POCOSIN LAKES WILDLIFE REFUGE
WATERSHED 1, PHASE 1
HYDROLOGY MODELING STUDY

Final Report

Abstract

A hydrologic study to provide insight on the effectiveness of restoration efforts, update management options, and inform future planning of Watershed Area 1 was completed. This report details the effects of various water level management scenarios on restoration efforts and potential downstream impacts. The results and maps are focused on a subset of the refuge, but may be used to improve management decisions on other areas.

Contents:

Introduction

Since the mid 1990's, the Pocosin Lakes National Wildlife Refuge (PLNWR) has been implementing wetland restoration efforts that have grown it to one of the largest sites of its kind in the world. The restoration work has primarily focused on using water control structures to reverse the effects of human drainage efforts and to promote natural hydrologic conditions. These structures are most prominent in an area of the Refuge mapped as Restoration Area 1, where substantial ditching was previously attempted by private landowners. The management system been largely informed by a 1994 study completed by the USDA Soil Conservation Service (now called Natural Resources Conservation Service) and adjusted by field experience. However, the 1994 study was prepared at a broad scale using data and technology available at that time. The huge scope of the plan and data limitations have led to some challenges with implementing parts of it at the field scale. In addition; field observations, downstream landowner concerns, and recent fires have all effected management decisions on the site.

This project is an attempt to revisit hydrologic restoration efforts at the Refuge using the latest technology and information. It also attempts to provide more detailed answers to specific issues that have been encountered in Restoration Area 1. The first portion of this work involves utilizing the newest elevation data to analyze potential water levels. This analysis provides insight into the spatial extent of ponding and storage, and the effect that potential changes to management might have. The second portion of the project includes an updated hydrology model which incorporates new weather data. The model results are used to describe management needs as they relate to natural wetland hydrology in the area. The results also provide insight on the differences in expected drainage volumes and runoff in various management scenarios. A final part of this project includes a simple canal analysis. This analysis shows the capacity of canals to transport the flow from different storm events. By combining these analyses together, the potential impacts to off-site drainage networks and flooding are also examined.

Background

Watershed Area 1 is generally defined in a gridded network of roads and adjacent canals. The area (nearly 20,000 acres) is broken down into multiple hydrologic management units (HMU). A HMU may be made of between one to four blocks. A block being generally defined by a half mile by mile area of land (320 acres) gridded off by a road/canal. Elevations across each block typically vary by a few feet. Each has a main north-south collector canal along the west side and an east-west canal along the southern edge. The east-west canal is connected to abandoned field ditches spaced throughout the blocks. The USFWS is currently managing the hydrology using flashboard weir control structures that are placed in the main collector canals at the south western corner of each HMU. These structures allow flashboards to be added or removed in order to set the normal drainage level of the adjacent canal. The large size of each HMU and the varying topography creates a challenge for flashboard management. Managing large areas with a single flashboard riser limits the ability to finely tune the water table towards natural conditions. In general, the most natural condition would involve keeping flashboards at or near the average ground surface in the adjacent HMU. In an HMU with several feet of topographic change, this would mean having flashboards above the surface (ponding water) on lower areas and below the surface (drier land) of higher areas. This is further complicated as the HMU's tend to have a north east to south west slope. This creates an appearance of ponded water near the riser leaving the drier land far away.

To date, decisions on where to manage flashboard riser elevations have been made using field judgment and experience. In some cases, adjustments are and have been made based on feedback or the needs of adjacent property owners. The current approach is based on attempting to achieve a normal water table at the ground surface on as much of an HMU area as possible. Due to topographic changes across HMUs, this approach may leave large areas of land in a ponded condition and large areas in a dry condition, with little in between. Refuge managers have attempted to adjust flashboards to prevent excessive ponding depths while also limiting excessive areas of dry land. An optimization of this management would determine how to maximize the area of land that is within a target distance of the water table.

Using newly acquired remote elevation data will allow the type of targeting needed to make well informed decisions about flashboard riser management on the Refuge. Combining this work with some simple and updated modeling will provide further insight into this management and how to make further improvements. This study utilized previous measurements of flashboard elevations, aerial photography, LiDAR elevation data, and water table data that had been collected for previous work. This data was used to help set a baseline for what is currently taking place with the hydrology of the refuge as well as to give an idea of how the climate and water table fluctuates throughout a yearly cycle.

Mapping Analysis

Mapping Methods

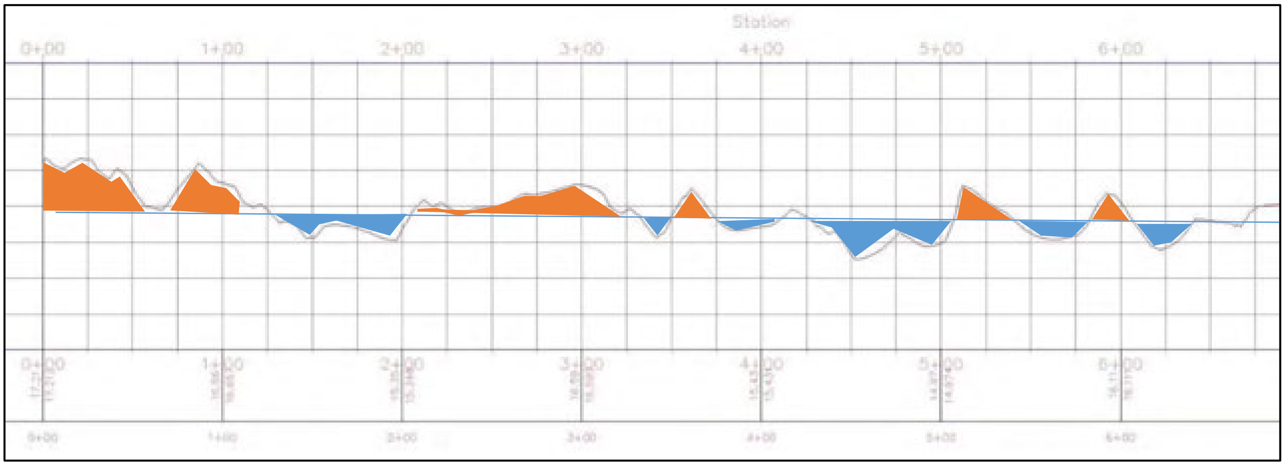
The first portion of this study was to utilize the latest elevation data to provide a fresh look at topography and potential water levels in various HMUs. Due to the tremendous size of the Refuge and the large number of HMUs, a small subset of them was chosen for initial analysis. HMUs were chosen to represent a variety of expected topographical patterns, drainage areas, and drainage level management approaches. Table 1 shows the selected HMUs and provides notes on why these areas were chosen for the analysis.

HMU/ Water Control Structure	Blocks, Number of Blocks	Notes
A10	A9-A10, 2 blocks	Managed in cooperation with NRCS
B7	B4-B7, 4 blocks	Large group, Available monitoring data
B12	B12, 1 block	Near Refuge outlet of Boerma Canal
C7	C7, 1 block	Monitoring site location
C14	C12-C14, 3 blocks	HMU restoration in progress – monitoring data
C15	C15. 1 block	HMU restoration in progress
D8	D7-D8, 2 blocks	Potentially controls a larger area
D10	D9-D10. 2 blocks	Typical blocks with topographic gradient
D11	D11, 1 block	Largest topographic gradient, monitoring data

At least one HMU was chosen in each of the A-D labeled areas of the Refuge. This subset represents a wide range of conditions that can be encountered across Restoration Area 1. It reflects blocks that are widely thought of as being successfully restored, blocks that are being managed at lower than optimal levels, blocks that are in the process of restoration, and blocks that have historic monitoring data.

The latest elevation data for the Refuge was collected in 2014 through a cooperative state and federal project. The data was collected using airborne light detecting and ranging (LiDAR) technology. This data was acquired, filtered, and compiled into a 5 foot gridded digital elevation model (DEM). The DEM was split up into individual HMUs, or groups of HMUs, and exported to AutoCAD Civil 3D as an existing ground surface. Once in this format, these surfaces could be examined to produce statistics on elevation ranges and used for other analyses. One analysis that was completed was a water surface overlay. This technique involves creating multiple surfaces that represent potential water elevations. The first surface was generated using a water elevation equal to the current elevation of flashboards at each HMU. These elevations were measured using GPS survey equipment. Additional surfaces were generated on an incremental and trial and error basis until analysis goals were met. These surfaces are then draped on top of the existing ground topography. The resulting combination can then be analyzed to determine the potential water table depth at every point on the ground surface. A map of these depths that shows the spatial extent and depth of surface ponding at that water level was then generated. A histogram was then recorded to show the percentage of land in an HMU that could be at various water levels. An example of what this analysis looks like in a cross section view is shown in Figure 1.

Figure 1. Example overlay analysis with water depths, Block D11, PLNWR. Blue hatching is ponded water and orange hatching is water table below ground.



This process was repeated with overlays at different elevations to generate statistics with water levels at different elevations. To define a good starting spot with respect to other water surface elevations, the existing ground surface was exported as its own DEM. A spreadsheet was then pulled from that to find the mean surface elevation. From there, the water level was increased in increments of 0.5 feet until water coverage reached 50% across the HMU. These overlays were then made into maps that show both the current hydrologic conditions as well as the optimized hydrologic conditions in each of the analyzed HMUs. These finished maps include a legend noting the percent of land that is six inches above or below the ground surface, as well as the percent of land that is not within this one foot range. There are two published maps for each HMU analyzed. One map depicts an existing condition and a second reflects where 50% of the land area would have a water level at the ground surface or above. Print maps are provided in Appendix A of this report.

With a few assumptions, this analysis can be used to anticipate the effect of flashboard risers managed at various elevations. The first is that water tables are flat across the landscape of the area analyzed. Based on data collected at this site, this assumption is largely valid, and is particularly so at this scale. In addition, determinations and calculations are made assuming the water table is at the elevation of the flashboard risers. This condition is referred to as the normal water level throughout the report. In the real world, this water level is very rarely constant and is in regular flux with rainfall and evapotranspiration.

Mapping Results

In general, the mapping results and analysis show that current flashboard elevations do not create large areas of ponded water on the Refuge. At the current flashboard elevations, the normal water table will be at the surface or above in less than 3% of areas analyzed. Every map resulted in the water table being below the ground surface on 97% or more of the affected area. The remaining open water areas are primarily confined to the canal and ditch system. The normal water table depth varied between the HMUs. In all HMUs, except for B7, the normal water table depth was greater than 1 foot below the ground for most of the surface area. Only three HMUs, B7, C7, and D8 had 50% of the area within 1 foot of the normal water table. Table 2 summarizes the results of the overlay analysis for each HMU in the study.

Table 2. Statistics with normal water level at existing flashboard elevations at PLNWR.

Blocks	Control Structure	% Land Cover	% Water Cover	% within 1' of surface	Elevation (ft)
A9-A10	A10	98%	2%	40%	9.6
B4-B7	B7	99%	1%	97%	13.7
B12	B12	98%	2%	42%	9.8
C7	C7	100%	0%	60%	13.8
C12-C14	C14	100%	0%	2%	7.3
C15	C15	100%	0%	2%	5.8
D7-D8	D8	97%	3%	48%	14.1
D9-D10	D10	98%	2%	20%	12.8
D11	D11	97%	3%	21%	12.3

The cells shaded in green show HMUs that are largely capable of bringing the normal water table within one foot of the ground surface. Although this water level may not duplicate natural conditions or provide substantial fire protection, it is likely that these areas meet a minimum for soil wetland conditions. This finding would also be supported with monitoring data where it has been collected. Blocks C14 and C15 were managed as free drainage at the time of this study. This is reflected in the low percentage of land area within one foot of the normal water table. Blocks D10 and D11 have greater elevation gradients, which also reduces the percentage of land within one foot of the water table.

In most HMUs, raising the flashboard elevation would be a very effective way of increasing the amount of land area near the normal water table. In most cases, small increases in the current elevation of flashboards can make a big change in the amount of land close to the water table. However, the potential effect of these changes on ponded water should be considered before determining exactly where and how adjustments should be implemented. The three HMUs shaded green in Table 2 (B7, C7, and D8), have higher percentages of land within one foot of the normal water table. This lowers the priority of considering adjustments to flashboard risers in these HMUs. Other HMUs such as A10, B12, and D10 have the potential for greater improvements. Table 3 includes the potential improvements and results that could be achieved with management adjustments.

Table 3. Statistics with adjusted water levels at PLNWR.

Blocks	Control Structure	% Land Cover	% Water Cover	% within 1' of surface	Elevation (ft)	Difference (ft)	Improvement
A9-A10	A10	51%	49%	61%	11.6	2	21%
B4-B7	B7	5%	95%	98%	14.7	1	1%
B12	B12	41%	59%	81%	11.8	2	39%
C7	C7	49%	54%	63%	15.3	1.5	3%
C12-C14	C14	50%	50%	83%	10.8	3.5	81%
C15	C15	45%	55%	78%	10.3	4.5	76%
D7-D8	D8	54%	46%	57%	15.6	1.5	9%
D9-D10	D10	46%	54%	32%	16.3	3.5	12%
D11	D11	51%	49%	28%	14.3	2	7%

This analysis allows for more detailed decisions to be made on potential management changes. For example, raising the flashboard elevation at B7 by just one foot would change the ponded area at normal water levels from 1% to 95%. The flat topography of this block makes it very sensitive to changes in flashboard elevation. As a result, raising the flashboards above the current level should only be done slowly and in small increments if desired. Another interpretation is that this block may provide tremendous storage above the ground surface. If a modified riser configuration was implemented in this block, nearly the entire surface area could be used to provide temporary storm storage.

Control Structures A10 and B12 stand out as flashboard risers that could be raised to generate larger improvements. The analysis indicates that current elevations could be raised as much as 2 feet to maximize the HMU area within a foot of the normal water table. Although maps indicate surrounding roads might accommodate this change, they also show that this increase will cause substantial ponded water along the main canals. Raising the boards would have to be completed with the understanding that the observable standing water will be increased. As a result, a smaller increase in the flashboard elevation may be the best adjustment.

Flashboard Risers at D10 and D11 are special examples. The elevation gradient of these areas makes it necessary to implement a big change in flashboard elevation to allow the normal water table to better approach the target range. Even with these levels, large areas will be have more than one foot of ponding or be further than one foot away from the water table. This can be visualized using the maps produced for these HMUs. The end result would bring only a small portion of the HMU into an optimized target range. Substantial changes such as new dikes and structures would be needed to maximize the benefits of water management in these HMUs.

Mapping Conclusions

The current amount of ponded water in normal conditions is very low (1-3%) and almost strictly limited to canal and ditch areas. These areas can easily be identified on most aerial photography, but are also confirmed with this analysis. In the current conditions, over 95% of each HMU is normally dry land. Although it appears that substantial areas would meet minimum wetland hydrology goals, over 50% of this land would have a normal water table depth greater than one foot below the surface. This provides substantial room in the soil for infiltration and storage of precipitation. Raising the flashboard elevation could further optimize water levels in several HMUs. However, careful consideration is needed to determine where such efforts will have the most positive effects and avoid undesirable changes. HMUs with a higher elevation range would need greater changes to optimize wetness conditions. Some flatter HMUs would experience substantial ponding if levels were raised. The data and information to help make these decisions is available. Additional analysis using the methods described here could be combined with detailed goals to make decisions on future flashboard riser management.

Print Maps

Print quality maps from this portion of the study are provided in Appendix A. The maps can be used to visualize the extent of changes that might occur with different management scenarios. Additional overlays can be completed easily using the methodology described in this report.

Hydrology Modeling

DRAINMOD Setup

The second phase of this project involved groundwater simulations to analyze the effectiveness of management decisions and to describe dynamics under different climate conditions. The computer program DRAINMOD was implemented for this portion of this study. This program is a water budgeting model that simulates the hydrology of poorly drained, high water table soils. The model tracks rainfall, infiltration, evapotranspiration, and runoff on an hourly basis over long periods of time (Skaggs et al.). DRAINMOD was used for the 1994 planning studies on the Refuge. However, additional tools and weather data can now be used to improve upon that work. For this site, a continuous weather record of 80 years was available for use from the nearby Plymouth weather station. Utilizing weather data over a long period of time allows results to be averaged over a large range of possible weather conditions. The model was populated with the same soils data that was used in the 1994 study. That information was developed in a study by Gregory et al. in 1984. The data and report describes an organic soil surface with very high infiltration and lateral conductivity. This overlays a deeper, more decomposed peat with substantially lower infiltration capacity, partially due to a high water content. In general, this results in most storms infiltrating the surface and then flowing laterally towards ditches at a shallow depth. To better represent current conditions on the site, a few parameters were adjusted compared with previous models. The effective rooting depth was increased to two feet to better simulate trees that now exist on the Refuge. Surface storage was also increased to represent macrotopography that has been observed on site and during the mapping portions of this work.

Simulations were created to represent natural pocosins and a typical block at the Refuge under various water management scenarios. These included simulations with no ditches, simulations with freely draining ditches, and simulations with flashboard risers set at the average ground surface elevation, one foot below the surface, and two feet below the surface. The results from 80 years of simulations were compiled to show general hydrology trends and also to examine seasonal and storm event trends.

Simulation Results

Model simulations confirm that these systems are primarily rainfall and evapotranspiration driven. These results are similar to other studies in the area and on similar peat systems. Table 4 summarizes how precipitation is processed in these landscapes under different scenarios.

Table 4. Predicted water budgets as a percentage of precipitation by scenario at PLNWR.

	Natural Pocosin	Free Drainage	Managed at Surface
Evapotranspiration	74%	73%	74%
Drainage	23%	26%	23%
Surface Runoff	3%	1%	3%
Total Outflow	26%	27%	26%

Natural Pocosin – simulation with no effective ditches or canals.
Free Drainage – simulation with completely open ditches and canals.
Managed at Surface – simulation with flashboard risers in canals set at the average ground surface.

The largest portion of rainfall in this area infiltrates into the high capacity surface soils. This high infiltration capacity generates good opportunity for evapotranspiration (ET). Even in a free drainage scenario (with open ditches), the water table will rarely drop far enough to make it unavailable to trees. This keeps ET rates high in all scenarios (73-74%). Excess water is almost entirely lost through subsurface drainage. This is water that flows laterally through the soil and into the ditch network. In a free drainage scenario, this percentage is higher because a lower ditch level encourages more of this type of lateral flow. Subsurface drainage can occur during baseflow and during the drawdown after storms. Surface runoff also contributes to the total outflow from an HMU. However, surface runoff from these soils is predicted to be very low (1-3%). Only the largest storms can bring water depths above the surface storage capacity to generate overland flow. In a free drainage scenario, the percentage of surface runoff is less than in a natural or flashboard riser scenario. The normally higher water table in the natural setting increases the potential for storms to exceed soil storage. Overall, free drainage has the most combined flow downstream, although the difference between scenarios is small.

Restoration Effectiveness

Drainmod results can be used to predict the effectiveness of flashboard riser management on wetland restoration efforts. This is accomplished by a counting routine that tracks periods where the water table is within 12 inches of the ground surface. Settings were created to count a successful year if a continuous period of 30 days or more is achieved. The simulations showed that a natural pocosin in these soils would meet this condition in 96% of all years. Managing flashboards at the average ground surface mimics these results very well. A freely drained scenario only meets this condition in 50% of simulation years. Additional simulations were completed with flashboards set at 6 inches, 12 inches, and 2 feet below the average ground surface. Flashboards set at 6 and 12 inches below the average ground were also very successful at achieving continuous periods of water table within one foot of the surface. When applying this result to the topographic ranges that exist on the site, it appears that many areas are already achieving wetland conditions. Further interpretation of this leads to the conclusion that flashboard risers in some HMUs could be adjusted without compromising wetland conditions. In general, modifications should be considered carefully for each HMU and with other impacts included other than wetland hydrology. This may provide flexibility in future water control structure management decisions at the Refuge.

Downstream Effects

Drainage outflow can also be summarized seasonally (Table 5). A freely draining scenario will produce more outflow during all times of the year. Outflows volumes are very similar during winter, when ET is lowest. Outflows in restored conditions are reduced the most (7%) during the summer and fall when ET is at a maximum. This reduces total flow downstream and the helps maintain the capacity of receiving drainage networks. Table 5 describes the differences in seasonal outflow for various management simulations on the Refuge. Outflow depth is a simplified way of describing outflow volume. These depths could be multiplied by the land areas of a block, an HMU, or the entire Refuge to estimate total outflow volumes.

Table 5. Seasonal outflow depths (inches) in various scenarios at PLNWR.

	Winter	Spring	Summer	Fall	Total
Natural Pocosin	5.5	3.2	2.2	3.0	13.8
Free Drainage	5.6	3.3	2.3	3.2	14.4
Restored at Surface	5.5	3.1	2.1	3.0	13.7

Natural Pocosin – simulation with no effective ditches or canals.
Free Drainage – simulation with completely open ditches and canals.
Managed at Surface – simulation with flashboard risers in canals set at the average ground surface.

Further examination of these results provides additional insights. Due to the low frequency of storms that generate surface runoff, subsurface drainage is responsible for 90% or more of the total drainage volume leaving the Refuge. When analyzed by itself, this volume would be 14% higher in a freely drained situation compared to being managed at the surface. If these depths are compiled into volumes of drainage water, the impact is magnified. The reduction in subsurface drainage on a typical Refuge block is over 14 million gallons of water per year. In general, the flow from around 10 blocks will be combined into a single downstream canal. This results in a combined reduction of over 140 million gallons per year.

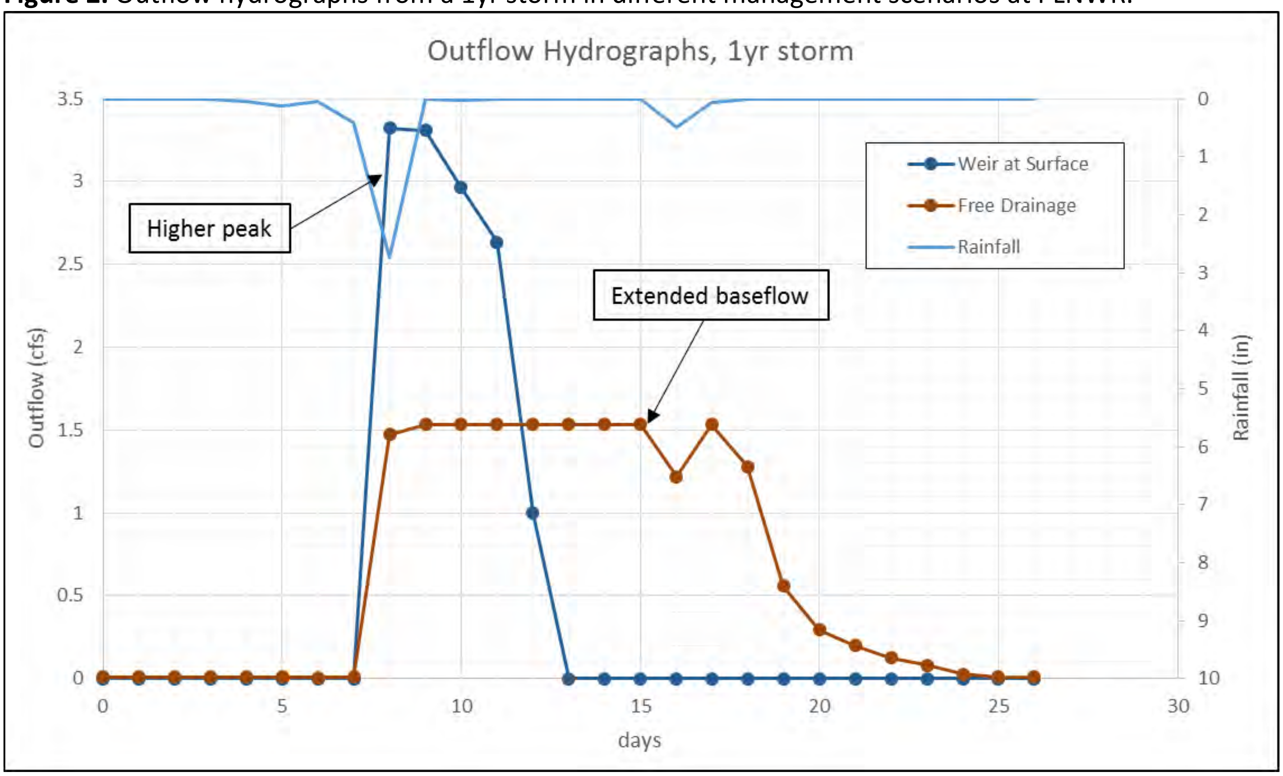
Storm Events

The effects of various management scenarios can also be analyzed during storm events. The initial analysis above already showed that surface runoff is greater in managed scenarios. With open ditches that keep water tables low (free drainage), very little surface runoff occurs. Less than 3% of total outflows would be generated through surface runoff. In a restored situation with flashboard risers set at the surface, water tables are closer to the ground, leading to more runoff. In the managed simulations (flashboard risers), runoff averages 12% of the total outflow. This increase in surface runoff associated with flashboard risers offsets some of the reductions in outflow that are achieved in subsurface drainage. However, because the total runoff volume is a very small part of the total annual outflow, managing flashboard risers at the surface will still provide a net reduction in total outflow volume.

A closer examination of the frequency and magnitude of storm events can further describe the potential effect of storms on downstream flows. Although DRAINMOD is technically not a storm event model, the outflow depths can be scaled to a typical block and over a 24 hour period to estimate flowrates. This technique has been used in prior studies on this site and similar shallow water table areas for storm flow estimation. This work is described in UNC-WRRI report 214, called Hydrologic and Water Quality Impacts of Peat Mining in North Carolina (Gregory, J.D. et al., 1983). The data can be used to generate flow frequency curves and estimate rates for return interval events. The data can also be plotted to examine hydrographs and compare scenarios.

Figure 2 is a hydrograph that plots total outflows from a 3 inch storm (approximately a 1yr return interval). This storm came after a relatively dry period where potential soil storage would be at a maximum before rainfall began. The storm is followed by a second smaller rainfall during the following week.

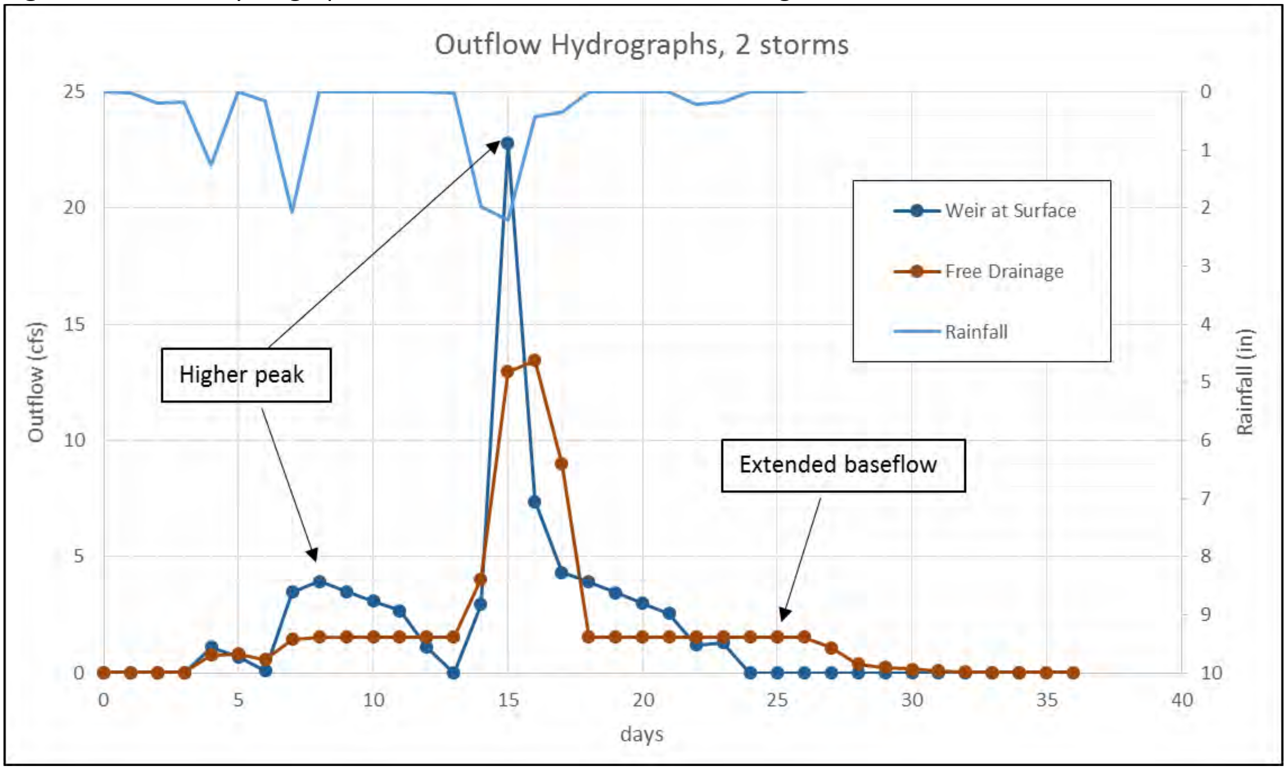
Figure 2. Outflow hydrographs from a 1yr storm in different management scenarios at PLNWR.



The plot shows the total outflow, which is a combination of subsurface drainage and runoff, and is what would be experienced in the Refuge canals. A higher peak flowrate was experienced with the flashboard riser scenario. This outflow peak receded in a period of a few days and returned to baseflow in 5 days. The free drainage scenario has a lower peak flowrate, but an extended period of higher flows. Flows remained elevated for 7 days and began to recede when another small storm occurs. This small storm bumps the free drainage outflow back up for several days. The flashboard riser scenario had already receded and absorbed this smaller storm with no change in outflow. Overall, the total volume of flow was higher in the free drained condition.

A second example if provided in Figure 3. This hydrograph shows the effect of two moderate sized storms back to back.

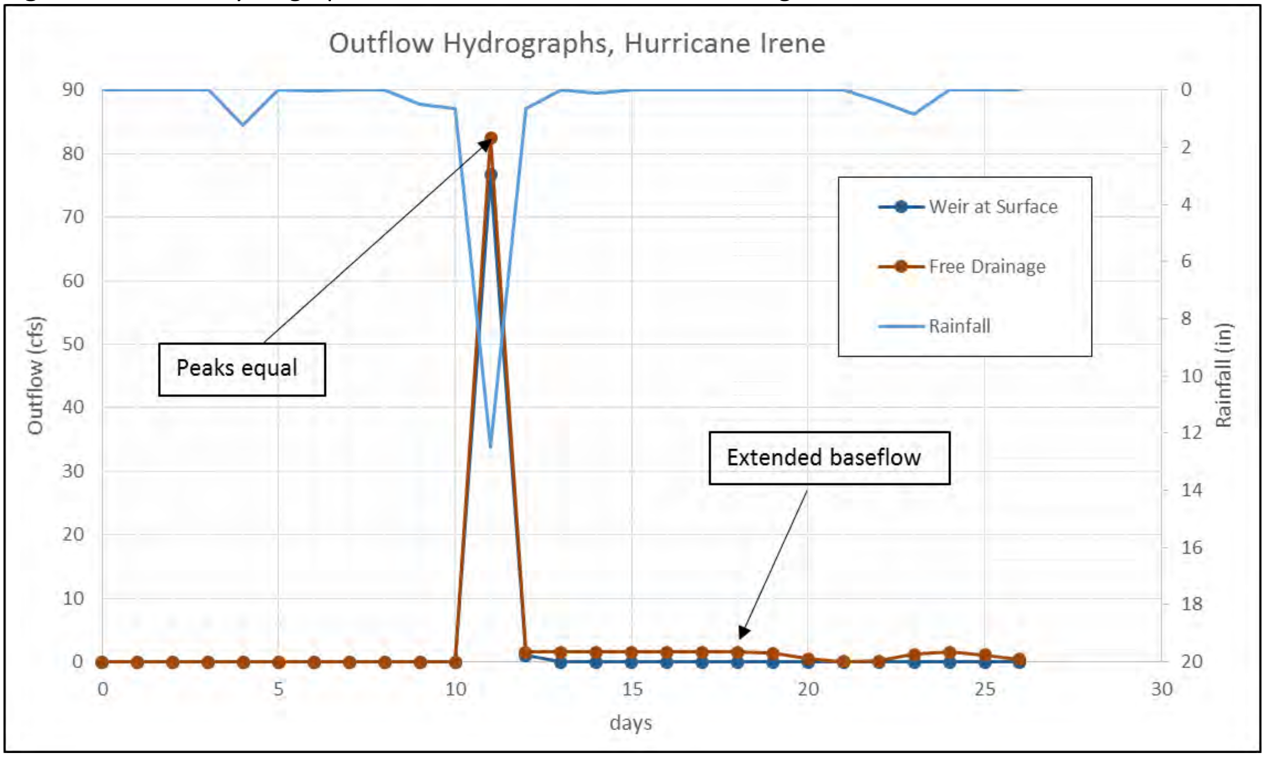
Figure 3. Outflow hydrographs from a 2 storms in different management scenarios at PLNWR.



The first storm is a 2 inch rainfall that occurs on day 7 of the plot. This storm does not generate any surface runoff in either scenario. The peak outflow rate is higher in the flashboard riser scenario, but drops back to baseflow one day sooner that the free drainage simulation. A second storm of over 4 inches occurs on days 14 and 15. This storm causes surface runoff in the flashboard riser simulation but not in the free drainage scenario. The same trend of a higher peak occurs. The two hydrographs cross each other a few times indicating different drawdown predictions. Overall, the free drainage scenario takes 4 days longer to return to baseflow conditions than the simulation with flashboard risers set to the average ground surface.

Figure 4 depicts the results of a simulation during Hurricane Irene in 2011. This is the largest single day rainfall on record for this weather station.

Figure 4. Outflow hydrographs from a 2 storms in different management scenarios at PLNWR.



The peak outflows for this storm are almost identical. When dramatic storms such as hurricanes occur, surface runoff becomes a higher percentage of the outflow. The free drainage scenario has an extended baseflow condition for 8 days after the storm, while the flashboard riser scenario returns to normal in 2 days.

Storm Event Results

Managing the Refuge to encourage more natural drainage conditions has a complex effect on the expected outflow hydrographs from storm events. There are some storms where the use of flashboard risers decreases peak runoff rates. This can occur when soil storage capacity is maximized but not exceeded. With these storms, a higher gradient exists for free drainage and a higher peak flow will occur. However, the peak flowrates that occur with flashboard risers are higher for most moderate sized storms (rainfalls of 3-5 inches). The difference in peaks is greatest on storms that may generate surface runoff with a flashboard scenario and not under free drainage. This can occur under a variety of conditions, but is more common when moderate storms occur back to back. When surface runoff occurs in both scenarios, the difference in the peaks is smaller. With very large storms, peak flowrates are almost identical. These larger storms are the ones more likely to overwhelm the drainage network in all scenarios.

In all storms, flow returns back to normal faster with flashboard risers than it does with free drainage. This is due to the volume of water that must be drained to return the water table down to the free drainage base level. These extended periods of drawdown keep flowrates up for several days longer than with flashboard risers in place. This drawdown also appears to be the cause of the increased outflow volumes that are predicted.

Discussion and Future Work

The effects of various management scenarios on restoration effectiveness, hydrology, and the impact to downstream drainage networks are complex. In general, the use the flashboard risers at their current elevations limits the extent of ponded surface water and appears very successful for accomplishing wetland hydrology goals. Some improvements to flashboard riser elevations and management could be made to better maximize the restoration effectiveness of these structures. The results of this study show that each HMU and block should be considered carefully before changes are implemented. The topography of adjacent HMUs is the primary driving factor for whether flashboard riser adjustment would be beneficial. A simple overlay analysis can be used to determine the effect of different riser elevations on ponded water and water table depths at normal conditions. Some flashboard risers are already maximizing the area that can achieve a normal water table within one foot of the ground surface. The flashboard risers at some HMUs could be raised to increase the percentage of land meeting target water table conditions. Other flashboard risers could be lowered and still meet wetland hydrology goals. Ground elevations and the height of adjacent roads are important pieces to factor into this decision making. The data and processes needed to apply this type of analysis are described in the report and are readily available for future use.

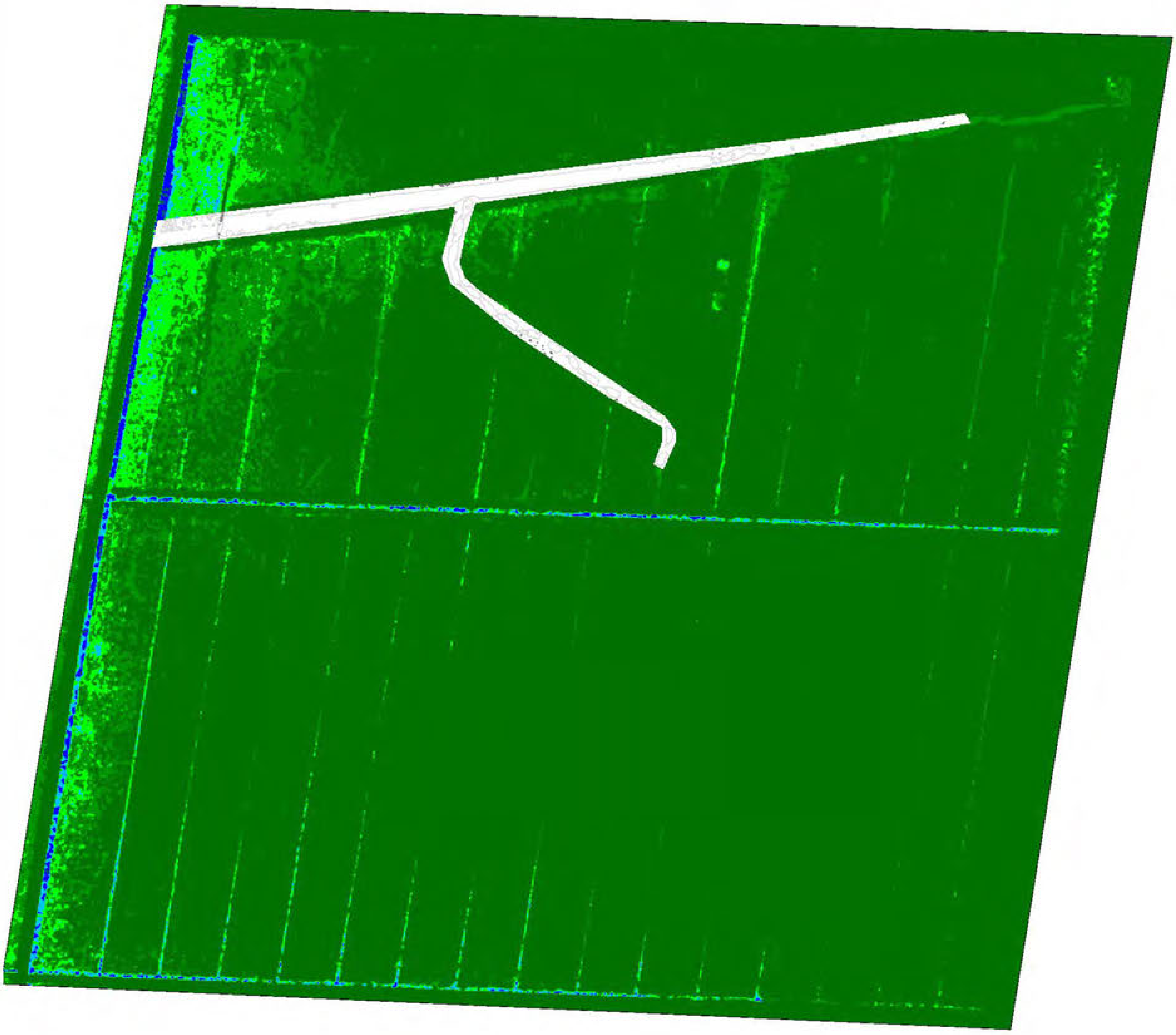
Simulations indicate that the use of flashboard risers on this site are very effective for meeting wetland hydrology goals. Even areas of the site that have ground elevations up to one foot above the normal flashboard elevation will achieve substantial periods of wetland hydrology. This may provide the Refuge with management flexibility that may allow other goals to be met while still maintaining water tables. However, the variability in topography across HMUs makes it difficult to implement a generalized approach across the entire Refuge. More specific hydrology goals should be developed for application to each HMU.

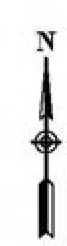
The differences between various management scenarios are best described by breaking them down into component pathways. Overall, there appears to be a net reduction in total downstream drainage volume by managing flashboard riser elevations at the ground surface. The relationship between different scenarios and peak flowrates is complex. In general, the peak flowrates from most moderate sized storm events would be higher with flashboard risers than in a freely drained situation. The expected increases are highest during times where multiple storms occur in a short timeframe. The higher peak flows associated with flashboard risers return to baseflow levels much faster than with free drainage. The lower peaks that occur with free drainage would be accompanied by extended periods of higher flows after storms.

It is unclear whether the increased peak flows associated with flashboard risers will have an adverse effect downstream. The events that indicate the greatest differences (rains of 3-5 inches) may already be exceeding downstream canal drainage capacities. This can only be fully analyzed with a model that extends downstream and links the combined effects of backwater from the entire network.

It appears that the higher peaks associated with storm events with flashboard risers may be mitigated with different flashboard riser configurations. A setup that will allow temporary storage of storm flow above the ground surface while restricting outflow may help further protect downstream drainage networks. The results of this study may be used to further investigate adjustments that might reduce downstream flow peaks.

Appendix A
Existing and Example Overlay Mapping



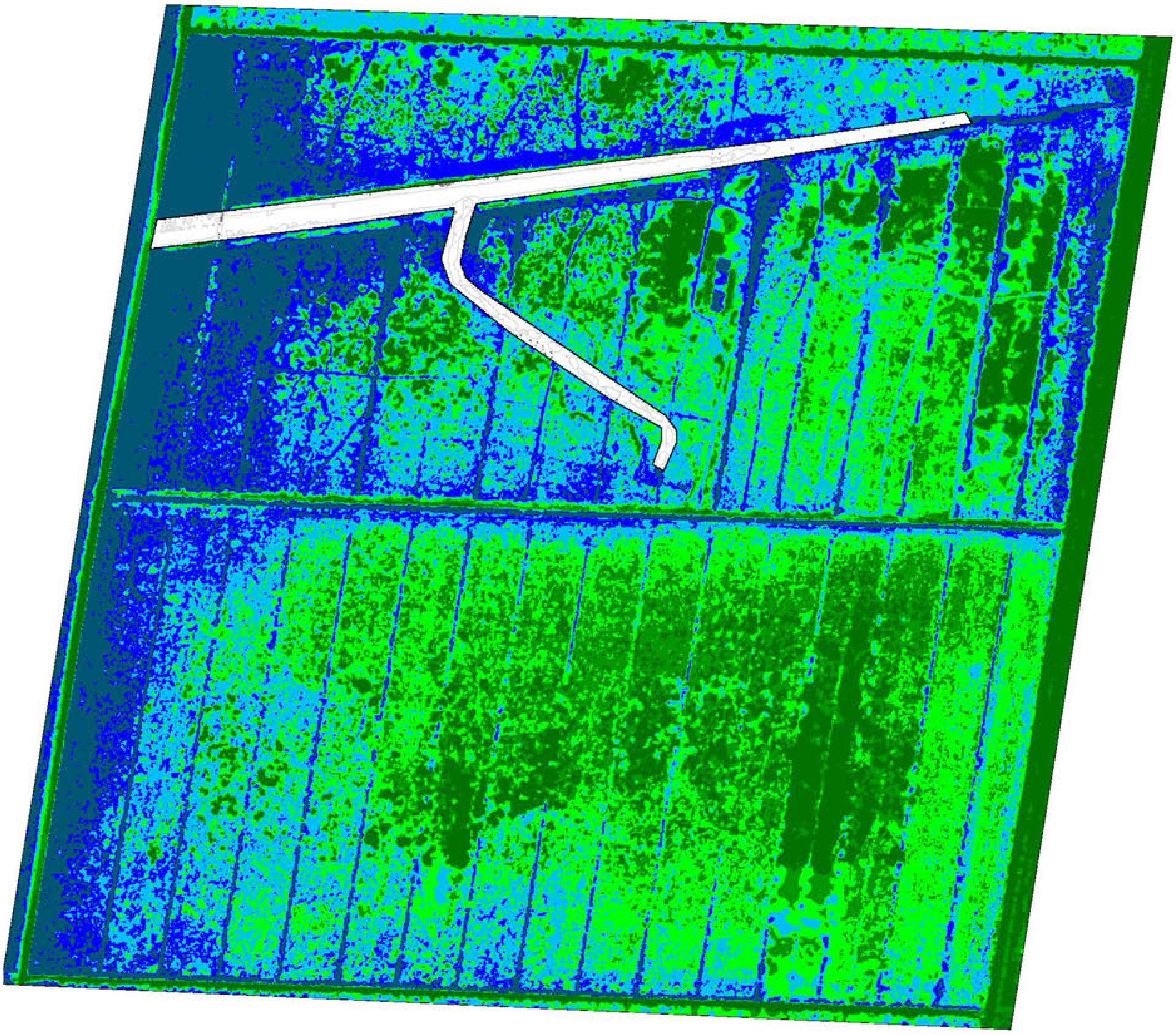


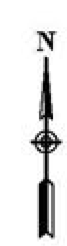
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	60%
	0.5–1 feet above water level	19%
	0–0.5 feet above water level	19%
	0–0.5 feet below water level	1%
	0.5–1 feet below water level	1%
	1+ feet below water level	0%

Legend

Water Level Overlay at Elevation: 9.6 ft
Current Conditions Map: Represents the average measured water level in the hydrologic management unit (HMU). This map shows blocks A9–A10.

Sheet 1 of 1	Drawing: block_a11	File No.	REVISIONS Date	Description	Approved	Kris Bass Engineering Raleigh, NC Kris Bass 919.960.1552 (c) kbass@kbeng.org	Pocosin Lakes Control Structure A10 Pocosin Lakes Wildlife Refuge	Designed klb,kdg Drawn kb,kg Checked kb Approved ______ Date ____ Title ______ Job Class JC





Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	22%
	0.5–1 feet above water level	11%
	0–0.5 feet above water level	18%
	0–0.5 feet below water level	19%
	0.5–1 feet below water level	13%
	1+ feet below water level	17%

Legend

Water Level Overlay at Elevation: 11.6 ft
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows blocks A9–A10.

Sheet 1 of 1

Drawing: block_a11

File No.

REVISIONS		
Date	Description	Approved

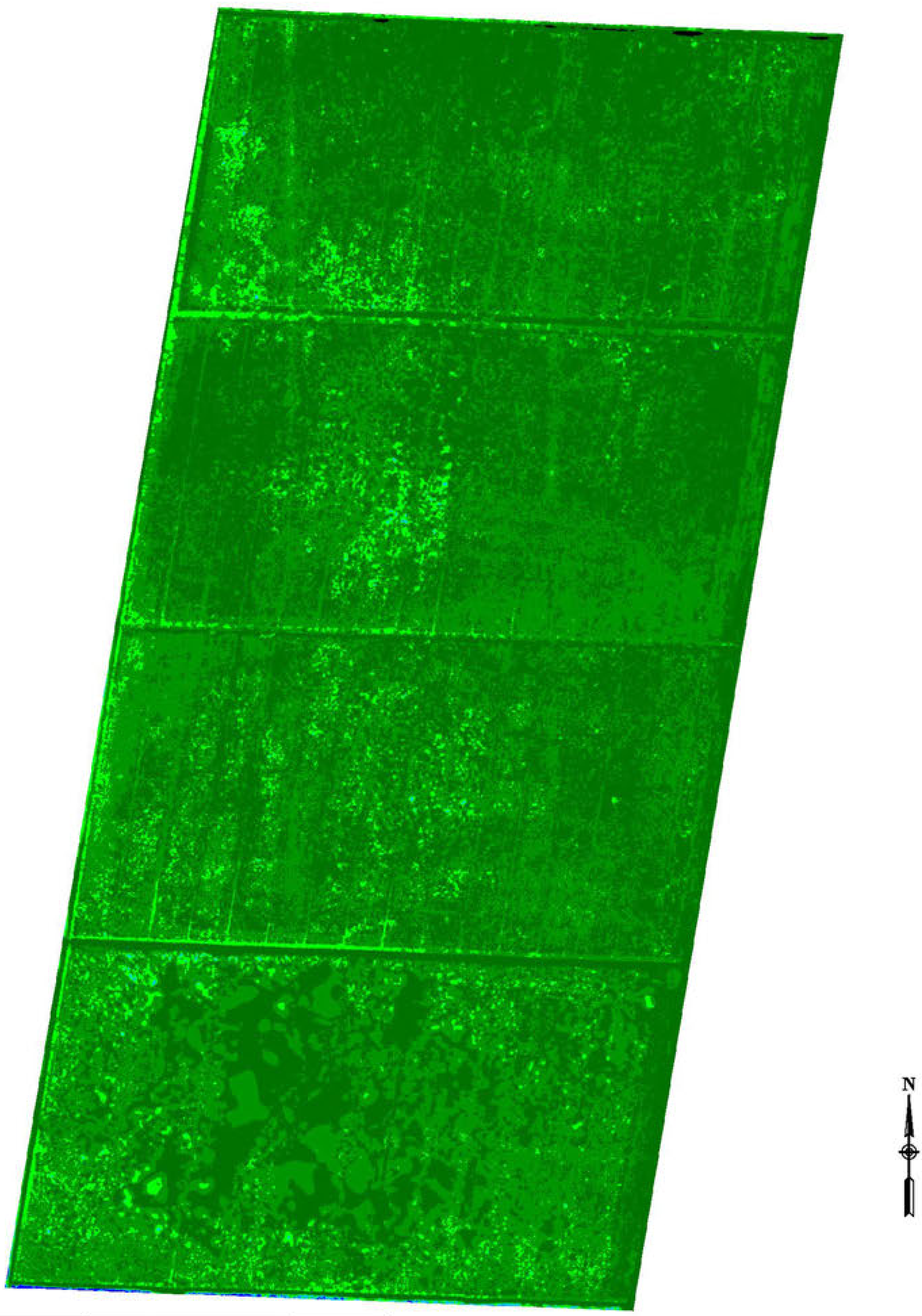
Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

Pocosin Lakes Control Structure A10

Pocosin Lakes Wildlife Refuge

Designed	klb,kdg
Drawn	kb,kg
Checked	kb

Approved ______ Date ____
Title ______ Job Class JC



Legend		
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	3%
	0.5–1 feet above water level	48%
	0–0.5 feet above water level	48%
	0–0.5 feet below water level	1%
	0.5–1 feet below water level	0%
	1+ feet below water level	0%

<u>Water Level Overlay at Elevation: 13.7 ft</u>
Current Conditions Map: Represents the average measured water level in the hydrologic management unit (HMU). This map shows blocks B4–B7.

Sheet 1 of 1
Drawing: block_b7.dwg
File No.

REVISIONS		
Date	Description	Approved

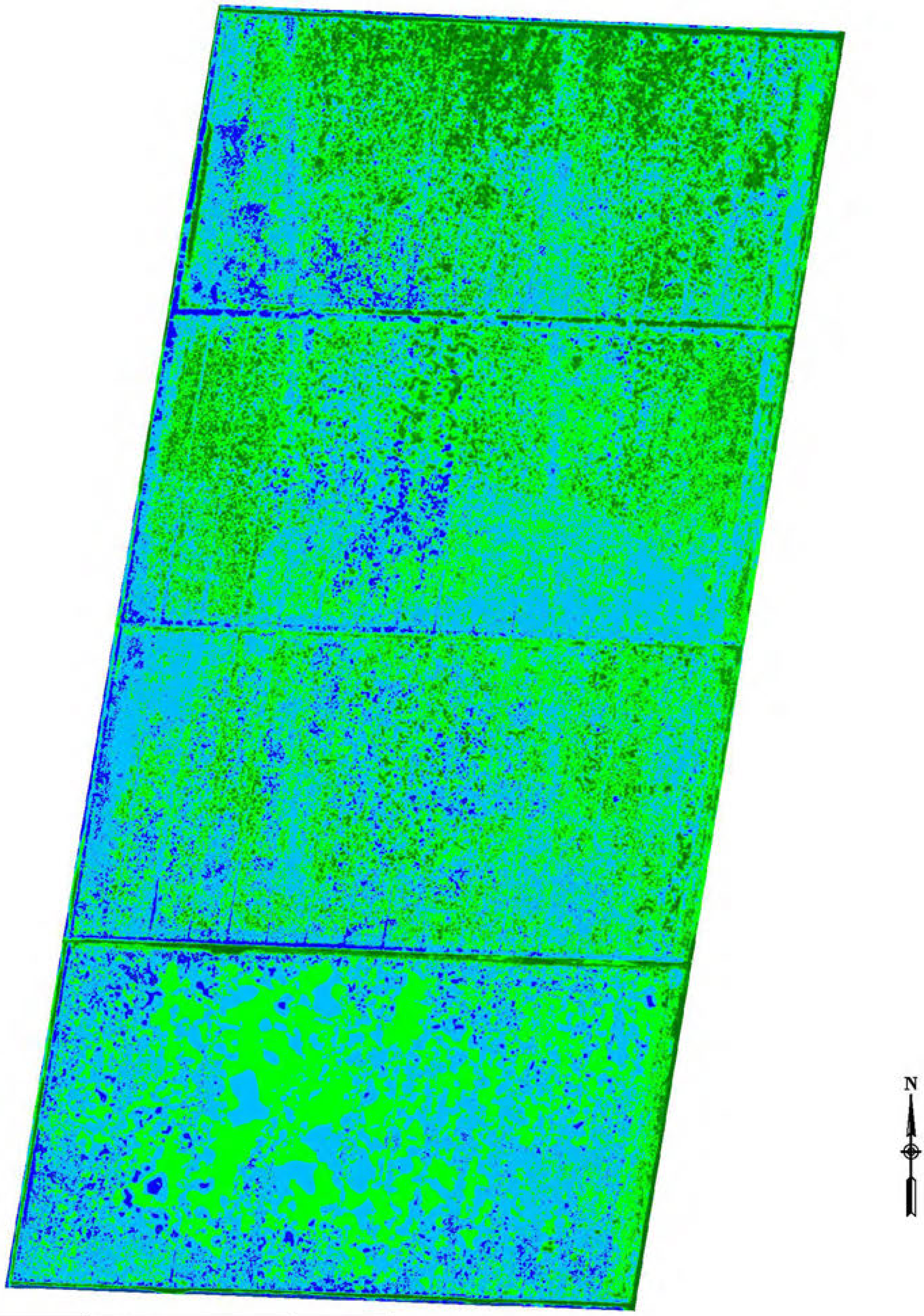
Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

Pocosin Lakes Control Structure B7

Pocosin Lakes Wildlife Refuge

Designed	klb,kdg
Drawn	kb,kg
Checked	kb

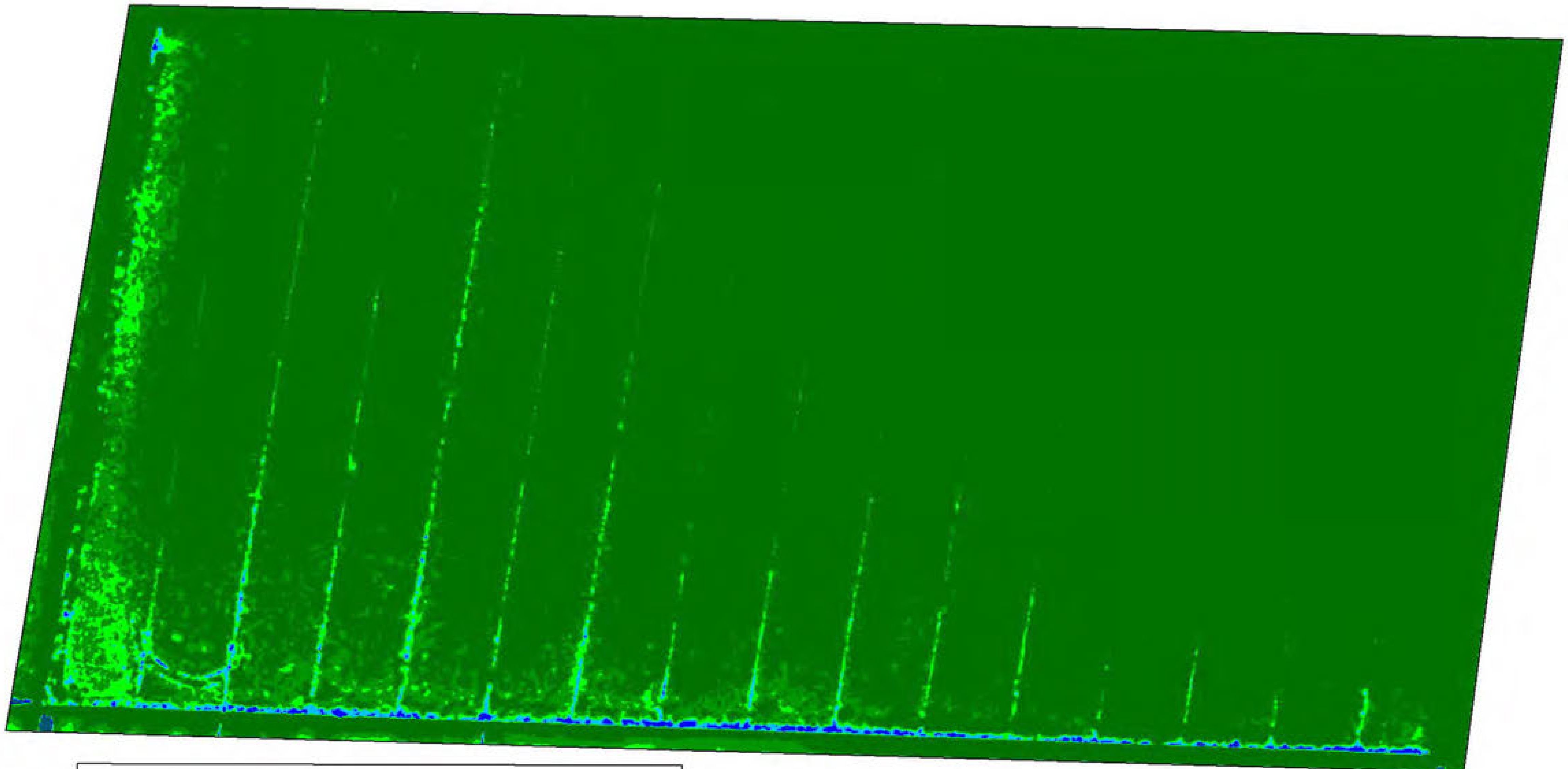
Approved ______ Date ____
Title ______ Job Class

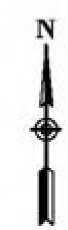


Legend		
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	1%
	0.5–1 feet above water level	2%
	0–0.5 feet above water level	2%
	0–0.5 feet below water level	47%
	0.5–1 feet below water level	47%
	1+ feet below water level	1%

<u>Water Level Overlay at Elevation: 14.7 ft</u>
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows blocks B4–B7.

Sheet 1 of 1	Drawing: block_b7.dwg	File No.	REVISIONS			Kris Bass Engineering Raleigh, NC Kris Bass 919.960.1552 (c) kbass@kbeng.org	Pocosin Lakes Control Structure B7	Designed	klb,kdg
			Date	Description	Approved			Drawn	kb,kg
								Checked	kb
							Pocosin Lakes Wildlife Refuge	Approved ______	Date ____
								Title ______	Job Class JC





Legend		
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	58%
	0.5–1 feet above water level	20%
	0–0.5 feet above water level	20%
	0–0.5 feet below water level	1%
	0.5–1 feet below water level	1%
	1+ feet below water level	0%

Water Level Overlay at Elevation: 9.8 ft
Current Conditions Map: Represents the average measured water level in the hydrologic management unit (HMU). This map shows block B12.

Designed	klb,kdg
Drawn	kb,kg
Checked	kb
Approved	
Date	
Title	
Job Class	JC

Pocosin Lakes Control Structure B12

Pocosin Lakes Wildlife Refuge

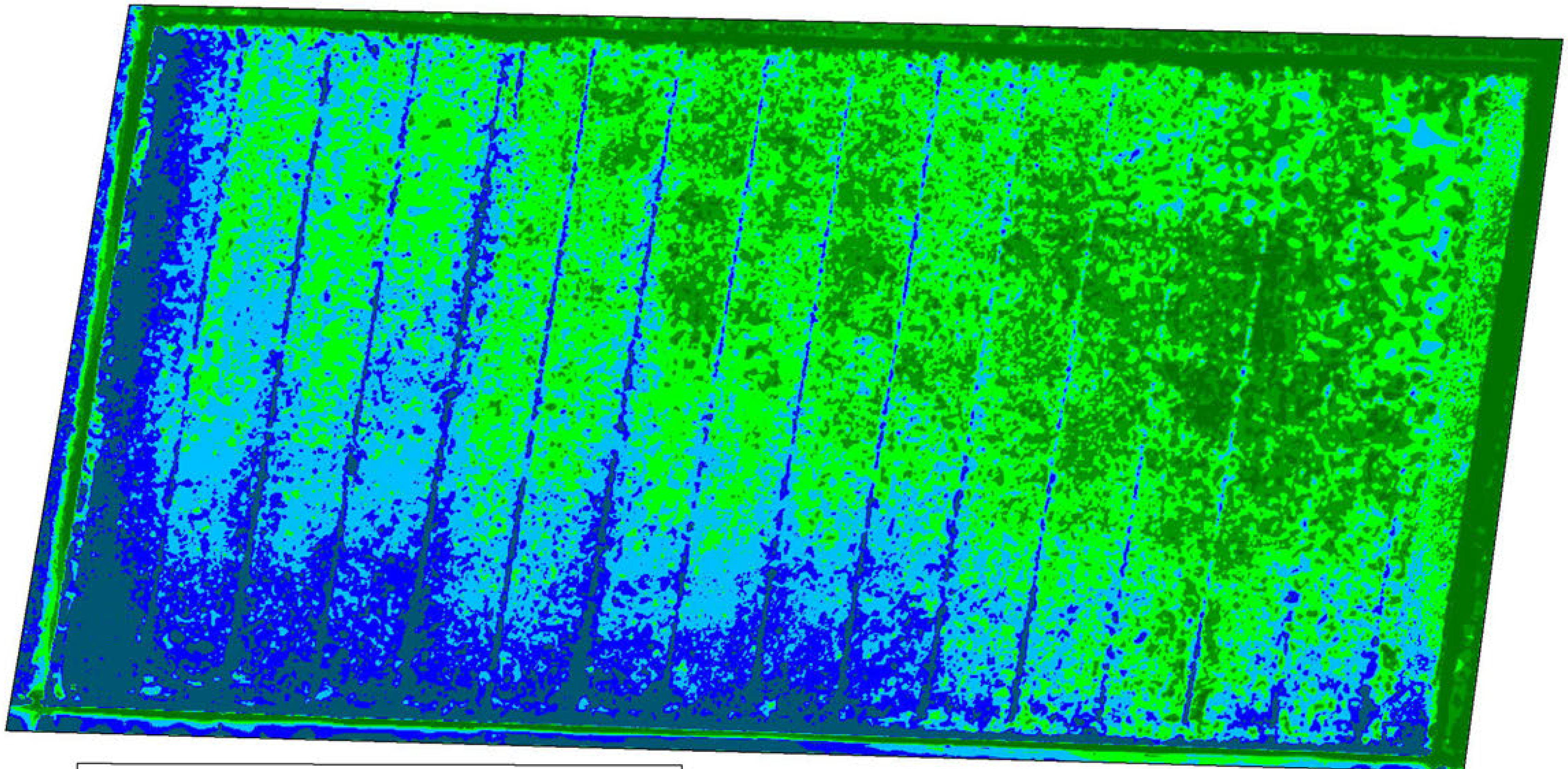
Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

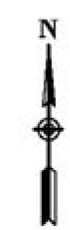
REVISIONS		
Date	Description	Approved

File No.

Drawing: block_d11

Sheet 1 of 1





Legend

Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	5%
	0.5–1 feet above water level	18%
	0–0.5 feet above water level	18%
	0–0.5 feet below water level	23%
	0.5–1 feet below water level	22%
	1+ feet below water level	14%

<u>Water Level Overlay at Elevation: 11.8 ft</u>
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows block B12.

Designed kb,kdg
Drawn kb,kg
Checked kb

Pocosin Lakes Control Structure B12

Approved ______ Date ______
Title ______ Job Class JC

Pocosin Lakes Wildlife Refuge

Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

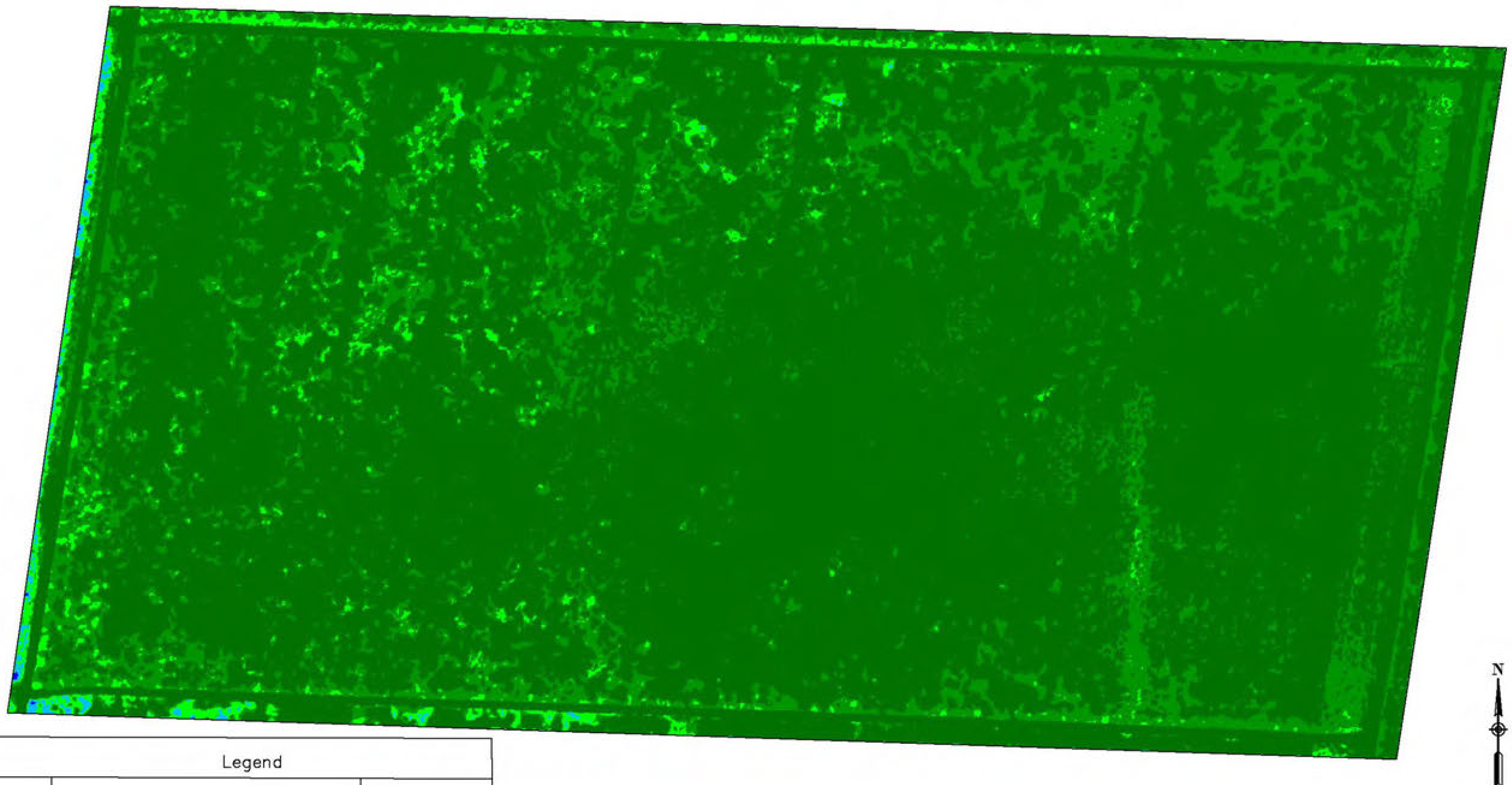
REVISIONS

Date	Description	Approved

File No.

Drawing: block_d11

Sheet 1 of 1



Legend

Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	40%
	0.5–1 feet above water level	30%
	0–0.5 feet above water level	30%
	0–0.5 feet below water level	0%
	0.5–1 feet below water level	0%
	1+ feet below water level	0%

Water Level Overlay at Elevation: 13.8 ft
Current Conditions Map: Represents the average measured water level in the hydrologic management unit (HMU). This map shows block C7.

Designed	klb,kdg
Drawn	kb,kg
Checked	kb

Approved ______ Date ______
Title ______ Job Class JC

Pocosin Lakes Control Structure C7

Pocosin Lakes Wildlife Refuge

Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

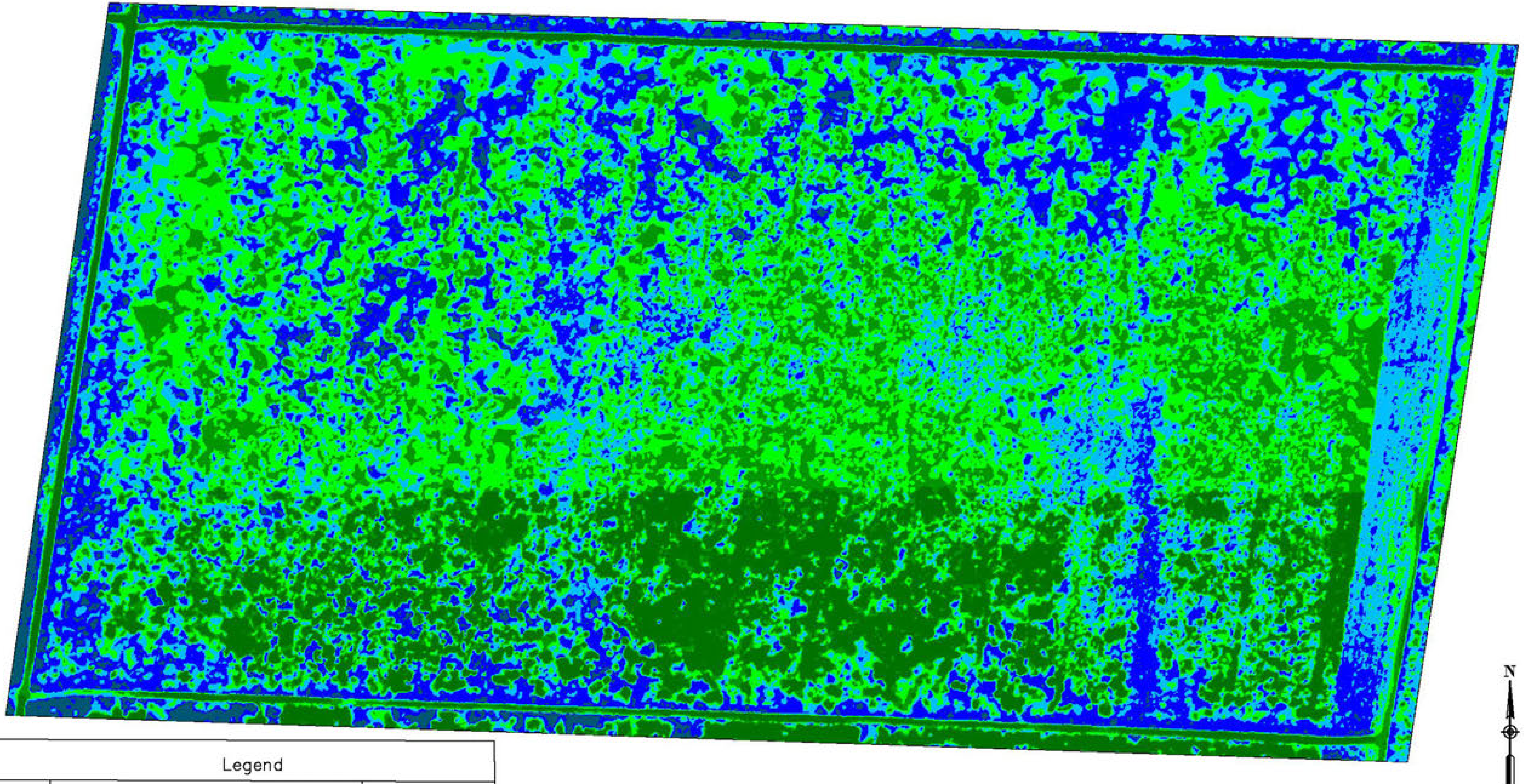
REVISIONS

Date	Description	Approved

File No.

Drawing: block_d11

Sheet 1 of 1



Legend

Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	20%
	0.5–1 feet above water level	6%
	0–0.5 feet above water level	20%
	0–0.5 feet below water level	20%
	0.5–1 feet below water level	17%
	1+ feet below water level	17%

Water Level Overlay at Elevation: 15.3 ft
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows block C7.

Designed klb,kdg
Drawn kb,kg
Checked kb
Approved
Date
Title
Job Class JC

Pocosin Lakes Control Structure C7

Pocosin Lakes Wildlife Refuge

Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

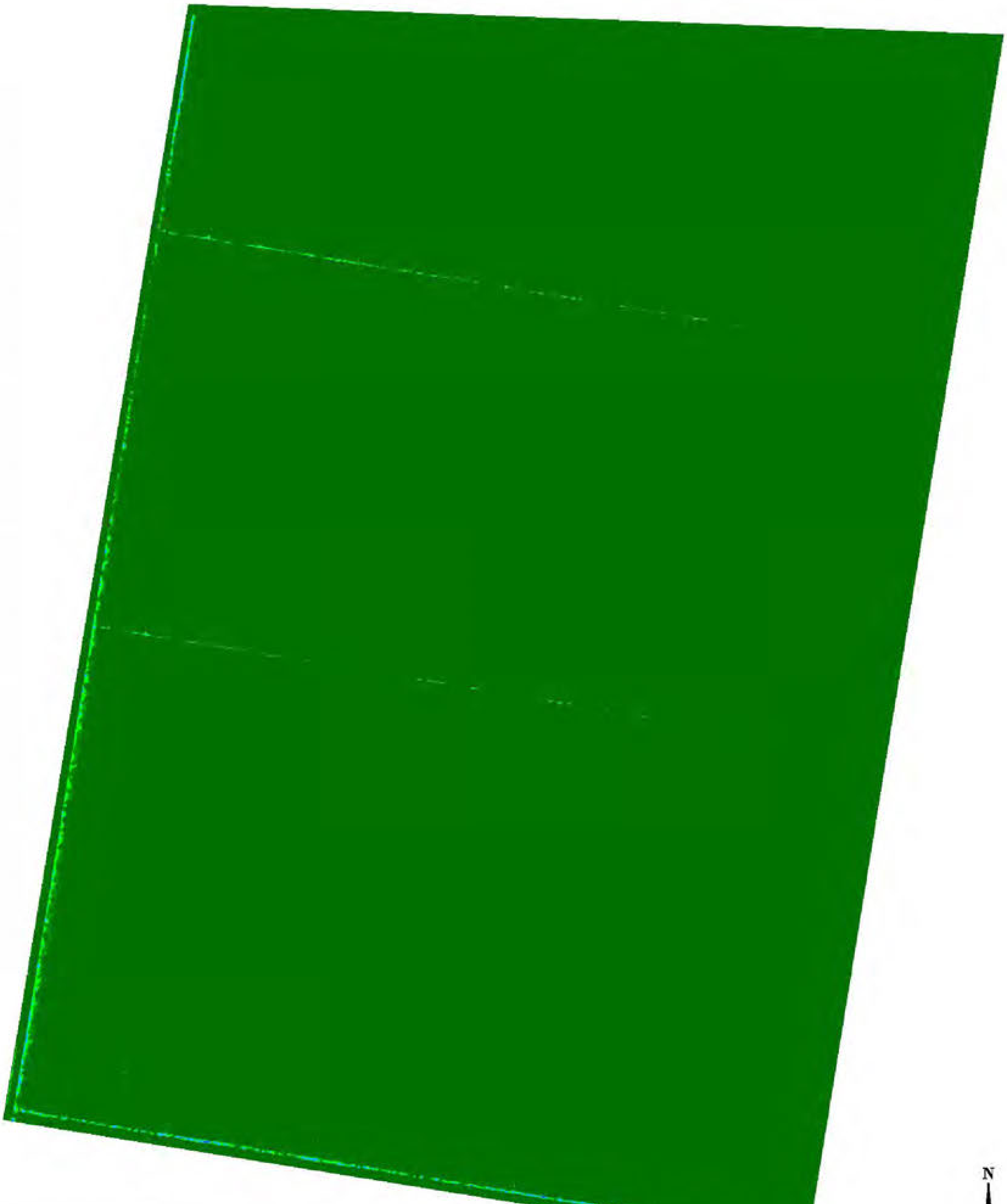
REVISIONS

Date	Description	Approved

File No.

Drawing: block_d11

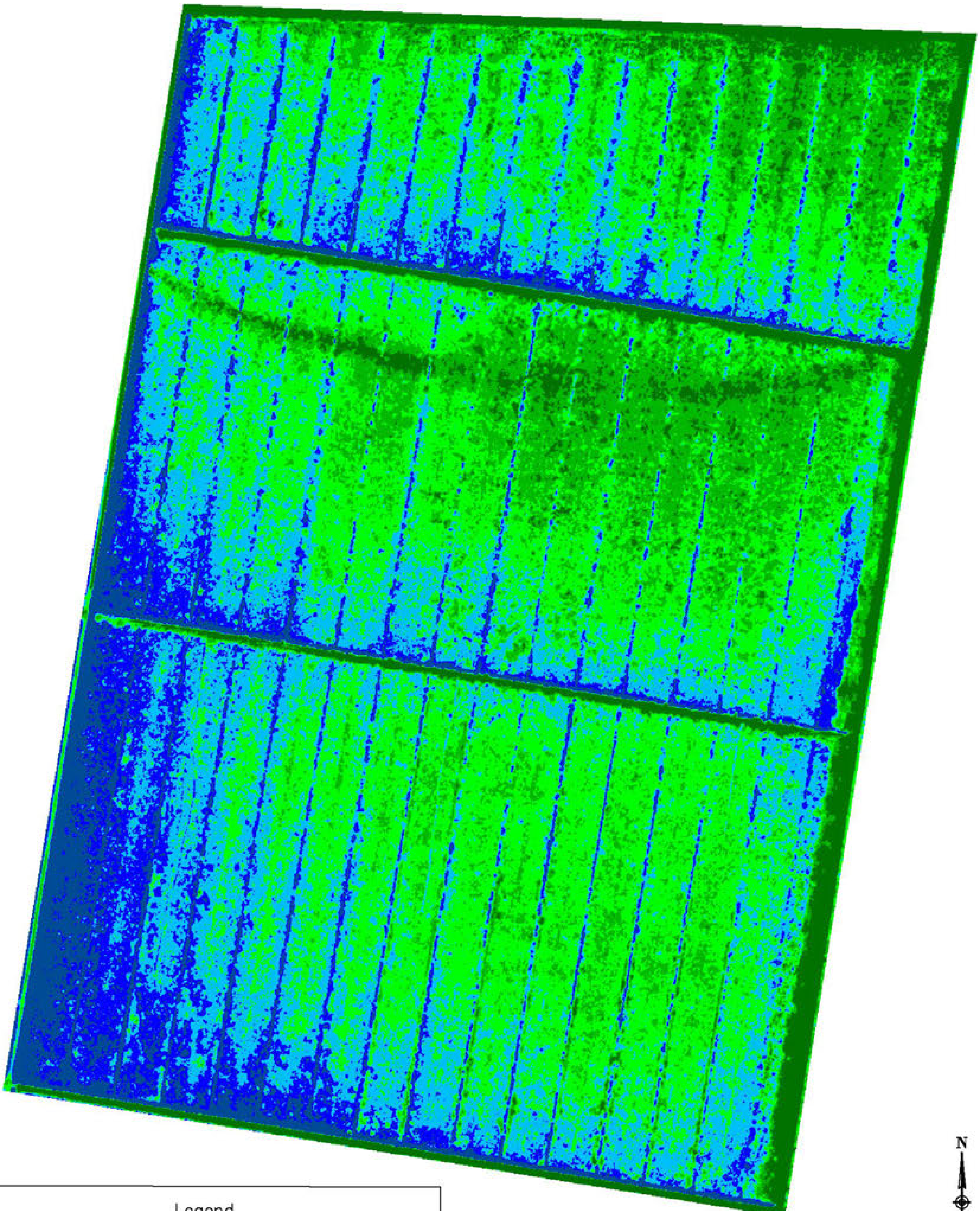
Sheet 1 of 1



Legend		
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	98%
	0.5–1 feet above water level	1%
	0–0.5 feet above water level	1%
	0–0.5 feet below water level	0%
	0.5–1 feet below water level	0%
	1+ feet below water level	0%

Water Level Overlay at Elevation: 7.3 ft
Current Conditions Map: Represents the average measured water level in the hydrologic management unit (HMU). This map shows blocks C12–C14.

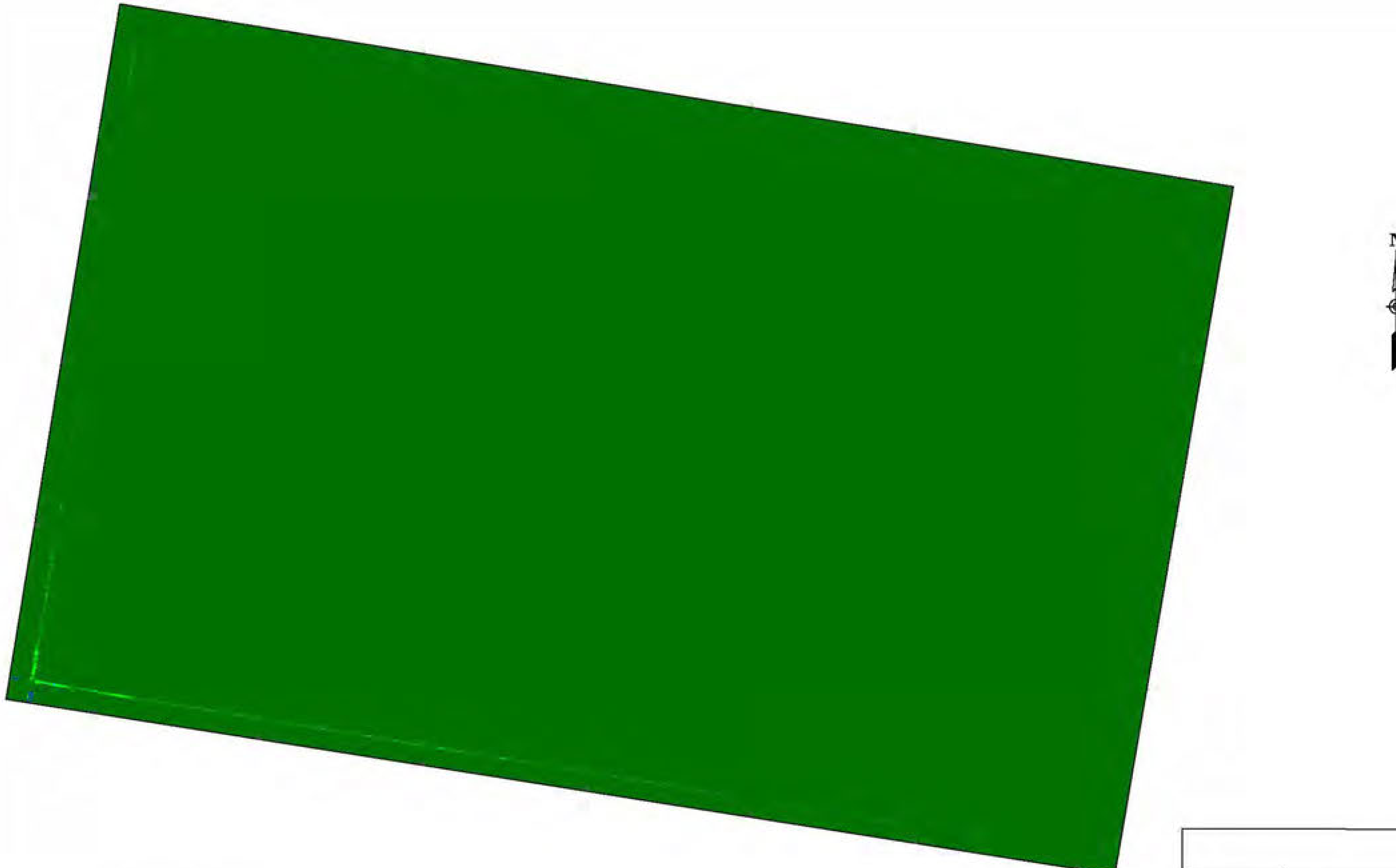
Sheet 1 of 1	Drawing: block_c14	File No.	REVISIONS			Kris Bass Engineering Raleigh, NC Kris Bass 919.960.1552 (c) kbass@kbeng.org	Pocosin Lakes Control Structure C14	Designed	klb,kdg
			Date	Description	Approved			Drawn	kb,kg
								Checked	kb
							Pocosin Lakes Wildlife Refuge	Approved ______ Date ____	
								Title ______ Job Class JC	



Legend		
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	7%
	0.5–1 feet above water level	21%
	0–0.5 feet above water level	22%
	0–0.5 feet below water level	20%
	0.5–1 feet below water level	20%
	1+ feet below water level	10%

Water Level Overlay at Elevation: 10.8 ft
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows blocks C12–C14.

Sheet 1 of 1	Drawing: block_c14	File No.	REVISIONS			Kris Bass Engineering Raleigh, NC Kris Bass 919.960.1552 (c) kbass@kbeng.org	Pocosin Lakes Control Structure C14	Designed: kib,kdg Drawn: kb,kg Checked: kb
			Date	Description	Approved		Pocosin Lakes Wildlife Refuge	Approved ______ Date ____ Title ______ Job Class JC



Water Level Overlay at Elevation: 5.8 ft
Current Conditions Map: Represents the average measured water level in the hydrologic management unit (HMU). This map shows block C15.

Legend

Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	98%
	0.5–1 feet above water level	1%
	0–0.5 feet above water level	1%
	0–0.5 feet below water level	0%
	0.5–1 feet below water level	0%
	1+ feet below water level	0%

Designed klb,kdg
Drawn kb,kg
Checked kb

Approved
Title
Date
Job Class JC

Pocosin Lakes Control Structure C15

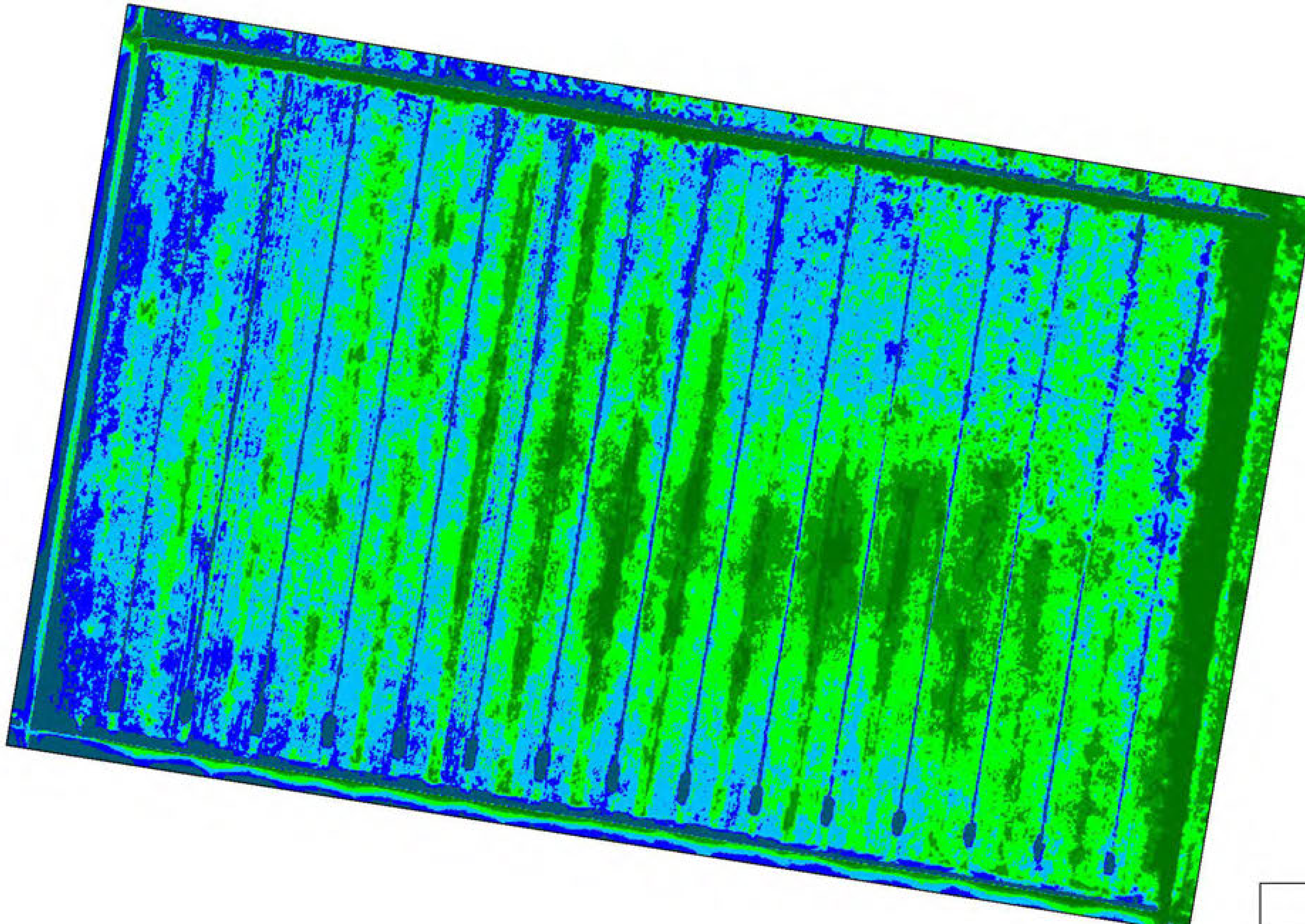
Pocosin Lakes Wildlife Refuge

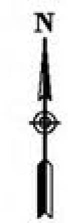
Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

REVISIONS
Date | Description | Approved

File No.

Drawing:
block_d11
Sheet 1 of 1





<u>Water Level Overlay at Elevation: 10.3 ft</u>
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows block C15.

Legend

Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	7%
	0.5–1 feet above water level	4%
	0–0.5 feet above water level	34%
	0–0.5 feet below water level	33%
	0.5–1 feet below water level	7%
	1+ feet below water level	15%

Designed klb,kdg
Drawn klb,kg
Checked klb

Approved ——— Date ———
Title ——— Job Class JC

Pocosin Lakes Control Structure C15

Pocosin Lakes Wildlife Refuge

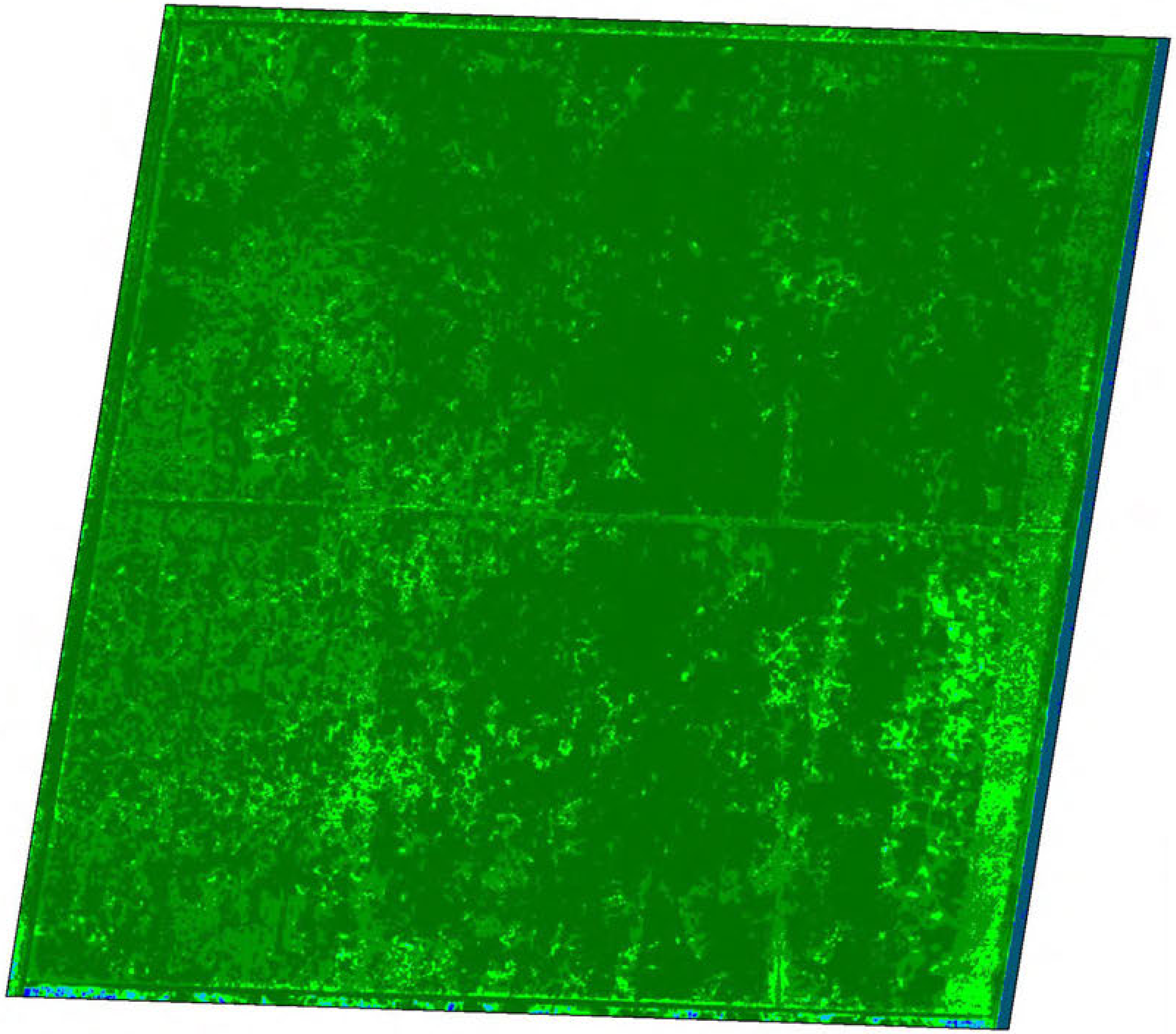
Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

REVISIONS
Date | Description | Approved

File No.

Drawing:
block_d11

Sheet 1 of 1



N

Legend		
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	49%
	0.5–1 feet above water level	24%
	0–0.5 feet above water level	24%
	0–0.5 feet below water level	0%
	0.5–1 feet below water level	0%
	1+ feet below water level	3%

Water Level Overlay at Elevation: 14.1 ft
Current Conditions Map: Represents the average managed water level in the hydrologic management unit (HMU). This map shows blocks D7–D8.

Designed kib,kdg
Drawn kb,kg
Checked kb
Approved ______ Date ______
Title ______ Job Class JC

Pocosin Lakes Control Structure D8

Pocosin Lakes Wildlife Refuge

Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

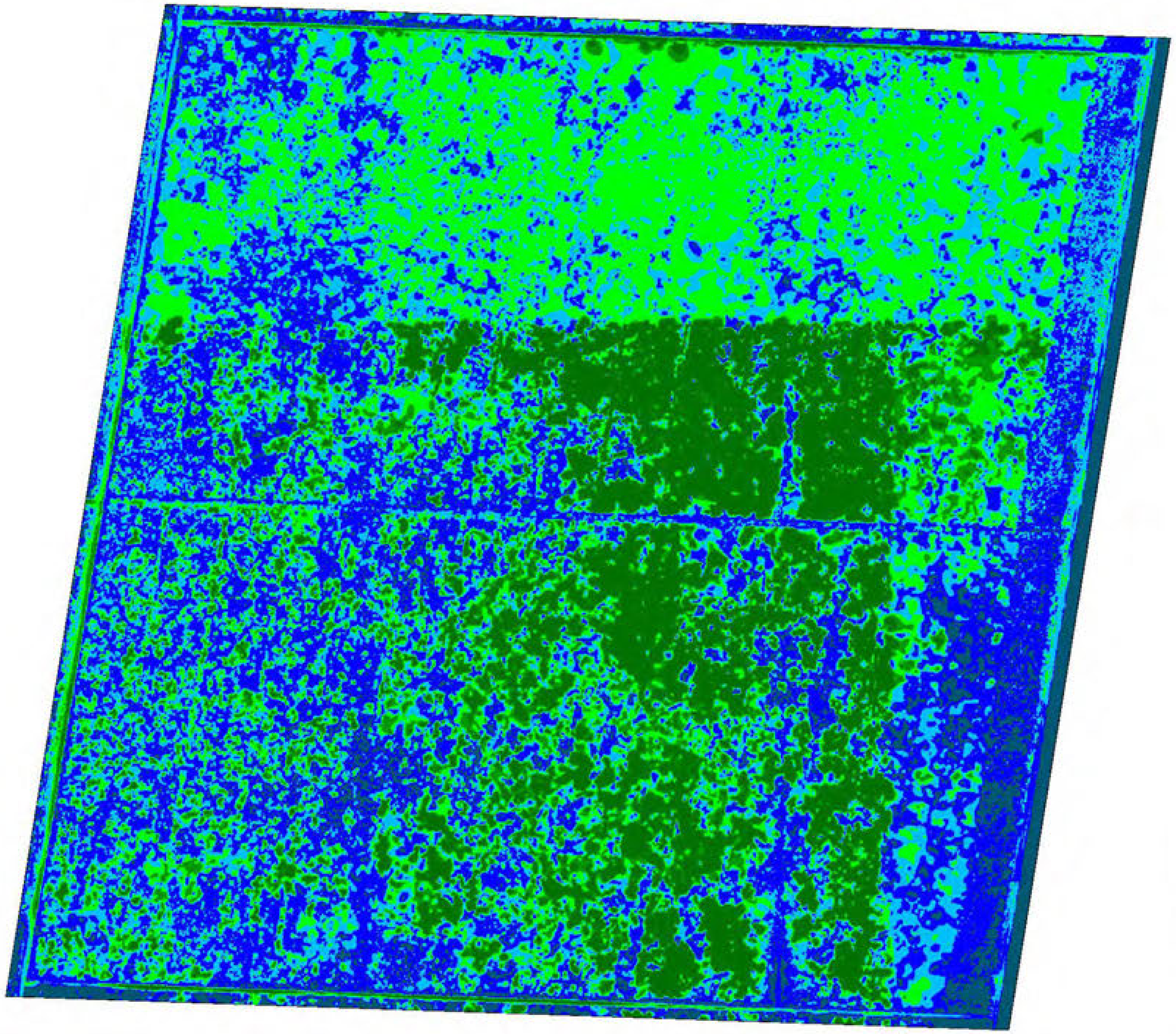
REVISIONS

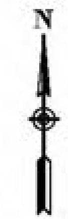
Date	Description	Approved

File No.

Drawing: block_d11

Sheet 1 of 1





Water Level Overlay at Elevation: 15.6 ft
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows blocks D7–D8.

Legend

Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	28%
	0.5–1 feet above water level	8%
	0–0.5 feet above water level	18%
	0–0.5 feet below water level	18%
	0.5–1 feet below water level	13%
	1+ feet below water level	15%

Designed klb,kdg
Drawn kb,kg
Checked kb
Approved
Title
Date
Job Class JC

Pocosin Lakes Control Structure D8

Pocosin Lakes Wildlife Refuge

Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

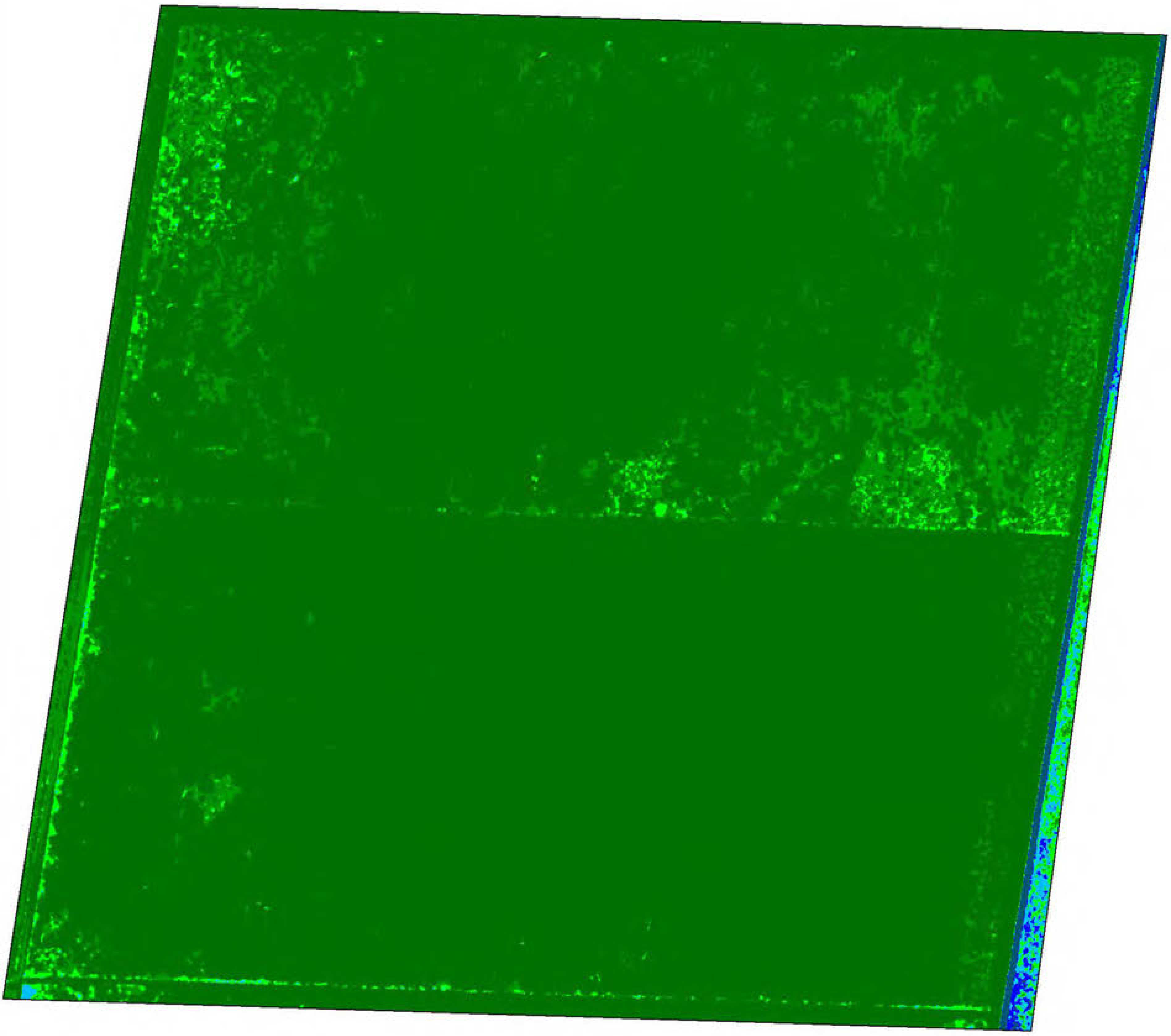
REVISIONS

Date	Description	Approved

File No.

Drawing: block_d11

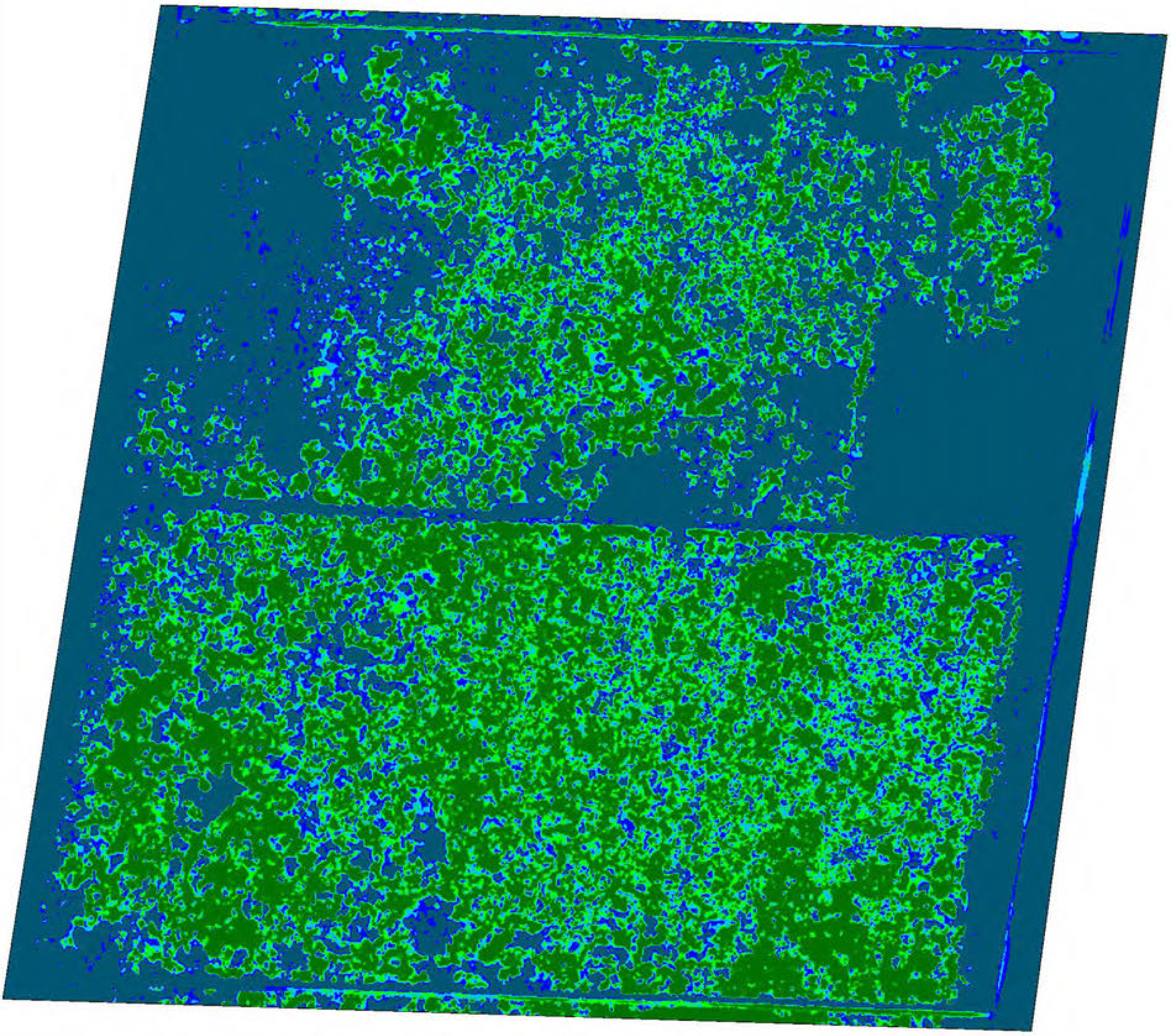
Sheet 1 of 1



Legend		
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	80%
	0.5–1 feet above water level	9%
	0–0.5 feet above water level	9%
	0–0.5 feet below water level	1%
	0.5–1 feet below water level	1%
	1+ feet below water level	0%

Water Level Overlay at Elevation: 12.8 ft
Current Conditions Map: Represents the average managed water level in the hydrologic management unit (HMU). This map shows blocks D9–D10.

Sheet 1 of 1	Drawing: block_d11	File No.	REVISIONS: Date / Description / Approved	Kris Bass Engineering Raleigh, NC Kris Bass 919.960.1552 (c) kbass@kbeng.org	Pocosin Lakes Control Structure D10 Pocosin Lakes Wildlife Refuge	Designed klb,kdg Drawn kb,kg Checked kb Approved ____ Date ____ Title ____ Job Class JC



Legend		
Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	30%
	0.5–1 feet above water level	8%
	0–0.5 feet above water level	8%
	0–0.5 feet below water level	8%
	0.5–1 feet below water level	8%
	1+ feet below water level	38%

N

<u>Water Level Overlay at Elevation: 16.3 ft</u>
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows blocks D9–D10.

Sheet 1 of 1
Drawing: block_d11
File No.

REVISIONS		
Date	Description	Approved

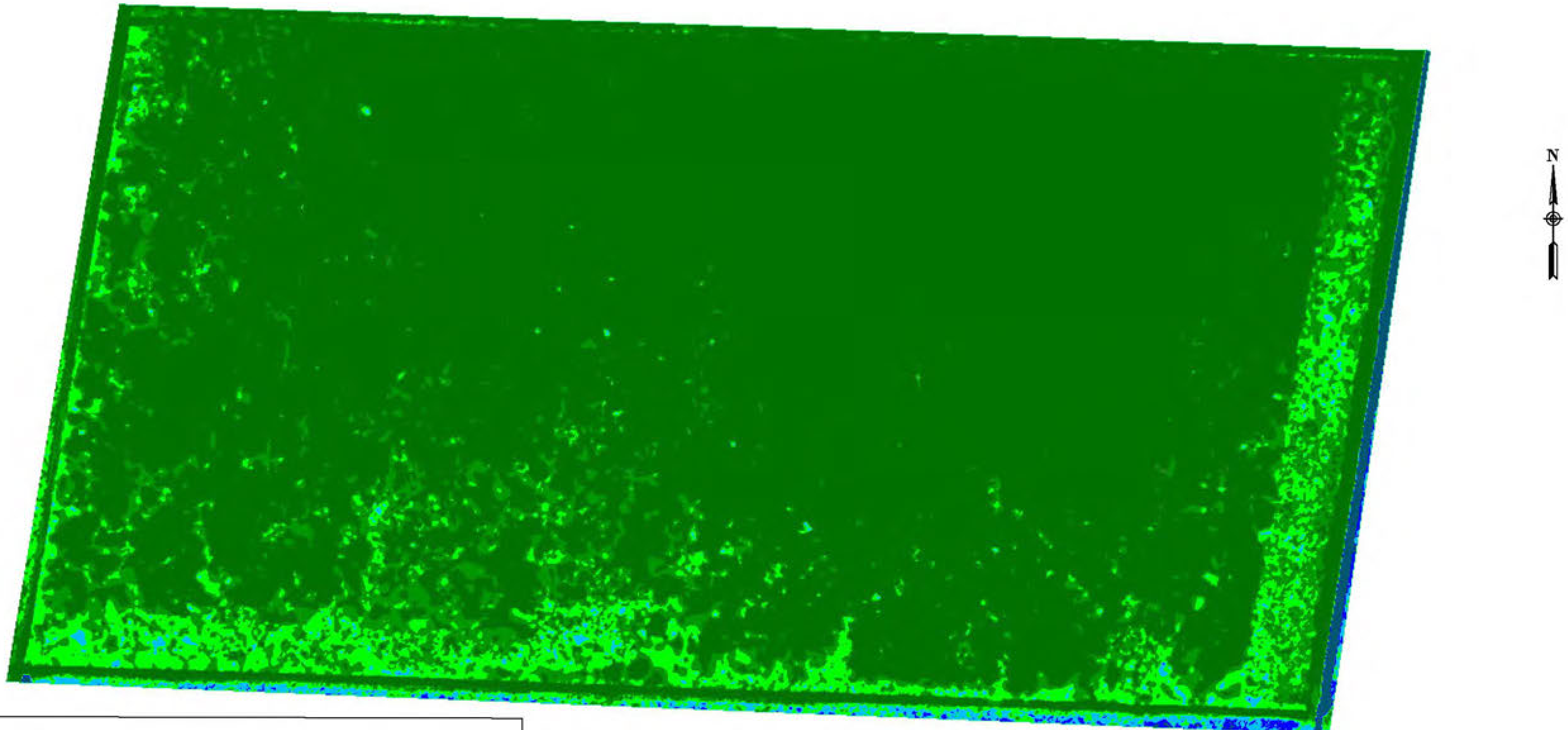
Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

Pocosin Lakes Control Structure D10

Pocosin Lakes Wildlife Refuge

Designed	klb,kdg
Drawn	kb,kg
Checked	kb

Approved ______ Date ______
Title ______ Job Class JC



Legend

Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	78%
	0.5–1 feet above water level	9%
	0–0.5 feet above water level	10%
	0–0.5 feet below water level	1%
	0.5–1 feet below water level	1%
	1+ feet below water level	1%

<u>Water Level Overlay at Elevation: 12.3 ft</u>
Current Conditions Map: Represents the average managed water level in the hydrologic management unit (HMU). This map shows block D11.

Designed	kb,kdg
Drawn	kb,kg
Checked	kb

Approved ______ Date ______
Title ______ Job Class JC

Pocosin Lakes Control Structure D11

Pocosin Lakes Wildlife Refuge

Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

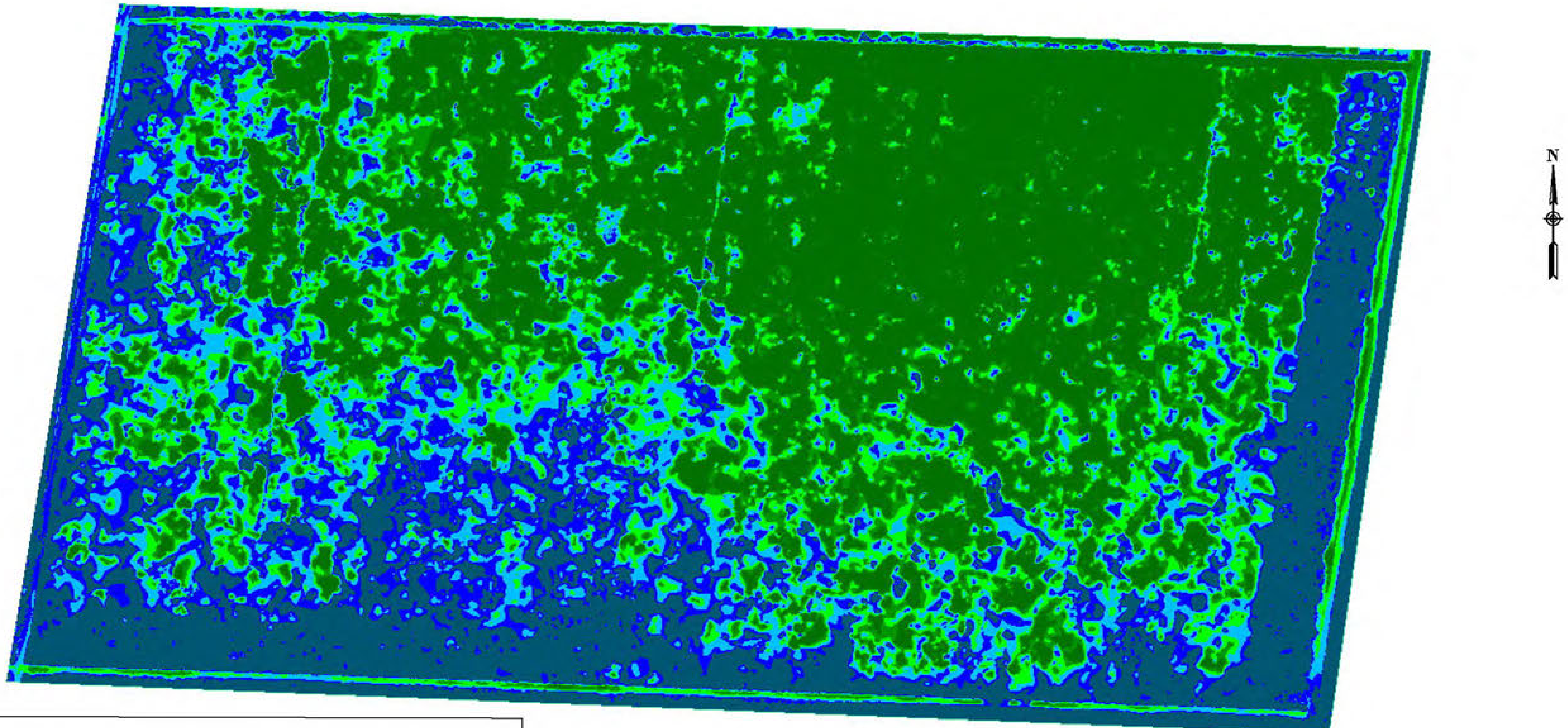
REVISIONS

Date	Description	Approved

File No.

Drawing: block_d11

Sheet 1 of 1



Legend

Color	Zone Depths	Percentage of Land in Zone
	1+ feet above water level	38%
	0.5–1 feet above water level	6%
	0–0.5 feet above water level	7%
	0–0.5 feet below water level	7%
	0.5–1 feet below water level	8%
	1+ feet below water level	34%

Water Level Overlay at Elevation: 14.3 ft
50% Map: Represents conditions needed to achieve a water level at ground surface for approximately 50% of the hydrologic management unit (HMU). This map shows block D11.

Designed	klb,kdg
Drawn	kb,kg
Checked	kb

Approved ______ Date ______
Title ______ Job Class JC

Pocosin Lakes Control Structure D11

Pocosin Lakes Wildlife Refuge

Kris Bass Engineering
Raleigh, NC
Kris Bass
919.960.1552 (c)
kbass@kbeng.org

REVISIONS

Date	Description	Approved

File No.

Drawing: block_d11

Sheet 1 of 1