FOND DU LAC BAND OF LAKE SUPERIOR CHIPPEWA, MINNESOTA CEDAR LAKE WILD RICE RESTORATION STUDY

SECTION 22, PLANNING ASSISTANCE TO STATES

FOND DU LAC BAND OF LAKE SUPERIOR CHIPPEWA
US ARMY CORPS OF ENGINEERS

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Table of Contents

Appendix A: Hydrology and Hydraulic Model Development Report

List of Figures

Purpose

Wild rice harvesting has played an important cultural and economic role for the Fond du Lac Band of Lake Superior Chippewa. This type of plant grows in shallow water in small lakes and slow-flowing streams. Lake fluctuations produced by storm events and downstream beaver activities have affected wild rice populations on Cedar Lake. As a result, the U.S. Army Corps of has been requested to assist the Fond du Lac Band of Lake Superior Chippewa (FDL) to develop hydrologic and hydraulic models to improve the knowledge and management of the Simian Creek watershed. Model results can be used to understand the impacts that hydrologic and hydraulic changes may have on wild rice growth and propagation due to water level fluctuations.

Cedar Lake Existing Conditions

The study area includes Simian Creek between the headwaters upstream of Cedar Creek to just downstream of Kultala Road, or just over 20 square miles of drainage area (Figure 1). Cedar Lake is located in the upper portion of the Simian Creek watershed, with a contributing area of just under 3 square miles. In addition to Cedar Lake, Twin Lakes are located in the headwaters of a small tributary on the eastern border of the Stoney Brook basin, and Simian Lake is located on Simian Creek in the lower portion of the watershed. The focus of this planning study is Cedar Lake. Cedar Lake is a shallow, 59 acres lake that historically supported wild rice. Since about 2004, water levels have been too high to support substantial stand of wild rice. In 2007, a test plot was seeded with wild rice seed, concurrently with beaver dam removal to promote lower water levels. Although some wild rice did seed with that effort, as of the fall of 2010, no wild rice was growing in the lake. Wild rice was seeded again in 2011, but after a large storm in 2012 little if any wild rice remains on Cedar Lake. (Baird/URS, 2012).

A judicial ditch conveys water from south of Big Lake Road to Cedar Lake. The ditch alignment south of Big Lake Road is not clear in aerial photography or LiDAR (Light Detection and Ranging) sources, but between Big Lake Road and Cedar Lake the location of the judicial ditch is clear and was able to be located and surveyed by FDL in 2015. The date of the ditch construction is unknown, but the location is clear in 1939 aerial photography, indicating this this hydrologic change occurred more than 78 years ago. The contributing drainage area south of Big Lake Road (bound by Big Lake Road to the north and Cary Road to the west) is just under 1 square mile, and a golf course comprises between 5-10% of the land cover in this contributing area.

Recent monitoring efforts by FDL to collect water levels in Cedar Lake during the 2015 and 2016 growing season show that there is little fluctuation in the water levels in Cedar Lake, but also that lake levels may be consistently too high for optimal wild rice production water depths of between 0.5 and 3 feet.

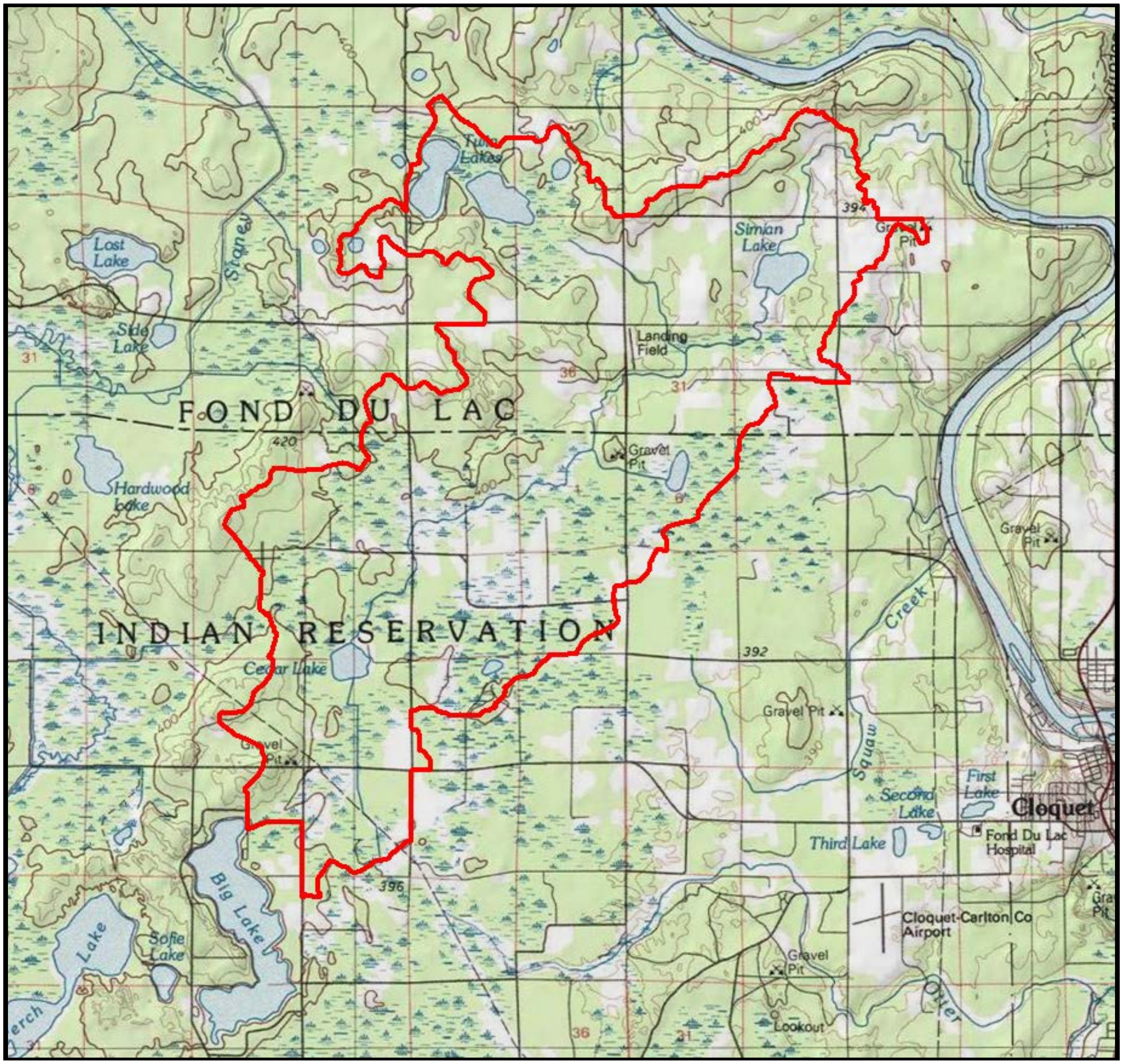

Figure 1: Simian Creek Study Area.

Available Data

Existing data has been collected from available sources to support this planning study. In addition, FDL performed valuable data collection to monitor precipitation, stage and flow conditions in Simian Creek. Some of this information was collected prior the initiation of this study, other data was collected as part of the study effort. Below is a brief summary of the data that was collected and how it was used to support this planning study.

Aerial Photography

Historical aerial photography provides valuable insight into hydrologic changes that may have an effect on the hydrology of a watershed. The earliest available aerial photography from 1939 shows that the hydrologic effects of the judicial ditch upstream of Cedar Lake occurred prior to 1939, many decades before the decline in wild rice production on Cedar Lake. There is a large time gap of available aerial photography between 1939 and 1975. Readily available photographs between 1991 and present show locations where beaver dams are likely causing significant increases in water levels throughout the watershed, including downstream of Cedar Lake (Figure 2).

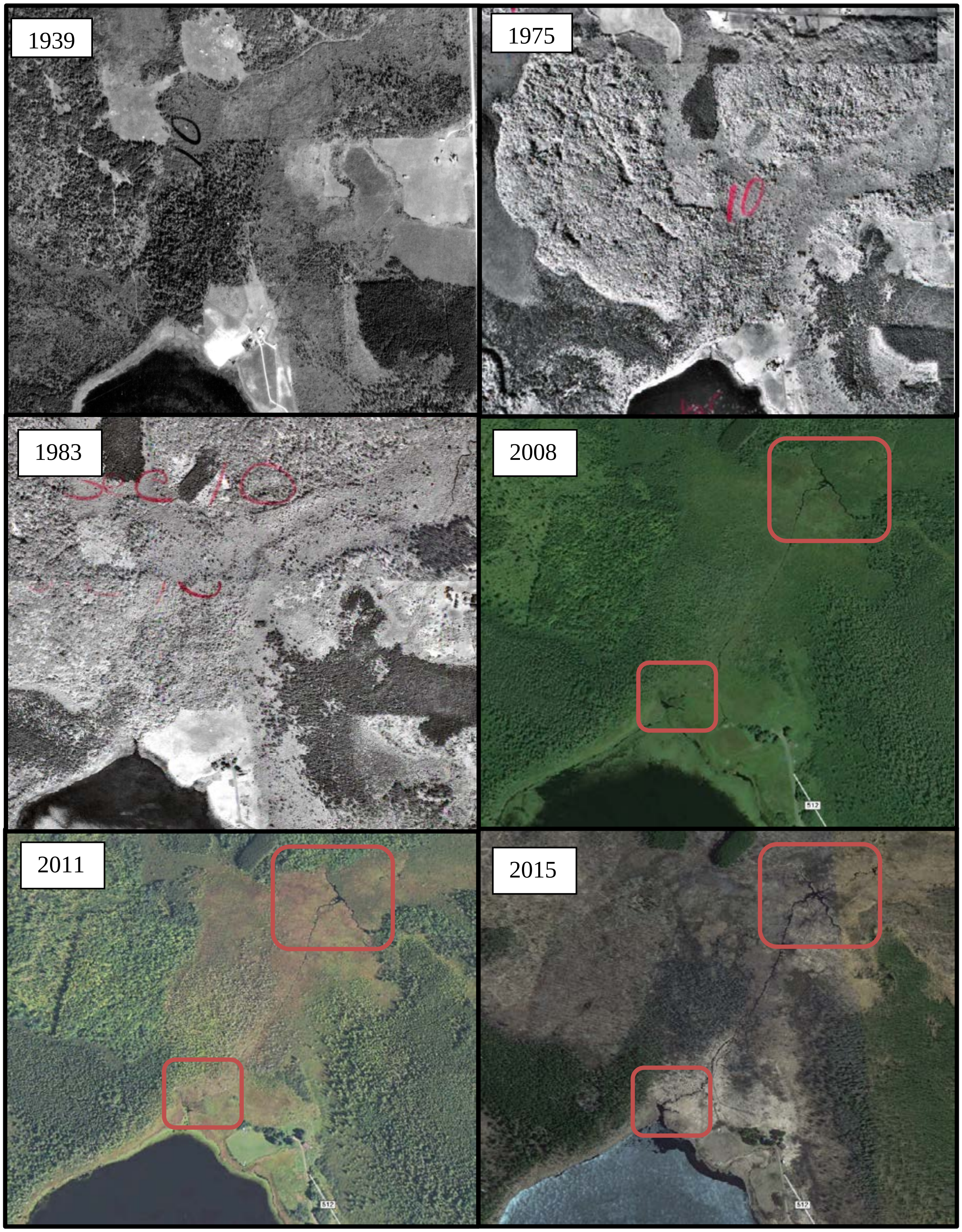

Figure 2: Aerial photography from 1939, 1975, 1983, 2008, 2011 and 2015. Beaver dams in the more recent photographs are circled in red. The dams do not appear to be present in the aerial photgraphy before 1983. The 1939 photography was obtained from Minnesota Historical Aerial Photographs Online Library. Photographs from 1975 and 1983 were provided by FDL. Later photographs were obtained from Google Earth.

Topography

The State of Minnesota recently obtained statewide LiDAR data. This publicly available information was used to create a high-resolution digital terrain model for the Simian Creek watershed. One of the limitations of LiDAR is that it does not typically penetrate water, so additional cross-section surveys are often required to add additional detail below water level and in channels. In 2015, FDL hired StraightLine Surveying to survey the channel, bridges and culverts in the Simian Creek watershed. FDL collected bathymetric data in Cedar Creek and Simian Creek. These bathymetric surveys were provided to the Corps of Engineers as depths. To covert these depths into lakebed elevations, they were subtracted from the lake level in the LiDAR elevation data set. This conversion process likely introduces some error into the lakebed elevations. The LiDAR data, surveyed channel cross-sections, and the bathymetry for Cedar and Simian Lakes were stitched into a seamless digital terrain model. Sub-basins for the hydrology model were delineated and the hydraulic model geometry was created using this terrain model.

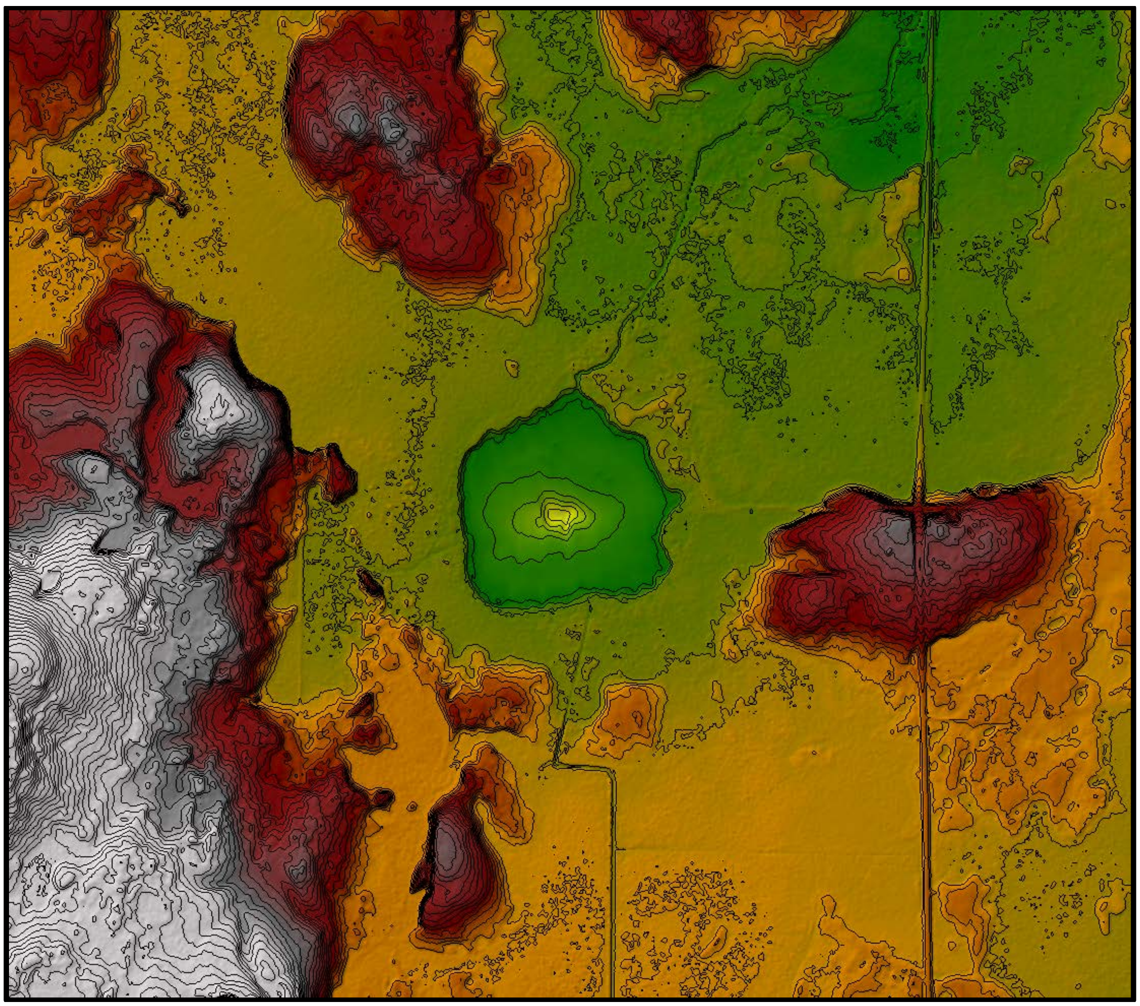

Figure 3: Terrain model created using the LiDAR, channel survey and bathymetric surveys of Cedar and Simian Lakes.

Water Level and Precipitation Gages

The Corps of Engineers and FDL developed at data collection network to collection water levels and precipitation throughout the watershed to assist with calibration of a hydrology and hydraulic model. The locations were distributed through the watershed for good spatial coverage, and were placed in locations where they could be physically accessed for readings. Some of the original locations were relocated due to access issues. Figure 4 shows the location of these water level and precipitation gages. In 2015, stations

1-4 and 6-7 included a tipping bucket rain gage and staff gages on each side of the road or bridge. In 2916, these were moved to Stations 1-3 and 6-7 because of technical difficulties with the tipping buckets. Station 7 includes a tipping bucket precipitation gage and a pressure transducer for continuous stage monitoring. These locations were monitored during the 2015 and 2016 growing season between April and October. FDL has operated the gage between May and October since 2010, but equipment problems during 2010 affected about one-half of the season, and the 2013 and 2014 season could not be recovered. FDL has performed periodic flow measurements to relate stage to discharge. Technical difficulties with the precipitation gages in 2015 and 2016 resulted in only two of the seven gages with continuous records through the growing season. In 2015, precipitation gages at Station 4 and 7 produced continuous records. In 2016, precipitation gages at Station 1 and 7 produced continuous records. In addition to the data collected by FDL since 2010, a gage downstream of Kultala Rd. was also operated by the United States Geological Survey between 1983 and 1984.

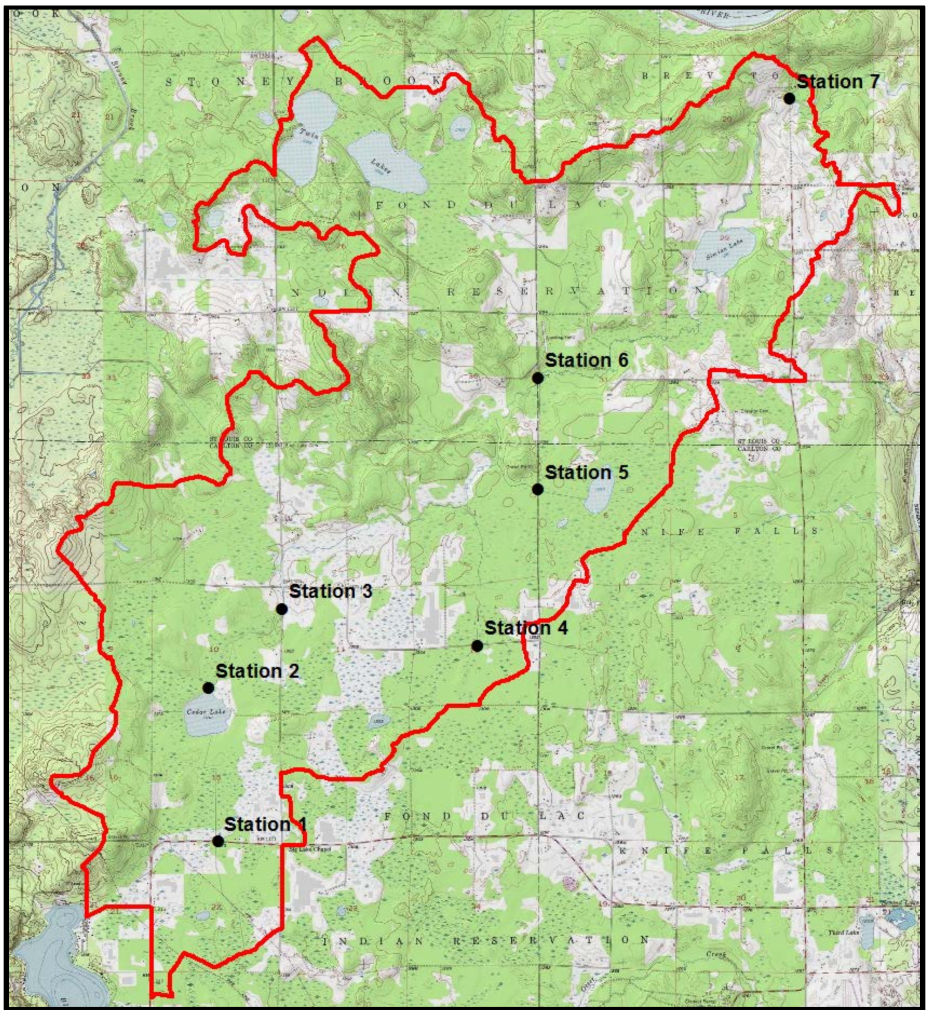

Figure 4: Data collection network for water level staff gages and precipitation gages.

Discharge Data

Between 2010 and 2014, FDL collected 18 stage-discharge measurements. The highest discharge of 54 cfs is the only reading to define the upper limit of the curve. These 18 stage-discharge measurements provide the only source of information to relate discharge to stage at the continuous gaging location downstream of Kultala Rd. For this study, this information was used to generate an estimated continuous flow time series for the growing season in 2010 (partial), 2011, 2012, 2015 and 2016 (partial). Additional future flow measurements to better define and extend the curve would be extremely beneficial to future model calibrations. The continuous operating gage at Kultala Rd is located in a relatively steep reach of Simian Creek (approximately 30 ft/mile). The range of stages is relatively narrow due to this steep channel grade. Figure 5 shows the stage – discharge readings performed by FDL at the continuous gaging location downstream of Kultala Rd.

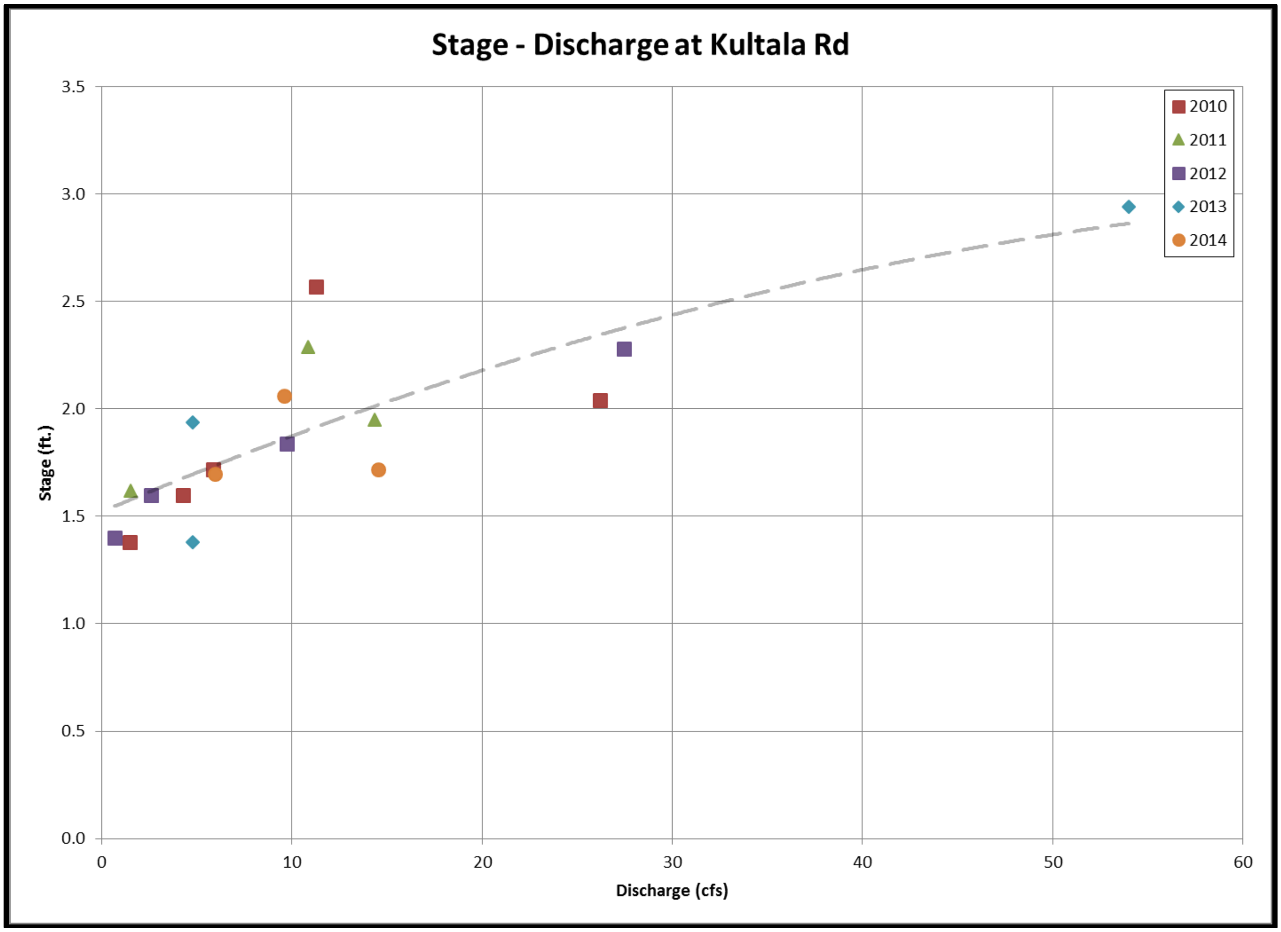

Figure 5: Stage – Discharge readings performed by FDL at the continuous gaging location downstream of Kultala Rd.

NEXRAD Precipitation

To supplement the precipitation data collected by FDL, NEXRAD (Next Generation Weather Radar) was obtained from the National Weather Service to provide a source of precipitation for the 2011 and 2012 growing season during the time when continuous gage data was collected downstream of Kultala Rd. NEXRAD provides hourly precipitation coverage on a 2-kilometer grid. HEC-HMS has the ability to read gridded data directly as a precipitation data source. Figure 6 shows the extracted NEXRAD precipitation data compared to the data collected by FDL at Station 2. The tipping bucket gage has missing data between the end of June and early July. The NEXRAD data shows some significant precipitation events during this period.

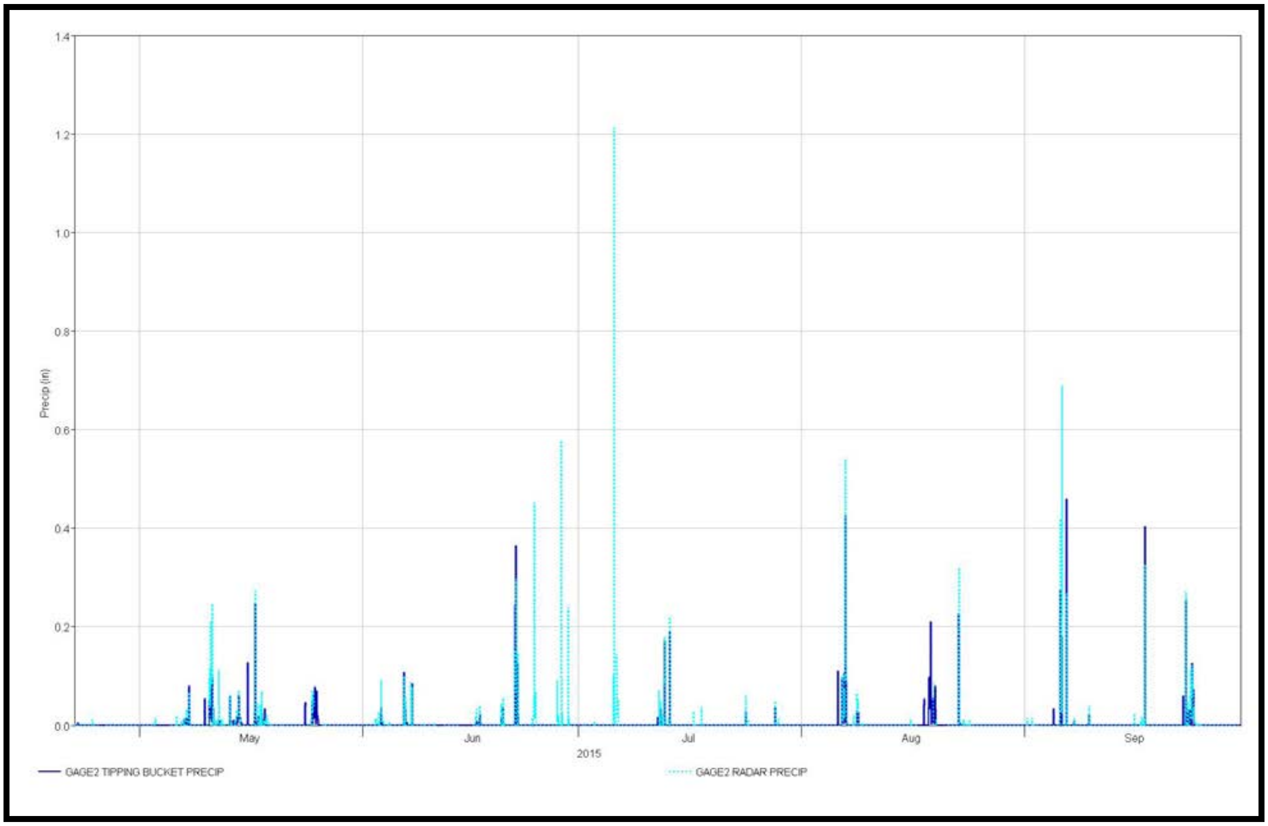

Figure 6: Comparison of NEXRAD data and the rain gage data collected by FDL in 2015 at Station 2.

Soils Data

The NRCS (Natural Resources Conservation Service) produces the SSURGO (Soil Survey Geographic Database) containing information about soil as collected by the National Cooperative Soil Survey over the course of a century. Gridded SSURGO (gSSURGO) is similar to the standard SSURGO database, but merges the traditional vector based SSURGO digital map data and tabular data. gSSURGO was used to derive maps for soils maximum infiltration rate, maximum percolation rate, maximum soil storage, maximum tension storage. These soil properties are used for developing a hydrologic basin model using the Soil Moisture Accounting (SMA) method in HEC-HMS. gSSURGO was also used to derive a map of hydrologic soil groups. This soil parameter is used to develop a hydrologic basin model using the Soil Conservation Service (SCS) runoff curve number method.

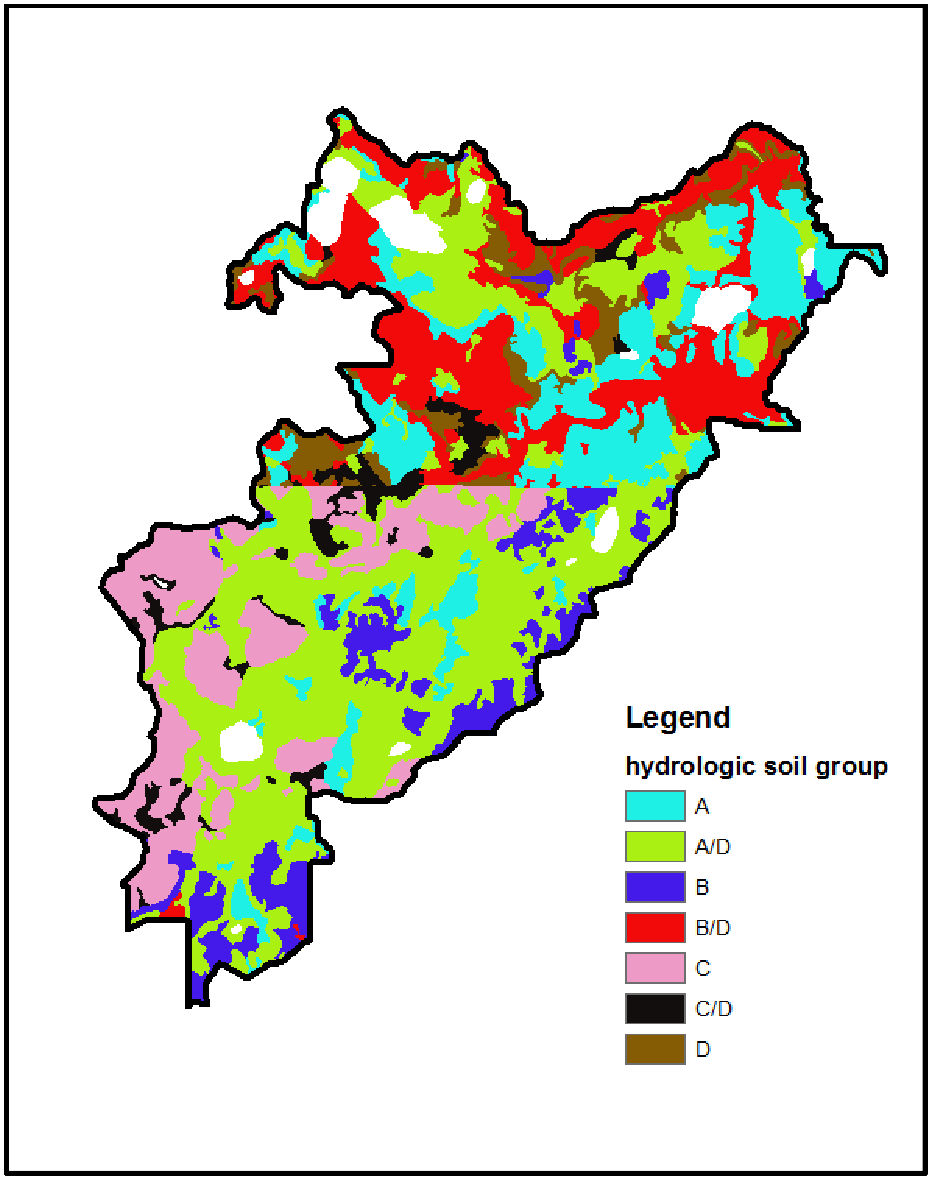

Figure 7: Hydrologic soil groups from the Simian Creek watershed.

Model Development

Hydraulics

A two-dimensional, one-dimensional integrated model was developed in HEC-RAS v. 5.0.3. Figure 8 shows the extents of the two-dimensional flow area around Cedar Lake. A grid spacing of 100 ft was used, but additional breaklines establish greater detail around the channels upstream and downstream of Cedar Lake. The two-dimensional flow area connects with the one-dimensional portion of the channel upstream of Twin Lakes Drive. The one-dimensional portion of the model extends downstream to just past Kultala Rd. A Manning's n value of 0.045 was used in the channel, and overbank areas varied between 0.06 up to 0.15 in areas of thick wetland vegetation.

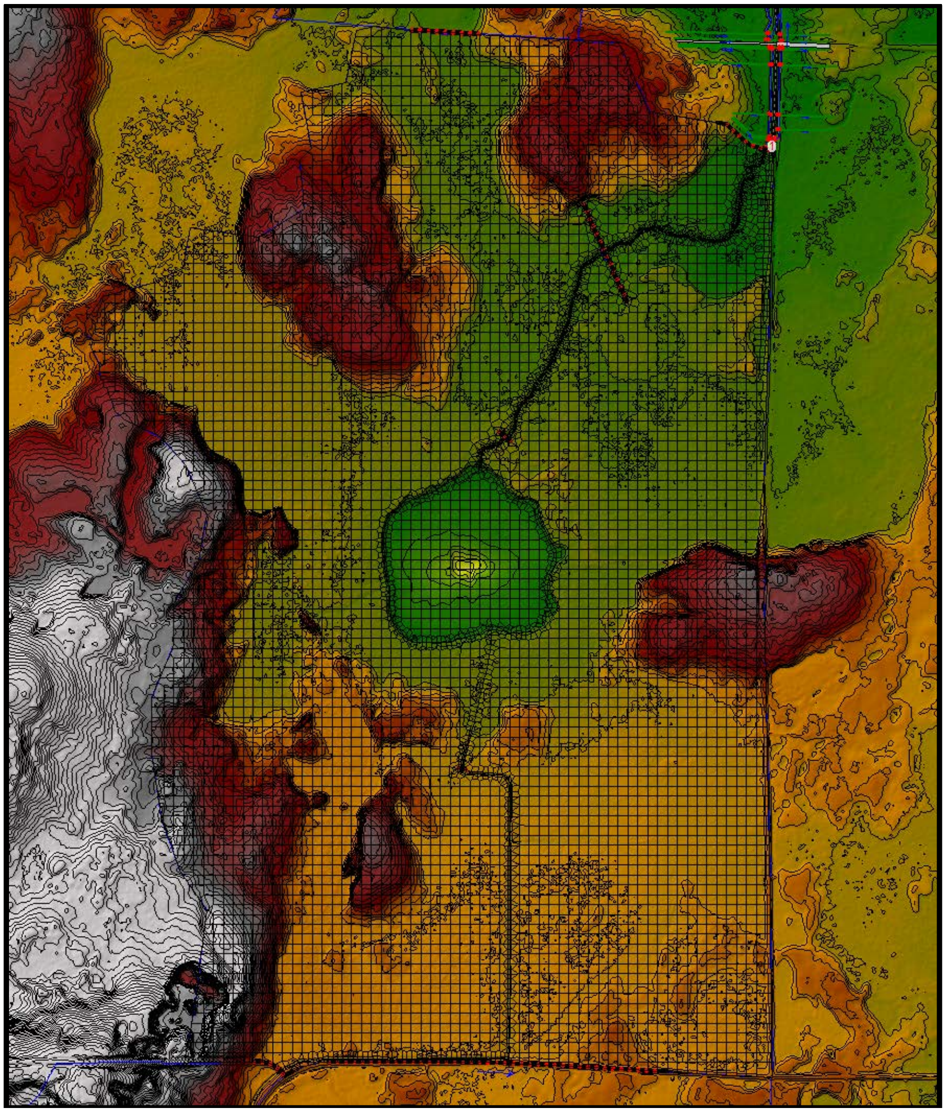

Figure 8: Two-dimensional flow are of the area around Cedar Lake.

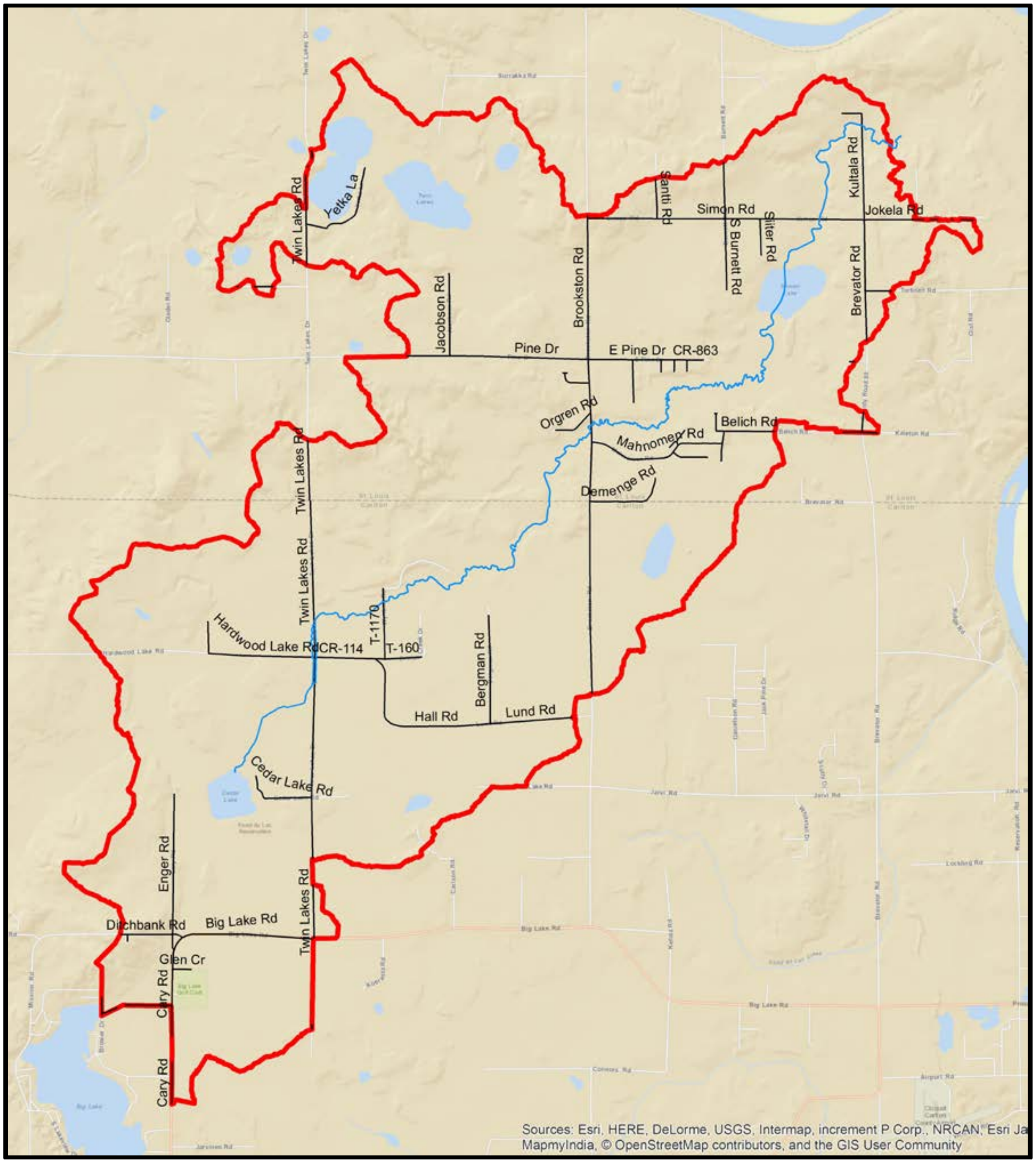

Figure 9: Limits of the one-dimensional portion of the HEC-RAS model.

Hydrology

A basin model was developed in HEC-HMS v. 4.1 using the Soil Moisture Accounting Method. The approximate 20 square mile watershed was subdivided into 15 sub-basins. The soil properties maps developed from the the gSSURGO data for maximum infiltration, maximum percolation rate, maximum soil storage and maximum tension storage were used to select representative properties for each sub-basin.

The Clark Unit Hydrograph method was used for hydrograph transformation, and the simple surface and canopy were used to account for surface and canopy storage. The potential evapotranspiration values used in the model were taken from the University of Wisconsin Extension. Their on-line system provides estimated daily evapotranspiration rates for Wisconsin and Minnesota. The evapotranspiration model uses atmospheric observations from ASOS stations and satellite-derived insolation estimates to predict water use by plants. The Linear Reservoir method was used to simulate baseflow. The initial flow, and Groundwater 1 and Groundwater 2 Coefficients were estimated based on best fit with the observed data.

Flow Calibration

For the 2015 simulation, precipitation data with full records collected by FDL was used to perform the continuous simulation between the mid-May through the end of September. For the 2016 simulation, precipitation data with full records collected by FDL was used to perform the continuous simulation between the mid-May through the early part of August to include information from the last data collection. Continuous simulations were also performed in 2011 and 2012 to compare to the observed data collected by FDL at Kultala Rd. NEXRAD was used as the precipitation source for these simulations.

Initially, the automated calibration tools in HEC-HMS were used to assist in the calibration process, but because much of the attenuation and travel time is simulated in the hydraulic model, this approach was did not produce parameters that resulted in a reasonable calibration after the hydrographs were simulated in the hydraulic model. As a first attempt to calibrate, one set of hydrologic parameters was developed for each sub-basin based on the dominate soil properties, and these properties were varied to provide a reasonable fit to the observed data. This approach presented challenges because many of the soil properties varied significantly across the sub-basin. On a smaller watershed like Simian Creek, the rainfall-runoff response was very sensitive to model changes in these soil properties. To provide a better representation of this variability, each sub-basin was subdivided into two to four representative parameter sets. The time-series generated by each individual parameter set were aggregated by sub-basin in HEC-DSSVue for input into the hydraulic model. A better calibration was achieved through this approach. Appendix A contains a table of the hydrologic parameters used in the HEC-HMS Soil Moisture Accounting method.

The 2015 and 2016 continuous simulations were used for model calibration. Unit hydrograph transformation parameters were found to not be highly sensitive, so few changes were made to these as part of the calibration process. Since the model includes the presence of many of the roadways culverts and bridges in the watershed, these structures likely have more of an influence on the travel time than the unit hydrograph parameters. In both 2015 and 2016, the model under simulates the first large runoff event of the season. This may be due to antecedent conditions from snow and ice melt. Adjustments to hydrologic parameters to better simulate these early events would cause over simulation throughout the rest of the simulation. Since the primary model purpose is to simulate flows through the summer months, use of model parameters that better simulate conditions throughout the remainder of the growing season is preferred. Figures 10 and 11 show the model results from the calibration effort from the 2015 and 2016 simulations along with the precipitation. Figures 12 and 13 show the model results for the 2011 and 2012 simulations performed to verify that the basin model provides reasonable result using the NEXRAD precipitation data.

Design storms (2-year through 500-year) were also created as for this planning effort. These storms likely do not necessary advance the understanding how wild rice production in Cedar Lake can be improved, but they may be useful for evaluating potential impacts of hydrologic changes and by providing an improved understanding of flood inundation in the watershed. Generating design storms from a continuous simulation model can be challenging because the rainfall-runoff relationship is dependent on antecedent conditions in a continuous simulation model. To simplify this complex antecedent condition, the Soil

Moisture Accounting basin model was converted to use the Soil Conservation Service Curve Number method. The same time of concentrations and storage coefficients were used in the design events. Precipitation frequencies and distributions from NOAA Atlas 14 were used to generate the design storms and a 24-hour duration storm was assumed. Figure 14 shows the NOAA Atlas 14 precipitation depths and distributions used in the design storms. Figure 15 shows the model results for the design events.

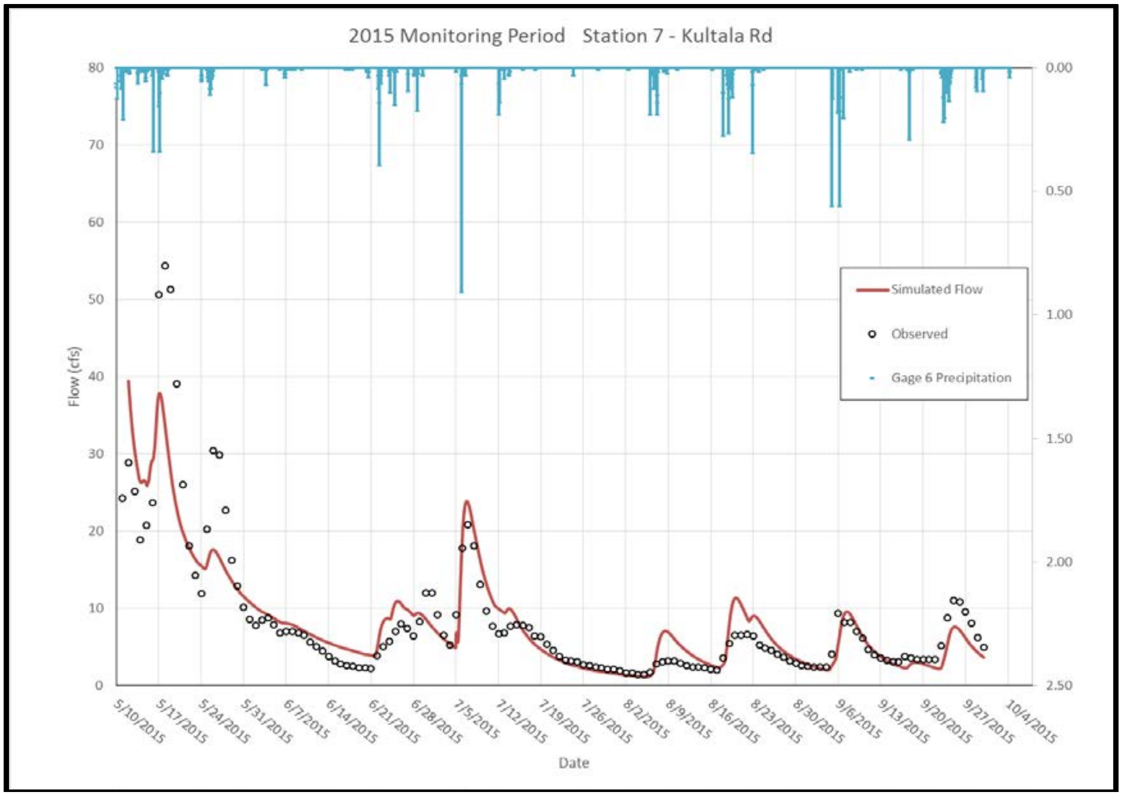

Figure 10: Observed and Simulated flows at Kultala Road during the 2015 monitoring period.

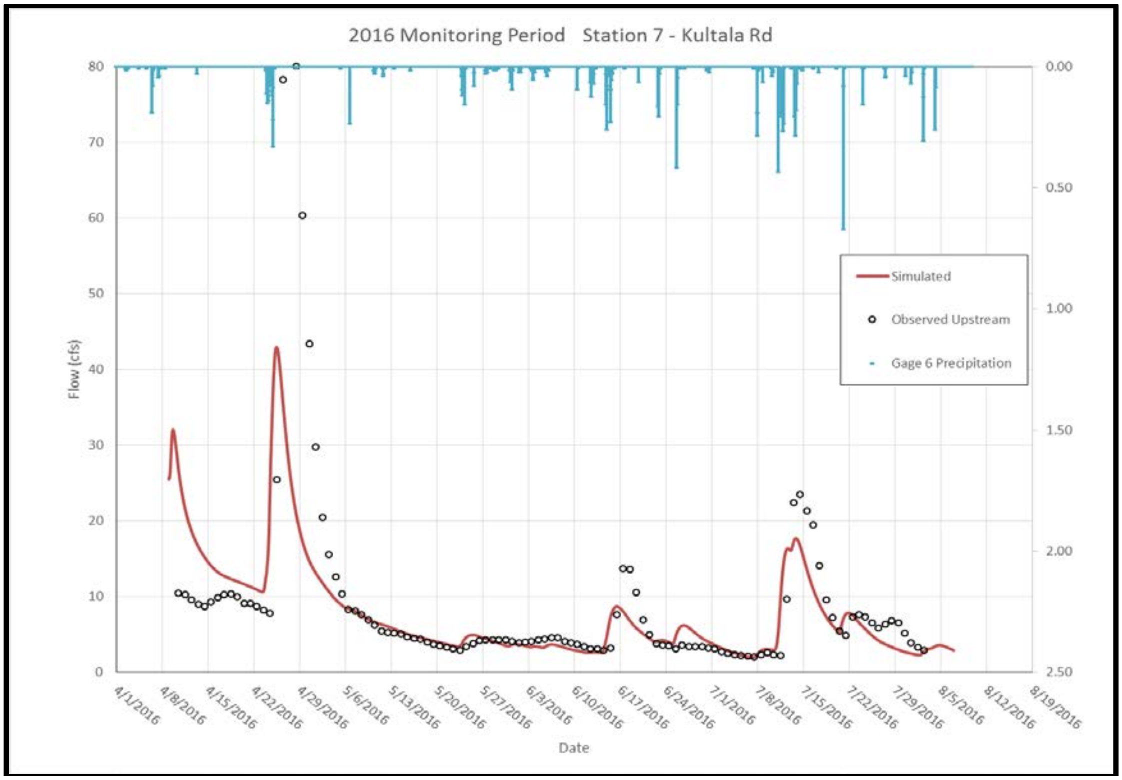

Figure 11: Observed and Simulated flows at Kultala Road during the 2016 monitoring period.

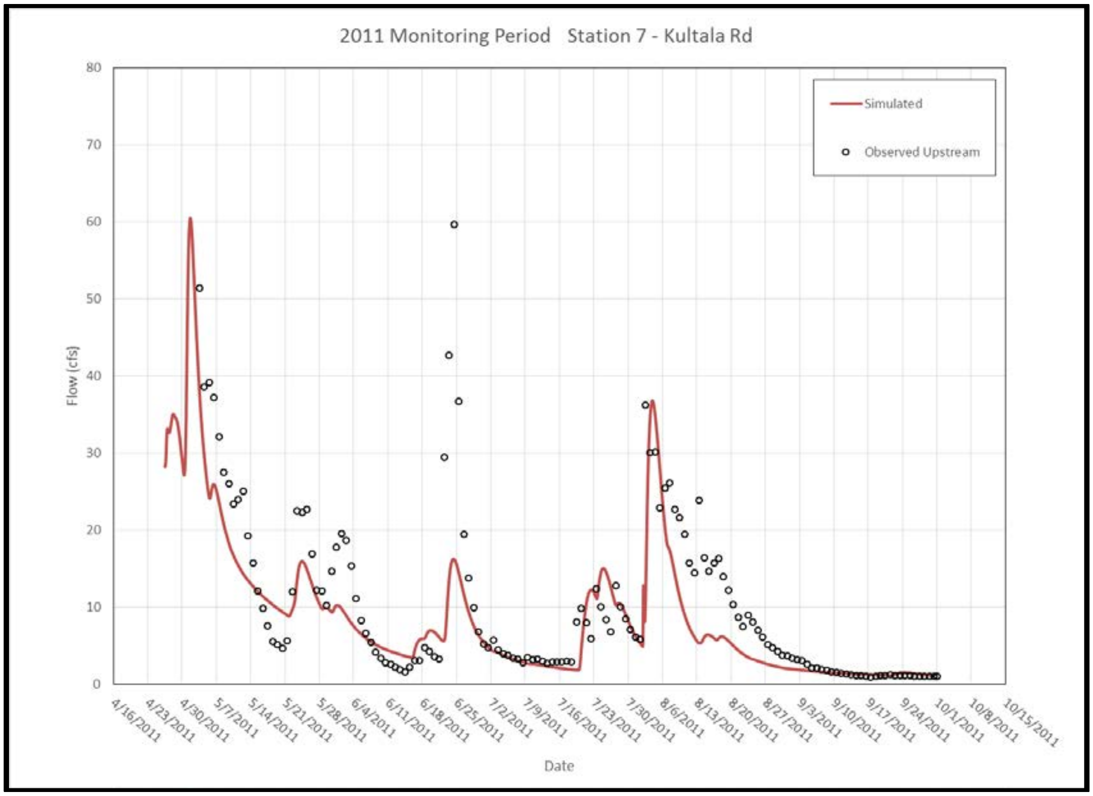

Figure 12: Observed and Simulated flows at Kultala Road during the 2011 monitoring period.

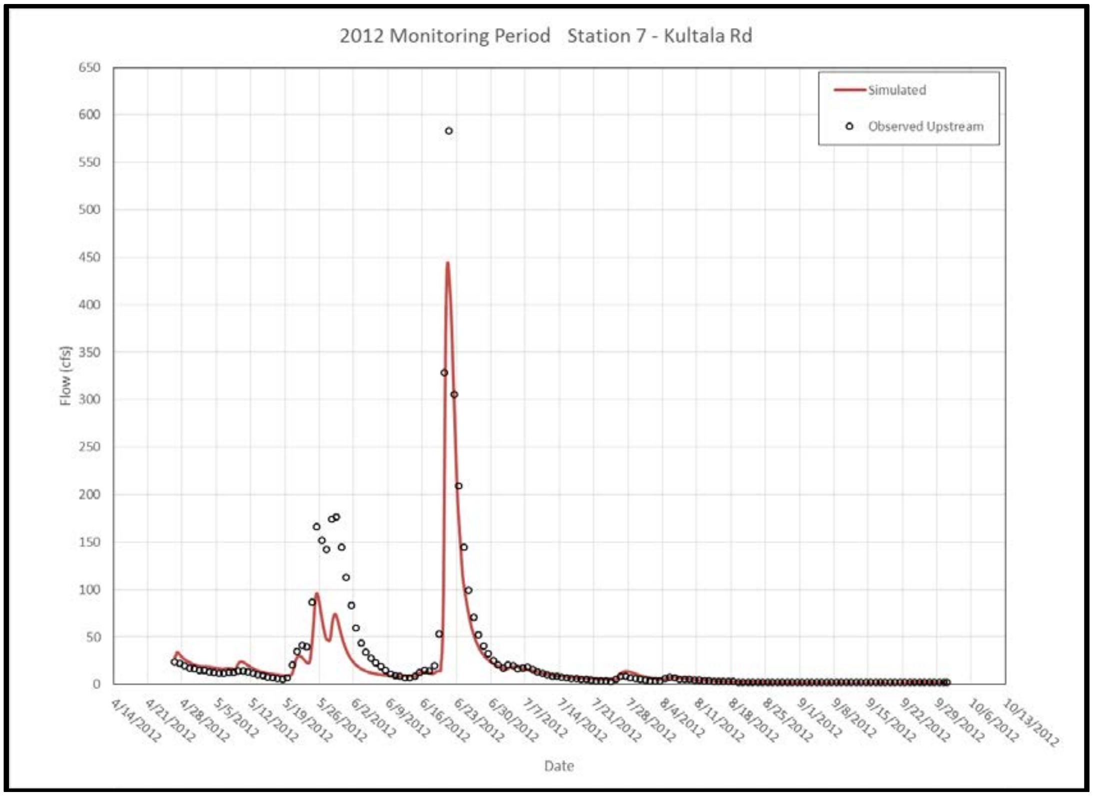

Figure 13: Observed and Simulated flows at Kultala Road during the 2012 monitoring period.

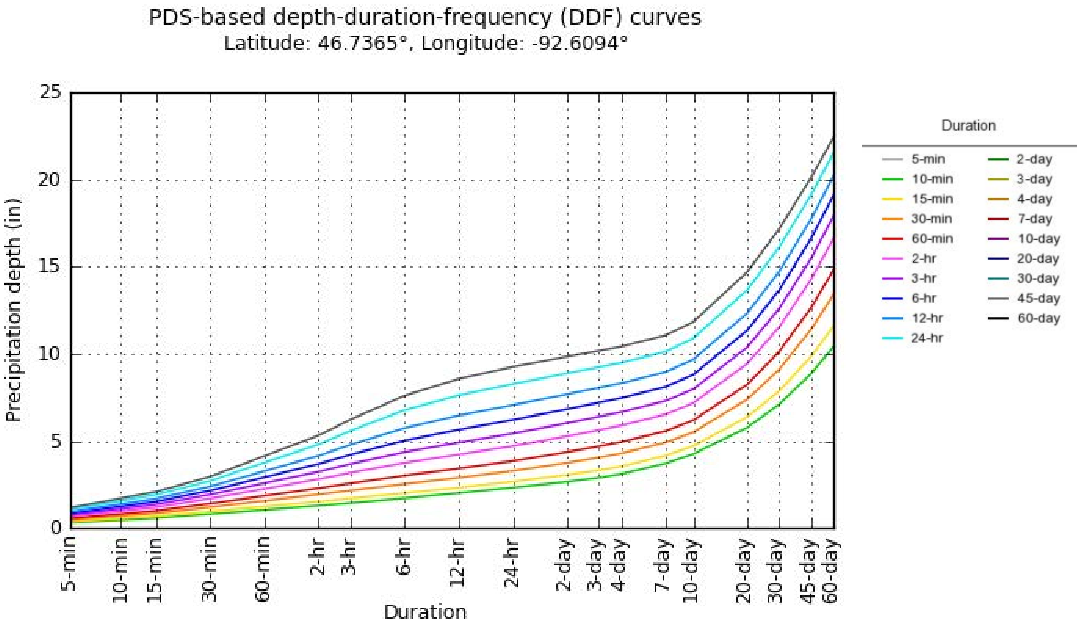

Figure 14: Depth, duration and frequency curves from NOAA Atlas 14 for the Simian Creek watershed.

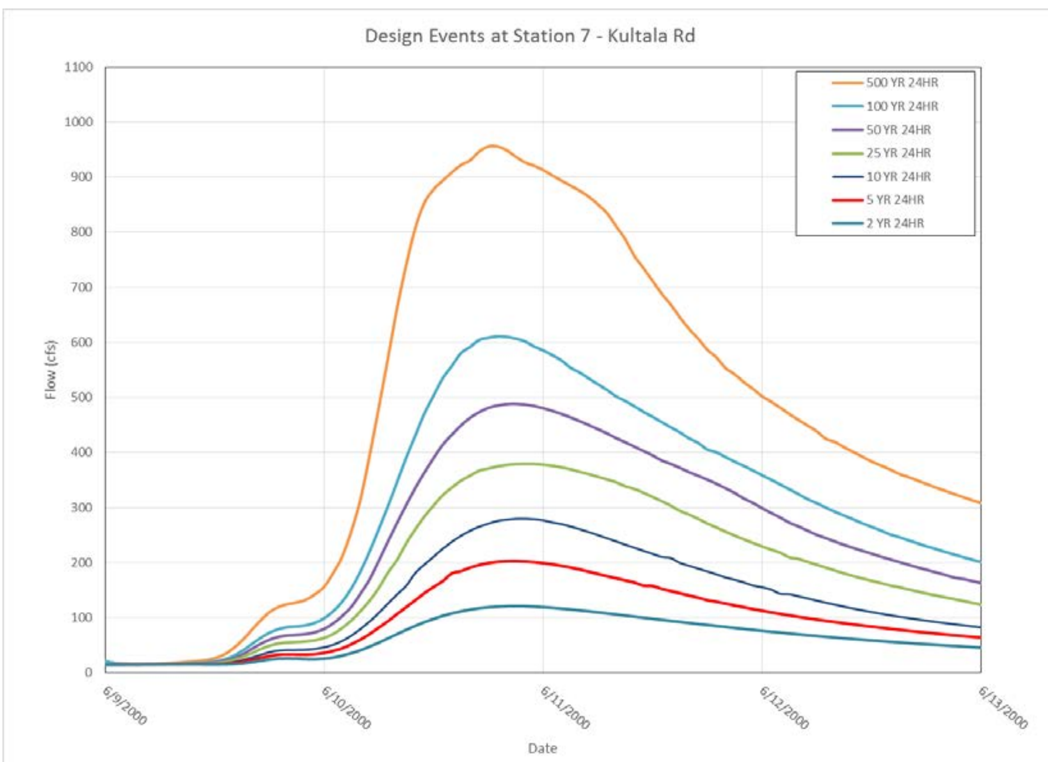

Figure 15: Flow hydrographs at Kultala Rd. for the design storms.

Stage Calibration

Simulation stage results were compared to the observed stages at each of the water level gaging locations. Simulated stages downstream of Cedar Lake (Station 2) were about 1 foot below the observed stages through most of the growing monitoring period in both 2015 and 2016. Reasonable changes to the Manning's n roughness values did not result in water surface elevation near the observed elevations. Aerial photography, surveyed water elevations, and LiDAR data were reviewed and compared in these locations. Aerial photography shows a significant amount of impounded water downstream of these locations from beaver dams. For the model simulations, the only way to match simulated water surface elevations with observed data was to place storage area connections and in-line structures in the model geometry to create backwater upstream of these beaver dam locations. These hydraulic structures represent a simplification of the hydraulic and hydrologic impacts of these beaver dams. Figures 16 and 17 show how these beaver dams were represented in the HEC-RAS model. Figures 18 and 19 show how the observed simulated stages compared after the hydraulic model was modified to include these beaver dams.

Similarly, low stages were simulated at monitoring stations at Twin Lakes Drive and at Brookston Road. Since these reaches of the hydraulic model are simulated using a one-dimensional modeling approach, in-line structures were used to represent the beaver dams that appear in aerial photography. Figures 18 through 21 show how the observed simulated stages compared after the in-line structures were added to the hydraulic model to represent the beaver dams downstream of Twin Lakes Drive and Brookston Road.

Existing Conditions

The observed water levels have slightly more fluctuation than the simulated water levels, but there is little overall rise and fall in the water levels in response to rainfall events in both the 2015 and 2016 monitoring period. In all of these locations, the water levels remain near the tops of the channel banks throughout most of the monitoring period. When using a hydraulic structure to represent a beaver dam, several simplifying modeling assumptions are made. The structure is assumed uniform in height and a complete hydraulic barrier. The structure is also assumed to remain constant throughout the simulation periods and does not simulate groundwater losses and evaporation in the pool. These simplifying assumptions likely contribute to the differences between the observed and simulated water levels.

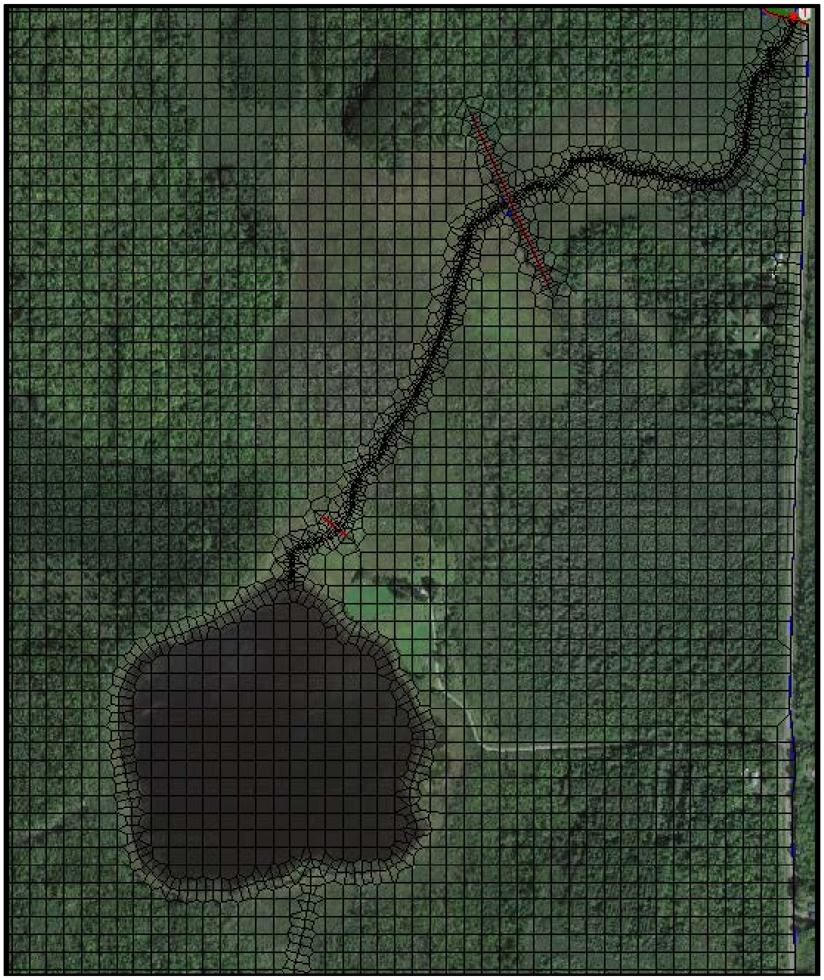

Figure 16: Flow area connections were used to represent beaver dams in the channel downstream of Cedar Lake.

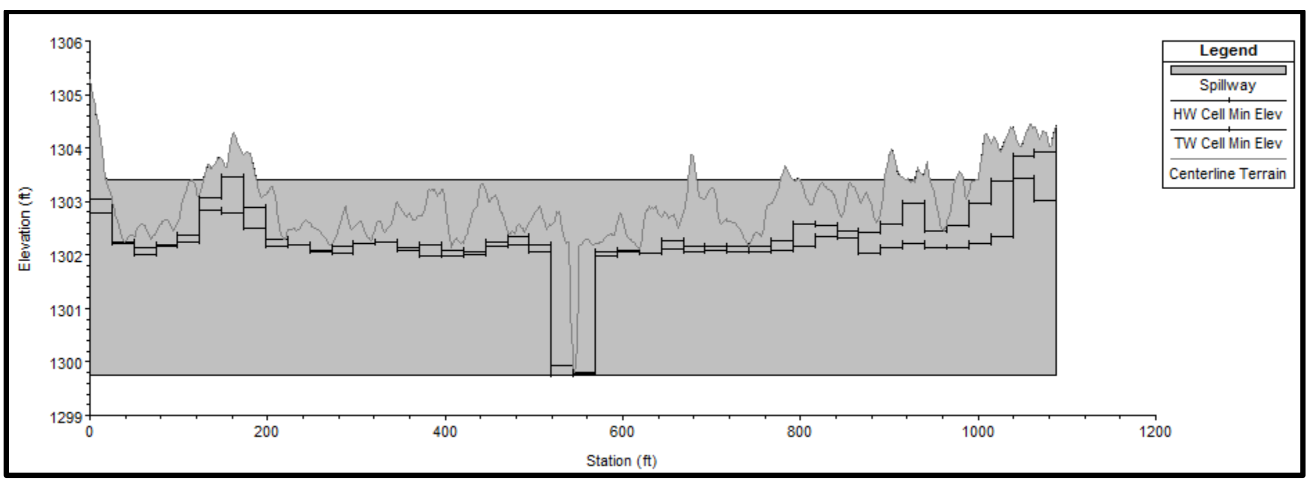

Figure 17: Cross-section view of the flow area connection used to represent the large beaver dam downstream of Cedar Lake.

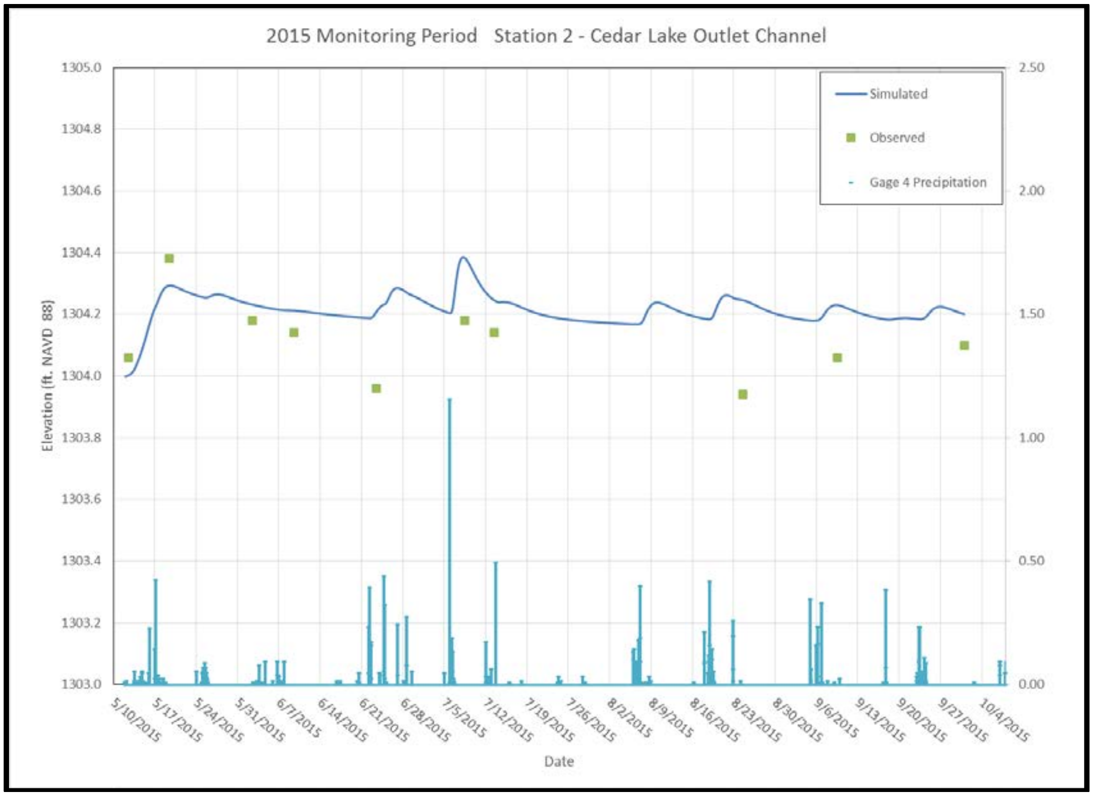

Figure 18: Observed and Simulated gages just downstream of Cedar Lake during the 2015 monitoring period.

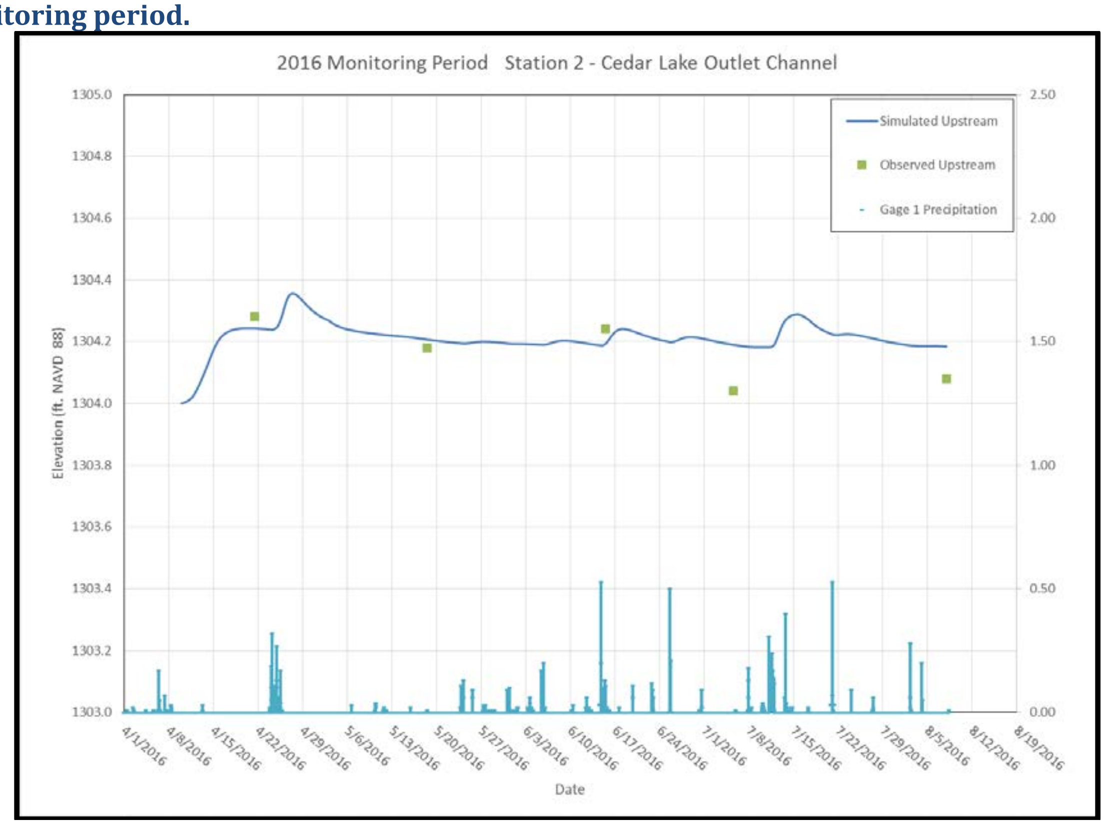

Figure 19: Observed and Simulated gages just downstream of Cedar Lake during the 2016 monitoring period.

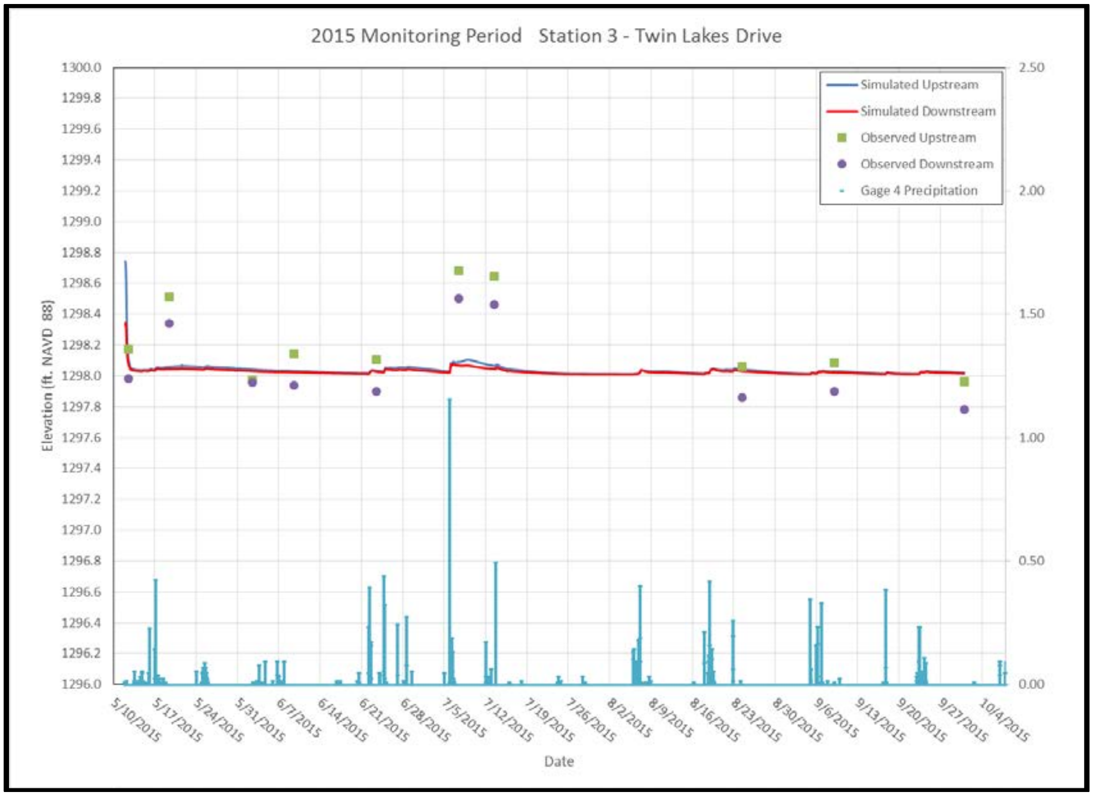

Figure 20: Observed and Simulated gages at Twin Lakes Drive during the 2015 monitoring period.

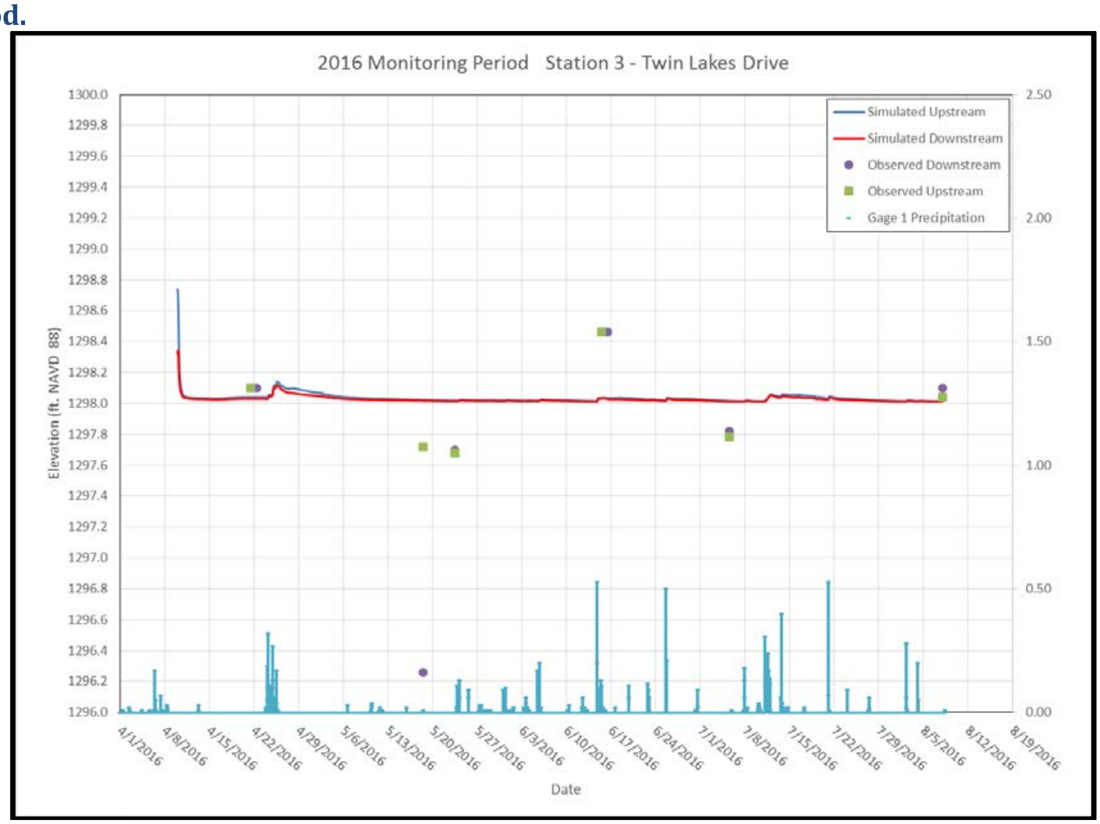

Figure 21: Observed and Simulated gages at Twin Lakes Drive during the 2016 monitoring period.

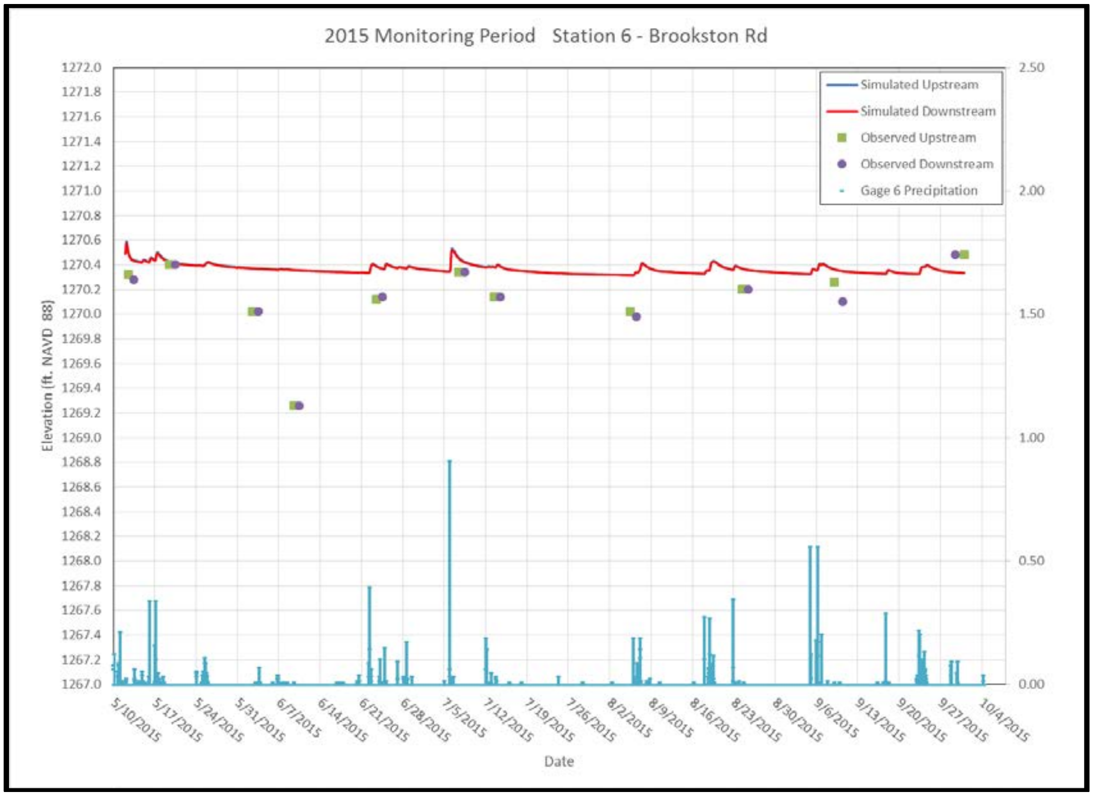

Figure 22: Observed and Simulated gages at Brookston Road during the 2015 monitoring period.

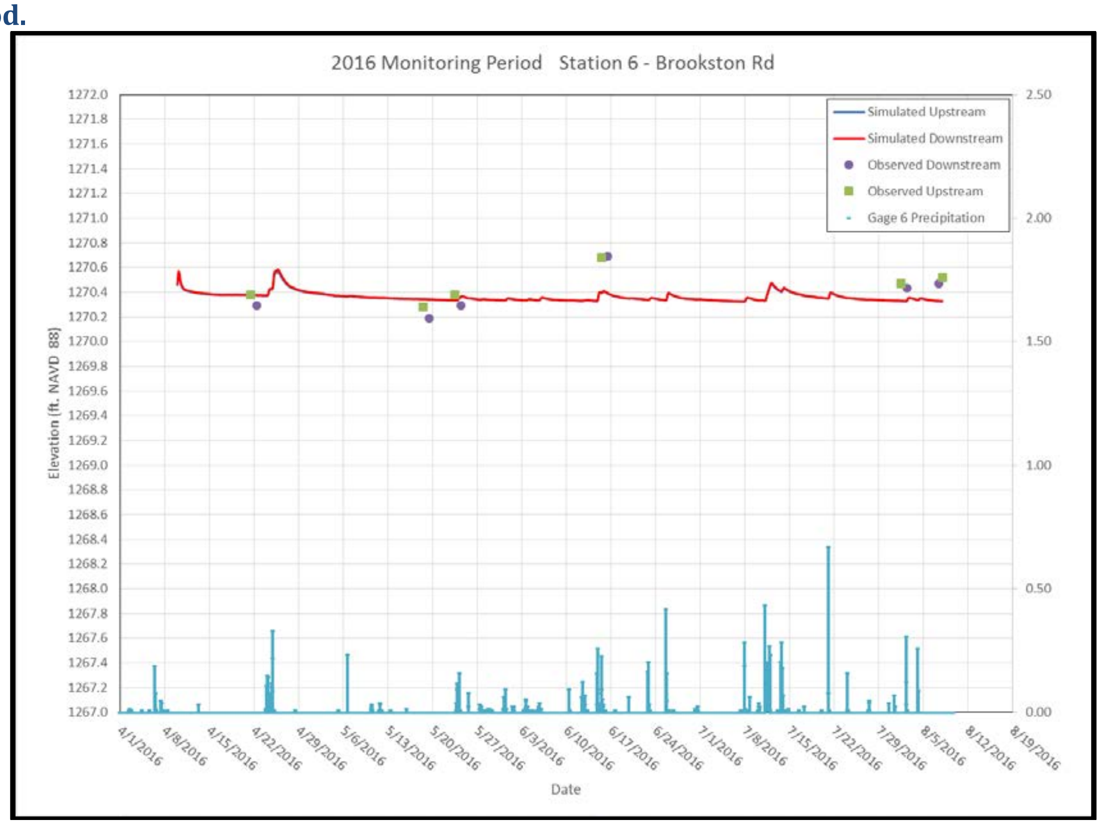

Figure 23: Observed and Simulated gages at Brookston Road during the 2016 monitoring period.

Alternatives to Reduce Water Levels in Cedar Lake

Optimal Lake Levels for Wild Rice

The optimal depth for wild rice is between 0.5 feet and 3.0 feet. The bathymetry data collected by FDL was used to calculate the surface area with depths between 0.5 and 3.0 feet for various water levels. Figure 24 contains a plot showing how little surface area is available in this depth band for the past two years of data collection when Cedar Lake was consistently near 1304 ft. NAVD 88. As the lake level drops below 1304 ft NAVD 88, the lake surface area with optimal conditions increases until it reaches a point where it begins to diminish. If a bathymetry survey is performed in the future with a direct tie to the NAVD 88 datum rather than estimated, the curve below can be further refined. Figure 25 shows the location and distribution of optimal water depth in Cedar Lake.

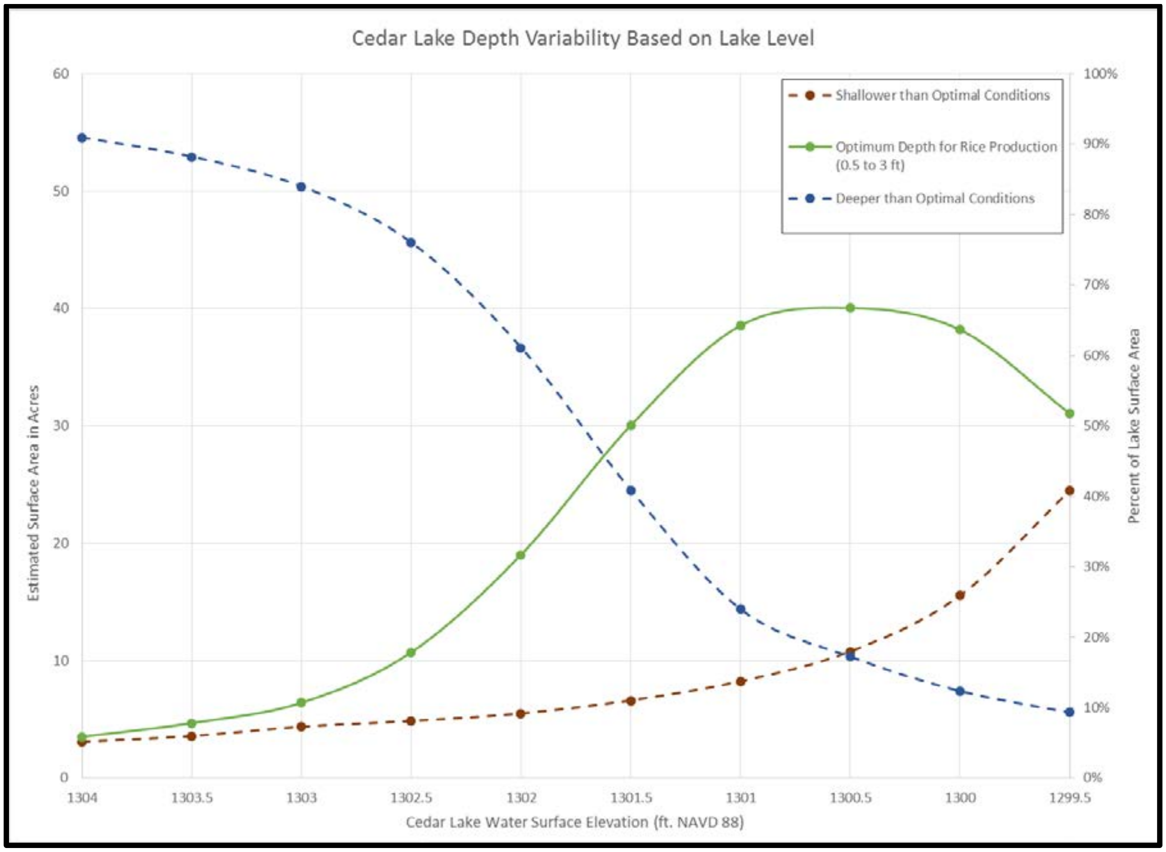

Figure 24: Relationship between lake level and depth in Cedar Lake.

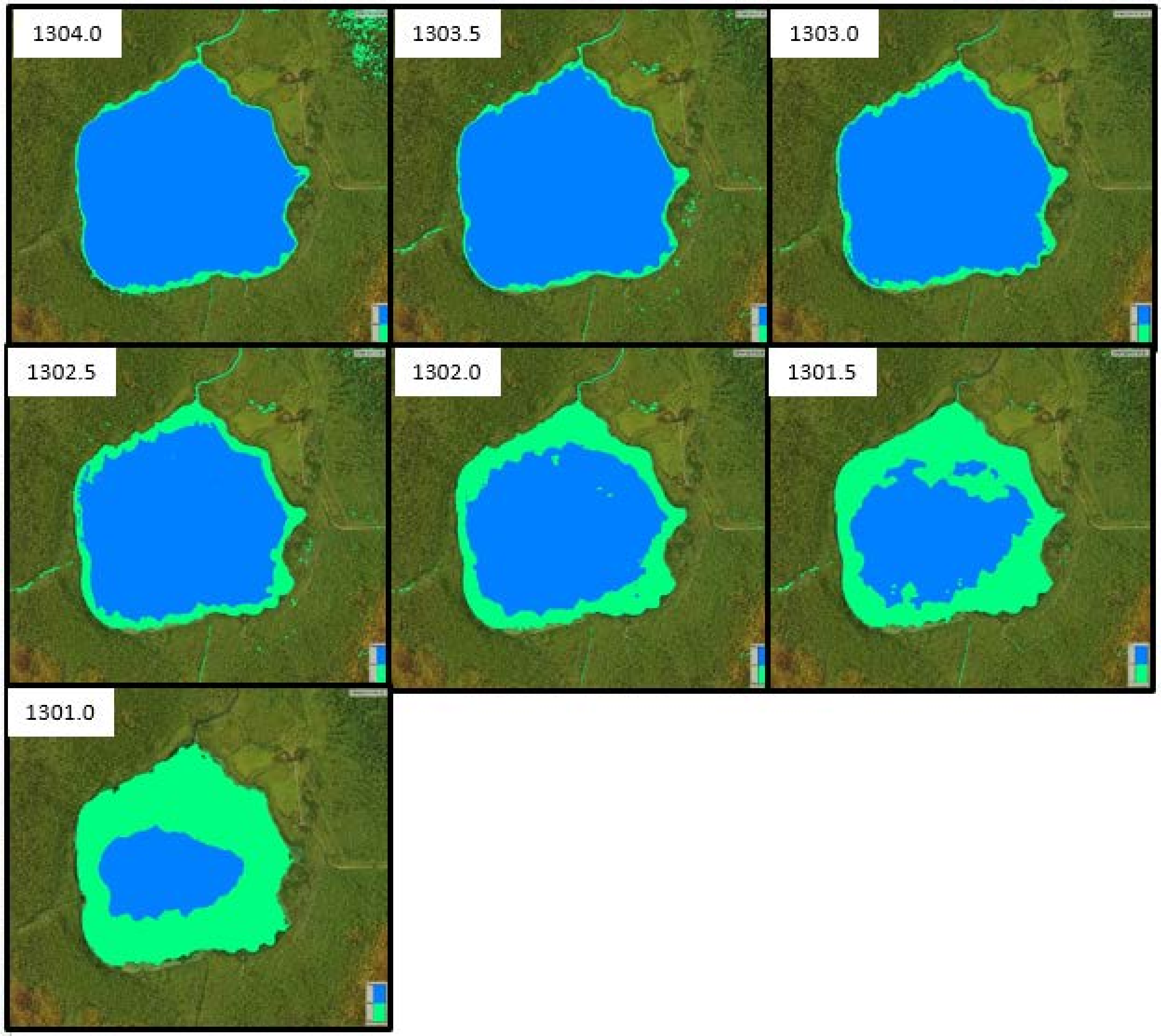

Figure 25: Estimated depths in Cedar Lake based on lake levels between 1304.0 and and 1301.0 ft NAVD 88. The green represents the ideal water depths between 0.5 and 3.0 ft.

Beaver Dam Removal

To evaluate the potential impact of beaver dam removals downstream of Cedar Lake, new simulations were completed with revised geometry that included the removal of the hydraulic structures representing the beaver dams downstream of Cedar Lake. Figure 22 show the results of these 2015 simulation. While the observed water levels in remained above 1304.0 ft NAVD 88 throughout most the period, removal of the beaver dams decreased water levels in Cedar Lake by a little more than 1 foot for most of that period. It also increased the fluctuation in lake levels in response to runoff events.

Figure 27 shows the changes to depth in Cedar Lake in response to the beaver dam removal. The green band represents the ideal conditions for growth of wild rice (between 0.5 and 3.0 feet). The left image shows the wild rice growth area for existing conditions, and the right shows the growth area simulated without beaver dams between Cedar Lake and Twin Lakes Drive. While the fringe of lakebed with depths ideal for wild rice growth is relatively narrow, the increase in area is significant.

There are a few important considerations when interpreting these model results. Since the channel downstream of Cedar Lake appears significantly submerged by backwater from the beaver dams, it is difficult to estimate the hydraulic capacity of the small channel downstream of Cedar Lake based on the data that has been collected to date. Prolonged periods of high water in the channel may have resulted in thick establishment of vegetation around or in the channel that could reduce channel conveyance even after the beaver dams are removed.

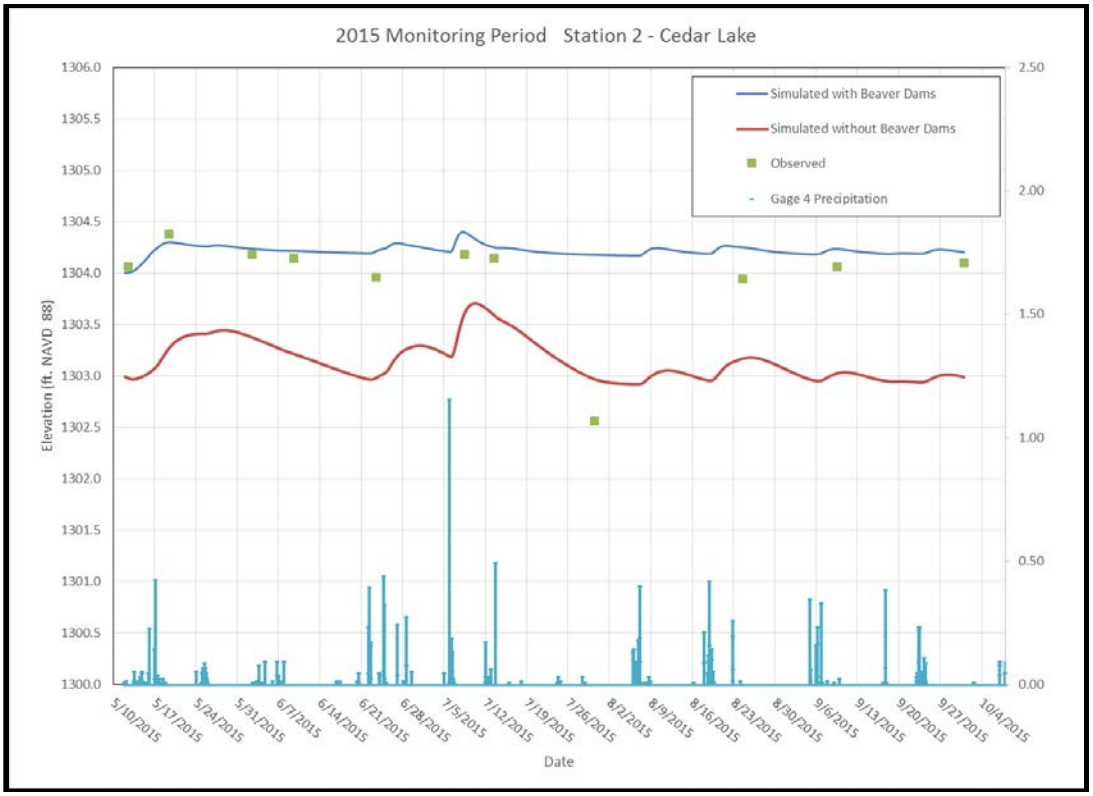

Figure 26: Comparison of the 2015 simulations at Cedar Lake. Removal of the beaver dams reduced the water levels by a little more than one foot throughout the growing season.

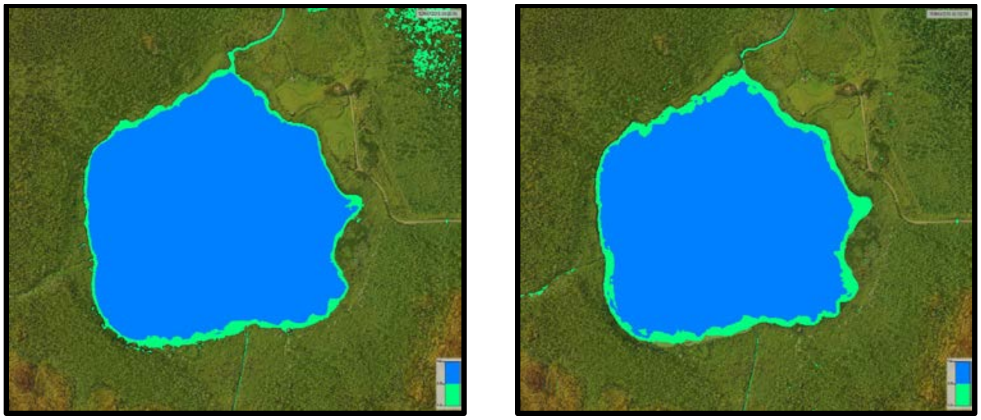

Figure 27: Comparison of the water depths for the 2015 simulation from between current conditions and with the beaver dams removed. Model results shows a reduction of approximately 1 foot from 1304.0 ft to 1303.0 ft NAVD 88. The green band around the perimeter of Cedar Lake delineates the estimated depth band between 0.5 ft and 3.0 ft.

The large beaver dam downstream of Twin Lakes Drive was also removed in the model to investigate whether the beaver dams downstream of Twin Lakes Drive have a significant impact on water levels in Cedar Lake. While the beaver dam lowered the simulated water levels at Twin Lakes Drive, it did not have any significant impact on the water levels at Cedar Lake.

Channel Clearing

In addition to the beaver dam removal, additional clearing at the outlet of Cedar Lake was evaluated by lowering the invert of the channel at the outlet to match the channel invert surveyed near the water level gage. The same approximate channel dimensions (width and depth) were used. Figure 26 below shows how moderate additional reductions in the Cedar Lake are observed in the model results. If the beaver dams are removed downstream of Cedar Lake, field investigation and survey work immediately downstream of Cedar Lake could confirm the channel size and invert elevations downstream to determine if additional reductions could be expected from some minor channel clearing.

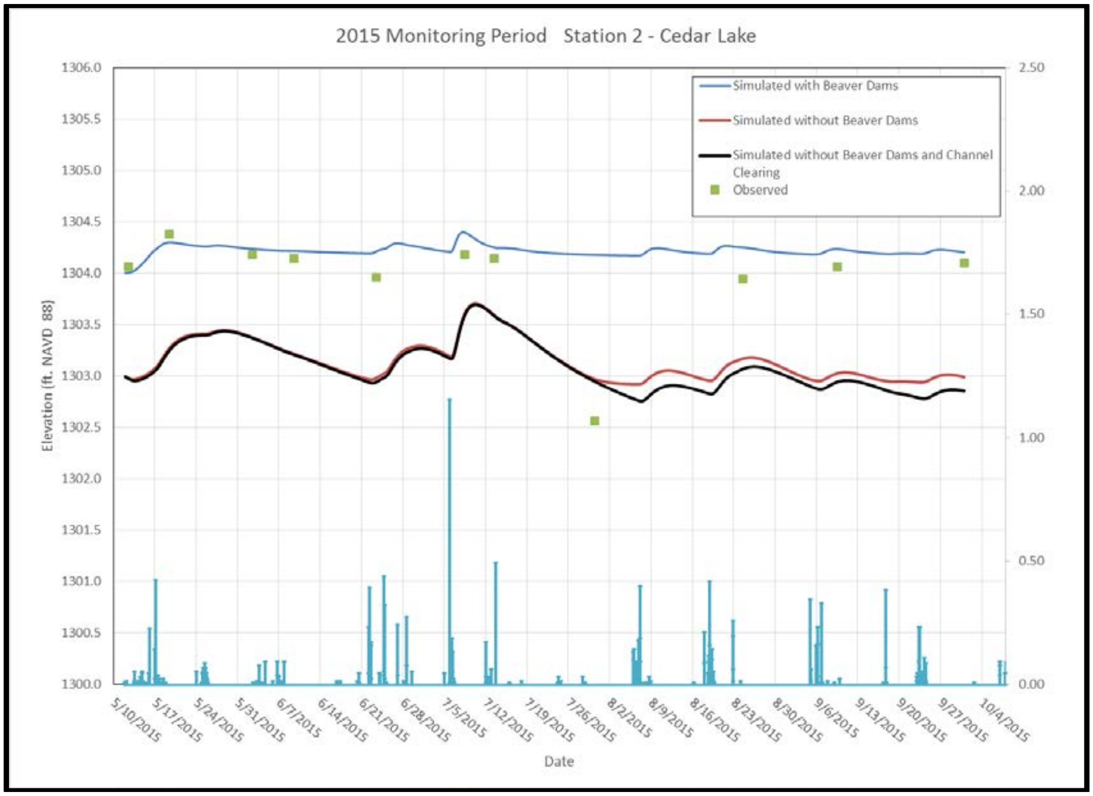

Figure 28: Comparison of the 2015 simulations at Cedar Lake. Removal of the beaver dams reduced the water levels by a little more than one foot throughout the growing season. There are some small reductions later in the growing season with some channel improvements at the outlet of Cedar Lake.

Channel Improvement

The third alternative considers the removal the beaver dams, but also a significant channel improvement to increase the conveyance of the channel downstream of Cedar Lake. Importantly, the evaluation of this alternative considered only the water levels in Cedar Lake, and does not consider wetland or other impacts. Three sub-alternatives were evaluated for the channel improvement. The first one considers a channel with a 12 ft bottom width with no lowering of the channel invert. Based on the survey data collected in this area this is an approximate 8-foot increase in the channel bottom width. The second sub-alternative considers a 0.5-foot reduction in the channel invert downstream of Cedar Lake with the same 12-foot channel bottom width. The third considers a 1.0 ft reduction in the channel invert with the 12-foot channel bottom width. Figures 29 – 30 show how each of these channel improvements reduces the stages in Cedar Lake during the 2015 growing season.

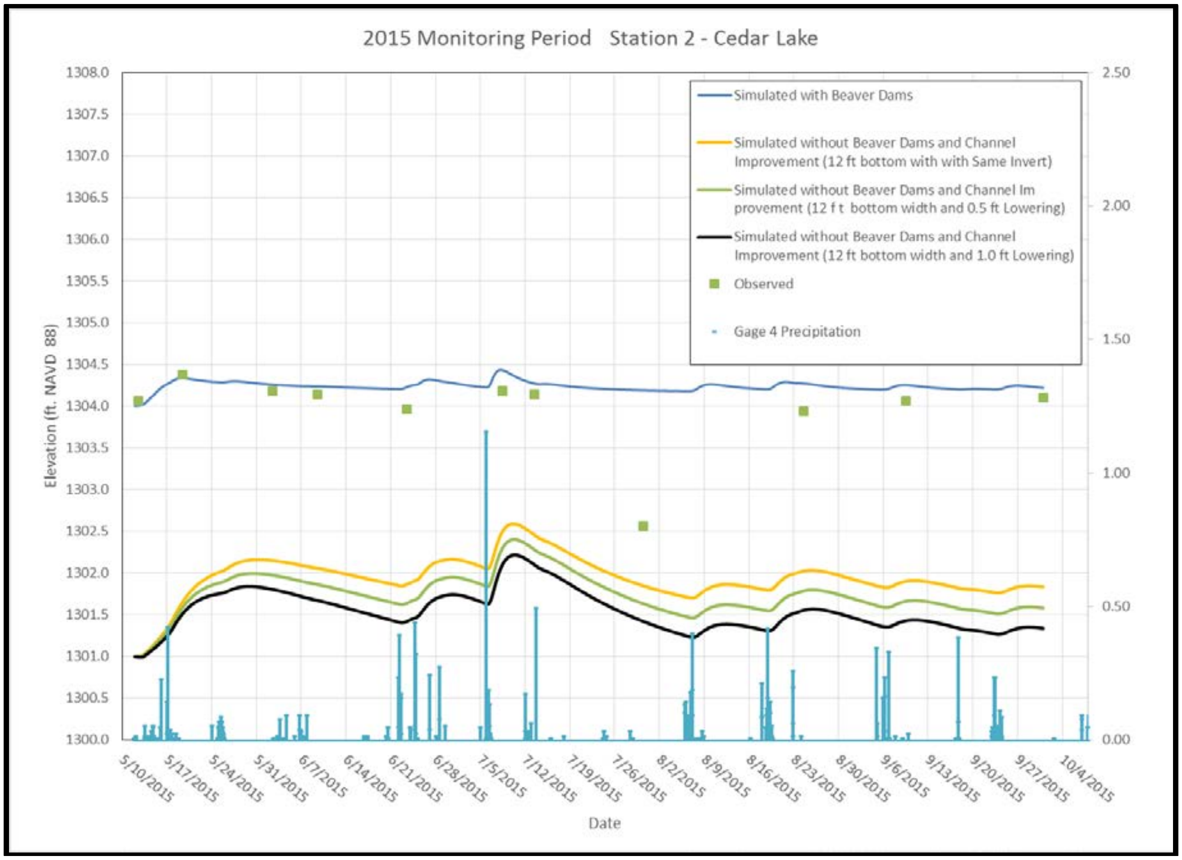

Figure 29: Comparison of the 2015 simulations at Cedar Lake. Removal of the beaver dams and increasing the channel cross-sectional area significantly reduces the water levels in Cedar Lake.

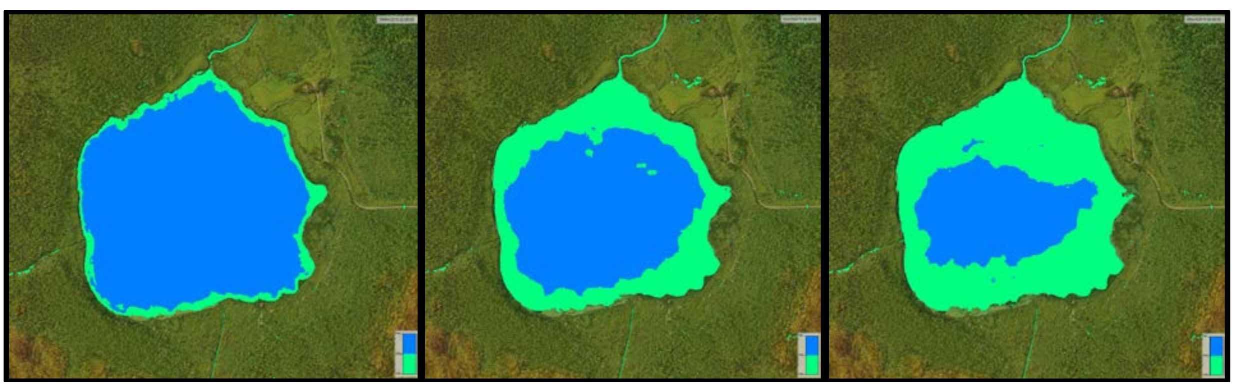

Figure 30: Comparison of the water depths for the 2015 simulation showing current conditions with beaver dams (first image), increased channel bottom width (second image) and increased channel bottom width along with lowering the channel invert one foot (third image).

Recommendations

The water level data collected over the past two growing seasons and the model results suggest that the water levels at Cedar Lake are elevated, and the backwater causing these elevated lake levels is likely due to beaver dams between the outlet of Cedar Lake and Twin Lakes Road. Removal of these beaver dams is expected to be an important step to reducing water levels in Cedar Lake. The surveyed cross-sections between Cedar Lake and Twin Lakes Road provide valuable information about the channel condition at specific locations; however, the sustained ponding in this reach makes it difficult to assess the condition of the channel, as overgrowth of vegetation may have reduced the channel efficiency. Some of these channel constrictions may not become apparent until after the beaver dams are removed.

A monitoring period of one season or more is recommended before even considering any channel improvements downstream of Cedar Lake. This period of time will allow verification of the water level response to the beaver dam removal. It will also allow additional assessment of the channel capacity downstream. An updated bathymetric survey of Cedar Lake (tied into the NAVD 88 datum) is also recommended. This updated bathymetry can be used to re-evaluate the optimal water level for rice production and will be useful for re-evaluating and changes that have occurred since the last bathymetry survey. If channel improvements are later considered, potential impacts to wetlands should be considered.

If the beaver dams are removed between the outlet of Cedar Lake and Twin Lakes Road, consideration should be given to releasing the impounded water at rate that does not induce flooding of roads or property downstream. It would be very beneficial to establish several more monitoring locations in Cedar Lake and downstream of Cedar Lake to observe the changes in water levels after removal. The locations of these monitoring stations could be adapted based on observation from one season to the next. Since any alternative to reduce water levels in Cedar Lake will require the removal of beaver dams between Cedar Lake and Twin Lakes Road, one adaptive management approach may be to closely monitor water levels in Cedar Lake and the response to the beaver dam removals. If water levels in Cedar Lake do not respond as predicted in the model simulations, a close network of water level gages will help identify potential barriers to drainage.

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Appendix A

Hydrology and Hydraulic Model Development Report

Hydraulics

Overview

The hydraulic model created for Simian Creek was developed with HEC-RAS 5.0.3. The river structure was created with four river reaches. Three river reaches represent the main portion Simian Creek, and an additional lateral channel was created to represent a flow split that occurs upstream of Twin Lakes Drive, approximately 1 mile downstream of Cedar Lake. While the channel and conveyance is small, additional detail was added to this portion of the model because of the close proximity to Cedar Lake, the focus of the study and modeling effort.

A two-dimensional flow area was used to simulate flows through Cedar Lake and the surrounding area. This flow area is located in the headwaters and is the upstream boundary for the one-dimensional model downstream. The location for the two-dimensional / one-dimensional interface was tested in various locations, but stability problems were encountered when the interface was located too close to the relatively small culvert structures and flow split at Twin Lakes Drive and Hardwood Road.

The hydraulic model was extended approximately 9 ¼ miles downstream to just past Kultala Road. The model was extended this far to include the gaging location where Fond du Lac (FDL) has operated a stream gage for several years. The channel grade increases downstream of Kultala Road as Simian Creek descends to the St. Louis River.

Table 1: Summary of river reaches and structures in the hydraulic model.

River	*Reach*	*Length (mi.)*	*Sections*	*Bridges/Culverts*	*Lateral Strs.*
Simian Creek	US Reach	0.1	3	0	0
Simian Creek	MID Reach	0.4	13	2	0
Simian Creek	DS Reach	8.8	111	7	1
Simian Creek1	Lateral Channel	0.5	13	2	3

Topography

The State of Minnesota recently obtained statewide LiDAR data. This publicly available information was used to create a high-resolution digital terrain model for the Simian Creek watershed. One of the limitations of LiDAR is that it does not typically penetrate water, so additional cross-section surveys are often required to add additional detail below water level and in channels. In 2015, FDL hired StraightLine Surveying to survey the channel, bridges and culverts in the Simian Creek watershed. FDL collected bathymetric data in Cedar Creek and Simian Creek. These bathymetric surveys were provided to the Corps of Engineers as depths. To covert these depths into lakebed elevations, they were subtracted from the lake level in the LiDAR elevation data set. This conversion process likely introduces some error into the lakebed elevations. The LiDAR data, surveyed channel cross-sections, and the bathymetry for Cedar and Simian Lakes were stitched into a seamless digital terrain model. Sub-basins for the hydrology model were delineated and the hydraulic model geometry was created using this terrain model.

Cross-Sections

Cross-section geometry was extracted using the HEC-GeoRAS v. 10.2. While seasonal flows are of primary interest to the study, FDL also expressed an interest in having a better understanding of flood inundation and depths, so cross-section geometry was extended to capture the full cross-sectional area during large flood events. Manning's n values were estimated from Table 3.1 of the HEC-RAS 5.0 Hydraulic Reference Manual (Version 5.0, February 2016). Most of the channel observed in the field and photographed by the surveyor shows a channel with significant high vegetation overhanging the banks, so a Manning's n value of 0.045 was selected for the entire length of the study area. While there is some variability in the overbank vegetation, most of this vegetation is thick vegetation. Table 3.1 in the Hydraulic Reference Manual includes a range of 0.07 to 0.16 for medium to dense brush in summer. Based on this range, a Manning's n value of 0.15 was selected for the thick wetland vegetation present in the overbank areas of Simian Creek.

The river stationing automatically computed in feet was replaced with river miles. Adjustments were made to the stationing to start the '0' point at the confluence with the St. Louis River. This convention was adopted to make any future model work downstream of Kultala Road easier to incorporate.

In previous versions of HEC-RAS, expansion and contraction losses were not used in unsteady flow. Forces due to contraction and expansion were in the accounted for in the momentum equation. Since the simulations performed in this analysis employ unsteady flow, the steady expansion and contraction are not used in the analysis. The current version of HEC-RAS does allow unsteady expansion and contraction coefficients to be used in special circumstances where sharp expansions or contractions exist. This was not encountered in study area, so no unsteady expansion or contraction coefficients were used.

To conform with normal practice, the steady expansion and contraction coefficients were adjusted to 0.3 and 0.5 respectively, upstream of bridges and culverts so they will be more appropriately set if the geometry is used for steady analysis in the future.

Bridges and Culverts

Bridges and culverts were added to the hydraulic model to account for the headloss these structures have on the water surface profiles. These structures were surveyed along with the channel cross-sections. Since none of the bridges are affected by piers for low flow, the energy method was used. Since the structures on Simian Creek have road embankments that are relatively large obstructions to flow, the pressure and weir methods were selected. Initially, these were modeled using energy and the conversion to 'pressure and weir' did not appear to significantly affect water surface profiles. The default weir coefficient of 2.6 was considered appropriate for conditions.

Storage Areas

Five storage areas were included in the hydraulic model to represent storage in the system. The stage-storage relationship all storage areas were computed using HEC-RAS's automated tool for calculating stage-storage with the associated underlying terrain ('Compute E-V table from Terrain').

The upstream most storage area represents storage downstream of Big Lake and upstream of the Ditchbank Road. A storage area connection conveys flow from this storage area to the two-dimensional flow area. Initially, channel cross-sections were developed for this area, but because the headwaters flow were too small and channel drying caused instability. Similarly, the upstream hydrograph from the south most sub-basin is routed through a storage area south of Big Lake Road. A storage area connection with a culvert conveys flow downstream to Cedar Lake.

Another storage area was created downstream of the two-dimensional flow area route high flows back to the channel downstream. After simulating the 2012 season, it was observed that during the large flood event in June, flow was ponding against the two-dimensional flow area boundary. To address this issue, a storage area connection and storage area were created to route flows to the downstream channel.

Two additional basins were added to the model to represent the unnamed tributary downstream of Twin Lakes. The culvert at Brookston Road is represented as a storage area connection, and connects the two storage areas. A lateral structure connects this tributary to Simian Creek. Initially, this portion of the channel was modeled with cross-sections, but similar to the channel downstream Big Lake, low flow and channel drying caused stability problems.

Two-Dimensional Flow Area

A two-dimensional flow area was created for the area around Cedar Lake. A grid spacing of 100 ft was used, but additional breaklines establish greater detail around the channels upstream and downstream of Cedar Lake. The two-dimensional flow area connects with the one-dimensional portion of the channel upstream of Twin Lakes Drive. The one-dimensional portion of the model extends downstream to just past Kultala Rd. A Manning's n value of 0.045 was used in the channel and 0.03 was used in Cedar Lake, and overbank areas varied between 0.06 up to 0.15 in areas of thick wetland vegetation. As with the Manning's n values, these Manning's n values were selected based on guidance in the 'Hydraulic Reference Manual (February, 2016). Spatially varied Manning's n values were hand digitized based on aerial photography.

In-Line Structures and Two-Dimensional Storage Area Connections

As described in the main report, calibrating stages throughout the system was not possible without recognizing the beaver dams. In the two-dimensional flow area, three beaver dams were used to represent beaver dams that can be observed in recent aerial photography. Five additional in-line structures were added to the one-dimensional portion of the model. These were added in locations where observed water levels clearly indicated backwater from in-channel obstructions, and where locations could be approximately by aerial photography. It is recognized that storage area connections are a very simplified approach to simulating the affects the beaver dams may have on water surface elevations.

Hydrology

Overview

The purpose of the models developed for this study is to evaluate how conditions can be improved for wild rice on Cedar Lake. A basin model was developed in HEC-HMS v. 4.1 using the Soil Moisture Accounting Method. The approximate 20 square mile watershed was subdivided into 15 sub-basins. The soil properties maps developed from the gSSURGO data for maximum infiltration, maximum percolation rate, maximum soil storage and maximum tension storage were used to select representative properties for each sub-basin. The Clark Unit Hydrograph method was used for hydrograph transformation, and the simple surface and canopy were used to account for surface and canopy storage. The Linear Reservoir method was used to simulate baseflow. The initial flow, and Groundwater 1 and Groundwater 2 Coefficients were estimated based on best fit with the observed data.

Sub-Basin Delineation

Sub-basins were delineated using a Digital Elevation Model (DEM) created from the LIDAR using manual methods and a basin wide delineation provided by the FDL. Most of the basin is intersected by roads, bridges and culverts. These structures provide logical sub-basin delineations as they physically separate portions of the watershed. The upper portion of the basin in located just downstream of Big Lake. This area is relatively flat, and flow patterns are somewhat unclear. Initially, Big Lake and its contributing area was included in the Simian Creek watershed, but through discussions with FDL and observations they made during runoff events, the sub-basin was removed based their observation that flow from the Big Lake moves to the south rather than to the east towards Simian Lake. The sub-basins and contributing areas are included in Table 2.

Times of Concentration

Times of concentration were computed for each sub-basin using the TR-55 method. Flow velocities were estimated for the longest flow paths for each sub-basin. Due to the flat topography in many of the sub-basins, the times of concentration estimates are high. In many of these flat sub-basins that are intersected by road culvert, peak simulations were found to not be sensitive to the time of concentration because of attenuation behind the culverts. Estimated times of concentration can be found in Table 2.

Runoff Curve Numbers

The National Land Cover Database (NLCD2011) and SSURGO Data (hydrologic soil groups) were used to estimate runoff curve numbers. Land cover was converted to the best match for cover descriptions found in Appendix A of the HEC-HMS Technical Reference Manual. ArcGIS was used to calculate the weighted average of the runoff curve number for each sub-basin. Runoff curve numbers are found in Table 2. Figure 1 contains the map used to compute the runoff curve number for each sub-basin.

Table 2: Sub-basin parameters for the Simian Creek HEC-HMS runoff curve basin model.

Name	Area (Sq. Miles)	Runoff Curve Number	Time of Concentration (hrs.)	Storage Coefficient (hrs.)
BIGLAKE1	0.25	75.9	4.7	18.6
CEDARLAKE1	2.58	77.0	10.2	40.8
DSKULTALA1	0.68	63.4	3.8	15.0
GOLF1	0.89	67.4	4.7	18.6
LITTLELK1	0.82	72.3	4.8	19.2
NORTHWEST1	1.76	76.4	3.9	18.0
SIMIANLAKE1	3.08	66.3	11.0	44.0
STEEP1	1.86	74.0	8.1	32.8
TWINLAKERDE1	0.57	74.3	5.2	20.8
TWINLAKERDS1	0.96	72.3	7.7	20.6
TWINLKLOW1	0.97	76.8	6.2	24.6
TWINLKUP1	3.14	75.9	11.3	45.0
USKULTALA1	0.32	72.7	1.4	5.4
USPRIVDR1	0.75	78.6	3.8	15.0
USSTEEP1	2.01	73.7	6.2	24.6

Canopy and Surface

SMA guidance developed by Purdue University (Purdue University, 2014) recommends a canopy coefficient range between 0.05 inches for general vegetation up to 0.1 inches for trees and coniferous trees. A canopy coefficient of 0.1 was selected for all the sub-basins. This guidance also recommends surface storage values of 0.04 inches for steep, smooth slopes up to 2.0 inches for flat, furrowed lands. A surface storage value of 0.25 inches was selected because it best matched the watershed characteristics of moderate to gentle slopes.

Potential Evapotranspiration

The potential evapotranspiration values used in the model were taken from the University of Wisconsin Extension. Their on-line system provides estimated daily evapotranspiration rates for Wisconsin and Minnesota. The evapotranspiration model uses atmospheric observations from ASOS stations and satellite-derived insolation estimates to predict water use by plants.

Baseflow

The Linear Reservoir method was used to simulate baseflow. The initial flow, and Groundwater 1 and Groundwater 2 Coefficients were estimated based on best fit with the observed data.

Soil Moisture Accounting Loss Method

For the Soil Moisture Accounting Loss Method, gSSURGO was used to derive maps for soils maximum infiltration rate, maximum percolation rate, maximum soil storage, maximum tension storage. These soil properties were used for developing a hydrologic basin model using the Soil Moisture Accounting (SMA) method in HEC-HMS. As a first attempt to calibrate, one set of hydrologic parameters was developed for each sub-basin based on the dominate soil properties, and these properties were varied to provide a reasonable fit to the observed data. This approach presented challenges because many of the soil properties varied significantly across the sub-basin. On a smaller watershed like Simian Creek, the rainfall-runoff response was very sensitive to model changes in these soil properties. To provide a better representation of this variability, each sub-basin was subdivided into two to four representative parameter sets. The time-series generated by each individual parameter set were aggregated by sub-basin in HEC-DSSVue for input into the hydraulic model. A better calibration was achieved through this approach. Table 3 contains the parameters used for the Soil Moisture Accounting loss method. Figures 2 through 5 contain the maps used to compute basin parameters.

Table 3: Parameters used for the Soil Moisture Accounting loss method.

Name	Max Infil. Rate (in/hr)	Soil Stor. (in)	Tension Stor.(in)	Soil Perc. (in)	GW 1 Stor. (in)	GW 1 Perc. (in/hr)	GW 1 Coeff. (hr)	GW 2 Stor.(in)	GW 2 Perc. (in/hr)	GW 2 Coeff. (hr)
BIGLAKE1	1	27.9	8.5	1.5	10	1.5	6	5	0.3	100
BIGLAKE2	3.3	23.5	12.2	11.1	10	11.1	6	5	0.3	100
BIGLAKE3	13	0.5	0.1	0	10	0	6	5	0.3	100
CEDARLAKE1	1	0.5	0.1	8.5	10	8.5	6	5	0.3	100
CEDARLAKE2	0.3	23	12.8	1.5	10	12.8	6	5	0.3	100
CEDARLAKE3	0	25.2	14.2	0.8	10	14.2	6	5	0.3	100
CEDARLAKE4	0	0.5	0.1	0	10	0.1	6	5	0.3	100
DSKULTALA1	3	23.6	8.5	16	10	16	6	5	0.3	100
DSKULTALA2	0.8	23.6	14.4	1.4	10	1.5	6	5	0.3	100
GOLF1	1	27.9	8.5	7.2	10	7.2	6	5	0.3	100
GOLF2	3.3	0.5	0.1	11.1	10	11.1	6	5	0.3	100
GOLF3	0	0.5	0.1	0	10	0	6	5	0.3	100
LITTLELK1	13	0.5	0.1	16	10	16	6	5	0.3	100
LITTLELK2	1	27.9	8.5	7.2	10	7.2	6	5	0.3	100
LITTLELK3	0	0.5	0.1	0	10	0	6	5	0.3	100
NORTHWEST1	13	25.2	14.2	8.5	10	8.5	6	5	0.3	100
NORTHWEST2	1.3	23.1	12.8	1.5	10	1.5	6	5	0.3	100
NORTHWEST3	0.3	0.5	0.1	0.7	10	0.7	6	5	0.3	100
SIMIANLAKE1	7.6	23.1	8.5	16	10	16	6	5	0.3	100
SIMIANLAKE2	0.9	20.7	12.4	1.3	10	1.3	6	5	0.3	100
SIMIANLAKE3	0	0.5	0.1	0	10	0	6	5	0.3	100
STEEP1	7.6	23.6	23	5.1	10	5.1	6	5	0.3	100
STEEP2	0.9	20.2	12.8	1.4	10	1.4	6	5	0.3	100
STEEP3	0	20.2	12.8	0.9	10	0.9	6	5	0.3	100
TWINLAKERDE1	13	0.5	0.1	8.5	10	8.5	6	5	0.3	100
TWINLAKERDE2	1	23.1	8.5	7.2	10	7.2	6	5	0.3	100
TWINLAKERDE3	0.3	25.2	14.2	0.7	10	0.7	6	5	0.3	100
TWINLAKERDS1	6.5	0.5	0.1	13.1	10	13.1	6	5	0.3	100

Name	Max Infil. Rate (in/hr)	Soil Stor. (in)	Tension Stor.(in)	Soil Perc. (in)	GW 1 Stor. (in)	GW 1 Perc. (in/hr)	GW 1 Coeff. (hr)	GW 2 Stor.(in)	GW 2 Perc. (in/hr)	GW 2 Coeff. (hr)
TWINLAKERDS2	1	23.1	8.5	7.2	10	7.2	6	5	0.3	100
TWINLAKERDS3	0	0.5	0.1	0	10	0	6	5	0.3	100
TWINLKLOW1	4	23.1	8	16	10	16	6	5	0.3	100
TWINLKLOW2	1	20	13.8	1.5	10	1.5	6	5	0.3	100
TWINLKLOW3	0.4	20	13.8	1.5	10	1.5	6	5	0.3	100
TWINLKUP1	13	20	13.8	16	10	16	6	5	0.3	100
TWINLKUP2	1	20	13.8	4.1	10	4.1	6	5	0.3	100
TWINLKUP3	0	0.5	0.1	0	10	0	6	5	0.3	100
USKATALA1	7.2	23.6	8.5	16	10	16	6	5	0.3	100
USKATALA2	1	20	13.8	1.5	10	1.5	6	5	0.3	100
USPRIVDR1	4	0.5	0.1	8.5	10	8.5	6	5	0.3	100
USPRIVDR2	1.2	23.1	12.8	1.2	10	1.2	6	5	0.3	100
USPRIVDR3	0.5	25.2	14.2	0.7	10	0.7	6	5	0.3	100
USSTEEP1	13	0.5	0.1	13.1	10	13.1	6	5	0.3	100
USSTEEP2	1	23.1	12.8	1.5	10	1.5	6	5	0.3	100
USSTEEP3	0.7	25.2	14.2	0.7	10	0.7	6	5	0.3	100

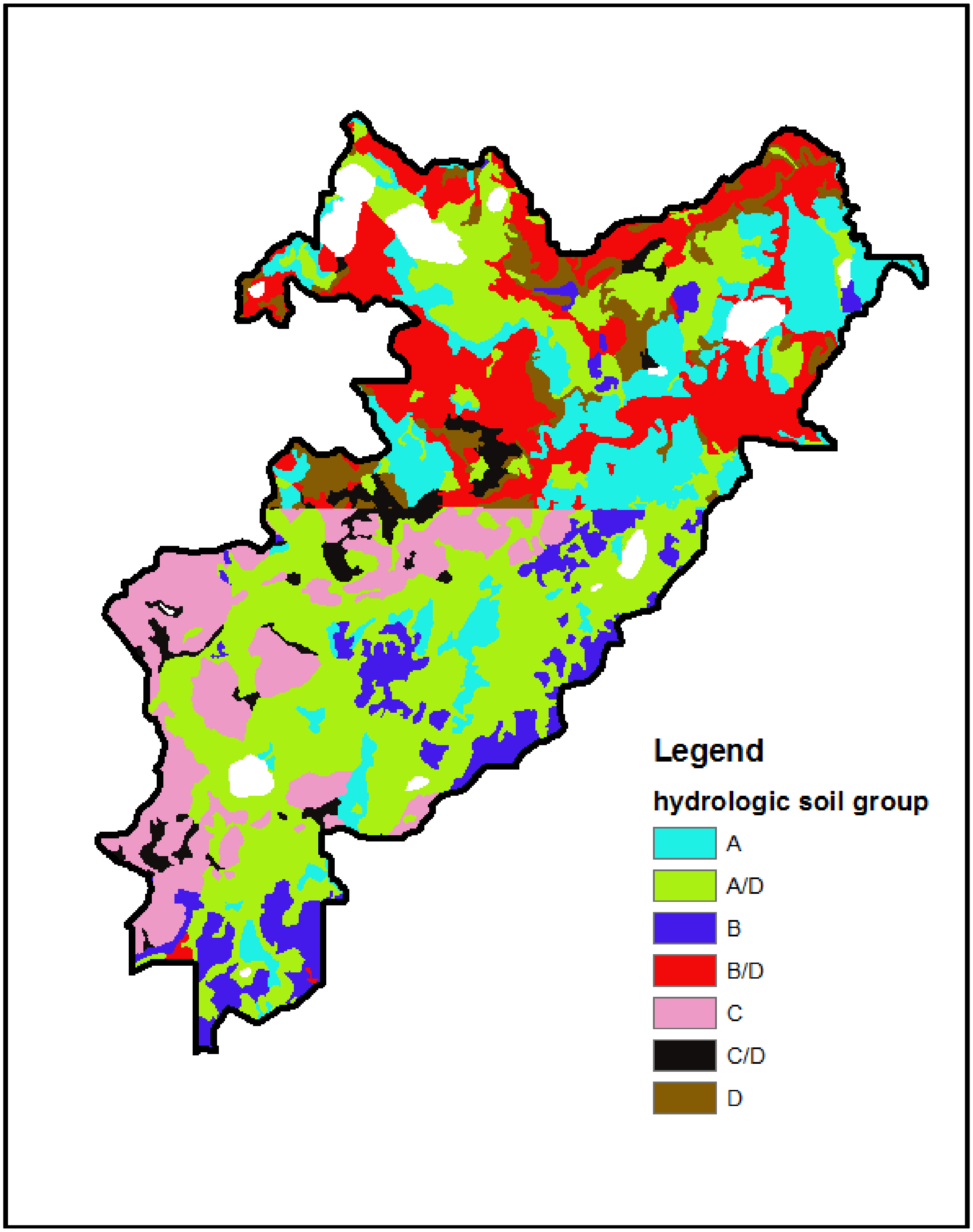

Figure 1: Hydrologic Soil Groups map used for the runoff curve number basin model.

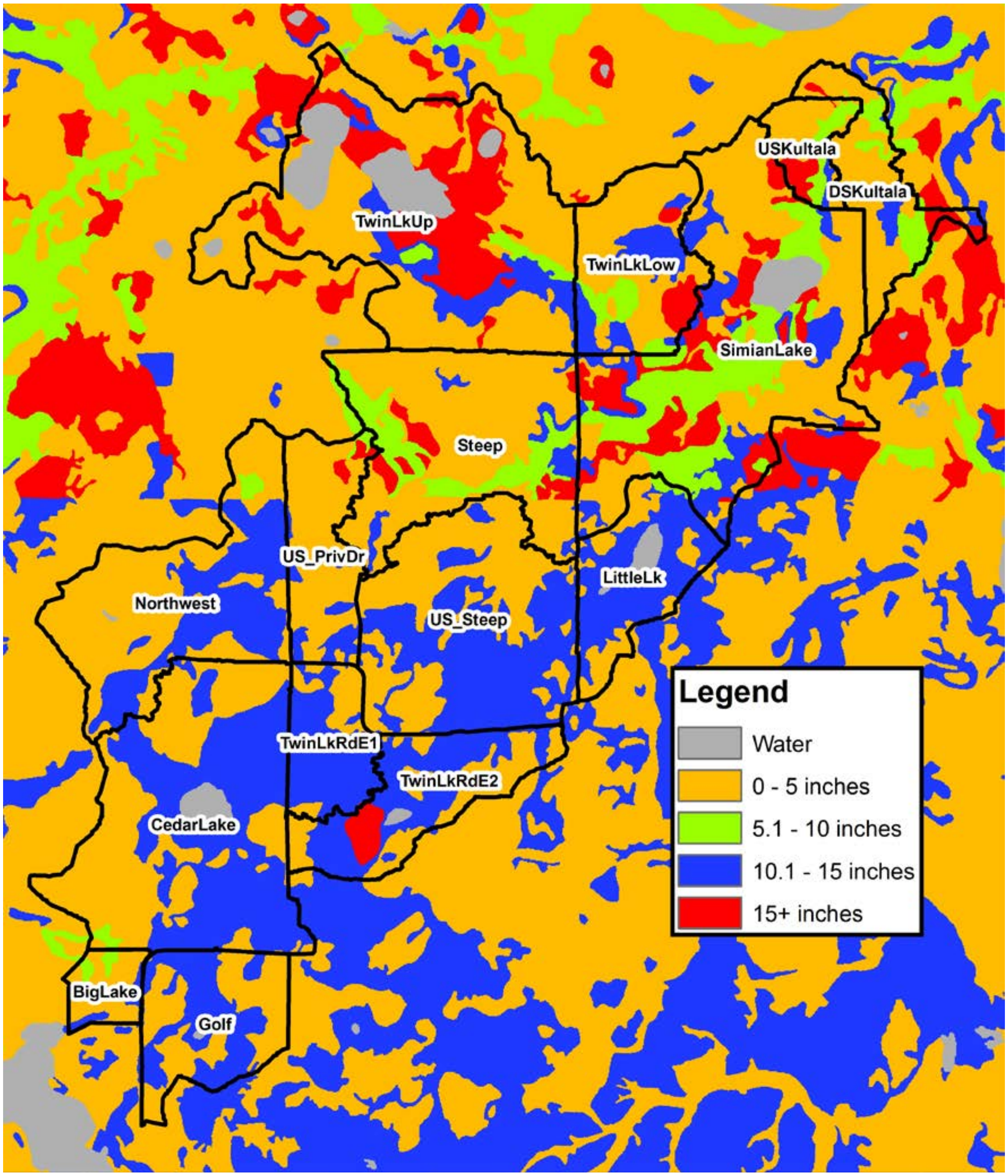

Figure 2: Maximum Infiltration Rate map (in/hr) used in the Soil Moisture Accounting Method basin model.

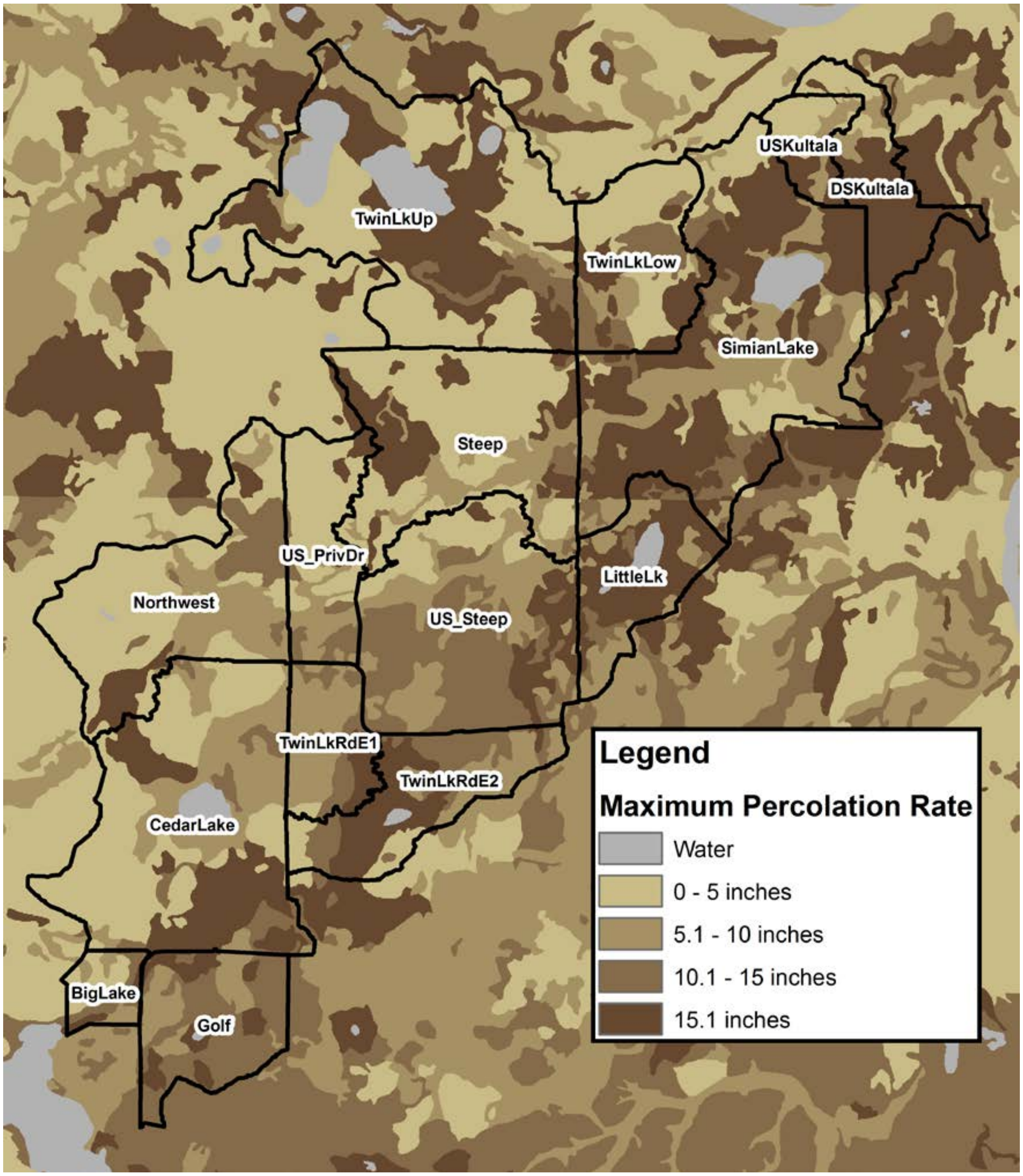

Figure 3: Maximum Percolation Rate map (in/hr) used in the Soil Moisture Accounting Method basin model.

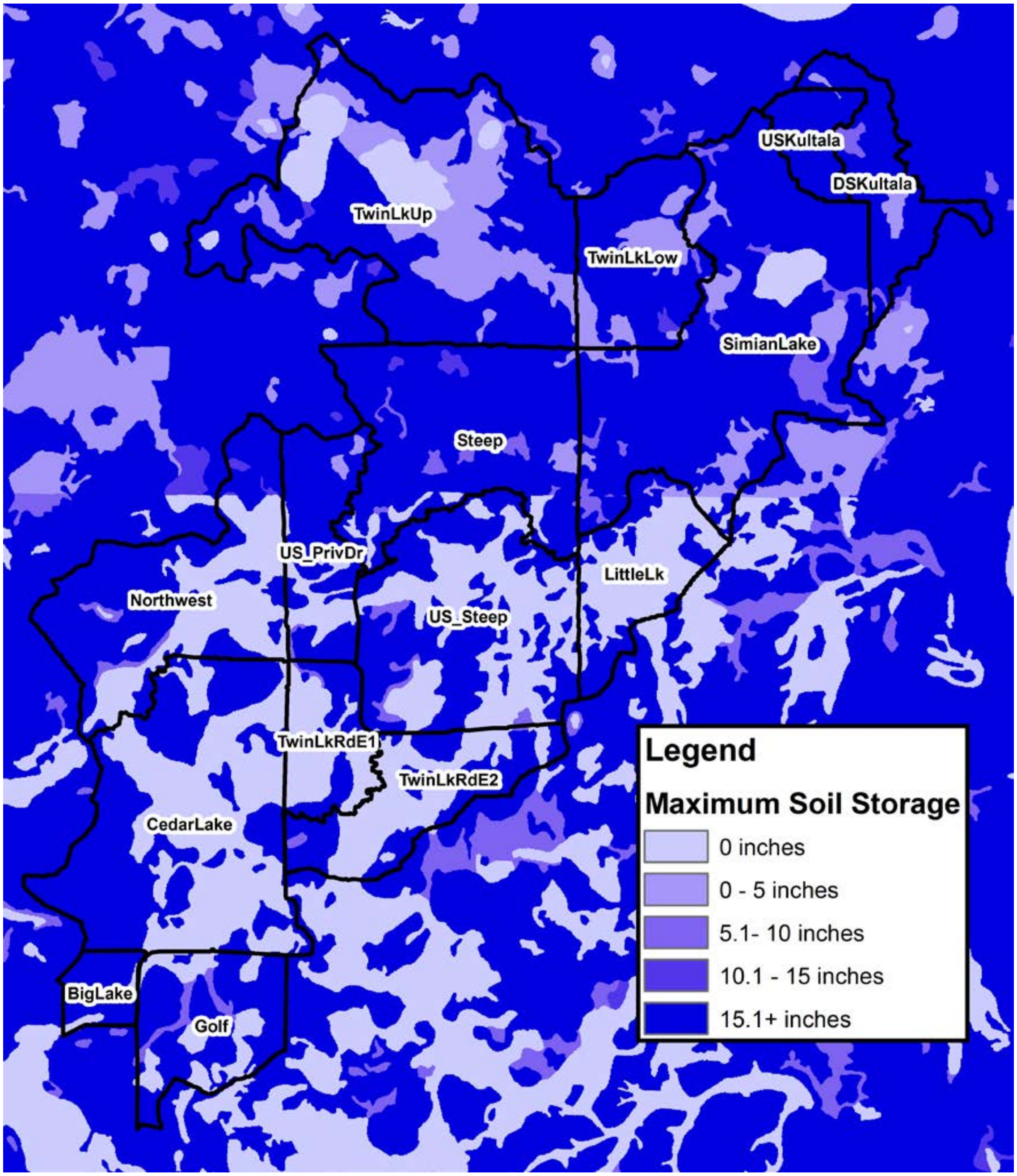

Figure 4: Maximum Soil Storage map (in/hr) used in the Soil Moisture Accounting Method basin model.

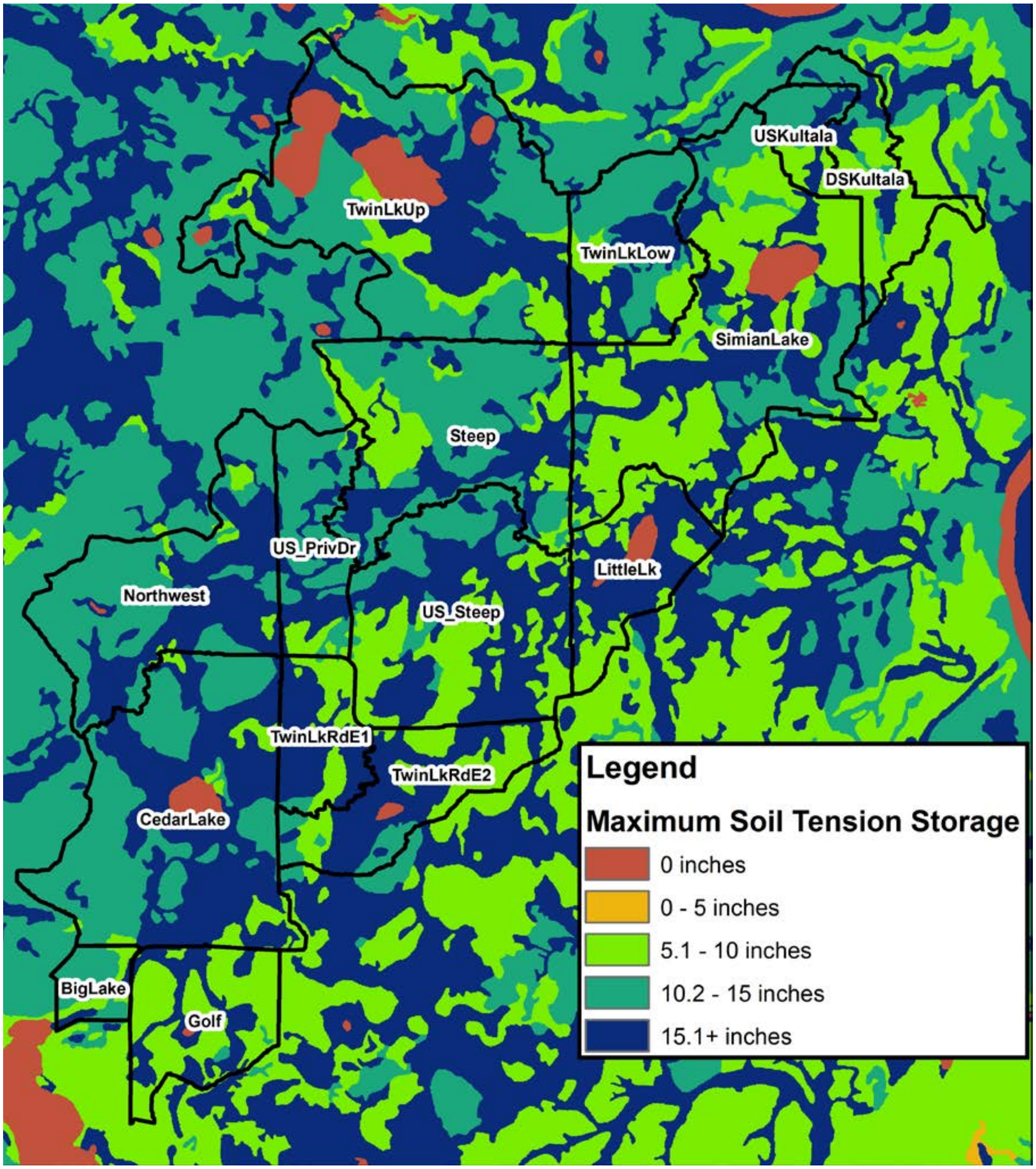

Figure 5: Maximum Soil Tension Storage map (in/hr) used in the Soil Moisture Accounting Method basin model.