Appendix G
Hydrologic and Hydraulic Engineering

The management units and Moist Soil Units (MSUs) for the Yorkinut Slough Habitat Rehabilitation and Enhancement Project (Project) lie within Two Rivers National Wildlife Refuge (Refuge). This Refuge is located within Calhoun County, Illinois. It is near the confluence of the Illinois River and the Mississippi River and is on the right-descending side of the Illinois River. An image taken from the computer program Google Earth Pro of the study area and its vicinity is shown in Figure 1. The black lines in this image outline the watersheds that were digitized for the development of hydrologic modeling of the study area and its vicinity. These watersheds will be discussed below in a section on the hydrologic modeling. The footprint, or aerial extent, of the management units and MSUs bounded by black lines is shown in Figure 1. This area is also one of the watersheds that was digitized for the hydrologic modeling.

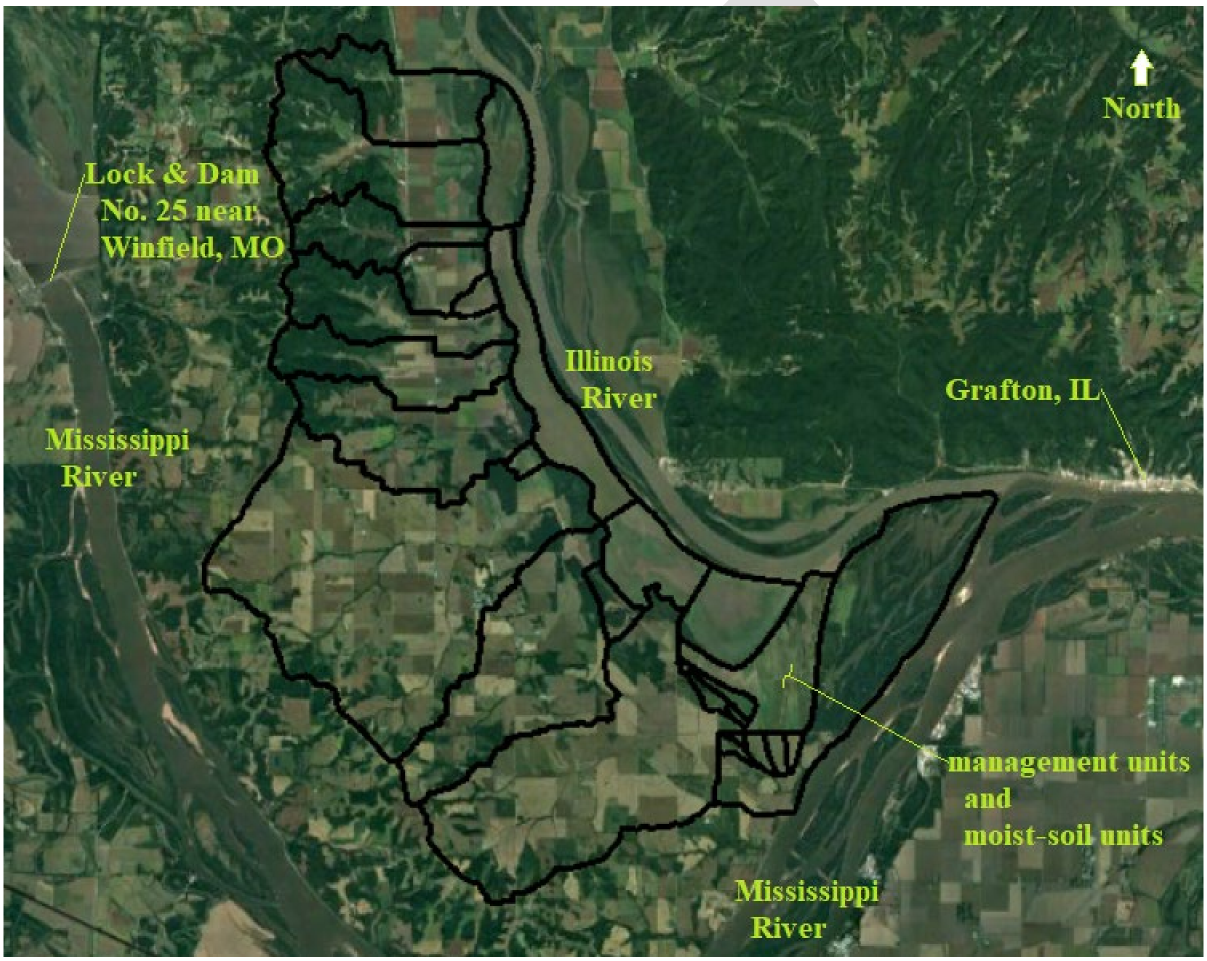

Figure 1. Google Earth Pro Image of Study Area and Vicinity.

The U.S. Geological Survey publishes detailed information and data pertaining to rivers and streams. Data pertaining to the Illinois River was reviewed to determine pertinent information for the Illinois River in the vicinity of Swan Lake and the UMRR project for Yorkinut Slough. The mouth of the Illinois River is at Mississippi River mile 217.5. The drainage area of the Illinois

River at its mouth (river mile 0.0) is 28,906 square miles. The Jersey County-Calhoun County line is located at Illinois River mile 18.4. U.S. Geological Survey gage 05587060 at Hardin, Illinois, is located at Illinois River mile 21.5. The drainage area of the Illinois River at Hardin is 28,690 square miles. Macoupin Creek enters the Illinois River at river mile 23.2 on the river's left-descending side.

For examining existing conditions, one of the main objectives was to develop a hydraulic model of the Yorkinut Slough management units that would enable the simulation of flow of water within and around the management units. Of interest was simulation of both draining and filling of the units. A hydraulic modeling technique known as two-dimensional modeling was used. This technique makes possible the depiction of the movement of water in accordance with gravity, details of the terrain, berms and water control structures. The calculations for two-dimensional hydraulic modeling are detailed, complex and time intensive. The advanced computing capability of contemporary computers makes routine use of this modeling technique possible. Several computer programs were used for the hydraulic modeling, one of which was used to perform the hydraulic calculations with the other programs providing support to the modeling process. Data that is required for development of a two-dimensional hydraulic model includes information on topography, water control structures and land cover.

Data used for Hydrologic and Hydraulic Modeling and Analysis

Two separate instances of surveying of existing water control structures and well pumps within the Yorkinut Slough management units were undertaken by USACE St. Louis District Geodesy, Cartography and Photogrammetry Branch (EC-S). In the first instance of surveying, data for most of the existing water control structures was acquired. Data was also acquired for all the existing well pumps. For each water control structure, data acquired included geographic coordinates, shape and material of pipe, dimensions of pipe, invert elevation of pipe and digital pictures. For each well pump, data acquired included geographic coordinates and elevations of key features of the well pump.

As the hydrologic and hydraulic work continued and as more experience was accrued with the project site through analysis of aerial photography and participation in site visits, the existence of additional water control structures was determined. In the second instance of surveying, data for these additional water control structures was acquired. Similar data was acquired for the water control structures during the second instance of surveying as was acquired during the first instance. As the hydraulic modeling (which will be discussed below) was proceeding, these additional water control structures were included in the modeling (with estimated parameters) as they were discovered. In the second instance of surveying, data was also acquired for several pertinent areas and features (e.g., ditches and swales) both inside and outside of the management units.

One set of topographic data used for the hydraulic modeling was LiDAR data that was received from USACE. This set of LiDAR data was collected specifically for this UMRR project, and the boundary of it lies just outside the managed area. The vertical datum for this LiDAR data set is the North American Vertical Datum of 1988 (NAVD88). An image of the study area LiDAR data is shown in Figure 2, and the various colors indicate ranges of topographic elevations. The highest elevations are depicted in dark red shading and the lowest elevations are depicted in dark blue shading. Also drawn in black lines in Figure 2 are the existing management units as they were digitized in ArcMap. The existing management units will be discussed further below.

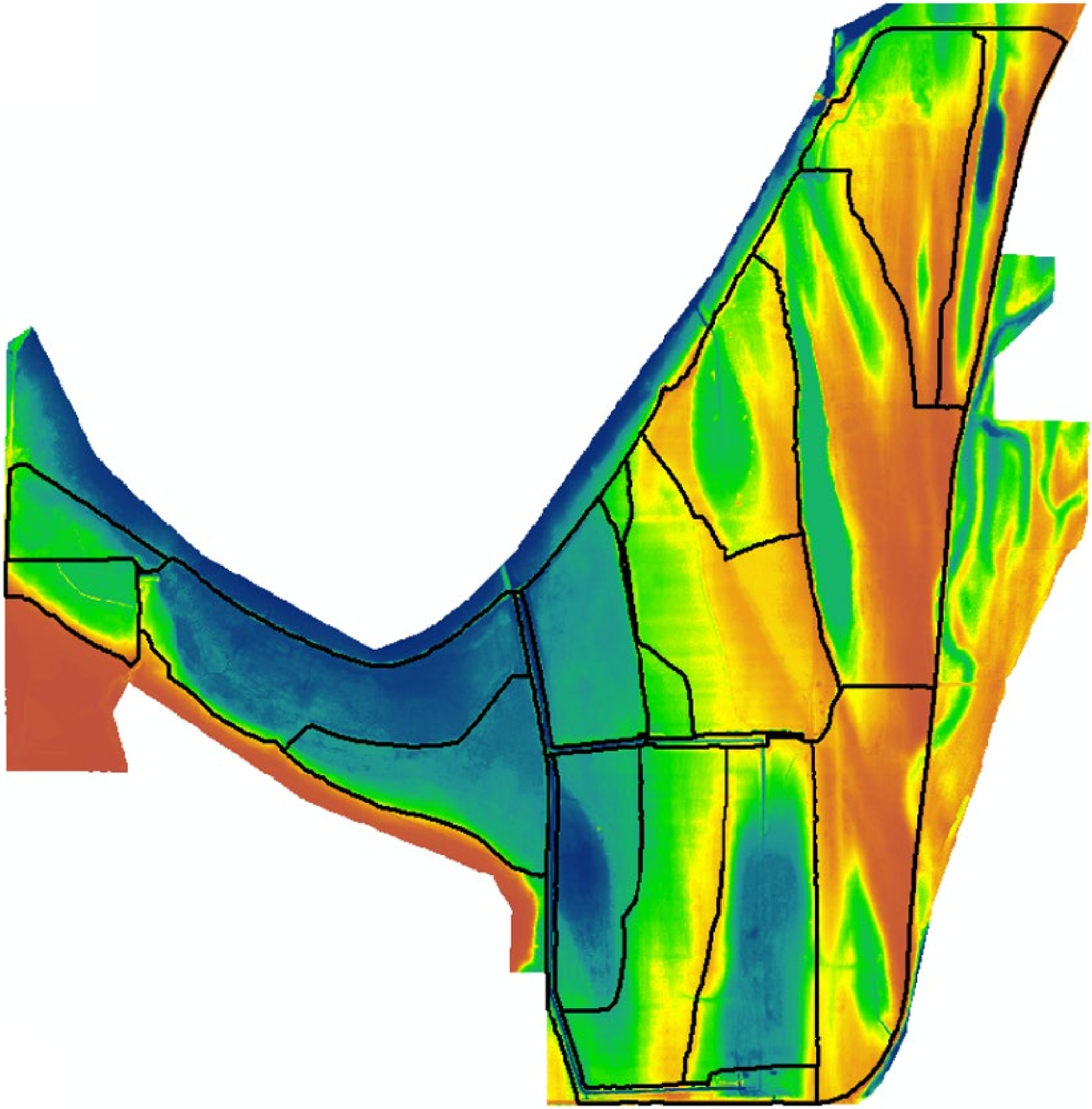

Figure 2. Image of study area LiDAR data.

A second set of topographic data used for the hydraulic modeling was LiDAR data for Calhoun County, Illinois. A third set of data used for the hydraulic modeling was bathymetric data for Swan Lake. The LiDAR data collected specifically for this UMRR project, the LiDAR data for Calhoun County and the bathymetry data for Swan Lake were all merged into one set of topography/bathymetry data for use in several of the hydraulic modeling efforts.

Another type of data that was used for hydrologic and hydraulic modeling and analysis was daily river elevation data. This information was obtained from USACE Water Control Management Section (EC-HW) databases. Data for frequency rainfall events was used in the hydrologic modeling.

Pertinent Features within and near the Yorkinut Slough Management Units

The management of Swan Lake, and the effect of the Illinois River upon Swan Lake, affects the management and operation of the Yorkinut Slough management units. A feature of the Upper Mississippi River System Environmental Management Program (EMP) project for Swan Lake was the construction of a berm between Swan Lake and the Illinois River. As features of the same EMP project, several water control structures were constructed through this berm. One of the water control structures is an uncontrolled spillway, which is essentially a low area along the berm. This uncontrolled spillway, which is located on the southern end of the Swan Lake berm, is about 1,970 feet (ft) in length. This spillway permits the uncontrolled, gradual back-flooding of Swan Lake if the Illinois River rises above the spillway's crest elevation.

In addition to the uncontrolled spillway, several other water control structures were constructed through the Swan Lake berm. At the extreme southern end of the Swan Lake berm is a gravity drainage structure, which is equipped with stop logs. A pumping station lies just north of the uncontrolled spillway. A second pumping station and a second gravity drainage structure lie in very close proximity to one another near the northern end of the Swan Lake berm. Like the first gravity drainage structure, the second one is also equipped with stop logs.

There are five documents of as-built drawings pertaining to the EMP project for Swan Lake. The titles of these documents are as follows:

* Swan Lake Habitat Rehabilitation, Item I, Readvertisement, Solicitation No. DACW43-95-B-0209 (November 1994)

* Swan Lake Habitat Rehabilitation and Pumping, Item II, Readvertisement, Solicitation No. DACW43-97-B-0235 (June 1997)

* Swan Lake Habitat Rehabilitation, Item III, Solicitation No. DACW43-95-B-0264 (May 1995)

* Swan Lake Habitat Rehabilitation and Enhancement Project, Swan Lake Lower Compartment Pump Station, Solicitation No. DACW43-02-R-0706 (October 2001)

* Swan Lake Lower Compartment Pump Station Modifications, Solicitation: W912P9-10-R-0734 (May 2010)

As mentioned above, the uncontrolled spillway in the berm between Swan Lake and the Illinois River permits uncontrolled and gradual back-flooding of Swan Lake if the Illinois River rises above the spillway's crest elevation. Calculated daily elevations of the Illinois River at the Swan Lake uncontrolled spillway during 2017 through 2020 (blue, red, green and purple lines, respectively) are shown in Figure 3. These daily elevations at the spillway were calculated by linear interpolation between daily elevations on the Illinois River at Hardin and the Mississippi River at Grafton. Also shown in this figure is the uncontrolled spillway incipient overtopping elevation (about 424.5 ft NAVD88) and the incipient overtopping elevation of the lowest areas of the remainder of the Swan Lake berm (about 427.0 ft NAVD88). The data in Figure 3 shows that the uncontrolled spillway was periodically overtopped during the four-year period, as were the lowest areas of the remainder of the Swan Lake berm. During this four-year period, there were instances of overtopping of the uncontrolled spillway when the remainder of the berm was not overtopped. At other times, the uncontrolled spillway and other areas of the berm were concurrently overtopped. Overtopping of the spillway and/or the remainder of the berm results in water from the Illinois River entering Swan Lake, and potentially causing backwater effects upon the water control structures of the Yorkinut Slough management units.

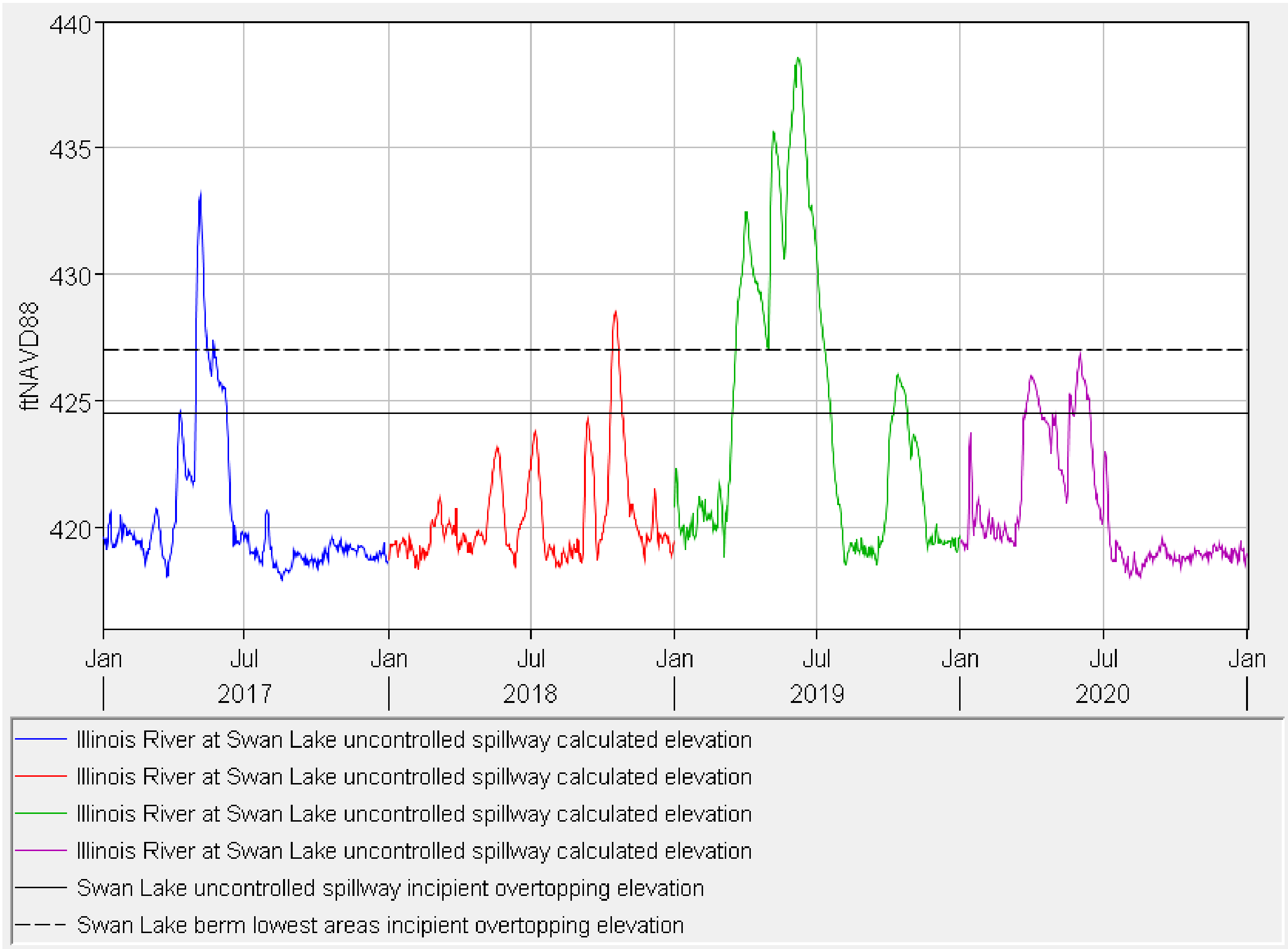

Figure 3. Illinois River at Swan Lake Uncontrolled Spillway Calculated Daily Elevations (2017-2020).

Fuller Lake lies just north of Swan Lake. The two lakes are separated by a small, constructed dike. The Swan Lake berm continues northward and in the upstream direction along the Illinois River and lies between Fuller Lake and the Illinois River. A survey of elevations along the Swan Lake - Fuller Lake berm was recently performed for the UMRR Swan Lake Flood Damage Assessment (UMRR SLFDA) project. The results of this survey and Illinois River frequency flood water-surface elevations are given in Figure 4, which is a plot developed by one of the engineers on the UMRR SLFDA project team. The Illinois River frequency flood water-surface elevations were taken from a computer program developed by USACE Rock Island District. This computer program is based upon the results of the report entitled “Upper Mississippi River System Flow Frequency Study” (January 2004). This report was developed by several agencies and stakeholders. The Swan Lake - Fuller Lake berm elevations, shown in Figure 4 as the green line, are along Illinois River miles from just upstream of mile 12.6 down to just upstream of mile 4.6. The uncontrolled spillway is evident near the downstream end of the berm. It is evident that the elevation along the Swan Lake - Fuller Lake berm varies significantly along its length. In several locations along the berm, its elevation is lower than the Illinois River 50% annual exceedance probability flood profile. The elevation of most of the berm is lower than the Illinois River 20% annual exceedance probability flood profile.

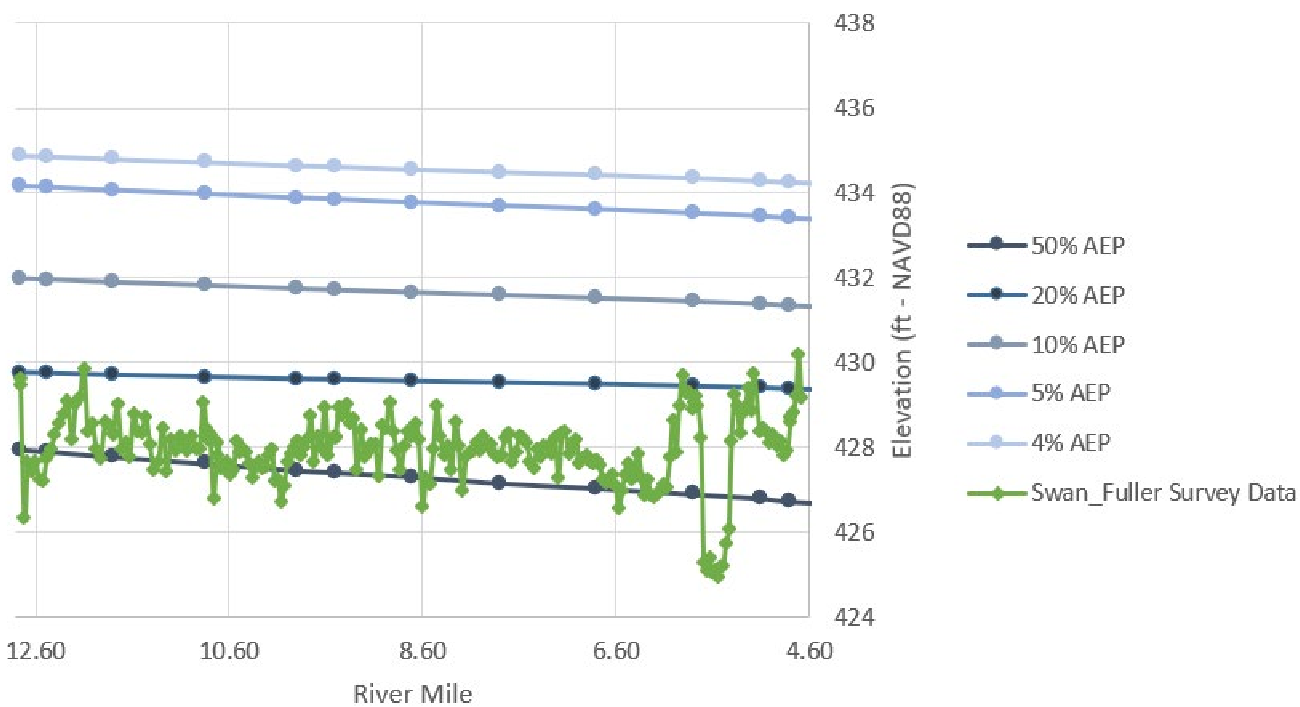

Figure 4. Results of Survey of Elevations along Swan Lake - Fuller Lake Berm and Illinois River Frequency Flood Water-Surface Elevations.

Currently, the Swan Lake water-surface elevation has a major effect upon the management and operation of the Yorkinut Slough management units. Several of the Yorkinut Slough management units have water control structures that are directly connected to Swan Lake by water control structures that pass through the berm that separates the lake from the units. The upstream and downstream invert elevations of these water control structures vary between 418.5 and 422.8 ft NAVD88. Depending upon the prevailing Swan Lake water-surface elevation, some or all these water control structures may not be able to be used for gravity drainage of the management units into Swan Lake.

Illinois Route 1 forms the eastern boundary, and part of the southern boundary, of the Yorkinut Slough management units. Several pipes pass under this route and connect the units with areas outside of the boundary of the Refuge. Water can thus pass into, or out of, the units by flowing through the pipes under Illinois Route 1. There are two pipes under this route that exist along the southern boundary of the Refuge, and these two pipes frequently carry rainfall runoff that occurs south of the road into the management units. This rainfall runoff can have a significant effect upon the management and operation of the units.

Computer Programs used for Hydrologic and Hydraulic Modeling and Analysis

The computer program that was used to perform the hydraulic modeling and calculations is the Hydrologic Engineering Center River Analysis System (HEC-RAS), Version 5.0.7 (March 2019). This program was developed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) (Davis, California). A second USACE HEC computer program that was used was the HEC Hydrologic Modeling System (HEC-HMS), Version 4.8 (April 2021). This program was used to perform hydrologic modeling and calculations. A third USACE HEC computer program that was used was HEC Data Storage System Viewer (HEC-DSSVue), Version 3.0 (August 2017). This program was used to visualize and plot hydrologic and hydraulic data. HEC-DSSVue was used to view data calculated by both HEC-RAS and HEC-HMS. It was also used to view data that was copied, or was manually entered, into its database.

Three computer programs were used to perform geometric drawing and calculations, all of which were developed by the Environmental Systems Research Institute, Inc (ESRI). The first program was ArcMap 10.3.1 (ESRI, 2015), the second was ArcGIS Pro 2.6 (ESRI, July 2020), and the third was ArcGIS Pro 2.8 (ESRI, May 2021). Visualization with aerial photography was accomplished with the computer program Google Earth Pro, Version 7.3.3 (Google Inc., July 2020). The computer program Microsoft Excel was used for spreadsheet calculations. Prior to the use of HEC-HMS to develop hydrologic modeling and calculations, the computer program USGS StreamStats (Version 4.4.0 and Version 4.3.11) was used to determine drainage patterns and to delineate tributary watersheds.

Hydrologic Modeling of Tributary Watersheds

Hydrologic modeling of tributary watersheds was developed so that the effect of rainfall events of various magnitudes upon the study area could be assessed. Rainfall runoff into Swan Lake and Fuller Lake affects the operation of the management units. Therefore, hydrologic modeling was developed for watersheds that contribute runoff to the Yorkinut Slough management units, to Swan Lake and to Fuller Lake. An image of the hydrologic modeling tributary watersheds depicted in Google Earth Pro is given in Figure 5. Hydrologic modeling was also developed for the neighboring EMP Calhoun Point study area, which lies to the east of the Yorkinut Slough management units.

The watersheds to the immediate south and southwest of the management units were purposefully drawn in a detailed manner (and are thus relatively small compared to most other watersheds) so that a detailed depiction of runoff into the management units would be produced. There is one named creek in the area that contributes runoff, Metz Creek with a watershed of 10.0 square miles. This watershed is the largest of those that contribute runoff to the Yorkinut Slough management units, Swan Lake and Fuller Lake. Swan Lake, and the immediate area around it, is shown in three sections. The lake is divided into three sections by two constructed berms. Fuller Lake, and the immediate area around it, is also shown.

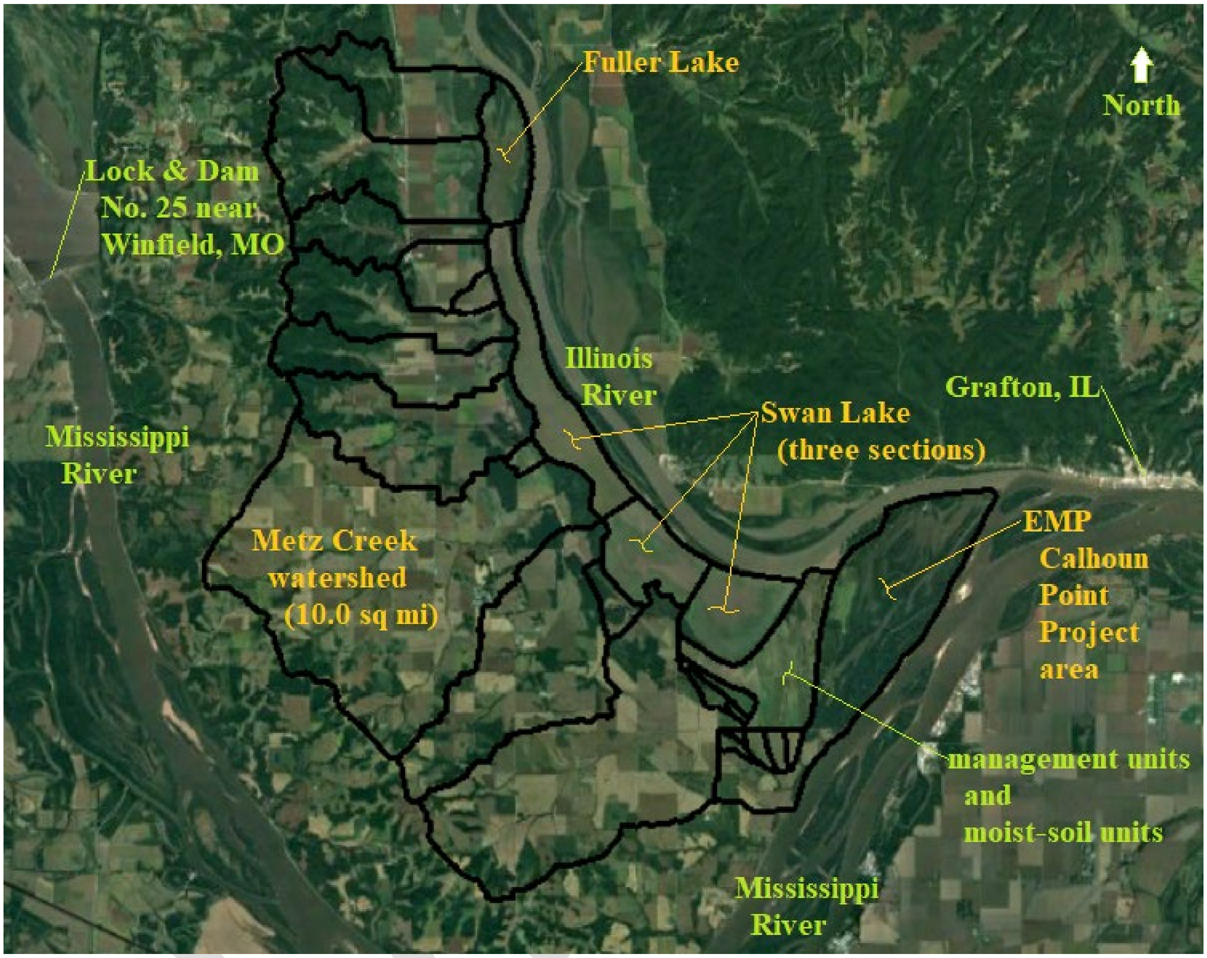

Figure 5. Image of Hydrologic Modeling Tributary Watersheds depicted in Google Earth Pro.

Inflow hydrographs were calculated for 10 different frequency rainfall events for all watersheds shown in Figure 5. The 10 frequency rainfall events were the 100%, 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, 0.2% and 0.1% annual exceedance probability (one-, two-, five-, 10-, 25-, 50-, 100-, 200-, 500- and 1000-year, respectively) events. The hydrographs that were calculated take land cover into account. In the hydrologic modeling, many different parameters are calculated. Precipitation parameters include incremental, cumulative, loss and excess. Flow rate parameters include baseflow, direct runoff and total. Some assumptions are made regarding antecedent soil moisture conditions.

Hydraulic Modeling of Gravity Drainage of Existing Management Units

The first hydraulic modeling effort involved developing a simulation of gravity drainage of the existing management units with the assumption of unimpeded flow of water through, and out of, the management units. A schematic obtained from the U.S. Fish and Wildlife Service (USFWS) and USACE that shows the names of existing management units, along with their general shapes, was used as a guide for digitizing the existing management units in ArcMap. This schematic is shown in Figure 6.

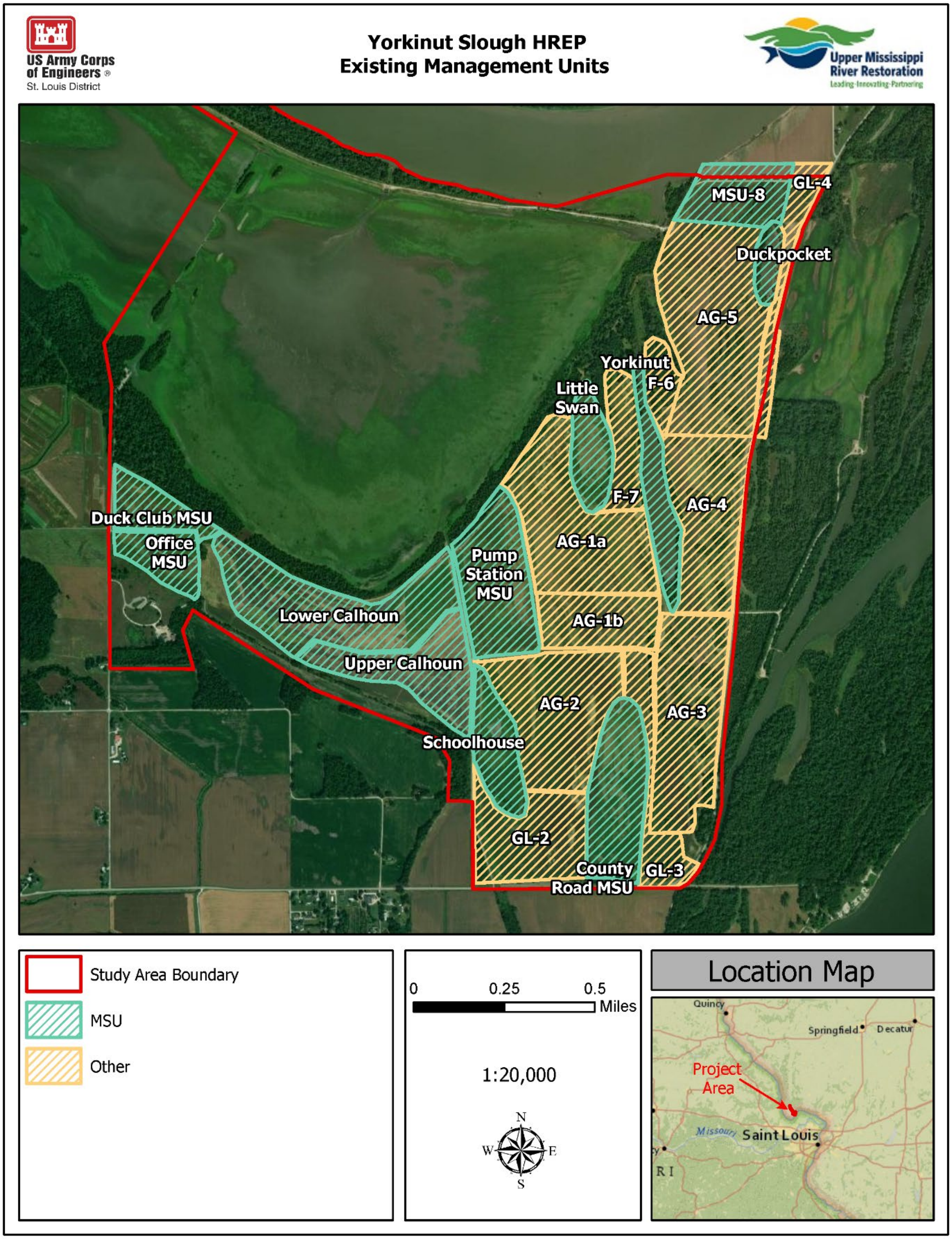

Figure 6. Names of Existing Management Units and their General Shapes.

The management units, as they were digitized in ArcMap, varied in their shapes from the shapes shown on the schematic. This variation in shapes is because the units were digitized more in conformity with topography, berms and drainage patterns. The existing management units, as they were digitized in ArcMap, are shown in Figure 7. The names given to each management unit are shown in this figure. Also shown are two features of the two-dimensional (2d) hydraulic modeling technique that was used. These features of the modeling are computation cells and representations of berms between some of the management units. For each timestep of a modeling simulation, computations are made for all cells within an area that is modeled with the 2d modeling technique. The results of these computations indicate the magnitude, speed and direction of water movement into or out of each cell. The red and black dashed lines in Figure 7 represent berms between some of the management units, which are referred to as 2d flow area connections in the computer program HEC-RAS. Water can flow over these berms, in either direction, if the hydraulic calculations show that such flow would occur. Water is also able to flow through these berms in pipes and culverts. There are two names of the form “reservoir xy,” which indicate artificial reservoirs into which water from the management units flowed. The reservoirs essentially served as external holding ponds (into which water from the management units flowed and was stored) that allowed water to leave the units. The volume of water that entered each pond was calculated by the computer program HEC-RAS. Three ditches with names of the form “ditch xy” are also shown.

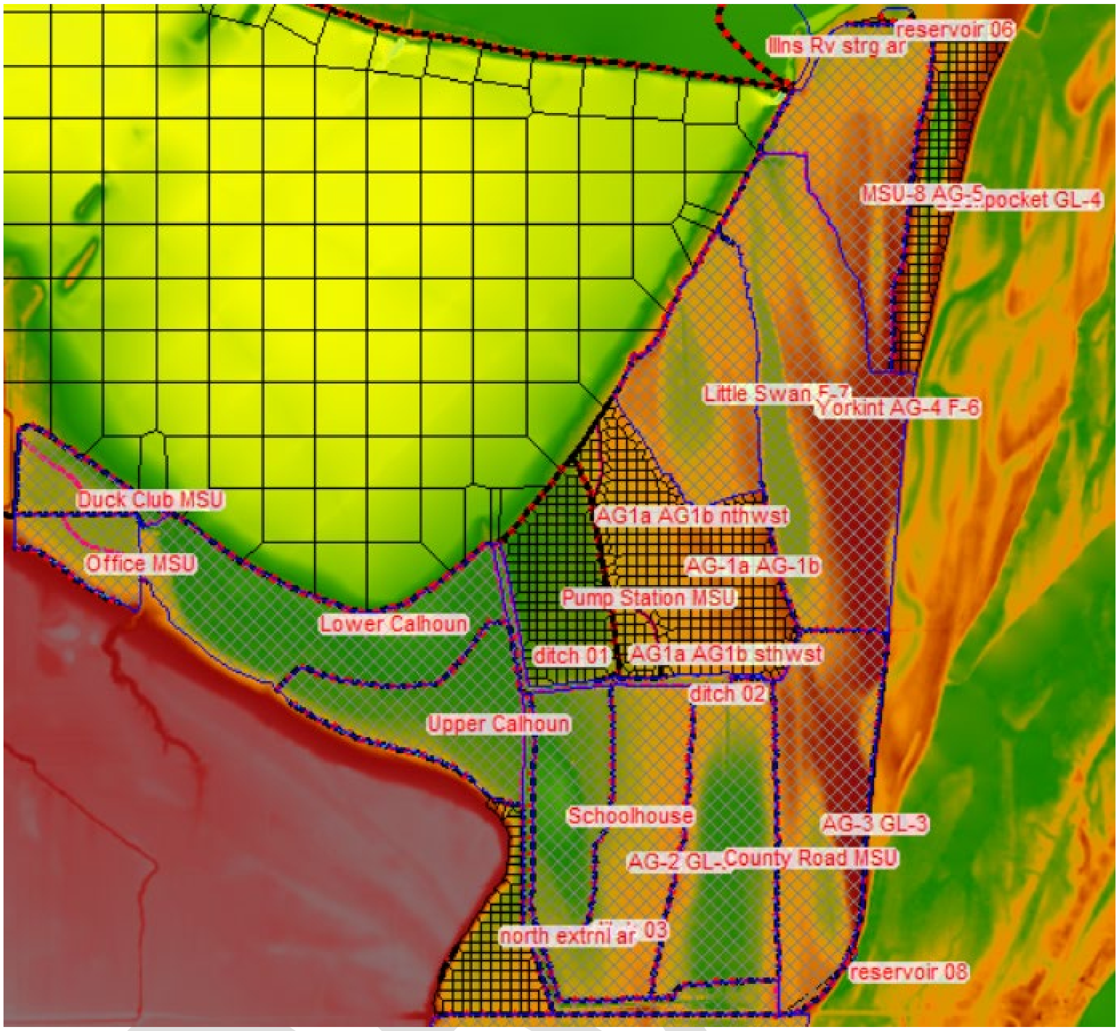

Figure 7. Existing Management Units as Digitized in ArcMap.

Pertinent elevation and area data for the existing management units as they were drawn in ArcMap is given in Table 1. For purposes of comparison, it is interesting to note that the area of Swan Lake when this body of water is near the level at which it is managed is about 2,500 acres. The ratio of the area of Swan Lake when this body of water is near the level at which it is managed to the area of the existing Yorkinut Slough management units is about 2.83 (i.e., 2,500 acres / 883.4 acres).

Table 1. Pertinent Elevation and Area Data for Existing Management Units as Drawn in ArcMap.

Management Unit (as drawn in ArcMap)	**Approximate Highest Elevation as depicted on the project area LiDAR data (feet NAVD88)**	**Approximate Lowest Elevation as depicted on the project area LiDAR data (feet NAVD88)**	**Difference between Highest Elevation and Lowest Elevation (feet)**	**Management Unit Area (as drawn in ArcMap) (square feet)**	**Management Unit Area (as drawn in ArcMap) (acres)**
Duck Club MSU	425.6	421.6	4.0	827592.2	19.00
Office MSU	426.6	423.3	3.3	861787.8	19.78
Lower Calhoun	426.6	420.6	6.0	3536469.8	81.19
Upper Calhoun	426.6	421.4	5.2	2183187.2	50.12
Pump Station MSU	425.0	420.0	5.0	1915724.1	43.98
Schoolhouse	423.8	420.4	3.4	1848894.8	42.44
AG-2 GL-2	427.8	423.0	4.8	2894263.5	66.44
County Road MSU	428.5	421.0	7.5	3207494.2	73.63
AG-3 GL-3	434.3	422.2	12.1	3546599.6	81.42
AG1a AG1b sthwst	425.5	423.2	2.3	337099.1	7.74
AG-1a AG-1b	429.2	425.1	4.1	3526066.9	80.95
AG1a AG1b nthwst	426.7	423.3	3.4	161966.3	3.72
Little Swan F-7	429.4	422.9	6.5	2706791.3	62.14
Yorkint AG-4 F-6	433.4	422.3	11.1	5954614.4	136.70
MSU-8 AG-5	432.2	422.8	9.4	3179530.8	72.99
Duckpocket GL-4	432.4	419.4	13.0	1790934.9	41.11
sum of YS units				**38479016.9**	**883.36**

The intent of this first modeling effort was to simulate draining of the management units, with the initial water levels being reasonable management water-surface elevations for each unit. Data for the existing water control structures collected during the first instance of surveying by USACE St. Louis District was included in the geometric data, and a Manning's n value of 0.06 was assumed for the entire modeled area. It was intended that a detailed representation of the land cover and associated Manning's n values would be included in the modeling of subsequent plans in HEC-RAS once this information could be developed, but with this first modeling effort the emphasis was on creating a detailed representation of geometric features (management units, water control structures, berms). This first modeling effort showed that the management units were able to be drained within four to five days, with some inundation remaining in some units having terrain that is relatively low compared to the surrounding ground. Currently a water control structure exists between Office MSU and Duck Club MSU, but no water control structure exists between Duck Club MSU and Swan Lake. So, water did not drain from either Office MSU or Duck Club MSU in this simulation. It was later learned that, to drain these two units at the desired time, USFWS degrades a short area of the berm between Duck Club MSU and Swan Lake so that draining will occur.

The hydraulic modeling was eventually expanded to include Swan Lake in the geometric data. With the expanded hydraulic modeling, a second hydraulic modeling effort of a simulation of gravity drainage of both the existing management units and Swan Lake was developed. The gravity drainage structure at the extreme southern end of the Swan Lake berm, which is equipped with stop logs, was included in the modeling. Outflow from both Swan Lake and the existing management units was assumed to enter the Illinois River in an unimpeded manner through this gravity drainage structure at the southern end of the Swan Lake berm. The stop logs in this structure were assumed to be completely removed during the simulation.

Only two of the reservoirs that served as external holding ponds in the first modeling effort were used in this second modeling effort (reservoirs 06 and 08), and a reservoir was created to represent the Illinois River. All three ditches used in the first modeling effort were used in the second modeling effort. A moderately high initial elevation for Swan Lake of 424.5 ft NAVD88 was assumed, which results in a backwater effect of Swan Lake upon some low areas of the Yorkinut Slough management units. To represent the short area of the berm between Duck Club MSU and Swan Lake that is currently degraded so that draining may occur, a water control structure with a pipe two ft in diameter was assumed to exist between the management unit and the lake. As in the first modeling effort discussed above, the initial management unit water levels were assumed to be reasonable management water surface elevations for each unit. This second modeling effort showed that the management units were able to be drained within 10 to 15 days (and some low-lying units draining within 20 days), with some inundation remaining in some units having terrain that is relatively low compared to the surrounding ground.

Hydraulic Modeling of Filling of Existing Management Units

A third hydraulic modeling effort of a simulation of filling of existing management units with existing well pumps was developed. The same geometric features that were used to represent the management units in the first two modeling efforts were used in this third effort, except for the external holding ponds. These ponds were not needed for this modeling effort because it was intended that no water leave the management units. There are three existing well pumps located throughout the management units, and all three well pumps have a pumping capacity of about 2,000 gallons per minute (about 4.45 cubic ft per second). The western-most well pump is located near the intersection of the units Duck Club MSU, Office MSU and Lower Calhoun.

This well pump is referred to by USFWS as pump no. 1. The eastern-most well pump is located near the intersection of the units AG-1a AG-1b, AG-3 GL-3 and County Road MSU. This well pump is referred to as pump no. 3. The last well pump (i.e., the middle well pump) is located about 1,550 ft directly west of the eastern-most well pump. This middle well pump is located near the intersection of the units Pump Station MSU, AG1a AG1b sthwst, AG-2 GL-2 and Schoolhouse. This well pump is referred to as pump no. 2. All three well pumps each have three fixed pipes emanating from them in different directions, and these pipes are used to direct the pump outflow into various management units.

Prior to this modeling of filling of existing management units, a detailed representation of the land cover and associated Manning's n values was developed. This land cover information was included in this modeling effort, and in all subsequent modeling efforts. This detailed representation of the land cover and associated Manning's n values, as depicted in HEC-RAS RAS Mapper, is given in Figure 8. (RAS Mapper is the mapping utility in HEC-RAS. It displays maps, map features and time-lapse depictions of simulations.) Areal location and extent of land cover from a geographic data system were provided. For each land cover type that is present in the study area, Manning's n values were determined. Typical minimum, average and maximum Manning's n values were determined. It was decided to use the average values in the hydraulic modeling.

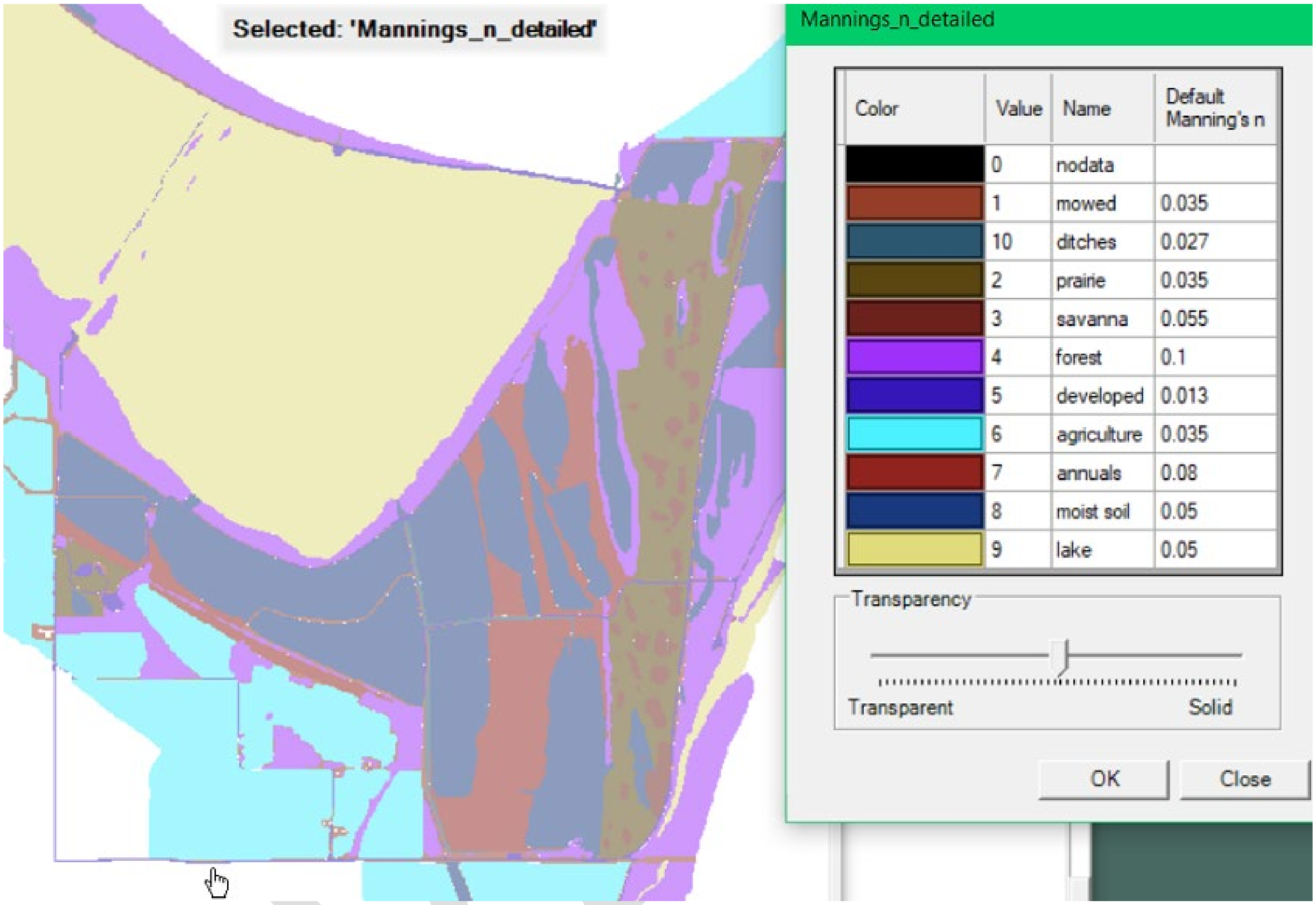

Figure 8. Detailed Representation of Land Cover and associated Manning's n Values, as depicted in RAS Mapper.

These Manning's n values were entered into the land cover feature in RAS Mapper. As shown in Figure 8, a total of 10 different land covers were used in the hydraulic modeling. In terms of land cover, quite a large amount of the land surface of the management units was classified as being covered by moist soil (especially the western and central parts of the managed area). Fairly large portions of the central part of the managed area were classified as being covered by annuals, and much of the eastern part is covered by prairie and savanna.

In simulating the filling of existing management units, the procedure followed in the field by the USFWS management personnel to perform filling was followed in the modeling. This procedure involves using one pipe of a given well pump to fill a chosen management unit to its desired water-surface elevation, and then sequentially using different pipes of the same well pump to fill other management units to their desired water-surface elevations. Some staggering in time of pumping with the three well pumps was used in the simulation to allow visualization of the intentional flooding and inundation of the management units. The modeling method used for this simulation does not account for the loss of pumped water to infiltration, evaporation or uptake by foliage (all of which depend upon many factors). Infiltration depends upon soils and their antecedent moisture conditions. Evaporation depends, in part, upon sunlight, sun angle and wind. Uptake by foliage depends, in part, upon the time of year. The simulation showed that depths of about 0.3 to 3.0 ft were achieved in the management units in a period of 12 days, depending upon topography and location within the units.

Hydraulic Modeling of Runoff from Frequency Rainfall Events

A fourth hydraulic modeling effort of simulation of rainfall runoff from tributary watersheds of the Yorkinut Slough management units, Swan Lake and Fuller Lake was developed. The intent of this simulation was to determine the effect of this runoff upon the management units. During several study team meeting conference calls, the manager of the Refuge has stressed that local rainfall runoff can have a major effect upon the management and operation of the management units. Therefore, a topographic and hydrologic study of the tributary streams and the land surface surrounding the management units and the two lakes was conducted. The shapes, areas and hydrologic parameters of the tributary watersheds were determined.

As discussed above, an image of the hydrologic modeling tributary watersheds depicted in Google Earth Pro is given in Figure 5. Runoff hydrographs were calculated for 10 different frequency rainfall events for all these watersheds with the computer program HEC-HMS. Runoff hydrographs for each tributary watershed can be entered into a hydraulic model developed with the computer program HEC-RAS so that the simultaneous effect of the rainfall event upon the management units, Swan Lake and Fuller Lake can be assessed. It was assumed that the same amount of total rainfall occurs over each tributary watershed, and that the same time distribution of the total rainfall occurs for each watershed. Runoff hydrographs for any of the frequency rainfall events modeled with HEC-HMS can be coupled with the hydraulic model to determine the effects of these events upon the system of management units and lakes.

Proposed Water Control Structures and Proposed Pump Station

Proposed water control structures and a proposed pump station were discussed and evaluated by the study team. Two separate documents, completed about five months apart from one another, were written by the study team hydrologic and hydraulic engineer to document the evaluation and design process. The first document dealt with proposed water control structures and a proposed pump station. As the Feasibility Phase proceeded after the first document was written, the study team determined that the analysis of a proposed pump station needed to be refined and analyzed in greater detail. So, the second document was written and it dealt only with a proposed pump station.

These two documents are given below in Sub-Appendix G1 and Sub-Appendix G2, respectively, for the purpose of documenting the evolution of the thought process and the Feasibility Phase design. Sub-Appendix G1 is the first document that was written and is entitled “First Document – Proposed Water Control Structures and Proposed Pump Station.” Sub-Appendix G2 is the second document that was written and is entitled “Second Document - Proposed Pump Station.

After the second document was written, a discussion was held between the lead engineer and the hydrologic and hydraulic engineer regarding the fact that the Maximum Alternative should provide very rapid evacuation of water from the impoundment downstream of the berm proposed to be constructed across Swan Lake (whether linear or curved) compared to the other alternatives. For the Maximum Alternative, it was decided to propose a pump station with 25 percent greater capacity than that of the existing pump station having the largest capacity (i.e., 48,000 gpm). So, a pump station with a capacity of 60,000 gpm was used for measure 16c in the alternative referred to as the Maximum Alternative.

For the remaining alternatives, the calculations given in the second document were used for the respective proposed pump stations. A pump station with a capacity of about 23,300 gpm was used for measure 16c in the alternative referred to as Intermediate B. A pump station with a capacity of about 19,400 gpm was used for measure 16a in the alternative referred to as Intermediate A. The three pump station capacities (60,000 gpm; 23,300 gpm; 19,400 gpm) were used for their respective alternatives in the economic analysis.

As stated above, the design of the proposed water control structures and the proposed pump station will be refined later in the Feasibility Phase and during Plans and Specifications. A hydraulic model of the Tentatively Selected Plan (TSP) will be developed with the computer program HEC-RAS. This hydraulic model will be used to refine the dimensions and the locations of the proposed structures and proposed pump station. The hydrologic modeling of tributary watersheds that was developed will be used in the hydraulic model of the TSP for simulations in which rainfall runoff needs to be considered and simulated for design purposes.

Hydraulic Modeling and Evaluation of Proposed Measures

Many of the proposed measures that were evaluated by the study team involved modifications of the terrain. Some of the proposed measures would affect a relatively small portion of the overall managed area, whereas others would affect a larger portion. Some of the measures included swales. The proposed measures that were evaluated were topographically modeled by the civil engineer. Using the topographic models that were developed by the civil engineer, the hydraulic engineer then viewed the topography for each of the proposed measures to qualitatively determine if the topography would promote drainage of the existing and proposed management units.

Using the topographic models, the hydraulic engineer then developed hydraulic models of the measures. Hydraulic models were developed for both draining and filling. The draining models assumed initial water-surface elevations within each management unit that would be expected for management purposes, and then subsequent gravity draining of the units with no impedance of drainage by backwater effects. The filling models assumed that the four well pumps proposed for construction by Ducks Unlimited were operating at full capacity. All four of these well pumps are proposed to have a capacity of 3,000 gpm. There were a large number of measures that were modeled, so the goal of the effort was to determine if any of the measures would pose issues for draining or for filling.

The hydraulic modeling showed that drainage and filling for the proposed measures did not result in any issues for draining or for filling. The swales that were included in some of the measures promoted drainage, and use of swales may result in advantages for the design of the final project topographic plan.

Drainage of External Fields to Calhoun Point via Managed Area

There is a farm field south of the Yorkinut Slough management units, and south of Illinois Route 1, that currently drains northward and into the Yorkinut Slough managed area via two existing culverts under the roadway. When the hydrologic modeling of the study area was developed, this farm field was divided into two sub-watersheds in accordance with its natural drainage to the culverts. These two sub-watersheds were designated as B_01 and B_02, respectively, in the hydrologic modeling. Figure 9 shows a Google Earth Pro image of the management units and hydrologically modeled sub-watersheds B_01 and B_02. Also shown in Figure 9 is Illinois Route 1.

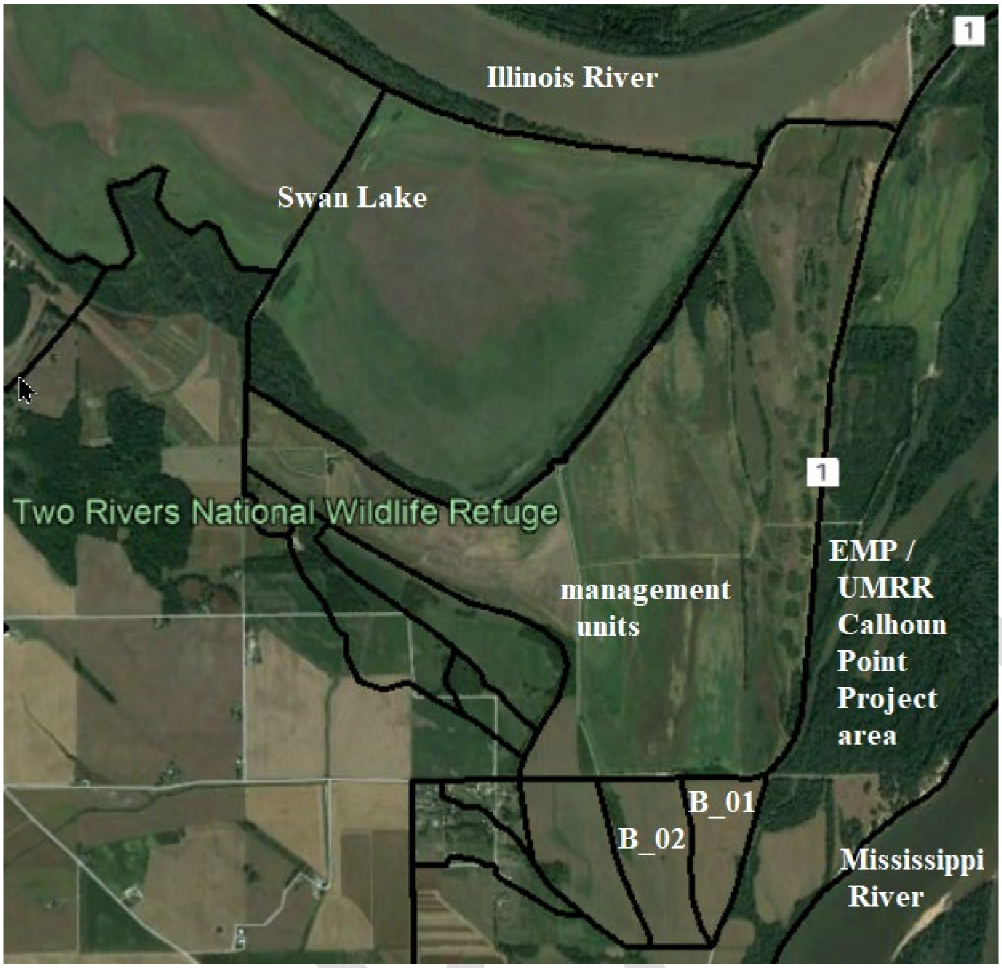

Figure 9. Google Earth Pro Image of Management Units and Hydrologically Modeled Sub-Watersheds B_01 and B_02.

The combined area encompassed by sub-watersheds B_01 and B_02 is 0.1826 square miles (116.9 acres). This combined area is 0.44 percent of the total study area watershed and is 12.1 percent the size of the Yorkinut Slough managed area. As mentioned above, this area currently drains northward and into the managed area via two culverts under Illinois Route 1. Both culverts are three-foot diameter concrete pipes. The drainage flows through the culverts and enters a ditch that drains generally westward and then northward along the periphery of some of the management units toward Swan Lake. Depending upon the water levels in both the ditch and the management units, the drainage from sub-watersheds B_01 and B_02 may or may not be able to flow into the managed area.

One of the proposed objectives of this project is to modify the management units such that the land area taken by the ditches within the managed area is incorporated into the modified units. The ditches would thus be eliminated. This proposed objective would necessitate a revised way of handling drainage from sub-watersheds B_01 and B_02. It is proposed that this drainage continue to flow into the managed area via the two culverts under Illinois Route 1, and then flow generally eastward to an existing culvert under Illinois Route 1. Specifically, the drainage would flow through low-lying terrain of existing management units County Road MSU and AG-3 GL-3 (and a proposed ditch or connection between these low areas) and toward an existing five-foot diameter plastic pipe under Illinois Route 1. This culvert lies under the curved portion of Illinois Route 1 near the northeast corner of sub-watershed B_01 and has a northwest-to-southeast orientation.

Water that flows southeastward through this five-foot diameter plastic pipe enters the EMP / UMRR Calhoun Point project area. The combined area of the Calhoun Point project area and its watershed is about 2.5 times as large as the area of the Yorkinut Slough managed area. The manager of the Calhoun Point project area and local landowners have been asked for their opinions on the proposed way of handing drainage from sub-watersheds B_01 and B_02 and are in favor of the plan. Additional consultation with interested and affected individuals will take place as the project continues.

The hydraulic modeling of existing conditions that was developed during the Feasibility Phase included a model of rainfall runoff entering the study area and calculation of the subsequent effects upon the water-surface elevations of the Yorkinut Slough management units, Swan Lake and Fuller Lake. This hydraulic model incorporated the information calculated by the hydrologic modeling that was developed of the study area watershed. It is planned that a hydraulic model of the TSP will be developed, and this hydraulic model will incorporate the information calculated by the hydrologic modeling that was developed of the study area watershed. The hydraulic model of the TSP will thus be able to calculate the effects of the revised way of handling drainage from sub-watersheds B_01 and B_02. A comparison of water-surface elevations calculated for existing conditions will be made to those calculated for the TSP within the area around sub-watersheds B_01, B_02, Illinois Route 1 and the southeastern portion of the managed area. Thus, the effects of the revised way of handling drainage from sub-watersheds B_01 and B_02 will be able to be determined. Several combinations of annual exceedance probability rainfall events and storm durations will be investigated. The hydraulic modeling of existing conditions and of the TSP will also provide an indication of the ability of the three culverts under Illinois Route 1 to adequately convey the drainage.

Hydraulic Design Implications of the Climate Assessment

Appendix H contains the climate assessment. There are several aspects of the climate assessment. The literature reviewed indicated a reasonable consensus of an increasing trend in observed temperature, precipitation, and streamflow. There was also a consensus that temperatures and precipitation are projected to increase in the future, with warmer and drier summers and wetter winters. There was no consensus in the literature on projected future streamflow. In terms of streamflow, two of the discharge datasets that were analyzed with the Non-stationarity Detection Tool (Mississippi River at Alton, Illinois; Macoupin Creek near Kane, Illinois) showed nonstationarity and one (Mississippi River at Grafton, Illinois) did not show nonstationarity. In terms of climate hydrology assessment, simulations using projected carbon emissions indicate increasing annual maximum of mean monthly flow rates for the Lower Illinois River watershed. The USACE Climate Hydrology Assessment Tool showed a statistically significant trend of increasing streamflow for the projected period that was analyzed. The USACE Vulnerability Assessment Tool indicated that the Lower Illinois (HUC 0713) watershed is not within the 20-percent most-vulnerable watersheds, and thus is not considered relatively vulnerable when compared to other watersheds in the CONUS. Not being considered relatively vulnerable does not mean that the watershed is not susceptible to climate change. Flood magnification was the dominant indicator in all scenarios analyzed. The residual risk to the Project as the result of climate change to the Project is classified as low.

The results of this climate assessment were qualitatively applied to the future hydraulic design of this Project. The literature review indicates an increasing trend in precipitation. The literature review and the climate hydrology assessment indicate inconclusive trends in projected streamflow.

This Project provides for a pump station that will be dedicated to evacuating water from the management units and a relatively small portion of Swan Lake. This dedicated pump station is a means to provide some independence for the management units from the adverse effects of Swan Lake and the Illinois River. Heavy precipitation within the Illinois River Basin and within the watershed of the study area is a major contributor to the adverse effects of Swan Lake and the Illinois River upon operation of the management units.

This Project also provides for the drainage of external fields to Calhoun Point rather than to Swan Lake. As discussed above in the section on drainage of external fields to the Calhoun Point project area via the managed area, these fields presently drain to Swan Lake via the management units. This Project proposes to direct the field drainage to Calhoun Point after it enters the southern end of the managed area, thus removing one existing component of drainage to the units.

Sub-Appendix G1: First Document - Proposed Water Control Structures and Proposed Pump Station

This document contains a summary of proposed water control structures and pump stations for the UMRR Yorkinut Slough Project. Where it is appropriate within this document, proposed measures are discussed relative to the proposed infrastructure.

The proposed infrastructure is summarized in five separate sections in this document. The first section contains a discussion of proposed water control structures within the management units and MSUs. The second section contains a discussion of proposed water control structures between these units and Swan Lake. The third section contains a discussion of proposed pump stations. The fourth section contains a discussion of proposed water control structures between Swan Lake and the Illinois River. The fifth section contains a discussion of proposed water control structures within Swan Lake.

In developing this information on proposed water control structures and pump stations, the assumption was made that existing water control structures and pump stations along the Swan Lake berm will not be removed but will be retained. It was further assumed that each individual existing water control structure within the management units and MSUs units will be either removed and replaced or will be removed and not replaced. Each existing water control structure within the management units and MSUs will be examined individually later in the Feasibility Phase to determine the course of action to be taken. Also, new water control structures may be placed within the management units and MSUs in locations at which no structure currently exists. Possible new water control structures will be examined later in the Feasibility Phase.

<u>Proposed Water Control Structures within Management Units and MSUs</u>

Discussions of all measures were held between the lead engineer (who is also the civil engineer) and the hydraulic engineer. Various diameters for pipes of water control structures were discussed. Ultimately, it was decided to propose a diameter of all water control structures within the management units and MSUs of 2.0 ft.

This decision was based upon the course of action that was followed by the study team for the UMRR Oakwood Bottoms Project. That team decided to use one diameter for the water control structures within the management units and MSUs of 2.0 ft, and stop logs of one size, so that the infrastructure would be interchangeable between structures and to standardize operation of the facility. This approach is beneficial for limited staffing situations.

<u>Proposed Water Control Structures between Management & MSUs and Swan Lake</u>

The discussions of all measures between the lead engineer and the hydraulic engineer ultimately led to the decision to propose a diameter of all water control structures between the units (management and moist soil) and Swan Lake of 3.0 ft. The same thought process of interchangeability between structures and standardization of operation of the facility contributed to the decision on the diameter of 3.0 ft.

The proposed sizes of water control structures within the management units and MSUs, and of water control structures between these units and Swan Lake, met with the approval of the manager of the Refuge. He was in favor of having stop logs for the water control structures, and interchangeability of parts and stop logs between structures. Also, the existing water control structures with the management units and MSUs which have diameters generally ranging from 2.0 ft to 3.0 ft provide reasonable draining times for cases when gravity drainage is possible.

<u>Proposed Pump Stations</u>

a. Proposed Measure 16c

For measure 16c, an essentially linear berm would be constructed across Swan Lake to create a separate impoundment downstream of this berm. One of the existing Swan Lake pump stations would be located within this separate impoundment. This pump station could then essentially serve to evacuate flood water from this separate impoundment, and from the Yorkinut Slough management units and MSUs, if gravity drainage of these areas into the Illinois River was prevented by persistent flooding of this river.

To determine the necessary pumping capacity to evacuate flood water from both the proposed lake impoundment and the Yorkinut Slough management units and MSUs, the water-surface elevation within these areas was assumed to be the top of the Six Mile Island berm. A reasonable estimate of the top elevation of the Six Mile Island berm at the impoundment is 428.0 ft NAVD88. A reasonable estimate of the water-surface elevation to which this impoundment and the units would be lowered is 421.0 ft NAVD88. So, the volume of water to be discharged from the impoundment and the units combined would be about 8,000 acre-feet (ac-ft) (based upon volumetric calculations made in a hydraulics computer program). The existing Swan Lake pump station has a capacity of about 48,000 gallons per minute (gpm), according to personnel who operate this pump station. This volume could be discharged in about 38 days. It should be noted that at least some gravity drainage may become possible prior to the end of the 38-day period.

Flood water within the remainder of Swan Lake (i.e, north of the berm to be constructed across Swan Lake but south of Fuller Lake) could be discharged by the second existing pump station within Swan Lake (i.e., the northern Swan Lake pump station) and a proposed pump station. The proposed pump station would likely be constructed just northwest of the berm that would be constructed across Swan Lake. A reasonable estimate of the top elevation of the

Swan Lake berm within the remainder of Swan Lake is 428.0 ft NAVD88. A reasonable estimate of the water-surface elevation to which the remainder of Swan Lake would be lowered is 421.0 ft NAVD88. So, the volume of water to be discharged from the remainder of Swan Lake would be about 15,400 ac-ft (based upon volumetric calculations made in a hydraulics computer program). To discharge this volume in about 40 days, a pumping capacity of about 90,000 gpm would be needed. According to the document ASB Swan Lake Item II ANSI B.pdf (as-built plans dated June 1997 and corrected in May 2001), the capacity of the northern Swan Lake pump station is 30,000 gpm. So, the pumping capacity for the proposed pump station would need to be about 60,000 gpm to discharge the flood water within the remainder of Swan Lake. It should be noted that at least some gravity drainage may become possible prior to the end of the 40-day period.

b. Proposed Measure 16a

For measure 16a, a curved berm would be constructed across Swan Lake to create a separate impoundment downstream of this berm. Neither of the existing Swan Lake pump stations would be located within this separate impoundment. Therefore, a pump station is proposed to be constructed within this separate impoundment. This proposed pump station could then essentially serve to evacuate flood water from this separate impoundment, and from the Yorkinut Slough management units and MSUs, if gravity drainage of these areas into the Illinois River was prevented by persistent flooding of this river.

To determine the necessary pumping capacity to evacuate flood water from both the lake impoundment and the Yorkinut Slough management units and MSUs, the water-surface elevation within these areas was assumed to be the top of the Swan Lake berm. A reasonable estimate of the top elevation of the Swan Lake berm at the impoundment is 428.0 ft NAVD88. A reasonable estimate of the water-surface elevation to which this impoundment and the units would be lowered is 421.0 ft NAVD88. So, the volume of water to be discharged from the impoundment and the units combined would be about 6,560 ac-ft (based upon volumetric calculations made in a hydraulics computer program). To discharge this volume in about 40 days, the pumping capacity for the proposed pump station would need to be about 38,000 gpm. It should be noted that at least some gravity drainage may become possible prior to the end of the 40-day period.

Flood water within the remainder of Swan Lake (i.e, north of the berm to be constructed across Swan Lake but south of Fuller Lake) could be discharged by the two existing pump stations within Swan Lake (i.e., the northern and the southern Swan Lake pump stations). A reasonable estimate of the top elevation of the Swan Lake berm within the remainder of Swan Lake is 428.0 ft NAVD88. A reasonable estimate of the water-surface elevation to which the remainder of Swan Lake would be lowered is 421.0 ft NAVD88. So, the volume of water to be discharged from the remainder of Swan Lake would be about 16,790 ac-ft (based upon volumetric calculations made in a hydraulics computer program). According to the document ASB Swan Lake Item II ANSI B.pdf (as-built plans dated June 1997 and corrected in May 2001), the capacity of the northern Swan Lake pump station is 30,000 gpm. The southern Swan Lake pump station has a capacity of about 48,000 gallons per minute (gpm), according to personnel who operate this pump station. So, the pumping capacity for the northern and southern Swan Lake pump stations is about 78,000 gpm. This volume could be discharged in about 50 days. It should be noted that at least some gravity drainage may become possible prior to the end of the 50-day period.

<u>Proposed Water Control Structures between Swan Lake and the Illinois River</u>

If either measure 16c or measure 16a is implemented, the gravity drainage structure located at the southern end of the Swan Lake berm will be located within the separate impoundment in Swan Lake. As discussed above several times, this separate impoundment would be located south of the berm that would be constructed across Swan Lake. The berm to be constructed across Swan Lake would be essentially linear for measure 16c and would be curved for measure 16a.

With the implementation of either measure 16c or measure 16a, the gravity drainage structure located at the southern end of the Swan Lake berm would essentially serve the separate impoundment created by the berm that would be constructed across Swan Lake. This gravity drainage structure would be essentially dedicated to evacuating water from this separate impoundment, and from the Yorkinut Slough management units and MSUs, if gravity drainage of these areas into the Illinois River was possible and was not completely hindered by flooding. Therefore, this structure would not be able to be used to evacuate water from the remainder of Swan Lake as it is currently able to do.

It is proposed that a new gravity drainage structure be constructed along the Swan Lake berm to essentially replace the structure located at the southern end of the berm. According to the document ASB Swan Lake Item II ANSI B.pdf (as-built plans dated June 1997 and corrected in May 2001), the two existing gravity drainage structures located along the Swan Lake berm have stoplog bays with an invert elevation of 412.0 ft NGVD29. There are four stoplog bays at each existing structure, with a horizontal opening of four feet for each bay. Both structures have a bridge deck, with the low chord elevation being 428.5 ft NGVD29. It is proposed that a structure with similar geometry be constructed along the Swan Lake berm northwest of the berm to be constructed across Swan Lake for either measure 16c or measure 16a.

<u>Proposed Water Control Structures within Swan Lake</u>

a. Proposed Measure 16c and Proposed Measure 16a

As discussed above in the previous section, if either measure 16c or measure 16a is implemented the gravity drainage structure located at the southern end of the Swan Lake berm would essentially serve the separate impoundment created by the berm that would be constructed across Swan Lake. This gravity drainage structure would be essentially dedicated to evacuating water from this separate impoundment, and from the Yorkinut Slough management units and MSUs, if gravity drainage of these areas into the Illinois River was possible and was not completely hindered by flooding. Therefore, this structure would not be able to be used to evacuate water from the remainder of Swan Lake as it is currently able to do.

However, the gravity drainage structure located at the southern end of the Swan Lake berm would be able to be used to assist in evacuation of water from the remainder of Swan Lake if a water control structure was added to the berm that would be constructed across Swan Lake for either measure 16c or measure 16a. Such a structure would allow water to move from Swan Lake north of the berm that would be constructed across Swan Lake into the impoundment created by the berm. The structure that would be constructed through the berm would need to be gated so that it could be closed when it was not being used.

The bathymetry data for Swan Lake shows that the bed elevation is around 417.0-417.5 ft NAVD88 in the vicinity of the location at which the berm would be constructed across Swan Lake for measure 16c or measure 16a. So, the invert elevation for the water control structure that would be constructed through the berm would likely be about 417.5-418.0 ft NAVD88. It is proposed that this water control structure have three three-foot-diameter pipes.

b. Proposed Measure 13b

The intent of measure 13b is to improve the existing berm that spans Swan Lake. This berm lies roughly in the middle along the length of Swan Lake, but somewhat further south along the length. The structure that would be constructed through this berm would need to be gated so that it could be closed when it was not being used.

The bathymetry data for Swan Lake shows that the bed elevation is around 417.0-418.0 ft NAVD88 in the vicinity of this berm. So, the invert elevation for the water control structure that would be constructed through the berm would likely be about 417.5-418.5 ft NAVD88. It is proposed that this water control structure have three three-foot-diameter pipes.

<u>Summary</u>

The sizes and types of proposed water control structures, and the capacity of the proposed pump station, will be refined later in the Feasibility Phase. The proposed infrastructure will depend to a large extent upon the measures, and the combinations of measures, that are chosen for further evaluation.

In recommending capacities for the proposed pump stations, the intent was to recommend capacities that were somewhat similar to the capacities of the existing pump stations. Another consideration was the fact that at least some gravity drainage may become possible during the period of pumping if the Illinois River begins to fall.

Sub-Appendix G2: Second Document - Proposed Pump Station

Proposed Pump Stations

The initial cost analysis for this Project showed that it was difficult to distinguish between the alternatives in terms of which one was the most cost-effective. A large portion of the cost of any of the alternatives is the respective proposed pump station. Therefore, the study team determined that the analysis of proposed pump stations should be refined and analyzed in greater detail.

According to the document ASB Swan Lake Item II ANSI B.pdf (as-built plans dated June 1997 and corrected in May 2001), the capacity of the northern Swan Lake pump station is 30,000 gallons per minute (gpm). According to personnel who operate the southern Swan Lake pump station, it has a capacity of about 48,000 gpm. So, the combined pumping capacity for the northern and southern Swan Lake pump stations is about 78,000 gpm.

The relationship of pumping capacity to volume will be used to analyze the existing pumping situation for Swan Lake and the management units. The unit of measure for water volumes that will be used in the analysis will be acre-feet (ac-ft). In developing this analysis, it will be assumed that no Swan Lake pump station (whether existing or proposed) will be responsible for pumping water in Fuller Lake. In the UMRR project for Swan Lake Flood Damage Analysis, one of the options being considered is operationally separating Fuller Lake and Swan Lake. In this option, the gravity drain that passes through the berm that separates Fuller Lake and Swan Lake will not be restored for use (it has been incapacitated and unusable for many years) but a new gravity drain will be constructed that will allow water from Fuller Lake to drain to the Illinois River. Also, Fuller Lake already has its own pump station that discharges to the Illinois River.

Pertinent data for measure 16a and for its two volumetric components (16a (1) and 16 a (2)), based upon hydraulic modeling of this measure and upon the combined pumping capacity for the northern and southern Swan Lake pump stations, is as follows:

ponding area 16a (1) volume at elevation 428.0 ft NAVD88 = 7,924 ac-ft
ponding area 16a (2) volume at elevation 428.0 ft NAVD88 = 23,991 ac-ft
total volume at elevation 428.0 feet NAVD88 = 31,915 ac-ft
pumping capacity / volume = 78,000 gpm / 31,915 ac-ft = 2.444 gpm / ac-ft

Pertinent data for measure 16c and for its two volumetric components (16c (1) and 16c (2)), based upon hydraulic modeling of this measure and upon the combined pumping capacity for the northern and southern Swan Lake pump stations, is as follows:

ponding area 16c (1) volume at elevation 428.0 ft NAVD88 = 10,128 ac-ft
ponding area 16c (2) volume at elevation 428.0 ft NAVD88 = 21,825 ac-ft
total volume at elevation 428.0 feet NAVD88 = 31,953 ac-ft
pumping capacity / volume = 78,000 gpm / 31,953 ac-ft = 2.441 gpm / ac-ft

Theoretically, the total volume of Swan Lake and the management units at elevation 428.0 ft NAVD88 calculated for the two proposed configurations of the cross-lake berm should be equal. However, inexactness in the digitizing of the two portions of the respective measures (16a and 16c) in the hydraulics computer program resulted in a relatively small difference in the calculation of the total volumes for the two ponding areas (31,915 ac-ft versus 31,953 ac-ft, a difference of 0.12 percent). Based upon data calculated for measure 16a and measure 16c, the average total volume at elevation 428.0 ft NAVD88 was 31,934 ac-ft.

Based upon the volumetric calculations shown above, the existing pumping capacity for Swan Lake and the management units provides 2.44 gpm per ac-ft of water that would be present if the water-surface elevation of Swan Lake and the management units was at elevation 428.0 ft NAVD88.

<u>Analysis for Proposed Measure 16c</u>

If measure 16c would be constructed, the existing southern Swan Lake pump station would be in the portion of the lake that lies east of the proposed cross-lake berm. So, this existing southern pump station would be responsible for pumping of water from the portion of Swan Lake that lies east of the proposed cross-lake berm and from the management units (i.e., ponding area 16c (1)). For ponding area 16c (1), the volume at elevation 428.0 ft NAVD88 is 10,128 ac-ft. The southern Swan Lake pump station has a capacity of about 48,000 gpm. As a result, the ratio of pumping capacity to volume for ponding area 16c (1) would be 48,000 gpm / 10,128 ac-ft = 4.74 gpm / ac-ft. The magnitude of this ratio is well above the 2.44 gpm / ac-ft ratio for the existing pumping situation for Swan Lake and the management units.

If measure 16c would be constructed, the existing northern Swan Lake pump station and a proposed pump station would be responsible for pumping water from the portion of Swan Lake that lies west of the proposed cross-lake berm. The capacity of the northern Swan Lake pump station is 30,000 gpm. For ponding area 16c (2), the volume at elevation 428.0 ft NAVD88 is 21,825 ac-ft. So, to maintain the existing pumping situation for Swan Lake and the management units, the following calculation was made to determine the capacity of the proposed pump station if measure 16c would be constructed:

2.44 gpm / ac-ft = (30,000 gpm + x) / 21,825 ac-ft
x = 23,253 gpm

This calculation shows that, if measure 16c would be constructed, the proposed pump station would need to have a capacity of about 23,300 gpm.

As a check on the pumping situation that would exist for Swan Lake and the management units if measure 16c would be constructed with a proposed pump of capacity of 23,300 gpm, the following calculation was made:

total pumping capacity / total volume at elevation 428.0 ft NAVD88 = (48,000 gpm + 30,000 gpm + 23,300 gpm) / (31,953 ac-ft) = 3.17 gpm / ac-ft > 2.44 gpm / ac-ft

This calculation shows that the pumping situation that would exist for Swan Lake and the management units if measure 16c would be constructed with a proposed pump of capacity of 23,300 gpm would be an improvement upon the existing pumping situation and would not lessen or compromise the existing pumping situation.

<u>Analysis for Proposed Measure 16a</u>

If measure 16a would be constructed, the existing southern Swan Lake pump station would be in the portion of the lake that lies west of the proposed cross-lake berm. So, this existing southern pump station plus the existing northern pump station would jointly be responsible for pumping water from the portion of Swan Lake that lies west of the proposed cross-lake berm (i.e., ponding area 16a (2)). For ponding area 16a (2), the volume at elevation 428.0 ft NAVD88 is 23,991 ac-ft. The southern and northern Swan Lake pump stations have a combined capacity of about 78,000 gpm. As a result, the ratio of pumping capacity to volume for ponding area 16a (2) would be 78,000 gpm / 23,991 ac-ft = 3.25. The magnitude of this ratio is well above the 2.44 gpm / ac-ft ratio for the existing pumping situation for Swan Lake and the management units.

If measure 16a would be constructed, a proposed pump station would be responsible for pumping water from the portion of Swan Lake that lies east of the proposed cross-lake berm. For ponding area 16a (1), the volume at elevation 428.0 ft NAVD88 is 7,924 ac-ft. So, to maintain the existing pumping situation for Swan Lake and the management units, the following calculation was made to determine the capacity of the proposed pump station if measure 16a would be constructed:

2.44 gpm / ac-ft = x / 7,924 ac-ft

x = 19,335 gpm

This calculation shows that, if measure 16a would be constructed, the proposed pump station would need to have a capacity of about 19,400 gpm.

As a check on the pumping situation that would exist for Swan Lake and the management units if measure 16a would be constructed with a proposed pump of capacity of 19,400 gpm, the following calculation was made:

total pumping capacity / total volume at elevation 428.0 ft NAVD88 = (48,000 gpm + 30,000 gpm + 19,400 gpm) / (31,915 ac-ft) = 3.05 gpm / ac-ft > 2.44 gpm / ac-ft

This calculation shows that the pumping situation that would exist for Swan Lake and the management units if measure 16a would be constructed with a proposed pump of capacity of 19,400 gpm would be an improvement upon the existing pumping situation and would not lessen or compromise the existing pumping situation.