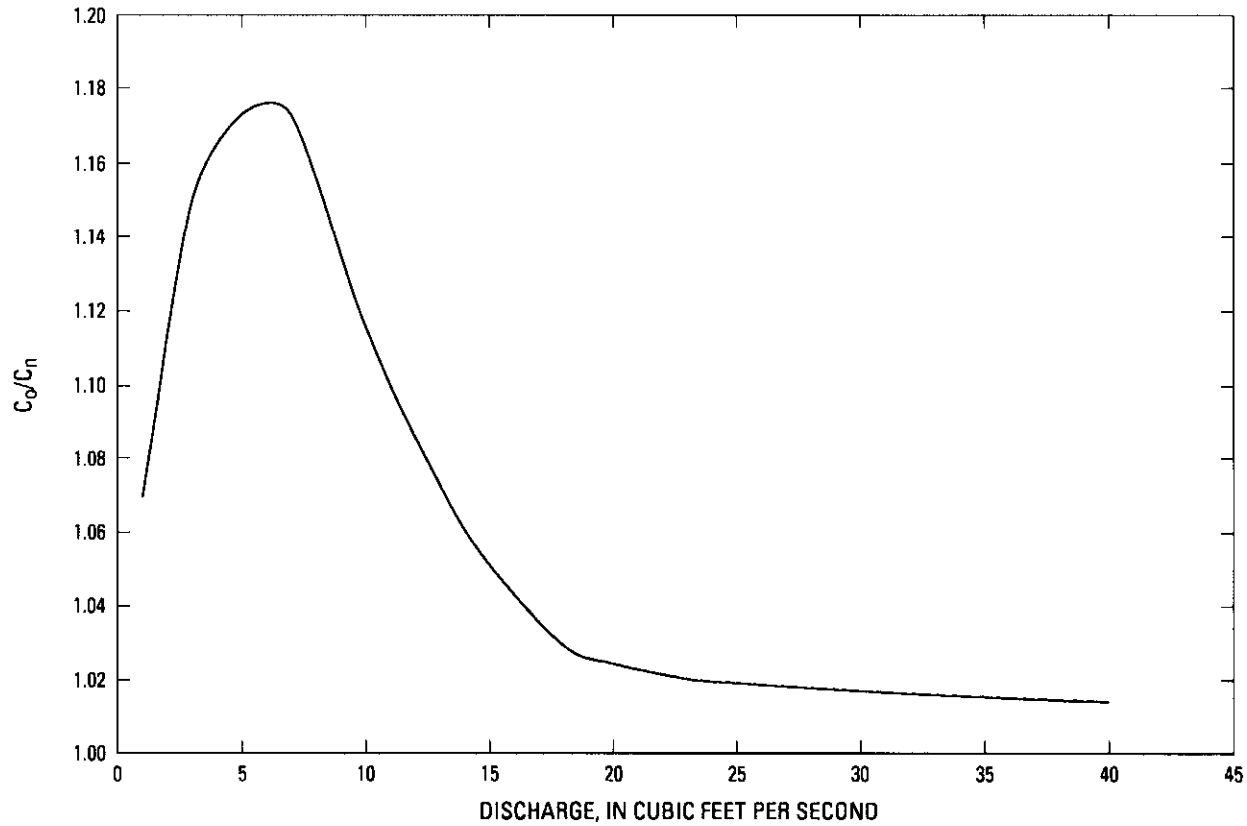


Figure A2. Coefficient of discharge ratio (C_o/C_n) in relation to discharge through tide gates.

Table A1. Head at culverts immediately upstream of tide gates for various combinations of culvert losses and orifice coefficient.

[K_L, culvert head-loss coefficient; C_n, orifice discharge coefficient]

Conditions	Head at nodes 551, 552, in feet
K_L = .646, C_n = NA	4.30
K_L = .5, C_n = 0.853	4.31
K_L = 1, C_n = NA	4.31
K_L = 0.5, C_n = NA	4.29

Appendix B. Simulated peak water-surface elevations for all nodes for Scenarios 1A, 2A, and 3A.

[WSE, water-surface elevation; n.a., not applicable; bold values indicate flooding.]

	Scenario 1A: Baseline Model, Median WSE= 2.0 feet						Scenario 2A: Open Tide-Gate Model, Median WSE = 2.0 feet						Scenario 3A: Lake Tecumseh Weir Model, Median WSE = 2.0 feet					
	Peak water-surface elevation, in feet						Peak water-surface elevation, in feet						Peak water-surface elevation, in feet					
Node	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
20	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**
70	9.51	11.13	**18.90**	**18.90**	**18.90**	**18.90**	9.51	11.13	**18.90**	**18.90**	**18.90**	**18.90**	9.51	11.13	**18.90**	**18.90**	**18.90**	**18.90**
60	12.96	13.69	14.02	14.80	**14.80**	**14.80**	12.96	13.69	14.02	**14.80**	**14.80**	**14.80**	12.96	13.69	14.02	**14.80**	**14.80**	**14.80**
71	8.21	8.66	8.90	9.19	9.27	9.36	8.21	8.66	8.90	9.19	9.27	9.36	8.21	8.66	8.90	9.19	9.27	9.36
75	7.07	7.30	7.44	7.63	7.68	7.74	7.07	7.30	7.44	7.63	7.68	7.74	7.07	7.30	7.44	7.63	7.68	7.74
90	8.56	10.36	**13.50**	**13.50**	**13.50**	**13.50**	8.56	10.38	**13.50**	**13.50**	**13.50**	**13.50**	8.56	10.36	**13.50**	**13.50**	**13.50**	**13.50**
91	10.11	13.35	**13.50**	**13.50**	**13.50**	**13.50**	10.11	13.35	**13.50**	**13.50**	**13.50**	**13.50**	10.11	13.35	**13.50**	**13.50**	**13.50**	**13.50**
169	8.91	10.60	11.04	**12.30**	**12.30**	**12.30**	8.91	10.63	**12.30**	**12.30**	**12.30**	**12.30**	8.91	10.60	**12.30**	**12.30**	**12.30**	**12.30**
170	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**
171	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**
172	10.65	11.13	11.42	11.88	11.98	12.10	10.65	11.13	11.42	11.88	11.98	12.10	10.65	11.13	11.42	11.88	11.98	12.10
92	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**
100	6.99	8.58	8.90	**12.10**	**12.10**	**12.10**	6.99	8.64	9.20	**12.10**	**12.10**	**12.10**	6.99	8.59	9.20	**12.10**	**12.10**	**12.10**
101	6.20	6.75	6.93	8.27	9.15	**12.10**	6.20	6.75	6.95	8.27	9.14	**12.10**	6.20	6.74	6.95	8.26	9.12	**12.10**
120	12.21	12.77	13.05	13.46	13.59	13.74	12.21	12.77	13.05	13.46	13.59	13.74	12.21	12.77	13.05	13.46	13.59	13.74
130	8.74	10.10	11.06	12.18	12.58	12.99	8.74	10.10	11.06	12.18	12.58	12.99	8.74	10.10	11.06	12.18	12.58	12.99
131	7.09	8.03	8.37	9.76	10.05	10.28	7.09	8.03	8.37	9.76	10.05	10.28	7.09	8.03	8.37	9.76	10.05	10.28
133	5.48	6.62	7.45	**8.00**	**8.00**	**8.00**	5.48	6.62	7.46	**8.00**	**8.00**	**8.00**	5.48	6.62	7.47	**8.00**	**8.00**	**8.00**
134	5.36	6.34	7.19	**8.00**	**8.00**	**8.00**	5.36	6.34	7.20	**8.00**	**8.00**	**8.00**	5.36	6.34	7.24	**8.00**	**8.00**	**8.00**
135	5.34	6.33	7.20	**8.60**	**8.60**	**8.60**	5.34	6.33	7.26	**8.60**	**8.60**	**8.60**	5.34	6.33	7.47	**8.60**	**8.60**	**8.60**
136	5.29	6.20	6.85	**8.60**	**8.60**	**8.60**	5.29	6.20	6.93	**8.60**	**8.60**	**8.60**	5.29	6.20	6.97	**8.60**	**8.60**	**8.60**

	Scenario 1A: Baseline Model, Median WSE= 2.0 feet						Scenario 2A: Open Tide-Gate Model, Median WSE = 2.0 feet						Scenario 3A: Lake Tecumseh Weir Model, Median WSE = 2.0 feet					
	Peak water-surface elevation, in feet						Peak water-surface elevation, in feet						Peak water-surface elevation, in feet					
Node	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
137	7.00	7.96	8.28	**10.30**	**10.30**	**10.30**	7.00	7.96	8.28	**10.30**	**10.30**	**10.30**	7.00	7.96	8.28	**10.30**	**10.30**	**10.30**
138	6.96	7.87	8.25	**10.20**	**10.20**	**10.20**	6.96	7.87	8.25	**10.20**	**10.20**	**10.20**	6.96	7.87	8.25	**10.20**	**10.20**	**10.20**
155	4.24	5.48	6.02	6.42	6.54	6.68	4.24	5.48	6.03	6.42	6.54	6.68	4.24	5.48	6.02	6.42	6.54	6.68
156	3.38	3.89	4.15	4.47	4.59	4.73	3.38	3.89	4.15	4.47	4.59	4.73	3.38	3.89	4.15	4.47	4.59	4.73
160	2.52	2.72	2.82	2.94	2.99	3.04	2.61	2.75	2.81	2.92	2.97	3.06	2.55	2.71	2.81	2.93	2.97	3.02
161	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.67	3.02	3.21	3.51	3.60	3.71
162	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.52	2.72	2.84	3.01	3.07	3.13
200	2.67	3.15	3.42	3.85	3.98	4.13	2.68	3.08	3.22	3.52	3.62	4.21	2.72	3.21	3.48	3.91	4.04	4.19
220	2.73	3.25	3.54	4.00	4.16	4.32	2.73	3.20	3.43	3.86	3.99	4.41	2.77	3.29	3.58	4.05	4.20	4.37
230	2.74	3.25	3.54	4.01	4.16	4.33	2.73	3.19	3.45	3.88	4.01	4.39	2.78	3.29	3.59	4.06	4.20	4.37
240	2.74	3.26	3.54	4.01	4.16	4.33	2.73	3.20	3.45	3.87	4.00	4.39	2.78	3.30	3.59	4.06	4.21	4.38
242	2.77	3.28	3.55	4.01	4.15	4.32	2.74	3.24	3.52	3.96	4.11	4.44	2.80	3.31	3.60	4.06	4.20	4.37
246	2.78	3.28	3.56	4.01	4.16	4.33	2.75	3.25	3.53	3.98	4.13	4.45	2.81	3.32	3.60	4.06	4.21	4.38
270	4.44	6.56	8.00	10.20	10.95	11.83	4.45	6.59	8.02	10.21	10.96	11.86	4.44	6.56	8.01	10.20	10.95	11.84
290	8.91	10.59	11.47	**12.10**	**12.10**	**12.10**	8.91	10.59	11.47	**12.10**	**12.10**	**12.10**	8.91	10.59	11.47	**12.10**	**12.10**	**12.10**
310	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**
309	2.93	3.59	3.97	4.60	4.81	5.07	2.95	3.63	4.03	4.67	4.88	5.08	2.95	3.60	3.99	4.62	4.83	5.08
311	2.65	3.13	3.40	3.82	3.94	4.09	2.63	3.15	3.50	3.96	4.10	4.11	2.69	3.17	3.45	3.86	3.99	4.14
314	4.17	**6.00**	**6.00**	**6.00**	**6.00**	**6.00**	4.17	**6.00**	**6.00**	**6.00**	**6.00**	**6.00**	4.17	**6.00**	**6.00**	**6.00**	**6.00**	**6.00**
315	2.54	2.97	3.22	3.61	3.73	3.86	2.58	3.06	3.38	3.81	3.95	3.88	2.57	3.00	3.25	3.64	3.76	3.90
316	2.23	2.40	2.52	2.72	2.79	2.87	2.23	2.42	2.58	2.81	2.88	2.88	2.23	2.41	2.54	2.73	2.81	2.88
317	2.18	2.31	2.39	2.53	2.58	2.63	2.18	2.32	2.42	2.58	2.62	2.63	2.18	2.31	2.39	2.53	2.58	2.63
318	2.09	2.15	2.20	2.27	2.30	2.33	2.09	2.16	2.21	2.29	2.32	2.34	2.09	2.15	2.20	2.28	2.30	2.33
330	2.40	2.71	2.90	3.19	3.29	3.40	2.40	2.73	2.95	3.26	3.36	3.41	2.40	2.72	2.91	3.20	3.30	3.41
331	2.26	2.47	2.61	2.84	2.92	3.01	2.26	2.48	2.63	2.88	2.96	3.01	2.27	2.48	2.62	2.85	2.92	3.01
340	2.03	2.05	2.06	2.07	2.08	2.08	2.04	2.05	2.06	2.07	2.08	2.09	2.04	2.05	2.06	2.07	2.08	2.08

	Scenario 1A: Baseline Model, Median WSE= 2.0 feet						Scenario 2A: Open Tide-Gate Model, Median WSE = 2.0 feet						Scenario 3A: Lake Tecumseh Weir Model, Median WSE = 2.0 feet					
	Peak water-surface elevation, in feet						Peak water-surface elevation, in feet						Peak water-surface elevation, in feet					
Node	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
350	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
400	4.07	5.54	6.66	6.70	6.70	6.70	4.07	5.54	6.66	6.70	6.70	6.70	4.07	5.54	6.67	6.70	6.70	6.70
410	3.93	5.53	6.66	6.72	6.72	6.72	3.93	5.54	6.65	6.72	6.72	6.72	3.93	5.54	6.66	6.72	6.72	6.72
420	4.21	5.67	6.64	7.10	7.10	7.10	4.21	5.67	6.63	7.10	7.10	7.10	4.21	5.67	6.64	7.10	7.10	7.10
430	3.14	4.06	4.49	5.06	5.21	5.37	3.20	4.06	4.46	4.96	5.09	5.43	3.17	4.06	4.52	5.08	5.23	5.40
440	2.99	3.62	4.04	4.66	4.88	5.14	2.99	3.61	4.03	4.63	4.84	5.15	3.00	3.62	4.05	4.67	4.89	5.15
450	4.81	5.98	6.76	7.89	**7.90**	**7.90**	4.81	5.97	6.75	7.89	**7.90**	**7.90**	4.81	5.98	6.76	7.89	**7.90**	**7.90**
460	4.04	5.42	6.36	**6.40**	**6.40**	**6.40**	4.04	5.42	6.36	**6.40**	**6.40**	**6.40**	4.04	5.42	6.36	**6.40**	**6.40**	**6.40**
470	5.17	6.54	7.46	**8.80**	**8.80**	**8.80**	5.17	6.54	7.46	**8.80**	**8.80**	**8.80**	5.17	6.54	7.46	**8.80**	**8.80**	**8.80**
480	2.33	2.56	2.71	2.93	3.00	3.08	2.30	2.53	2.72	2.96	3.04	3.07	2.34	2.58	2.73	2.95	3.02	3.10
490	2.74	3.26	3.54	4.01	4.16	4.33	2.73	3.20	3.45	3.87	4.01	4.39	2.78	3.29	3.59	4.06	4.21	4.38
495	4.00	4.00	4.00	4.39	4.57	4.79	4.00	4.00	4.00	4.36	4.55	4.80	4.00	4.00	4.00	4.40	4.58	4.80
500	3.48	4.76	5.61	7.04	**7.10**	**7.10**	3.52	4.82	5.66	7.09	**7.10**	**7.10**	3.48	4.77	5.61	7.05	**7.10**	**7.10**
510	3.17	4.17	4.82	5.57	5.66	5.74	3.22	4.22	4.84	5.53	5.59	5.77	3.18	4.18	4.84	5.58	5.68	5.76
520	3.20	4.26	4.92	**5.20**	**5.20**	**5.20**	3.26	4.32	4.94	**5.20**	**5.20**	**5.20**	3.21	4.27	4.94	**5.20**	**5.20**	**5.20**
530	3.20	4.26	4.93	5.21	5.21	5.21	3.26	4.32	4.95	5.21	5.21	5.21	3.21	4.27	4.94	5.21	5.21	5.21
540	3.52	5.09	**5.80**	**5.80**	**5.80**	**5.80**	3.56	5.13	**5.80**	**5.80**	**5.80**	**5.80**	3.52	5.09	**5.80**	**5.80**	**5.80**	**5.80**
549	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.68	3.06	3.15	3.39	3.46	4.18	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
550	3.73	5.68	**6.50**	**6.50**	**6.50**	**6.50**	3.75	5.71	**6.50**	**6.50**	**6.50**	**6.50**	3.73	5.68	**6.50**	**6.50**	**6.50**	**6.50**
551	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.68	3.06	3.15	3.39	3.46	4.80	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
552	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.68	3.06	3.15	3.39	3.46	4.80	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
560	2.73	3.24	3.53	4.01	4.16	4.33	2.73	3.20	3.45	3.86	4.01	4.39	2.77	3.29	3.59	4.06	4.21	4.38
570	2.70	3.36	3.66	4.03	4.15	4.29	2.71	3.37	3.68	4.05	4.18	4.32	2.70	3.36	3.67	4.03	4.15	4.29
580	2.52	2.72	2.88	3.14	3.23	3.33	2.61	2.76	2.94	3.21	3.30	3.40	2.55	2.72	2.89	3.15	3.24	3.33
581	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.63	3.23	3.50	3.97	4.12	4.59	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
582	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.63	2.23	3.50	3.97	4.12	4.59	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

	Scenario 1A: Baseline Model, Median WSE= 2.0 feet						Scenario 2A: Open Tide-Gate Model, Median WSE = 2.0 feet						Scenario 3A: Lake Tecumseh Weir Model, Median WSE = 2.0 feet					
	Peak water-surface elevation, in feet						Peak water-surface elevation, in feet						Peak water-surface elevation, in feet					
Node	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
590	3.87	5.16	5.75	6.22	6.33	6.44	3.87	5.16	5.75	6.22	6.33	6.44	3.87	5.16	5.75	6.22	6.33	6.44
591	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.63	3.22	3.50	3.97	4.12	4.20	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
600	5.28	6.19	6.84	**8.30**	**8.30**	**8.30**	5.28	6.19	6.87	**8.30**	**8.30**	**8.30**	5.28	6.19	6.86	**8.30**	**8.30**	**8.30**
610	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**
620	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**
630	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**
640	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**
650	9.63	10.64	**11.40**	**11.40**	**11.40**	**11.40**	9.62	10.66	**11.40**	**11.40**	**11.40**	**11.40**	9.63	10.64	**11.40**	**11.40**	**11.40**	**11.40**
660	8.95	11.49	**12.30**	**12.30**	**12.30**	**12.30**	8.95	11.46	**12.30**	**12.30**	**12.30**	**12.30**	8.95	11.51	**12.30**	**12.30**	**12.30**	**12.30**
670	9.82	10.83	11.39	12.28	12.54	12.92	9.82	10.84	11.45	12.27	12.54	12.95	9.82	10.83	11.45	12.30	12.52	12.97
680	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
690	2.69	3.18	3.46	3.90	4.03	4.19	2.70	3.12	3.30	3.62	3.73	4.26	2.74	3.23	3.52	3.96	4.09	4.24
700	4.23	5.48	6.02	6.42	6.55	6.69	4.23	5.48	6.02	6.42	6.87	7.60	4.23	5.48	6.02	6.42	6.61	6.69
710	4.22	5.46	6.00	6.41	6.54	6.68	4.22	5.47	6.01	6.41	6.85	7.56	4.22	5.46	6.01	6.41	6.60	6.68
720	3.00	3.73	4.15	4.72	4.89	5.08	3.06	3.75	4.11	4.61	4.75	5.13	3.03	3.77	4.18	4.75	4.92	5.11
730	3.24	4.09	4.63	5.43	5.68	5.97	3.30	4.14	4.64	5.41	5.67	6.01	3.24	4.10	4.64	5.43	5.69	5.98
740	3.66	4.15	4.66	5.43	5.68	5.97	3.66	4.17	4.66	5.42	5.67	6.01	3.66	4.16	4.67	5.44	5.69	5.98

Appendix C. Simulated peak water-surface elevations for all nodes for Scenarios 1B, 2B, and 3B.

[WSE, water-surface elevations; n.a., not applicable; Bold values indicate flooding.]

	Scenario 1B: Baseline Model, Maximum WSE= 3.2 feet						Scenario 2B: Closed Tide-Gate Model, Maximum WSE = 3.2 feet						Scenario 3B: Lake Tecumseh Weir Model, Maximum WSE = 3.2 feet					
	Peak water-surface elevation, in feet						Peak water-surface elevation, in feet						Peak water-surface elevation, in feet					
Node	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
20	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**
70	9.51	11.13	**18.90**	**18.90**	**18.90**	**18.90**	9.51	11.13	**18.90**	**18.90**	**18.90**	**18.90**	9.51	11.13	**18.90**	**18.90**	**18.90**	**18.90**
60	12.96	13.69	14.02	**14.80**	**14.80**	**14.80**	12.96	13.69	14.02	**14.80**	**14.80**	**14.80**	12.96	13.69	14.02	**14.80**	**14.80**	**14.80**
71	8.21	8.66	8.90	9.19	9.27	9.36	8.21	8.66	8.90	9.19	9.27	9.36	8.21	8.66	8.90	9.19	9.27	9.36
75	7.07	7.30	7.44	7.63	7.68	7.74	7.07	7.30	7.44	7.63	7.68	7.74	7.07	7.30	7.44	7.63	7.68	7.74
90	8.56	11.30	**13.50**	**13.50**	**13.50**	**13.50**	8.56	10.41	**13.50**	**13.50**	**13.50**	**13.50**	8.56	10.40	**13.50**	**13.50**	**13.50**	**13.50**
91	10.11	13.35	**13.50**	**13.50**	**13.50**	**13.50**	10.11	13.35	13.35	**13.50**	**13.50**	**13.50**	10.11	13.35	**13.50**	**13.50**	**13.50**	**13.50**
169	8.91	10.98	**12.30**	**12.30**	**12.30**	**12.30**	8.91	10.69	**12.30**	**12.30**	**12.30**	**12.30**	8.91	10.67	**12.30**	**12.30**	**12.30**	**12.30**
170	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**
171	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**	**11.60**
172	10.65	11.13	11.42	11.88	11.98	12.10	10.65	11.13	11.42	11.88	11.98	12.10	10.65	11.13	11.42	11.88	11.98	12.10
92	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**	**18.00**
100	6.97	**12.10**	**12.10**	**12.10**	**12.10**	**12.10**	6.98	8.63	9.19	**12.10**	**12.10**	**12.10**	6.97	8.64	9.18	**12.10**	**12.10**	**12.10**
101	6.18	6.73	7.28	8.80	**12.10**	**12.10**	6.19	6.74	7.10	8.50	**12.10**	**12.10**	6.18	6.73	7.28	8.86	**12.10**	**12.10**
120	12.21	12.77	13.05	13.46	13.59	13.74	12.21	12.77	13.05	13.46	13.59	13.74	12.21	12.77	13.05	13.46	13.59	13.74
130	8.74	10.10	11.05	12.18	12.58	12.99	8.74	10.10	11.05	12.18	12.58	12.99	8.74	10.10	11.05	12.18	12.58	12.99
131	7.08	8.03	8.37	9.74	10.03	10.27	7.08	8.03	8.37	9.75	10.04	10.28	7.08	8.03	8.37	9.74	10.03	10.27
133	5.56	6.74	**8.00**	**8.00**	**8.00**	**8.00**	5.51	6.67	7.75	**8.00**	**8.00**	**8.00**	5.56	6.75	**8.00**	**8.00**	**8.00**	**8.00**
134	5.50	6.51	7.68	**8.00**	**8.00**	**8.00**	5.42	6.41	7.43	**8.00**	**8.00**	**8.00**	5.50	6.52	7.68	**8.00**	**8.00**	**8.00**
135	5.49	6.51	**8.60**	**8.60**	**8.60**	**8.60**	5.41	6.40	7.42	**8.60**	**8.60**	**8.60**	5.49	6.51	8.60	**8.60**	**8.60**	**8.60**
136	5.44	6.36	7.24	**8.60**	**8.60**	**8.60**	5.36	6.27	7.10	**8.60**	**8.60**	**8.60**	5.44	6.36	7.24	**8.60**	**8.60**	**8.60**
137	6.99	7.96	8.28	**10.30**	**10.30**	**10.30**	7.00	7.96	8.28	**10.30**	**10.30**	**10.30**	6.99	7.96	8.28	**10.30**	**10.30**	**10.30**

	Scenario 1B: Baseline Model, Maximum WSE= 3.2 feet						Scenario 2B: Closed Tide-Gate Model, Maximum WSE = 3.2 feet						Scenario 3B: Lake Tecumseh Weir Model, Maximum WSE = 3.2 feet					
	Peak water-surface elevation, in feet						Peak water-surface elevation, in feet						Peak water-surface elevation, in feet					
Node	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
138	6.95	7.87	8.25	**10.20**	**10.20**	**10.20**	6.95	7.87	8.25	**10.20**	**10.20**	**10.20**	6.95	7.87	8.25	**10.20**	**10.20**	**10.20**
155	4.94	5.90	6.24	6.64	6.75	6.88	4.68	5.80	6.15	6.55	6.66	6.79	4.94	5.90	6.24	6.64	6.75	6.88
156	3.72	4.11	4.32	4.66	4.77	4.98	3.64	4.03	4.25	4.59	4.70	4.83	3.72	4.10	4.32	4.66	4.77	4.89
160	3.27	3.32	3.35	3.42	3.44	3.47	3.27	3.32	3.35	3.42	3.45	3.48	3.27	3.32	3.35	3.41	3.44	3.46
161	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3.41	3.57	3.67	3.86	3.93	4.01
162	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3.31	3.38	3.42	3.51	3.55	3.58
200	3.59	3.88	4.04	4.32	4.41	4.51	3.62	4.01	4.25	4.65	4.80	4.95	3.61	3.91	4.07	4.36	4.46	4.56
220	3.64	4.00	4.21	4.55	4.66	4.80	3.67	4.08	4.34	4.77	4.91	5.13	3.66	4.01	4.23	4.57	4.68	4.82
230	3.64	3.99	4.23	4.57	4.69	4.83	3.66	4.07	4.31	4.76	4.91	5.07	3.66	4.01	4.24	4.59	4.71	4.85
240	3.65	4.00	4.24	4.56	4.68	4.82	3.66	4.07	4.32	4.77	4.92	5.08	3.66	4.02	4.25	4.58	4.70	4.84
242	3.69	4.06	4.29	4.66	4.78	4.93	3.69	4.12	4.36	4.80	4.94	5.11	3.70	4.07	4.30	4.67	4.80	4.95
246	3.70	4.07	4.30	4.68	4.80	4.95	3.69	4.13	4.36	4.82	4.95	5.13	3.70	4.08	4.31	4.69	4.82	4.97
270	5.52	7.57	8.98	11.16	11.90	12.13	5.03	7.10	8.52	10.70	11.44	12.11	5.52	7.57	8.98	11.16	11.90	12.13
290	8.86	10.49	11.31	**12.10**	**12.10**	**12.10**	8.89	10.51	11.36	**12.10**	**12.10**	**12.10**	8.86	10.49	11.31	**12.10**	**12.10**	**12.10**
310	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**	**16.00**
309	3.87	4.41	4.75	5.34	5.54	5.79	3.85	4.37	4.70	5.25	5.44	5.68	3.88	4.42	4.76	5.35	5.56	5.80
311	3.59	3.88	4.04	4.31	4.39	4.49	3.51	3.75	3.89	4.11	4.18	4.26	3.60	3.90	4.06	4.34	4.43	4.53
314	4.69	**6.00**	**6.00**	**6.00**	**6.00**	**6.00**	4.69	**6.00**	**6.00**	**6.00**	**6.00**	**6.00**	4.69	**6.00**	**6.00**	**6.00**	**6.00**	**6.00**
315	3.51	3.75	3.90	4.13	4.21	4.29	3.47	3.68	3.81	4.01	4.07	4.14	3.52	3.76	3.91	4.15	4.23	4.32
316	3.31	3.39	3.45	3.55	3.58	3.63	3.30	3.38	3.43	3.51	3.54	3.57	3.31	3.40	3.45	3.56	3.59	3.64
317	3.27	3.33	3.36	3.42	3.44	3.46	3.27	3.33	3.36	3.41	3.43	3.45	3.28	3.33	3.36	3.42	3.44	3.46
318	3.24	3.27	3.29	3.32	3.33	3.35	3.24	3.27	3.29	3.32	3.33	3.35	3.24	3.27	3.29	3.32	3.34	3.35
330	3.44	3.63	3.75	3.94	4.01	4.09	3.44	3.62	3.74	3.93	3.99	4.07	3.44	3.63	3.75	3.95	4.01	4.09
331	3.37	3.51	3.59	3.73	3.78	3.84	3.37	3.50	3.58	3.72	3.77	3.83	3.37	3.51	3.59	3.73	3.78	3.84
340	3.22	3.23	3.24	3.25	3.25	3.26	3.22	3.23	3.24	3.25	3.25	3.26	3.22	3.23	3.24	3.25	3.25	3.26
350	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20

	Scenario 1B: Baseline Model, Maximum WSE= 3.2 feet						Scenario 2B: Closed Tide-Gate Model, Maximum WSE = 3.2 feet						Scenario 3B: Lake Tecumseh Weir Model, Maximum WSE = 3.2 feet					
	Peak water-surface elevation, in feet						Peak water-surface elevation, in feet						Peak water-surface elevation, in feet					
Node	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
400	4.89	6.49	**6.70**	**6.70**	**6.70**	**6.70**	4.23	5.83	**6.70**	**6.70**	**6.70**	**6.70**	4.89	6.49	**6.70**	**6.70**	**6.70**	**6.70**
410	4.89	6.48	6.72	6.72	6.72	6.72	4.22	5.83	6.71	6.72	6.72	6.72	4.89	6.48	6.72	6.72	6.72	6.72
420	4.97	6.49	**7.10**	**7.10**	**7.10**	**7.10**	4.76	6.18	**7.10**	**7.10**	**7.10**	**7.10**	4.98	6.50	**7.10**	**7.10**	**7.10**	**7.10**
430	4.08	4.77	5.16	5.53	5.64	5.78	4.02	4.64	5.12	5.57	5.71	5.87	4.09	4.78	5.17	5.54	5.66	5.80
440	3.97	4.54	4.91	5.52	5.73	5.98	3.48	4.10	5.12	5.15	5.36	5.62	3.97	4.54	4.92	5.52	5.74	5.98
450	4.88	6.07	6.86	**7.90**	**7.90**	**7.90**	4.78	5.99	6.81	**7.90**	**7.90**	**7.90**	4.88	6.07	6.86	**7.90**	**7.90**	**7.90**
460	4.87	6.22	**6.40**	**6.40**	**6.40**	**6.40**	4.43	5.84	**6.40**	**6.40**	**6.40**	**6.40**	4.87	6.22	**6.40**	**6.40**	**6.40**	**6.40**
470	5.29	6.67	7.61	**8.80**	**8.80**	**8.80**	5.16	6.56	7.52	**8.80**	**8.80**	**8.80**	5.29	6.67	7.61	**8.80**	**8.80**	**8.80**
480	3.36	3.49	3.57	3.70	3.75	3.80	3.34	3.45	3.52	3.63	3.66	3.71	3.37	3.50	3.59	3.72	3.76	3.82
490	3.65	4.00	4.20	4.57	4.69	4.82	3.66	4.07	4.32	4.77	4.91	5.07	3.66	4.01	4.25	4.58	4.70	4.84
495	3.20	3.52	3.98	4.68	4.88	5.11	4.20	4.20	4.38	4.88	5.06	5.27	3.20	3.53	3.99	4.69	4.89	5.12
500	4.61	5.84	6.66	**7.10**	**7.10**	**7.10**	4.48	5.71	6.52	**7.10**	**7.10**	**7.10**	4.61	5.85	6.66	**7.10**	**7.10**	**7.10**
510	4.23	5.13	5.53	5.84	5.87	5.91	4.10	5.06	5.51	5.91	5.96	6.01	4.24	5.15	5.54	5.85	5.88	5.92
520	4.27	**5.20**	**5.20**	**5.20**	**5.20**	**5.20**	4.13	5.15	**5.20**	**5.20**	**5.20**	**5.20**	4.27	**5.20**	**5.20**	**5.20**	**5.20**	**5.20**
530	4.27	5.20	5.21	5.21	5.21	5.21	4.13	5.15	5.21	5.21	5.21	5.21	4.27	5.20	5.21	5.21	5.21	5.21
540	4.63	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	4.36	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**	4.63	**5.80**	**5.80**	**5.80**	**5.80**	**5.80**
549	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
550	4.88	**6.50**	**6.50**	**6.50**	**6.50**	**6.50**	4.51	6.44	**6.50**	**6.50**	**6.50**	**6.50**	4.88	**6.50**	**6.50**	**6.50**	**6.50**	**6.50**
551	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3.66	4.06	4.28	4.67	4.81	4.96	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
552	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
560	3.65	4.01	4.29	4.55	4.66	4.80	3.66	4.08	4.33	4.77	4.91	5.21	3.66	4.03	4.24	4.57	4.68	4.82
570	3.65	4.12	4.29	4.57	4.67	4.79	3.64	4.11	4.28	4.56	4.65	4.77	3.65	4.12	4.30	4.57	4.67	4.83
580	3.44	3.63	3.74	3.93	3.99	4.06	3.43	3.62	3.74	3.93	3.99	4.06	3.43	3.62	3.74	3.93	3.99	4.06
581	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
582	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
590	4.59	5.62	5.99	6.41	6.52	6.68	4.34	5.51	5.89	6.35	6.43	6.55	4.59	5.62	5.99	6.41	6.52	6.67

	Scenario 1B: Baseline Model, Maximum WSE= 3.2 feet						Scenario 2B: Closed Tide-Gate Model, Maximum WSE = 3.2 feet						Scenario 3B: Lake Tecumseh Weir Model, Maximum WSE = 3.2 feet					
	Peak water-surface elevation, in feet						Peak water-surface elevation, in feet						Peak water-surface elevation, in feet					
Node	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm	2-yr storm	10-yr storm	25-yr storm	50-yr storm	100-yr storm	500-yr storm
591	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3.51	3.75	3.89	4.11	4.18	4.26	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
600	5.44	6.36	7.20	**8.30**	**8.30**	**8.30**	5.35	6.26	7.01	**8.30**	**8.30**	**8.30**	5.44	6.36	7.18	**8.30**	**8.30**	**8.30**
610	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**	**6.20**
620	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**	**6.10**
630	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**	**13.90**
640	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**
650	9.62	**11.40**	**11.40**	**11.40**	**11.40**	**11.40**	9.62	10.68	**11.40**	**11.40**	**11.40**	**11.40**	9.62	10.67	**11.40**	**11.40**	**11.40**	**11.40**
660	8.95	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	8.95	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	8.95	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**
670	9.82	10.85	11.45	12.31	12.52	12.91	9.82	10.84	11.45	12.37	12.60	12.89	9.82	10.83	11.45	12.37	12.49	12.92
680	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20	3.20
690	3.60	3.92	4.11	4.38	4.48	4.59	3.65	4.04	4.28	4.69	4.82	4.98	3.62	3.94	4.13	4.41	4.51	4.63
700	4.94	5.90	6.24	6.76	**7.60**	**7.60**	4.68	5.80	6.15	7.11	7.44	**7.60**	4.94	5.90	6.24	7.28	7.54	**7.60**
710	4.93	5.89	6.23	6.75	7.56	7.56	4.67	5.79	6.14	7.09	7.40	7.56	4.93	5.89	6.23	7.25	7.50	7.56
720	3.93	4.50	4.84	5.26	5.39	5.55	3.91	4.38	4.81	5.31	5.47	5.65	3.94	4.51	4.85	5.28	5.41	5.57
730	4.18	4.98	5.47	6.15	6.39	6.65	4.13	4.66	5.16	5.87	6.11	6.39	4.18	4.98	5.47	6.16	6.39	6.66
740	4.23	4.98	5.47	6.16	6.39	6.65	3.88	4.64	5.16	5.87	6.11	6.39	4.23	4.99	5.48	6.16	6.39	6.66