2009

Hydrologic Design of a Wetland Impoundment: Kingsbury County, SD.

Seth W. Trobec

WETLAND IMPOUNDMENT DESIGN PROPOSAL: Kingsbury County, SD.

Prepared by:

Seth W. Trobec

A Geological Engineering Design Proposal

Geology and Geological Engineering Department
University of North Dakota

July 2009

EXECUTIVE SUMMARY

An embankment is proposed to create a wetland, as classified by the Army Corps of Engineers (1987), in southeastern South Dakota as part of a geological engineering senior design project. The wetland will lie within the Prairie Pothole Region of the Upper Midwest. It is within this region that the presence of wetlands has been declining over recent decades. The wetland will provide habitat supportive of waterfowl which make bi-annual flights over the area during migration. The embankment will incorporate a sharp-crested weir capable of passing a 25-yr, 24-hr rainfall event. Stop logs will be incorporated into the weir to allow periodic drainage of the wetland. This will promote plant growth within the wetland, making the wetland more attractive to waterfowl. The purpose of this report is to provide a design proposal for an environmentally sound and economically feasible embankment and associated wetland.

The report includes information on the following features pertinent to the proposed site: soils present, climate, topography, and presence of farmsteads. Also included are embankment design criteria as defined by Ducks Unlimited, Inc. (R. Smith, Personal Communication 2009). This document will propose design methodologies associated with the proposed embankment, in order to analyze and optimize wetland dimensions and sustainability.

Lastly, an economic evaluation of various design options will be completed to attain a preferred design.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I would like to thank Scott Korom for his assistance throughout this project and throughout my academic career at the University of North Dakota. I would also like to thank Lance Yarbrough. Lance provided me with ArcGIS data that was very useful and will prove to be crucial in the next stages of this project. Finally, I would like to acknowledge the efforts of Roger Smith and others at the Ducks Unlimited Great Plains Regional Office. It is their involvement in projects such as this one which inspired me to take on a similar challenge for this project.

INTRODUCTION

An embankment is proposed to create a wetland, as classified by the Army Corps of Engineers (1987), in southeastern South Dakota as part of a geological engineering senior design project. Ducks Unlimited, Inc. has requested the hydrologic design of an embankment that, once constructed, will conform to design specifications used by Ducks Unlimited, Inc. Figure 1 illustrates the location of the project, in Kingsbury County, approximately 4.5 miles west of the town of Badger. The watershed associated with the wetland will be approximately 3550 acres. Preliminary design analysis will assess embankments of 655 and 695 foot lengths as well as 7 and 8 foot heights. The embankment will incorporate a sharp-crested weir capable of passing a 25-yr, 24-hr rainfall event, while allowing one foot of freeboard to the top of the embankment.

PROBLEM DEFINITION AND OBJECTIVE

The long-term decline of wetlands in the prairie pothole region has become a growing concern for wildlife enthusiasts and hunters alike. Without the continued intervention of organizations such as Ducks Unlimited, Inc., a continued decline in wetland numbers could have negative impacts on the waterfowl population in the region. The purpose of this report is to provide a design proposal for an environmentally sound and economically viable embankment that will create a wetland and will not threaten the environment or structures, such as roads and farmsteads. The wetland will create duck habitat, offer storage for floodwaters, and act as a storage area for sediments transported via waterways. Creation of the wetland will be achieved through the construction of a hydraulic control structure downstream of the proposed wetland site. The design proposal will address site characteristics such as soils, topography, climate,

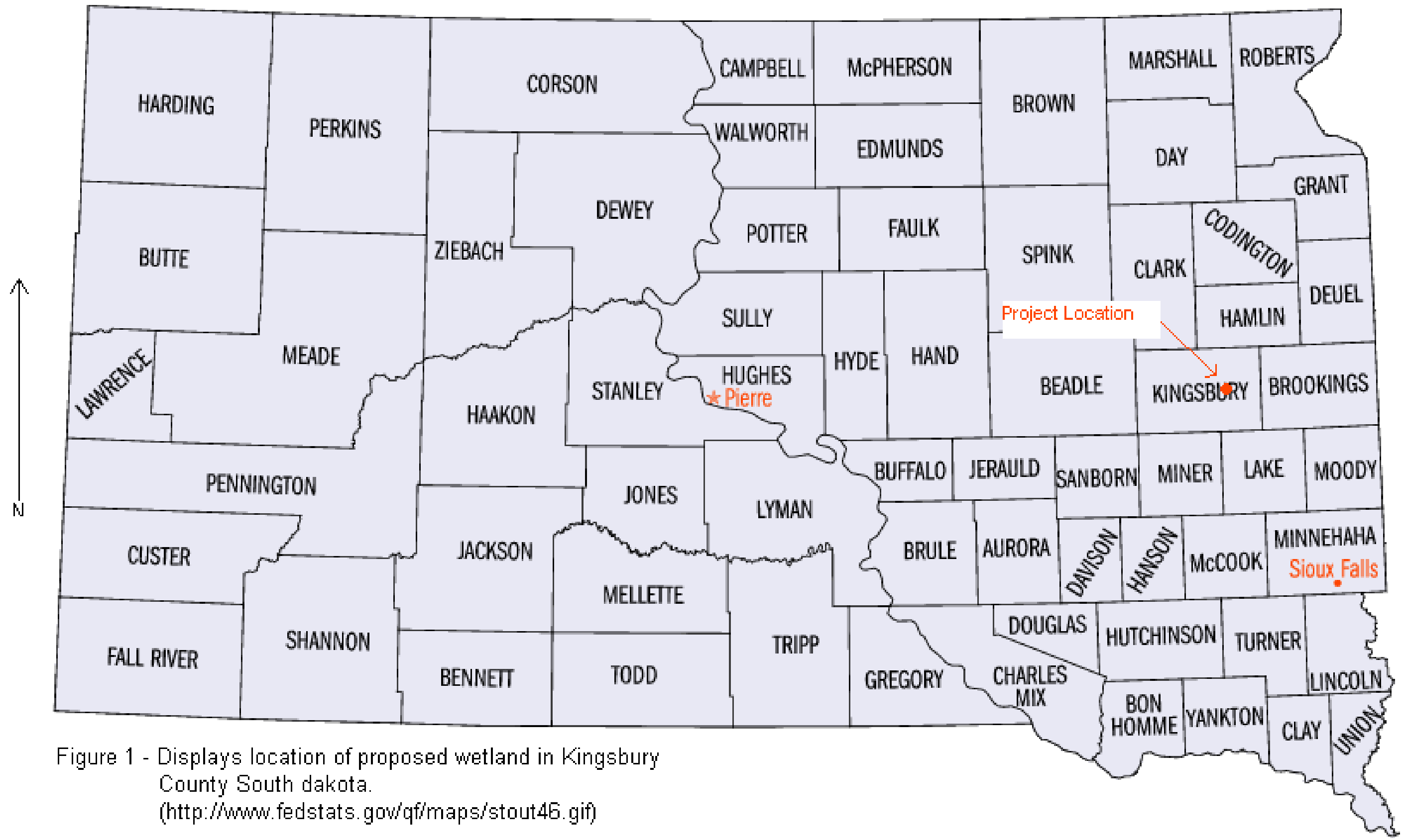

Figure 1 - Displays location of proposed wetland in Kingsbury County South dakota. (http://www.fedstats.gov/qf/maps/stout46.gif)

proximity to households, and potential for an environment beneficial to waterfowl.

BACKGROUND INFORMATION

Prairie Pothole Region

The location of the proposed wetland lies within the Prairie Pothole Region. The Prairie Pothole Region (Figure 2) was shaped by glaciers as they retreated northward approximately 12,000 years ago (USGS 2006). The terrain that was left behind consisted of millions of shallow depressions full of plant and animal life (Ducks Unlimited, Inc. 2009). In recent decades the abundance of wetlands in the Prairie Pothole Region has declined significantly. This decline has been attributed to the drainage of wetlands to create farmlands (Dahl and Johnson 1991). The prairie pothole region has been known for its importance in the life cycle of migrating waterfowl. Not only does the region offer nesting opportunities in its expanse of grasslands, the shallow wetlands also provide food for nesting and resting ducks as they make their bi-annual migration over the area. In response to the reduced number of wetlands, the North American Wetlands Conservation Act was initiated in 1989. This act provided matching grants to organizations and individuals who have developed partnerships to carry out wetlands conservation projects in the United States, Canada, and Mexico for the benefit of wetlands-associated migratory birds and

Figure 2 - Prairie Pothole Region in red. (Ducks Unlimited – www.ducks.org)

other wildlife (U.S. Fish and Wildlife Service 2009). As a result, organizations such as Ducks Unlimited, Inc. have become forerunners in the reclamation of wetlands in the Upper Midwest and have created design specifications for embankments which control wetland dimensions.

Characteristics of a Wetland

The three fundamental diagnostic characteristics that interact to form a wetland are hydrology, plant-life, and soils present. In order for an area to be considered a wetland, the following four criteria must be met (Army Corps of Engineers 1987):

- The ground surface must be inundated with water for at least 5 percent of the growing season each year
- Mean water depths are < 6.6 feet
- Soils which underlie the wetland must be anaerobic
- Prevalent vegetation must be hydrophilic, capable of persisting in anaerobic soil conditions.

Hydrology is the driving force which regulates the soil conditions and plant-life that are present. Once an area is inundated with water the soils are less exposed to oxygen in the atmosphere and over time become anaerobic; this in-turn leads to the presence of hydrophilic plants, as others can not persist in such an environment. Soil groups C and D, as classified by the Natural Resources Conservation Service (NRCS) (Web Soil Survey 2009), are preferential within the watershed associated with a wetland. These soils have low permeability, allowing for extended periods of inundation (Table 1). A desirable topography is one that has a gradual slope which provides shallow areas near shorelines suitable for dabbling ducks to feed.

Table 1 - Displays soil group classifications, definitions, and examples of each group as classified by NRCS (http://websoilsurvey.nrcs.usda.gov).

Soil Type	**NRCS Description**	**Soil Type**
A	Soils having a high infiltration rate (low runoff potential) when thoroughly wet. High rate of water transmission.	Deep, well-drained sands or gravelly sands
B	Soils having a moderate infiltration rate when thoroughly wet. Moderate rate of water transmission.	moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture
C	Soils having a slow infiltration rate when thoroughly wet. Slow rate of water transmission.	Chiefly soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture
D	Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. Very low water transmission rate.	Chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a clay layer at or near the surface, and soils that are shallow over nearly impervious material.
Dual (A/D, B/D, C/D)	First letter represents drained areas, and second represents un-drained conditions.	Only the soils that in their natural condition are in group D are assigned to dual classes

Also, it would not be appropriate to create a wetland in the bottom of a valley where surface water levels could change tens of feet very quickly during an intense rainstorm (Maryland Cooperative Ext. not dated). A desirable watershed is one that spans no more than 4 to 5 sections, for simplicity, but is of such areal extent that significant overland flow will occur.

Waterfowl and Wetlands

Many waterfowl rely on an abundance of wetlands and their associated grasslands during the most crucial phases of the waterfowl life cycle (Ducks Unlimited, Inc. 2009). Figure 3 displays the life cycle of a mallard. During the pre-nesting phase the female duck searches for suitable nesting grounds. The creation of wetlands promotes new places of nesting. Also, presence of predator-free islands within a wetland have been found to increase nest densities and nest success (Hammond and Mann 1956, Newton and Campbell 1975, Duebbert et al. 1983). Therefore, areas consisting of topography suitable for the creation of islands were preferential while searching for a project location. Brood rearing and post breeding are the two most critical phases in the waterfowl life cycle. Once a hen has given birth to ducklings, food must be available in order for the newborns to live. The hens themselves must also have a source of energy to fuel the activities involved in caring for their young. Nesting near a wetland, or on an island in the wetland, provides easily attainable food sources such as plant life and macro-organisms that provide the hen and her young with essential proteins (Ducks Unlimited, Inc. 2009). Furthermore, stop logs in hydraulic control structures have been used to promote plant growth

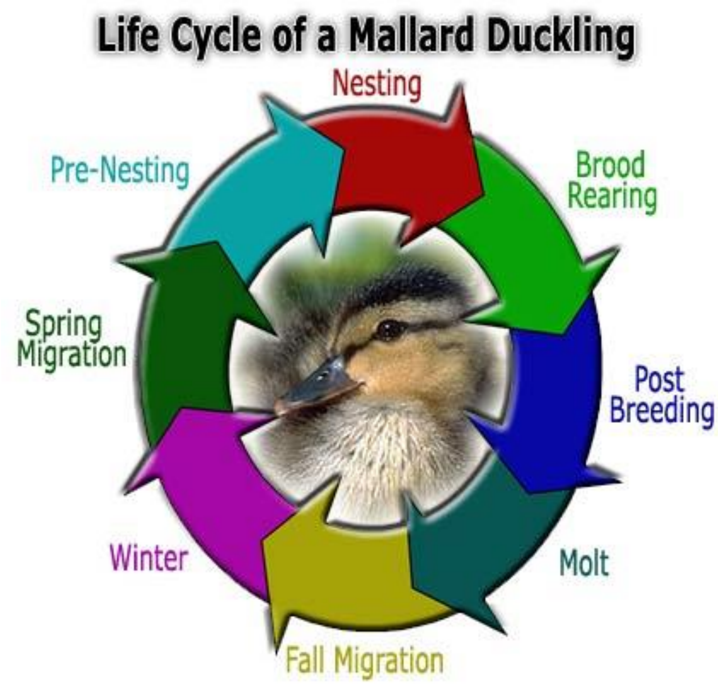

Figure 3 - Life cycle of mallard, also representative of other dabbling ducks. (Ducks Unlimited - www.ducks.org)

within a wetland. Basic impoundment management involves draining wetlands during the growing season. Plant growth on these exposed soils will greatly exceed the growth that would occur if water is maintained on the area throughout the year, thus providing a larger quantity of waterfowl food. Finally, wetland size influences the variety of waterfowl which inhabit the wetland. Larger wetlands, greater than 25 acres, have a higher probability of having varying water depths, vegetation types, vegetation densities, and interspersion of open water. As the diversity of these factors increase, so does the diversity of waterfowl (Maryland Cooperative Ext. not dated). Wetland dimensions will be governed by the location and size of the embankment, and will be taken into consideration during the design portion of this project.

DESIGN CONSTRAINTS

Soils

The watershed consists of approximately 71% B-type soils, 15% C-type soils, 14%D-type soils (Figure 4), as classified by NRCS (Web Soil Survey 2009). The aforementioned percentages were calculated using results attained from an NRCS Web Soil Survey (2009), assuming undrained soil conditions. Although the watershed consists primarily of group B soils, the area to be inundated has a higher ratio of group C: B soils than the majority of the watershed that should promote sustained inundation of the wetland. Some soils in the area of the proposed wetland could be excavated and used for embankment fill material. Extraction of soils could also contribute to the design of the wetland itself, creating shallow bays which promote isolation from other waterfowl, and possibly creating one or more islands that would provide ideal nesting habitat.

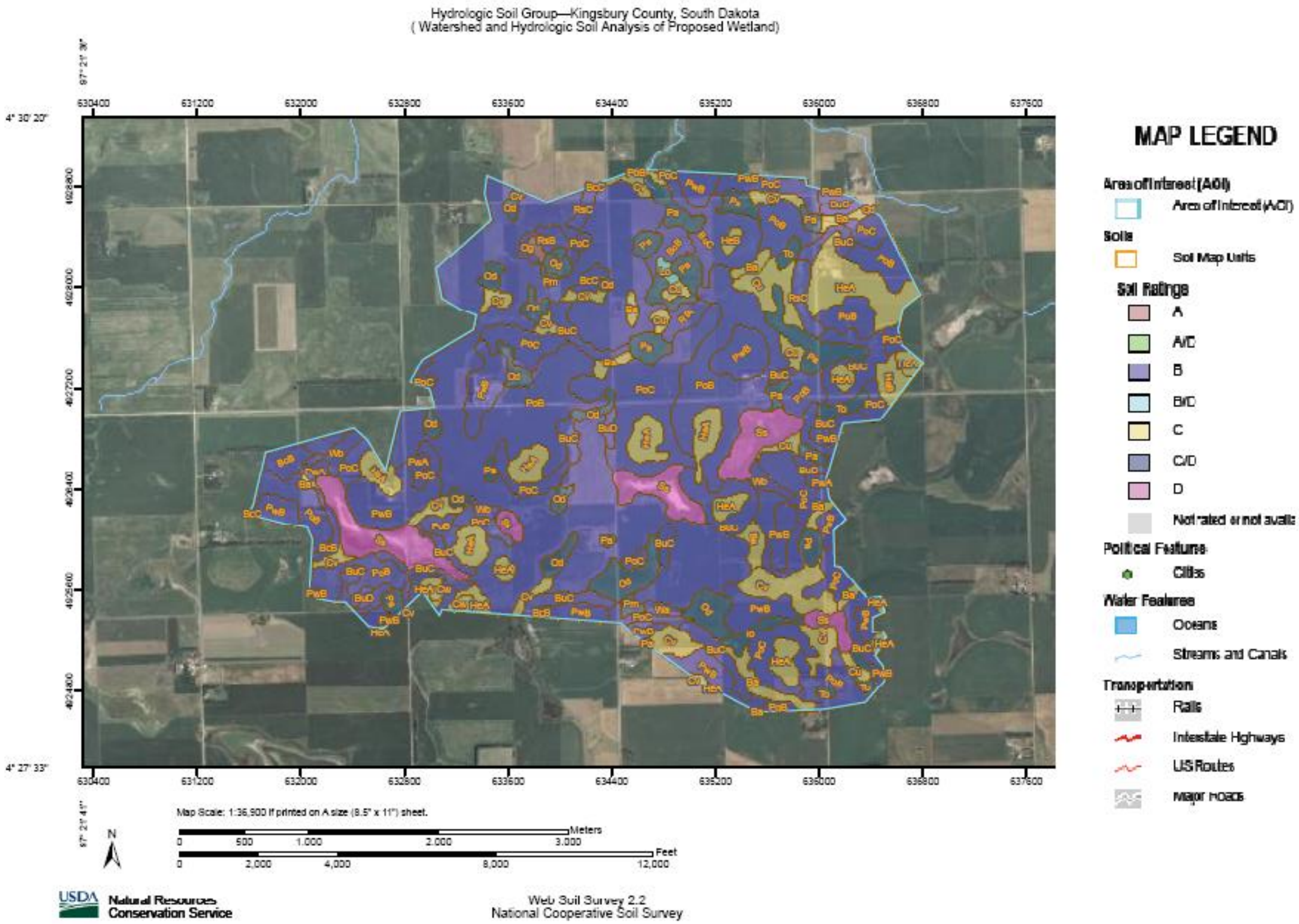

Figure 4 - Displays general watershed extent, along with soil groups present at project location (NRCS Web Soil Survey)

Topography

Figure 5 depicts the general topography, drainage basin, and extent of the proposed wetland at the site. The watershed associated with the wetland in this proposal was measured to be 3550 ac., approximately 5.5 $mi.^2$, and has a modest slope, that becomes more gradual at the proposed wetland site. Present along the eastern and southern edges of the proposed wetland are areas of much lower relief than the rest of the site. Also present in the watershed are depressions which form ponds during periods of greater-than-average precipitation.

Proximity to Homesteads

Several houses were located within the drainage area of the wetland; however, only one was in close proximity to the proposed wetland. A farmstead was located approximately 0.19 miles away from the western edge of the proposed wetland. Although this is close, the house was located about fourteen feet above the surface water level of the proposed wetland. Further reducing the risk of potential flood is an area of low relief to the southwest of the proposed wetland that would be capable of holding a large volume of storm runoff before any risk would be posed to the home.

Climate

The site in southeastern South Dakota has an interior continental climate, with hot summers, extremely cold winters, high winds, and periodic droughts. The average monthly low temperatures vary from 5.3°(F) in January to 60.7°(F) in July. Average monthly high temperatures vary from 23.5°(F) in January to 82.6°(F) in July. The yearly average precipitation is 23.68 inches. Most of the precipitation occurs between the months of April and September.

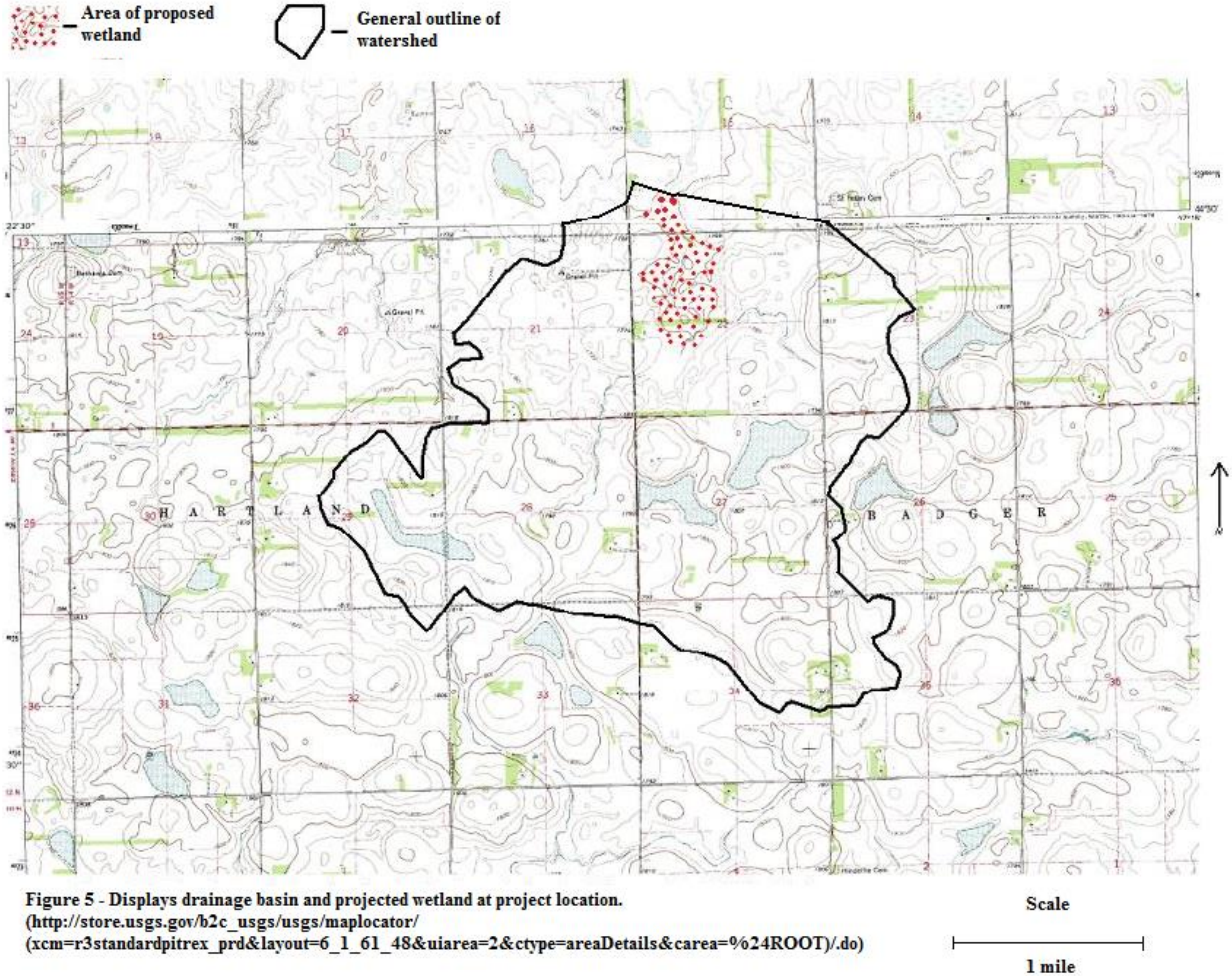

Figure 5 - Displays drainage basin and projected wetland at project location.
(http://store.usgs.gov/b2c_usgs/usgs/maplocator/
(xcm=r3standardpitrex_prd&layout=6_1_61_48&uiarea=2&ctype=areaDetails&carea=%24ROOT)/.do)

June is the wettest month with an average precipitation of 4.12 inches (High Plains Regional Climate Center 2009).

Safety Concerns

Human safety must be taken into account both during and after construction of the proposed embankment. During construction heavy equipment will be used; compliance to safety regulations will minimize any potential risks. Upon completion of the project, safety considerations include failure of the embankment, flooding of nearby farmsteads, and misuse of the wetland, such as for swimming. The projected size and location of the proposed embankment suggests that each of the aforementioned safety risks is low. The proposed wetland is to be quite shallow, reducing risk of drowning, and is at a location such that no farmsteads appear to be in danger of downstream flooding if failure were to occur.

Embankment Dimensions

The proposed embankment is to be earthen, composed of clays, and must conform to specifications defined by Roger Smith at the Midwest Regional Office of Ducks Unlimited, Inc. (Personal Communication 2009) which include the following:

- 3H:1V slopes along both upstream and downstream faces
- 2H:1V slopes where a weir is present
- A 12 foot width across the top of the embankment
- Embankment must be compacted to 95% of maximum density determined by the standard proctor test.
- The proposed embankment must be designed to pass a 25-yr, 24-hr rainfall event.

DESIGN APPROACH

The final design proposal for this site focuses on design methodologies associated with the proposed embankment and includes embankment construction material and weir dimensions. A work plan was followed which includes the calculation or creation of the following components:

- Curve Number (CN)
- Time of Concentration (Tc)
- Amount of rainfall associated with a 25-yr, 24-hr rainfall event
- Storage capacity curves
- Hydrograph
- Elevation-Storage and Elevation-Discharge relationships

A proposed project schedule is also included which shows dates associated with the completion of various components of the project. Lastly, an economic evaluation will be completed on the various design options.

Work Plan/Methods

Curve Number

A curve number is used to approximate the amount of runoff associated with a rainfall event in a particular area; curve numbers range from 0 to 100. A greater value of curve number is indicative of low permeability ground cover; whereas, a lesser number indicates ground that is more permeable. Therefore, determination of CN for an area means analyzing soil types present at the ground surface; the results of an NRCS Web Soil Survey (2009) display the soil groups present (Figure 4). When determining a value for CN land use must also be considered, as human interaction with soils often results in changing soil properties (Dahl and Johnson 1991). Agricultural land use was determined through analysis of county agricultural maps located at the USDA website. The areal extent of roads, farmsteads, and open water within the drainage area were found through analysis of satellite images. The area of the roads was determined by measuring the total distance of roads within the watershed and multiplying this distance by an assumed road width of 45 feet. Everything else present within the watershed appeared to be row crops. Soil groups present within each of the aforementioned areas was determined through visual analysis of Figure 4. A curve number was determined using Tables 3-1 and 3-2 along with the method displayed in Example 1 on page 3-7 of the Hydrology Manual of North Dakota (HMND) (U.S. Department of Agriculture not dated).

Time of Concentration

The time of concentration (Tc) for a given watershed represents the time it takes for a particle of water to travel from the furthest extent of the watershed boundary to the watershed outlet, or embankment in this case. The Tc was determined by breaking up a particle's apparent flow path into reaches of similar flow conditions, as determined by Figures 4-1 through 4-4 in the HMND (U.S. Department of Agriculture not dated). Next, the slope of each reach was measured and converted to a percent slope. Figure 4-1 through 4-4 in the HMND (U.S. Department of Agriculture not dated) was then be used to estimate a velocity for each reach. Lastly, the time spent in each reach was determined by dividing reach length by velocity. The time spent was then summed for each of the reaches, resulting in a value for Tc. USGS topographic maps were used, along with satellite images, to determine reach lengths and flow conditions.

Rainfall Depth

The depth of precipitation for a 25-yr, 24-hr rainfall event was approximated using Technical Paper 40 (US Weather Bureau 1961). Technical Paper 40 consists of rainfall depth contours for various storm durations and intensities, and was constructed using decades of rainfall data. Upon identification of the proposed project site on the 25-yr, 24-hr rainfall map, interpolation was made between contours to decipher the rainfall depth at the location.

Storage Capacity Curve

A storage capacity curve displays the storage area within a wetland associated with each foot of head above the designed weir. It is determined by measuring the aerial extent of each contour located within the proposed wetland, along with two or more contours above the proposed surface water level. A storage capacity curve plots height above weir vs. storage area; therefore, at the surface water level storage is zero. Storage capacities were found by measuring total volume of storage associated with each level, in one foot increments, above the weir. A polynomial trend line was then fitted to the storage capacity curve in order to determine an equation which relates storage capacity to height above the weir. This equation was then entered into an Excel spreadsheet where it was used to compute the changes in storage capacity and head relative to time during a 25-yr,24-hr rainfall event.

Hydrograph

A hydrograph was created using the method displayed in Example 1 on page 6-2 in the HMND (U.S. Department of Agriculture not dated). A hydrograph displays changes in the volume of water flowing through the watershed over the time interval during which flow will occur. First, a hydrograph family was determined using Figure 5-1 in the HMND (U.S. Department of Agriculture not dated). A tabulated hydrograph was then selected from Figure 6-6 in the HMND (U.S. Department of Agriculture not dated), using the curve number and hydrograph family.

Elevation-Storage and Elevation-Discharge Relationships

Finally, several spreadsheets were created, each for weirs of different lengths. The spreadsheets were then be analyzed in order to determine which lengths would most sufficiently pass a 25-yr, 24-hr rainfall event. Sufficiently, in this case, means that the embankment would allow one foot of freeboard and the total cost associated with the embankment would be minimized. The spreadsheets incorporate data derived from all of the aforementioned work plan components. The following coefficients needed to be determined from Figures 5-3a and 5-3b in Brater and King (1976), and were incorporated into each spreadsheet: effective weir discharge coefficient (Ce), effective weir length (Le), and the effective head (He).

Design Assumptions

In some cases assumptions were made in order to advance the design process. The first assumption is that the embankment will be compacted to 85% of the in-situ density of the soils that will be used to create the embankment. Secondly, it is assumed that the soil to be excavated for embankment fill material will have a 35% swell associated with its removal from in-situ conditions. Peurifoy (1979) determined that 35% swell is common in most clays.

Next, a major assumption in this project is that an influx of water sufficient to create a wetland at the proposed project site will occur on a yearly basis. Major sources of wetland water will be precipitation and melt-water associated with spring thaw. The presence of water bodies within the area of the proposed wetland has been observed through visual analysis of satellite images of the area. This, along with the presence of C and D-type soils within the proposed wetland site, suggests that the area already acts as a small scale storage area for runoff.

Finally, in analyzing costs associated with the embankment, a value of $40/sq. ft. was used for weir material, structural steel. This value is assumed to include construction costs associated with weir dimensioning and emplacement. It is also assumed that a weir embedment of 5 ft. into the embankment will be sufficient. These values were given by Roger Smith at the Midwest Regional Office of Ducks Unlimited, Inc. in Bismarck, North Dakota (Personal Communication 2009). Finally, it is assumed that a walking bridge would be embedded no less than 10% of the weir length on either side of the weir where applicable.

Preliminary Design Options

As previously mentioned, the calculations discussed earlier in the work plan/methods section were used to create a spreadsheet which relates weir length and height of the surface water level above the weir during a 25-yr, 24-hr rainfall event. Knowing this information is essential in determining potential weir dimensions; as the chosen dimensions must allow one foot of freeboard during the period of maximum water height above the weir. Weir lengths of 20, 30, 50, and 75 ft. were analyzed for this site.

A bridge above the weir would be useful in the removal of stop logs to allow drainage of the wetland. A wooden bridge would be more cost effective than a metal bridge; however, wood may deteriorate faster than metal. This was taken into consideration when determining final project costs.

The embankment itself will be constructed of earth. Constructing an earthen embankment will allow materials to be taken from areas within the proposed wetland area and lower costs associated with embankment construction. Taking materials from within the project side could also promote the creation of an island which would create added nesting for waterfowl.

FINAL DESIGN

Calculations

This section includes the results of calculations made for all of the aforementioned components of the work plan/methods, along with volume calculations for two potential embankment sizes.

Curve Number

A curve number of 79.4 was calculated for the proposed project site. This number was rounded up to 80 for simplicity. Using Tables 3-1 and 3-2 in the HMND (U.S. Department of Agriculture not dated), CN values associated with good crop conditions were used. Figure 6 displays the components of this calculation along with the resulting CN value. Also calculated were the CN values associated with varying crop conditions (Figures 11 and 12 in Appendix). As row crops encompass the majority of the watershed, it was determined that variations in surface conditions in these areas would have the most significant effect on the CN value. For the first calculation, curve numbers corresponding to poor crop conditions were used; whereas, the values displayed in Figure ii were calculated assuming mulch till conditions. The results show that the curve numbers vary slightly under different surface conditions. However, all the calculated values fall between 78 and 81 and correspond to the same hydrograph family [Figure 5-1 in the HMND (U.S. Department of Agriculture not dated)]. Therefore, it has been determined that using a CN value of 80 is acceptable for this project.

Time of Concentration

Table 2 displays the calculation of Tc. The calculated Tc value for this watershed was approximately 2.4 hours. This number was rounded down to two hours for use in this project. Using a lower value of Tc is done to remain conservative, as lower Tc values are indicative of a watershed in which overland flow occurs more rapidly, increasing peak head. The calculated number was created assuming reach conditions which became less retardant further downstream of the flow path. Also, channel flow was assumed for the majority of the path, having increased depths downstream. In reality, the flow paths likely consist of rough ditches and broad swales that would likely create a greater Tc value. It is unlikely that conditions would exist that are more conducive to rapid flow than those assumed for this project.

Farmsteads (Soil Types)	Acres	%	Acres	CN	%	Acres	CN	%	Acres	CN	ΣCN*A
A	0.0	0.375	0.0		0.375	0.0		0.25	0.0		0.0
B	2437.0	0.375	913.9	78	0.375	913.9	75	0.25	609.3	75	185516.6
C	515.0	0.375	193.1	85	0.375	193.1	83	0.25	128.8	83	43131.3
D	335.0	0.375	125.6	89	0.375	125.6	87	0.25	83.8	87	29396.3
	3287.0										258044.1
	Length	ROW	Area	Acres	CN	ΣCN*A					
Roads	61776	45	2.8E+06								
B	57450	45	2.6E+06	59.3	82.0	4866.6					
C	2471	45	1.1E+05	2.6	87.0	222.1					
D	1853	45	8.3E+04	1.9	89	170.3688					
				63.8		5259.1					
					+	258044.1					
						263303.21					
Homesteads	Acres	CN	ΣCN*A								
B	36	74	2664								
C	17	82	1394								
D	1	86	86								
			4144								
		+	263303.21								
			267447.21								
Open Water	Acres	CN	ΣCN*A								
	145	100	14500			CN					
		+	267447.21			79.4	80				
			281947.21								

Figure 6- Displays calculation of curve number

Table 2 – Displays calculation of Tc

Reach	Flow Condition	Length (ft.)	Drop (ft.)	Slope	S%	Velocity (ft./s)	Travel time (s)	Time (min)
1	Overland-Cultivated Minimum Till	1478	15	0.0101	1.015	0.55	2687	44.8
2	Open water/Pond	3960	5	0.0013	0.126	3960.0	1	0.0
3	High Retardance-d=1-2 b=2-8	2217	10	0.0045	0.451	1.3	1705	28.4
4	Med. Retardance-d=1-2 b=2-8	2640	10	0.0038	0.379	1.75	1509	25.1
5	Med Retardence-d=1-2 b=2-20	2112	20	0.0095	0.947	2.9	728	12.1
6	Low Retardance-d=2-3 b=2-8	2957	10	0.0034	0.338	3.25	910	15.2
7	Low Retardance-d=3-4 b=2-8	3802	10	0.0026	0.263	3.5	1086	18.1
							Total min	143.78
						Tc=	2.40	Hrs.
							Use Tc = 2.0	

Rainfall Depth

Upon analysis, it was observed that the proposed project location was located between the four-inch and five-inch precipitation depth contours. A straight line was drawn through the project location, having endpoints on each of the aforementioned contours (Figure 7). The distance from endpoint to endpoint was measured to be 270 miles; whereas, the distance from the four inch contour to the proposed project location was 140 miles. Through interpolation of these distances it was determined that the rainfall depth for a 25-yr, 24-hr rainfall event at the site was 4.52 inches. This value was then used to calculate runoff within the watershed using Figure 3-2 in the HMND (U.S. Department of Agriculture not dated). A value of 2.5 inches was determined for runoff depth.

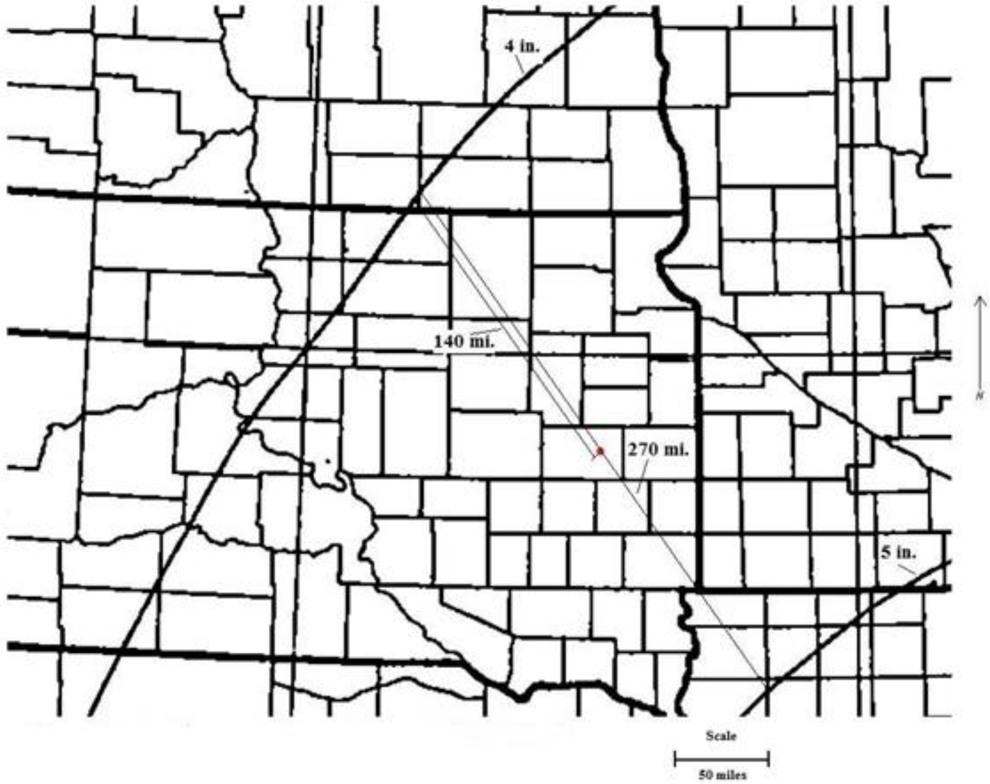

Figure 7 - Displays project location between 4 in. and 5 in. rainfall depth countours for a 25-yr, 24-hr rainfall event. (US Weather Bureau 1961)

Storage Capacity Curve

Table 3 displays the calculation of storage capacity for the proposed location, and Figure 8 displays the resultant storage capacity curve. A third order polynomial trend line was fitted to plotted data points which relate head above the weir to storage capacity. The y-component represents head and the x-component represents storage capacity. Similarly this equation would be entered into a spreadsheet which calculates elevation-storage and elevation-discharge relationships. The equation will occupy a column denoted H. This column will display the free surface water level at any point during a 25-yr, 24-hr rainfall event at the proposed site.

Table 3- Displays calculation of storage capacity at proposed project site.

Elevation (Ft.)	Reservoir Area (Ft.^{2})	Reservoir Area (Acres)	Reservoir Capacity (acre-ft.)	Storage Capacity (acre-ft.)	Head (ft.)
1750	1234871	28.3	0	0	0
1751	2778450	63.8	46	0	0
1752	4927788	113.1	135	0	0
1753	5478520	125.8	254	0	0
1754	6032299	138.5	386	0	0
1755	6429100	147.6	529	143	1
1756	6877533	157.9	682	296	2
1757	7487463	171.9	847	461	3
1758	7950716	182.5	1024	638	4

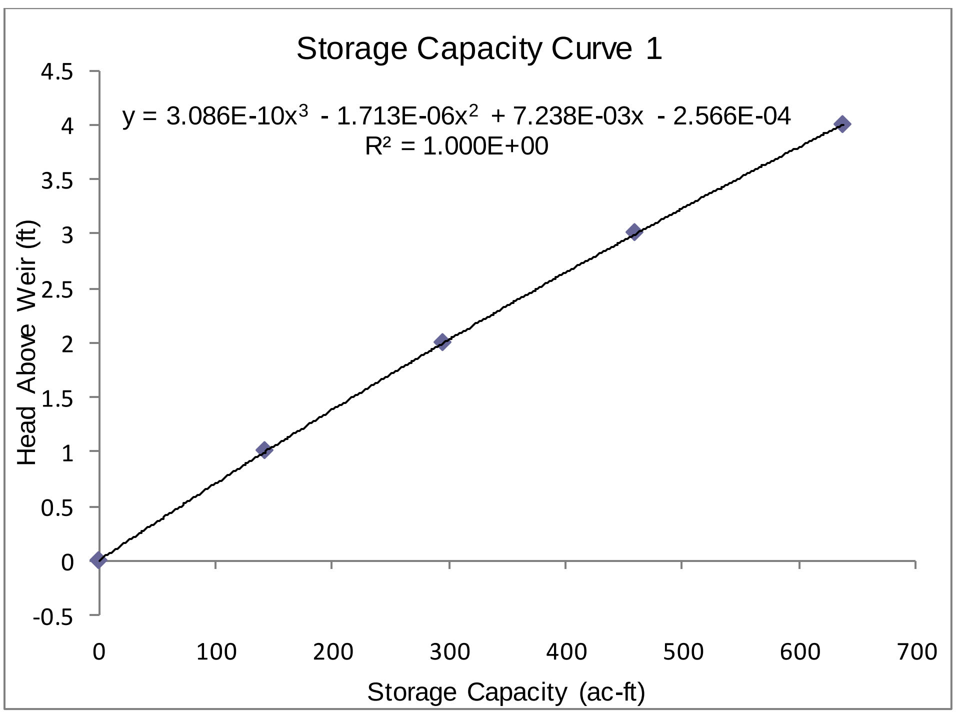

Figure 8- Displays example of a storage capacity curve for project location. Y-axis is height above weir in ft.; X-axis- is storage capacity in acre-ft. Also shown is polynomial expression for trendline through the data points.

Hydrograph

The hydrograph created for the proposed project site is displayed in Figure 9. A hydrograph family of 1 was determined using Figure 5-1 in the HMND (U.S. Department of Agriculture not dated). The hydrograph for the proposed project location shows that the maximum inflow of runoff is approximately 1685 cfs and it occurs just over 11 hours into the 25-yr, 24-hr rainfall event. This will be the final component needed to create a spreadsheet that routes the flood.

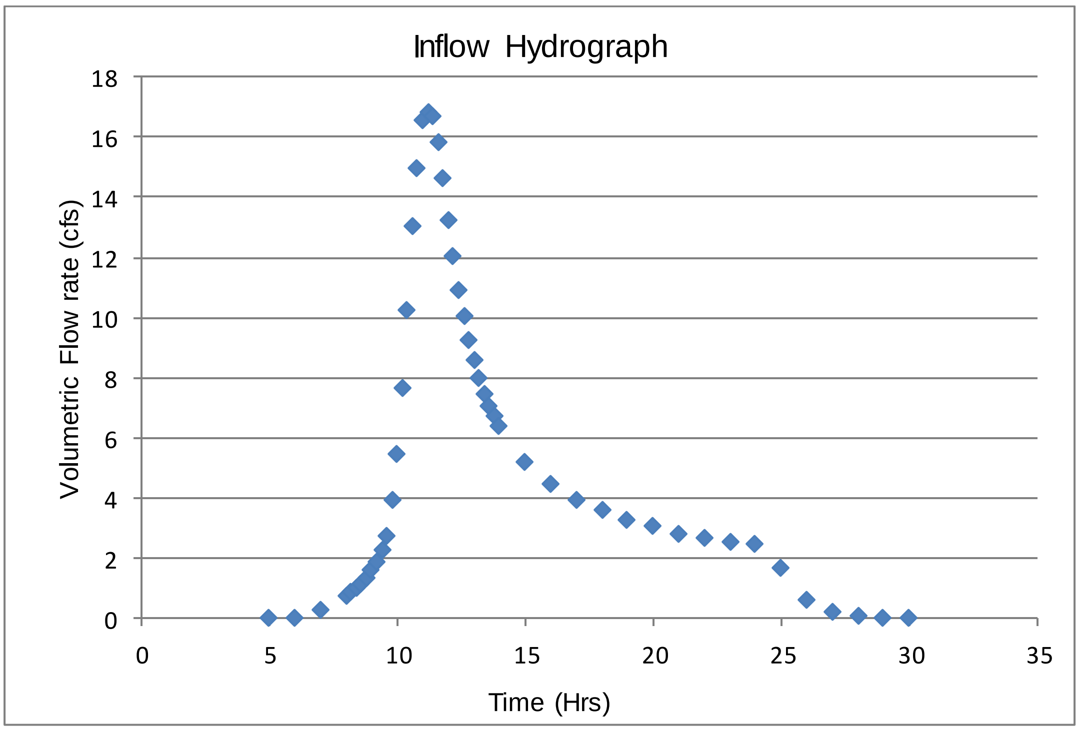

Figure 9- Displays hydrograph for the drainage basin at the proposed project location along with values used to create the hydrograph. Where: X- axis is time in hrs. and the Y-axis is volumetric flow rate in cfs.

Elevation-Storage and Elevation-Discharge Relationships

All of the aforementioned calculations in some way contributed to the creation of spreadsheets (Figures 13, 14, 15, and 16 in Appendix) which display head above the weir at any moment during a 25-yr, 24-hr rainfall event. The spreadsheets calculate the maximum heights the free surface level reaches for weirs of varying lengths (20, 30, 50, and 75 ft.). Using the resulting heights, design specifications were made for embankments having weirs of varying lengths. It was determined that weirs of lengths 20, 30, and 50 ft. would require an embankment height of 8 ft. in order to allow one foot of freeboard (assuming 1 ft. increments are most plausible for embankment design). The 75 ft. weir would require an embankment height of just 7 ft.

In order to correctly determine the relationships between costs associated with weirs of different lengths, total embankment volumes were determined (Tables 4 and 5 in Appendix). In this case, embankment heights of 7 feet and 8 feet were analyzed, as these heights correspond with the weir lengths that will be analyzed for this project. For each of the heights, total embankment length was first determined. Lengths were determined by measuring the distance between equal contours (1757 ft. for seven foot embankment and 1758 ft. for eight foot embankment) on opposite sides of the stream channel across which the embankment will be constructed. Length measurements were made using measuring tools in ArcGIS. Next, the cross sectional area was determined for each case. The cross sectional area was measured, assuming the base would be at 1750 ft., for each potential embankment height, as this is where the ground slope will be equal to zero. In determining the volume associated with the middle portion of each embankment, the cross-sectional area was simply multiplied by the length of the middle portion. In determining the volumes associated with the sides of the embankment, the same process was performed; however, the resulting values were divided by two, as trapezoids having a height of zero at the outer reaches of the embankment and heights of 7 ft. and 8 ft. at the inner were assumed. Also calculated was the haul volume of the embankment material (Table 6 In Appendix). The calculation assumes that final embankment volume will be 85% of in-situ volume. Furthermore, the in-situ soil to be excavated is assumed to have a swell index of 1.35, common in clays.

Cost Estimates

As costs associated with construction of the embankment are of utmost importance in this project, a cost assessment was performed to determine which construction methodology would be most cost effective. Two methodologies were analyzed. The first would incorporate the use of two sheepsfoot rollers and five self propelled scrapers. The other method would incorporate three 60 C.Y. dump trucks, two sheepsfoot rollers, and two front end loaders. Tables 7 and 8 in the Appendix display the total daily costs associated with each method. It can be observed that the latter method, utilizing three 60 C.Y. dump trucks, two sheepsfoot rollers, and two front end loaders, would cost greater than $7,000 less per day while producing a nearly equivalent output.

Next, a cost assessment was created for the varying weir lengths which includes all costs associated with construction of the embankment (Table 9 in Appendix).

Although using a shorter weir length would reduce costs associated with the weir material, it could also require a taller embankment, in order to pass a 25-yr, 24-hr rainfall event, which would increase costs associated with embankment fill material. A longer weir would increase costs associated with weir material, but may require less fill material be used to construct the embankment. In this case, it has been determined that the amount of structural steel used is the main factor associated with cost. Therefore, a shorter weir is desired in order to remain cost efficient. Using a weir of 20 feet in length would be preferred; however, one design constraint associated with this project states that the embankment will have 2H: 1V side slopes where the weir is present. This poses a problem with the 20 foot weir. The weir base will be four feet above the ground surface meaning that at 2H: 1V side slopes the embankment would extend eight feet laterally on each side of the weir. This leaves only four lateral feet of separation between the east and west sides of the embankment. During flooding events this short channel width at the base of the weir may not be adequate to pass floodwaters effectively. Therefore, a weir length of 30 feet will be utilized for this project.

Plans and Specifications

The construction of an embankment will involve a site preparation, which was included in daily excavation/construction costs, and the emplacement of fill material. Original embankment construction will not take into account Ducks Unlimited, Inc. design specifications for slopes near the weir (R. Smith personal Communication 2009), as these will be applied later. Instead, the total required volume of fill material will first be calculated for an embankment having 3H: 1V sides throughout. Upon emplacement of this material, proper slopes will be cut into the embankment to conform to design specifications.

Material for the earthen embankment will consist of C and D group soils, which would be extracted from the area encompassed by the 1750 ft. contour in the proposed wetland (Figure 10).

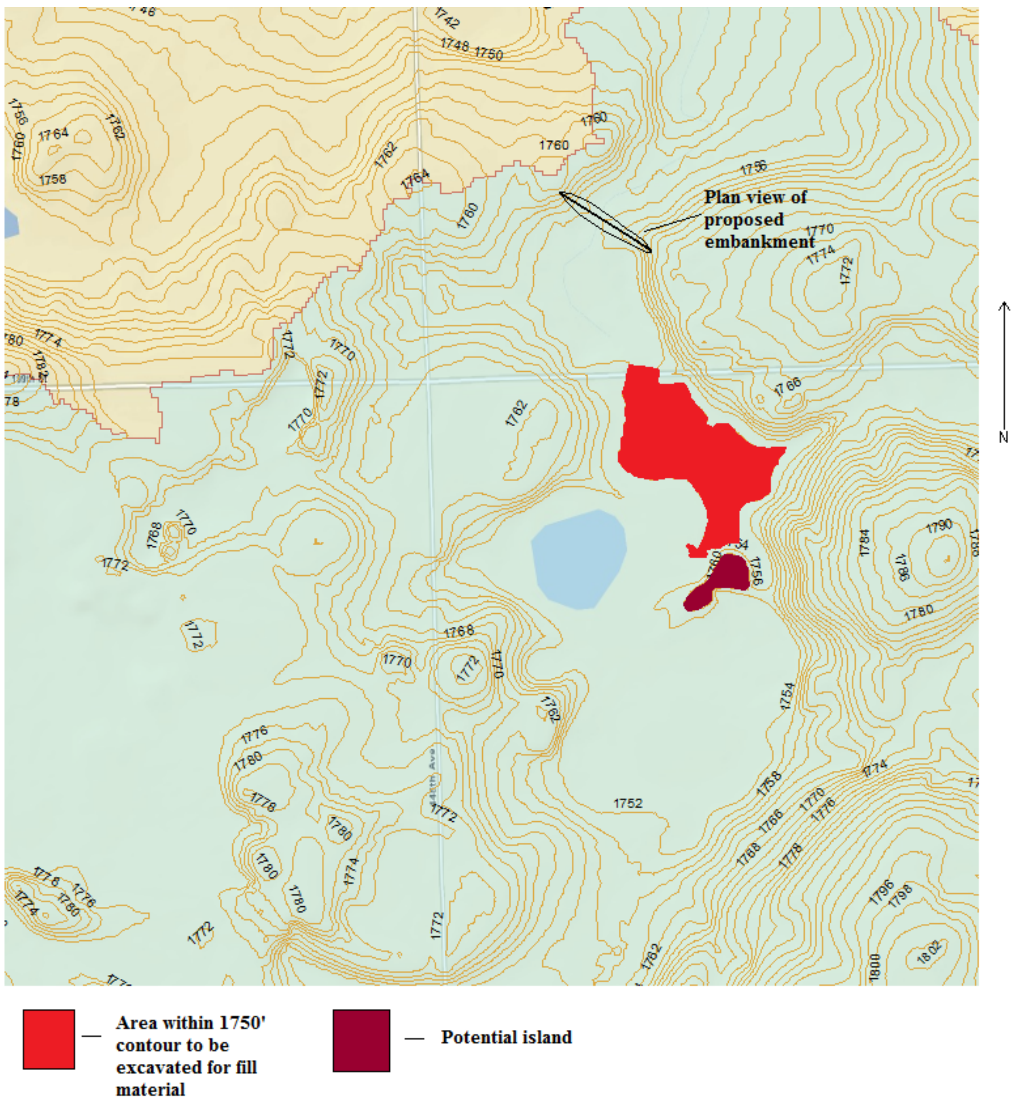

Figure 10- Displays area from which embankment fill material will be excavated, potential island, and plan view of proposed embankment.

The embankment will consist of a weir containing stop logs. Stop logs will be emplaced to allow drainage of the wetland in order to promote plant growth within the wetland. Also present will be 12 inch gabions at the base of the weir on the downstream side of the embankment and 9 inch gabions along the 2H: 1V sloped sides near the weir. The weir will be emplaced once the embankment material is in place, and stop logs will be the last component added to the structure once all other components have been completed.

Figures 17 – 20 in Appendix display dimensions associated with the proposed embankment including: plan view, cross-section, and side view. These drawings do not include the proposed bridge.

Proposed Schedule

A proposed schedule for the completion of this project is as follows:

- First draft of design proposal – November 2009
- Final draft of design proposal – December 2009
- Begin contracting for bids – January 2010
- Begin construction – Late Spring 2010
- Project completion – By Summer 2010

CONCLUSIONS

It has been determined that the proposed wetland site in South-Eastern South Dakota is a suitable location for the construction of an embankment to create a wetland. Several potential designs were analyzed and a final design was chosen which was estimated to have a total construction cost of approximately $78,000, and would require approximately 3 days to construct. The embankment would be 695 ft. long and would allow a wetland of nearly 140 acres to exist at full capacity. Although the wetland likely will not be full most of the time, at half the maximum depth a wetland having an areal extent of approximately 115 ac. would persist. Even this is large enough to allow several hens to raise their broods. The embankment would be constructed of material removed from the project location and will incorporate a bridge to be used for maintenance or leisure. It does not appear that there will be any resulting safety or environmental concerns associated with the completed embankment, as it is of marginal size and no homesteads exist downstream of the embankment within a proximity that would be considered dangerous if failure should occur.

Upon completion of the embankment it will be at the discretion of Ducks Unlimited Inc. to take steps to enhance the suitability of the wetland to sustaining waterfowl. Enhancement of the wetland could include emplacement of artificial islands, or even implementation of a small excavation to create a large island within the wetland, at the location shown in Figure 10.

FINAL STATEMENT

If this project is accepted it should be noted that a final design may or may not require an emergency spillway. This aspect was not analyzed as it was assumed beyond the scope of this project. Also, wetland biologists should be contacted to determine specifics regarding the promotion of plant-life within the wetland as well as specific times to allow drainage of the wetland. This report focused primarily on the hydrologic design of an embankment to create a wetland, taking into account project goals, design constraints, and economic concerns.

Furthermore, should this project be accepted, soils to be excavated would require attention in order to determine specific compaction and plastic properties.

REFERENCES

Brater, E. F., and King, H. W. (1967). *Handbook of Hydraulics*, 6th Ed., McGraw Hill, New York. Ch. 5, pp 5-2 – 5-15.

Dahl and Johnson. (1991). *Wetlands Status and Trends in the Conterminous United States Mid 1970s to Mid 1980s*. U.S. Department of Interior, Fish and Wildlife Service, Washington D.C. 28 pages.

Duebbert, H. F. (1982). Nesting of waterfowl on islands in Lake Audubon, North Dakota. Wildlife Society Bulletin 10:232-237

Ducks Unlimited (2009). <http://www.ABSTRACT.docducks.org/>. (Feb.-June 2009.)

Hammond, M. C., and G. E. Mann. (1956). Waterfowl nesting islands. Journal of Wildlife Management. (May 2009).

Hershfield, David, M.. United States. (1961). Department of Commerce. *Technical Paper No. 40*. Washington, D.C.: GPO.

High Plains Regional Climate center (2008). <http://www.hprc.unl.edu> (February 2009).

Maryland Cooperative Extension (not dated). Fact Sheet 610. *Dabbling Ducks,* College Park, MD. (March 2009)

National Resources Conservation Service. (2009). <http://websoilsurvey.nrcs.usda.gov> . (February 2009).

Newton, I., and C. R. G. Campbell. (1975). Breeding of ducks at Loch Leven, Kinross. Wildfowl 26:83-102

Peurifoy, R. L. (1979). Construction, Planning, Equipment, and Methods 3rd edition. McGraw Hill, New York. Ch. 5, pp105-110.

RS Means. “Heavy Construction Cost Data” 16th edition. 2002. RS Means Co., Inc. Kingston MA.

U.S. Army Corps of Engineers (1987). "Corps of Engineers wetland delineation manual." Technical report Y-87-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Department of Agriculture (not dated). "Hydrology manual for North Dakota." U.S. Department of Agriculture, Soil Conservation Service, Bismarck, ND.

U.S. Fish and Wildlife Service. (Updated 2009). <http://www.fws.gov/birdhabitat/Grants/NAWCA/index.shtm > (May 2009).

USGS. Maps, Imagery, and Publications*: Downloadable Topo Maps* – 1968 <http://www.usgs.gov/pubprod/> (February 2009).

USGS. Northern Prairie Wildlife Research center. (2006). Wetlands of the Prairie region: *Invertebrate Species Composition, Ecology, and management.* <http://www.npwrc.usgs.gov/resource/wetlands/pothole/prairie.htm> (July 2009).

APPENDIX

Column1	Column2	Corn	Column3	Column4	Soybean	Column5	Column6	Wheat	Column7	Column8	Column9
	Acres	%	Acres	CN	%	Acres	CN	%	Acres	CN	ΣCN*A
A	0.0	0.375	0.0		0.375	0.0		0.25	0.0		0.0
B	2437.0	0.375	913.9	81	0.375	913.9	75	0.25	609.3	75	188258.3
C	515.0	0.375	193.1	88	0.375	193.1	83	0.25	128.8	83	43710.6
D	335.0	0.375	125.6	91	0.375	125.6	87	0.25	83.8	87	29647.5
	3287.0										261616.4
	Length	ROW	Area	Acres	CN	ΣCN*A					
Roads	61776	45	2.8E+06								
B	57450	45	2.6E+06	59.3	82.0	4866.6					
C	2471	45	1.1E+05	2.6	87.0	222.1					
D	1853	45	8.3E+04	1.9	89	170.3688					
				63.8		5259.1					
					+	261616.4					
						266875.46					
Homesteads	Acres	CN	ΣCN*A								
B	36	74	2664								
C	17	82	1394								
D	1	86	86								
			4144								
		+	266875.46								
			271019.46								
Open Water	Acres	CN	ΣCN*A								
	145	100	14500			CN					
		+	271019.46			80.4	81				
			285519.46								

Figure 11- Displays calculation of curve number assuming poor crop conditions

Column1	Column2	Corn	Column3	Column4	Soybean	Column5	Column6	Wheat	Column7	Column8	Column9
	Acres	%	Acres	CN	%	Acres	CN	%	Acres	CN	ΣCN*A
A	0.0	0.375	0.0		0.375	0.0		0.25	0.0		0.0
B	2437.0	0.375	913.9	76	0.375	913.9	74	0.25	609.3	74	182165.8
C	515.0	0.375	193.1	84	0.375	193.1	82	0.25	128.8	82	42616.3
D	335.0	0.375	125.6	87	0.375	125.6	86	0.25	83.8	86	28935.6
	3287.0										253717.6
	Length	ROW	Area	Acres	CN	ΣCN*A					
Roads	61776	45	2.8E+06								
B	57450	45	2.6E+06	59.3	82.0	4866.6					
C	2471	45	1.1E+05	2.6	87.0	222.1					
D	1853	45	8.3E+04	1.9	89	170.3688					
				63.8		5259.1					
					+	253717.6					
						258976.71					
Homesteads	Acres	CN	ΣCN*A								
B	36	74	2664								
C	17	82	1394								
D	1	86	86								
			4144								
		+	258976.71								
			263120.71								
Open Water	Acres	CN	ΣCN*A								
	145	100	14500			CN					
		+	263120.71			78.2	78				
			277620.71								

Figure 12- Displays calculation of curve number assuming mulch till crop conditions

A	3550	acres	Weir Dimensions							
T_c	2	hours	P	4.0				Fig 5-3a		
CN	80		El	b (ft.)	H	L (ft.)	L/b	k_L	L_e	
Precip	4.5	inches	1758	695	0	20	0.029	0.008	20.008	
			K_h	0.003						
$Q=C_eL_eH_e$^3/2										
L_e=L+k_L			C_e=Fig 5-3b=3.19+0.025(H/P)							
H_e=H+k_H			L_e=15.010+.0025H							
			H=-1.38448E-04(S_{cap}^2)+4.66376E-02(S_{cap})							

Time (Hrs.)	Time (days)	Time interval	Q_{in} (cfs)	V_{in} (ft.^{3})	V_{out} (ft.^{3})	S_{cap} (ft.^{3})	S_{cap} (acre-ft.)	H (ft.)	H/P	C_e	H_e	L_e	Q_{out} (cfs)	WS El (ft.)
5.0	0.21		0	0	0	0	0	0	0	3.19	0.003	20.01	0.010439	1754
6.0	0.25	3600	2.773438	4992.188	0	4992.188	0.11460486	0.000829	0.000207	3.190005	0.003829	20.01	0.015127	1754.001
7.0	0.29	3600	24.96094	49921.88	46.10797	54867.95	1.25959492	0.009114	0.002279	3.190057	0.012114	20.01002	0.085112	1754.009
8.0	0.33	3600	72.10938	174726.6	180.4296	229414.1	5.26662276	0.038072	0.009518	3.190238	0.041072	20.0101	0.531368	1754.038
8.2	0.34	720	84.58984	56411.72	221.9326	285603.9	6.55656275	0.047383	0.011846	3.190296	0.050383	20.01012	0.721942	1754.047
8.4	0.35	720	98.45703	65896.88	451.1916	351049.6	8.05898891	0.05822	0.014555	3.190364	0.06122	20.01015	0.965998	1754.058
8.6	0.36	720	115.0977	76879.69	608.0185	427321.2	9.8099455	0.070839	0.01771	3.190443	0.073839	20.01018	1.280952	1754.071
8.8	0.37	720	135.8984	90358.59	809.2619	516870.6	11.8657153	0.085642	0.021411	3.190535	0.088642	20.01021	1.684912	1754.086
9.0	0.38	720	159.4727	106333.6	1067.711	622136.4	14.2822874	0.103025	0.025756	3.190644	0.106025	20.01026	2.204158	1754.103
9.2	0.38	720	187.207	124804.7	1400.065	745541.1	17.1152678	0.123377	0.030844	3.190771	0.126377	20.01031	2.868477	1754.123
9.4	0.39	720	228.8086	149765.6	1826.148	893430.5	20.5114908	0.147739	0.036935	3.190923	0.150739	20.01037	3.73638	1754.148
9.6	0.40	720	274.5703	181216.4	2377.928	1072319	24.6170573	0.177136	0.044284	3.191107	0.180136	20.01044	4.881995	1754.177
9.8	0.41	720	395.2148	241122.7	3102.795	1310339	30.0812415	0.21617	0.054042	3.191351	0.21917	20.01054	6.552451	1754.216
10.0	0.42	720	544.9805	338470.3	4116.4	1644693	37.7569511	0.270826	0.067707	3.191693	0.273826	20.01068	9.151563	1754.271
10.2	0.43	720	768.2422	472760.2	5653.445	2111800	48.4802457	0.346839	0.08671	3.192168	0.349839	20.01087	13.21763	1754.347
10.4	0.43	720	1024.785	645489.8	8052.908	2749236	63.1137842	0.449917	0.112479	3.192812	0.452917	20.01112	19.47476	1754.45
10.6	0.44	720	1303.516	838188.3	11769.26	3575655	82.0857544	0.582424	0.145606	3.19364	0.585424	20.01146	28.62662	1754.582
10.8	0.45	720	1497.656	1008422	17316.5	4566761	104.838403	0.739637	0.184909	3.194623	0.742637	20.01185	40.91398	1754.74
11.0	0.46	720	1655.742	1135223	25034.62	5676950	130.324032	0.913513	0.228378	3.195709	0.916513	20.01228	56.11413	1754.914
11.2	0.47	720	1684.863	1202618	34930.12	6844638	157.131256	1.093824	0.273456	3.196836	1.096824	20.01273	73.49072	1755.094
11.4	0.48	720	1666.836	1206612	46657.75	8004591	183.760135	1.270297	0.317574	3.197939	1.273297	20.01318	91.95613	1755.27
11.6	0.48	720	1585.02	1170668	59560.86	9115699	209.267644	1.436834	0.359208	3.19898	1.439834	20.01359	110.6127	1755.437
11.8	0.49	720	1462.988	1097203	72924.79	10140057	232.703669	1.588171	0.397043	3.199926	1.591171	20.01397	128.543	1755.588
12.0	0.50	720	1325.703	1003929	86096.07	11057889	253.854211	1.721959	0.43049	3.200762	1.724959	20.0143	145.1317	1755.722
12.2	0.51	720	1205.059	911074.2	98522.89	11870441	272.507823	1.838958	0.45974	3.201493	1.841958	20.0146	160.134	1755.839
12.4	0.52	720	1092.734	827205.5	109913.7	12587733	288.974577	1.941105	0.485276	3.202132	1.944105	20.01485	173.7285	1755.941
12.6	0.53	720	1003.984	754010.7	120208.5	13222343	303.543224	2.030582	0.507645	3.202691	2.033582	20.01508	185.8937	1756.031
12.8	0.53	720	926.3281	694912.5	129464	13787791	316.524135	2.109594	0.527399	3.203185	2.112594	20.01527	196.8646	1756.11
13.0	0.54	720	855.6055	641496.1	137793	14291494	328.087567	2.17941	0.544852	3.203621	2.18241	20.01545	206.7335	1756.179
13.2	0.55	720	800.1367	596067.2	145295.3	14742266	338.435865	2.241431	0.560358	3.204009	2.244431	20.0156	215.6363	1756.241
13.4	0.56	720	747.4414	557128.1	152053.1	15147341	347.735107	2.296795	0.574199	3.204355	2.299795	20.01574	223.6897	1756.297
13.6	0.57	720	707.2266	523680.5	158157.4	15512864	356.126363	2.346451	0.586613	3.204665	2.349451	20.01587	230.9972	1756.346
13.8	0.58	720	669.7852	495724.2	163687.3	15844901	363.748881	2.391309	0.597827	3.204946	2.394309	20.01598	237.6664	1756.391
14.0	0.58	720	639.2773	471262.5	168713.9	16147445	370.694326	2.431975	0.607994	3.2052	2.434975	20.01608	243.7676	1756.432
15.0	0.63	3600	522.793	2091727	866581.2	17372590	398.819792	2.594617	0.648654	3.206216	2.597617	20.01649	268.6849	1756.595
16.0	0.67	3600	445.1367	1742273	922414.4	18192449	417.641165	2.701618	0.675404	3.206885	2.704618	20.01675	285.5196	1756.702
17.0	0.71	3600	393.8281	1510137	997568	18705018	429.408123	2.767759	0.69194	3.207298	2.770759	20.01692	296.0975	1756.768
18.0	0.75	3600	357.7734	1352883	1046911	19010990	436.432276	2.806963	0.701741	3.207541	2.809963	20.01702	302.4236	1756.807
19.0	0.79	3600	327.2656	1233070	1077347	19166713	440.007194	2.826835	0.706709	3.207668	2.829835	20.01707	305.655	1756.827
20.0	0.83	3600	306.4648	1140715	1094550	19212878	441.066982	2.832716	0.708179	3.207704	2.835716	20.01708	306.6121	1756.833
21.0	0.88	3600	282.8906	1060840	1102081	19171637	440.120219	2.827463	0.706866	3.207672	2.830463	20.01707	305.7571	1756.827
22.0	0.92	3600	267.6367	990919.2	1102265	19060321	437.564772	2.813264	0.703316	3.207583	2.816264	20.01703	303.1504	1756.813

Figure 13 – Displays calculation of height above weir for 20 ft. weir. Where: P= height from base of embankment to base of weir, L= length of weir, H is surface water height above weir, b is embankment width, and KL, Le, Ce, and He are coefficients determined by Figures 5-3a and 5-3b in Brater and King (1976). Highlighted row represents time of maximum surface water level.

A	1550	acres		Weir Dimensions						
T_r	2	hours		P	4.0				Fig 5-3a	
CN	80			El	b (ft.)	H	L (ft.)	L/b	k_L	L_e
Precip	4.5	inches		1758	695	0	30	0.043	0.013	30.013
				K_h	0.003					
$Q=C_eL_eH_e$^3/2										
L_e=L+k_L				C_e=Fig 5-3b=3.19+0.025(H/P)						
H_e=H+k_H				L_e=15.010+.0025H						
				H=-1.38448E-04(S_{cap}^2)+4.66376E-02(S_{cap})						

Time (Hrs.	Time (days)	Time interval	Q_{in} (cfs)	V_{in} (ft.^{3})	V_{out} (ft.^{3})	S_{cap} (ft.^{3})	S_{cap} (acre-ft.)	H (ft.)	H/P	C_e	H_e	L_e	Q_{out} (cfs)	WS El (ft.)
5.0	0.21		0	0	0	0	0	0	0	3.19	0.003	30.0125	0.015732	1754
6.0	0.25	3600	2.773438	4992.188	0	4992.188	0.114604865	0.000829	0.000207	3.190005	0.003829	30.0125	0.022688	1754.001
7.0	0.29	3600	24.96094	49921.88	69.15619	54844.91	1.259065802	0.00911	0.002278	3.190057	0.01211	30.01252	0.127597	1754.009
8.0	0.33	3600	72.10938	174726.6	270.5129	229301	5.264025618	0.038054	0.009513	3.190238	0.041054	30.0126	0.796438	1754.038
8.2	0.34	720	84.58984	56411.72	332.6524	285380	6.551423835	0.047346	0.011836	3.190296	0.050346	30.01262	1.081626	1754.047
8.4	0.35	720	98.45703	65896.88	676.103	350600.8	8.048686737	0.058145	0.014536	3.190363	0.061145	30.01265	1.447734	1754.058
8.6	0.36	720	115.0977	76879.69	910.5694	426569.9	9.792697712	0.070715	0.017679	3.190442	0.073715	30.01268	1.916414	1754.071
8.8	0.37	720	135.8984	90358.59	1211.093	515717.4	11.83924272	0.085452	0.021363	3.190534	0.088452	30.01271	2.519004	1754.085
9.0	0.38	720	159.4727	106333.6	1596.75	620454.3	14.2436698	0.102747	0.025687	3.190642	0.105747	30.01276	3.292969	1754.103
9.2	0.38	720	187.207	124804.7	2092.31	743166.6	17.06075835	0.122986	0.030746	3.190769	0.125986	30.01281	4.282363	1754.123
9.4	0.39	720	228.8086	149765.6	2727.12	890205.1	20.43629797	0.1472	0.0368	3.19092	0.1502	30.01287	5.57478	1754.147
9.6	0.40	720	274.5703	181216.4	3548.572	1067873	24.51499022	0.176405	0.044101	3.191103	0.179405	30.01294	7.277845	1754.176
9.8	0.41	720	395.2148	241122.7	4626.945	1304369	29.94418469	0.215192	0.053798	3.191345	0.218192	30.01304	9.762054	1754.215
10.0	0.42	720	544.9005	338470.3	6134.364	1636705	37.57356027	0.269523	0.067381	3.191685	0.272523	30.01317	13.62812	1754.27
10.2	0.43	720	768.2422	472760.2	8420.464	2101044	48.23334083	0.345093	0.086273	3.192157	0.348093	30.01336	19.67623	1754.345
10.4	0.43	720	1024.785	645489.8	11989.57	2734545	62.77650603	0.447549	0.111887	3.192797	0.450549	30.01362	28.98032	1754.448
10.6	0.44	720	1303.516	838188.3	17516.36	3555217	81.61654101	0.579162	0.144791	3.19362	0.582162	30.01395	42.57671	1754.579
10.8	0.45	720	1497.656	1008422	25760.53	4537878	104.1753414	0.735082	0.18377	3.194594	0.738082	30.01434	60.79968	1754.735
11.0	0.46	720	1655.742	1135223	37215.5	5635886	129.3821351	0.907124	0.226781	3.19567	0.910124	30.01477	83.28139	1754.907
11.2	0.47	720	1684.863	1202618	51869.18	6786635	155.7996922	1.084931	0.271233	3.196781	1.087931	30.01521	108.882	1755.085
11.4	0.48	720	1666.836	1206612	69178.81	7924067	181.9115587	1.258132	0.314533	3.197863	1.261132	30.01565	135.9403	1755.258
11.6	0.48	720	1585.02	1170668	88136.03	9006599	206.7630723	1.420591	0.355148	3.198879	1.423591	30.01605	163.0907	1755.421
11.8	0.49	720	1462.988	1097283	107651.2	9996231	229.4818889	1.567051	0.391763	3.199794	1.570051	30.01642	188.9519	1755.567
12.0	0.50	720	1325.703	1003929	126735.3	10873425	249.6194821	1.695209	0.423802	3.200595	1.698209	30.01674	212.6087	1755.695
12.2	0.51	720	1205.059	911074.2	144561.8	11639937	267.2161855	1.805907	0.451477	3.201287	1.808907	30.01701	233.7848	1755.806
12.4	0.52	720	1092.734	827205.5	160701.7	12306441	282.5170076	1.901175	0.475294	3.201882	1.904175	30.01725	252.5437	1755.901
12.6	0.53	720	1003.984	754818.7	175078.3	12886181	295.8260177	1.98329	0.495822	3.202396	1.98629	30.01746	269.0994	1755.983
12.8	0.53	720	926.3281	694912.5	187791.5	13393302	307.4679134	2.054542	0.513635	3.202841	2.057542	30.01764	283.7493	1756.055
13.0	0.54	720	855.6055	641496.1	199025.5	13835773	317.6256396	2.116268	0.529067	3.203227	2.119268	30.01779	296.6505	1756.116
13.2	0.55	720	800.1367	596067.2	208943.9	14222896	326.5127663	2.169933	0.542483	3.203562	2.172933	30.01792	308.0232	1756.17
13.4	0.56	720	747.4414	557120.1	217602.5	14562342	334.3053640	2.216727	0.554102	3.203855	2.219727	30.01804	318.0567	1756.217
13.6	0.57	720	707.2266	523680.5	225388.8	14860633	341.1532002	2.257645	0.564411	3.20411	2.260645	30.01814	326.9189	1756.258
13.8	0.58	720	669.7852	495724.2	232191.2	15124166	347.2030856	2.293637	0.573409	3.204335	2.296637	30.01823	334.7817	1756.294
14.0	0.58	720	639.2773	471262.5	238212.2	15357217	352.5531844	2.325342	0.581335	3.204533	2.328342	30.01831	341.76	1756.325
15.0	0.63	3600	522.793	2091727	1217775	16231168	372.6163515	2.443194	0.610798	3.20527	2.446194	30.01861	368.1217	1756.443
16.0	0.67	3600	445.1367	1742273	1277787	16695655	383.2794918	2.505156	0.626289	3.205657	2.508156	30.01876	382.2449	1756.505
17.0	**0.71**	**3600**	**393.8281**	**1510137**	**1350660**	**16855131**	**386.940575**	**2.526322**	**0.63158**	**3.20579**	**2.529322**	**30.01882**	**387.1103**	**1756.526**
18.0	0.75	3600	357.7734	1352883	1384839	16823175	386.2069526	2.522085	0.630521	3.205763	2.525085	30.01881	386.1347	1756.522
19.0	0.79	3600	327.2656	1233070	1391841	16664404	382.5620782	2.501002	0.625251	3.205631	2.504002	30.01875	381.2925	1756.501

Figure 14 – Displays calculation of height above weir for 30 ft. weir. Where: P= height from base of embankment to base of weir, L= length of weir, H is surface water height above weir, b is embankment width, and KL, Le, Ce, and He are coefficients determined by Figures 5-3a and 5-3b in Brater and King (1976). Highlighted row represents time of maximum surface water level.

A	3550	acres		Weir Dimensions						
T_c	2	hours		P	4.0			Fig 5-3a (Brater & King)		
CN	80			El	b (ft.)	H	L (ft.)	L/b	k_L	L_e
Precip	4.5	inches		1758	695	0	50	0.072	0.008	50.008
				K_h	0.003					
$Q=C_eL_eH_e$^3/2										
$L_e=L+k_L$				C_e=Fig 5-3b=3.19+0.025(H/P)						
$H_e=H+k_H$				L_e=15.010+.0025H						
				H=-1.38448E-04(S_{cap}^2)+4.66375E-02(S_{cap})						

Time (Hrs.	Time (days	Time interv	Q_{in} (cfs)	V_{in} (ft.^{3})	V_{out} (ft.^{3})	S_{cap} (ft.^{3})	cap (acre-ft	H (ft.)	H/P	C_e	H_e	L_e	Q_{out} (cfs)	WS El (ft.)
5.0	0.21		0	0	0	0	0	0	0	3.19	0.003	50.008	0.026213	1754
6.0	0.25	3600	2.773438	4992.188	0	4992.188	0.114605	0.000829	0.000207	3.190005	0.003829	50.008	0.037804	1754.001
7.0	0.29	3600	24.96094	49921.88	115.2307	54798.83	1.258008	0.009103	0.002276	3.190057	0.012103	50.00802	0.212405	1754.009
8.0	0.33	3600	72.10938	174726.6	450.3764	229075	5.258839	0.038016	0.009504	3.190238	0.041016	50.0081	1.325239	1754.038
8.2	0.34	720	84.58984	56411.72	553.5517	284933.2	6.541166	0.047272	0.011818	3.190295	0.050272	50.00812	1.798271	1754.047
8.4	0.35	720	98.45703	65896.88	1124.464	349705.6	8.028136	0.057997	0.014499	3.190362	0.060997	50.00814	2.403501	1754.058
8.6	0.36	720	115.0977	76879.69	1512.638	425072.6	9.758325	0.070467	0.017617	3.19044	0.073467	50.00818	3.177117	1754.07
8.8	0.37	720	135.8984	90358.59	2009.023	513422.2	11.78655	0.085073	0.021268	3.190532	0.088073	50.00821	4.170283	1754.085
9.0	0.38	720	159.4727	106333.6	2645.064	617110.7	14.16691	0.102195	0.025549	3.190639	0.105195	50.00826	5.443957	1754.102
9.2	0.38	720	187.207	124804.7	3461.126	738454.3	16.95258	0.122209	0.030552	3.190764	0.125209	50.00831	7.06952	1754.122
9.4	0.39	720	228.8086	149765.6	4504.852	883715.1	20.28731	0.146132	0.036533	3.190913	0.149132	50.00837	9.189959	1754.146
9.6	0.40	720	274.5703	181216.4	5853.412	1059070	24.31309	0.174961	0.04374	3.191094	0.177961	50.00844	11.90037	1754.175
9.8	0.41	720	395.2148	241122.7	7621.32	1292579	29.67354	0.213261	0.053315	3.191333	0.216261	50.00853	16.05028	1754.213
10.0	0.42	720	544.9805	338470.3	10091.04	1620959	37.21209	0.266953	0.066738	3.191668	0.269953	50.00867	22.38699	1754.267
10.2	0.43	720	768.2422	472760.2	13837.42	2079881	47.74751	0.341658	0.085414	3.192135	0.344658	50.00885	32.30055	1754.342
10.4	0.43	720	1024.785	645489.8	19687.51	2705684	62.11395	0.442898	0.110724	3.192768	0.445898	50.00911	47.54113	1754.443
10.6	0.44	720	1303.516	838188.3	28743	3515129	80.69626	0.572762	0.143191	3.19358	0.575762	50.00943	69.77418	1754.573
10.8	0.45	720	1497.656	1008422	42233.51	4481317	102.8769	0.726157	0.181539	3.194538	0.729157	50.00982	99.47068	1754.726
11.0	0.46	720	1655.742	1135223	60928.15	5555613	127.5393	0.894625	0.223656	3.195591	0.897625	50.01024	135.9104	1754.895
11.2	0.47	720	1684.863	1202618	84737.19	6673493	153.2023	1.067563	0.266891	3.196672	1.070563	50.01067	177.0839	1755.068
11.4	0.48	720	1666.836	1206612	112678	7767427	178.3156	1.234431	0.308608	3.197715	1.237431	50.01109	220.1343	1755.234
11.6	0.48	720	1585.02	1170668	142998.6	8795097	201.9076	1.389034	0.347259	3.198681	1.392034	50.01147	262.7335	1755.389
11.8	0.49	720	1462.988	1097283	173832.4	9718547	223.1071	1.526155	0.381539	3.199538	1.529155	50.01182	302.5778	1755.526
12.0	0.50	720	1325.703	1003929	203512.1	10518964	241.4822	1.643611	0.410903	3.200273	1.646611	50.01211	333.1806	1755.644
12.2	0.51	720	1205.059	911074.2	230673	11199365	257.102	1.742428	0.435607	3.20089	1.745428	50.01236	369.1485	1755.742
12.4	0.52	720	1092.734	827205.5	254638.5	11771932	270.2464	1.824847	0.456212	3.201405	1.827847	50.01256	395.6666	1755.825
12.6	0.53	720	1003.984	754818.7	275333.4	12251417	281.2538	1.893345	0.473336	3.201833	1.896345	50.01273	418.1723	1755.893
12.8	0.53	720	926.3281	694912.5	292982	12653348	290.4809	1.950395	0.487599	3.20219	1.953395	50.01288	437.2342	1755.95
13.0	0.54	720	855.6055	641496.1	307946.4	12986898	298.1381	1.997484	0.499371	3.202484	2.000484	50.01299	453.1817	1755.997
13.2	0.55	720	800.1367	596067.2	320549.7	13262415	304.4632	2.036203	0.509051	3.202726	2.039203	50.01309	466.4384	1756.036
13.4	0.56	720	747.4414	557128.1	331063.2	13488480	309.6529	2.067854	0.516964	3.202924	2.070854	50.01317	477.3702	1756.068
13.6	0.57	720	707.2266	523680.5	339771.1	13672389	313.8749	2.093523	0.523381	3.203086	2.096523	50.01323	486.2985	1756.094
13.8	0.58	720	669.7852	495724.2	346920.7	13821193	317.2909	2.11424	0.52856	3.203214	2.11724	50.01329	493.5448	1756.114
14.0	0.58	720	639.2773	471262.5	352743.6	13939712	320.0117	2.130708	0.532677	3.203317	2.133708	50.01333	499.3304	1756.131
15.0	0.63	3600	522.793	2091727	1737175	14244263	327.0033	2.172886	0.543221	3.203581	2.175886	50.01343	514.2526	1756.173
16.0	0.67	3600	445.1367	1742273	1824449	14162087	325.1168	2.161524	0.540381	3.20351	2.164524	50.0134	510.2185	1756.162
17.0	0.71	3600	393.8281	1510137	1844048	13828176	317.4512	2.115211	0.528803	3.20322	2.118211	50.01329	493.8854	1756.115

Figure 15 - Displays calculation of height above weir for 50 ft. weir. Where: P= height from base of embankment to base of weir, L= length of weir, H is surface water height above weir, b is embankment width, and KL, Le, Ce, and He are coefficients determined by Figures 5-3a and 5-3b in Brater and King (1976). Highlighted row represents time of maximum surface water level.

A	3550	acres		Weir Dimensions						
T_c	2	hours		P	4.0			Fig 5-3a (Brater & King)		
CN	80			El	b (ft.)	H	L (ft.)	L/b	k_L	L_e
Precip	4.5	inches		1754	655	0	75	0.115	0.008	75.008
				K_h	0.003					
$Q=C_eL_eH_e$^3/2										
$L_e=L+k_L$				C_e=Fig 5-3b=3.19+0.025(H/P)						
$H_e=H+k_H$				L_e=15.010+.0025H						
				H=-1.38448E-04(S_{cap}^2)+4.65376E-02(S_{cap})						

Time (Hrs.)	Time (days)	Time interval (s)	Q_{in} (cfs)	V_{in} (ft.^{3})	V_{out} (ft.^{3})	S_{cap} (ft.^{3})	S_{cap} (acre-ft.)	H (ft.)	H/P	C_e	H_e	L_e	Q_{out} (cfs)	WS El (ft.)
5.0	0.21		0	0	0	0	0	0	0	3.19	0.003	75.008	0.039317	1754
6.0	0.25	3600	2.773438	4992.188	0	4992.188	0.11460436	0.000829	0.000207	3.190005	0.003829	75.008	0.056704	1754.001
7.0	0.29	3600	24.96094	49921.88	172.8369	54741.23	1.25668562	0.009093	0.002273	3.190057	0.012093	75.00802	0.318212	1754.009
8.0	0.33	3600	72.10938	174726.6	674.8487	228792.9	5.25236316	0.037969	0.009492	3.190237	0.040969	75.00809	1.984353	1754.038
8.2	0.34	720	84.50904	56411.72	820.9206	284375.7	6.52836856	0.047179	0.011795	3.190295	0.050179	75.00812	2.689032	1754.047
8.4	0.35	720	98.45703	65396.88	1682.707	348589.9	8.00252302	0.057812	0.014453	3.190361	0.060812	75.00814	3.588695	1754.058
8.6	0.36	720	115.0977	76379.69	2260.27	423209.3	9.71554914	0.070159	0.01754	3.190438	0.073159	75.00818	4.735159	1754.07
8.8	0.37	720	135.8984	90358.59	2996.696	510571.2	11.7211024	0.084602	0.02115	3.190529	0.087602	75.00821	6.204957	1754.085
9.0	0.38	720	159.4727	106333.6	3938.55	612966.3	14.0717691	0.101511	0.025378	3.190634	0.104511	75.00825	8.085961	1754.102
9.2	0.38	720	187.207	124804.7	5144.731	732626.2	16.8187837	0.121248	0.030312	3.190758	0.124248	75.0083	10.48188	1754.121
9.4	0.39	720	228.8086	149765.6	6684.421	875707.4	20.1034762	0.144814	0.036204	3.190905	0.147814	75.00836	13.60184	1754.145
9.6	0.40	720	274.5703	181216.4	8670.137	1048254	24.0645935	0.173183	0.043296	3.191082	0.176183	75.00843	17.70088	1754.173
9.8	0.41	720	395.2148	241122.7	11268.98	1278107	29.3413078	0.21089	0.052722	3.191318	0.21389	75.00853	23.67914	1754.211
10.0	0.42	720	544.9005	338470.3	14096.01	1601681	36.7695334	0.263007	0.065952	3.191649	0.266007	75.00866	32.99296	1754.264
10.2	0.43	720	768.2422	472760.2	20401.96	2054039	47.1542487	0.337461	0.084365	3.192109	0.340461	75.00884	47.56545	1754.337
10.4	0.43	720	1024.785	645489.8	29001.03	2670528	61.3068815	0.43723	0.109307	3.192733	0.44023	75.00909	69.95126	1754.437
10.6	0.44	720	1303.516	838183.3	42306.02	3466410	79.5778272	0.564981	0.141245	3.193531	0.567981	75.00941	102.5387	1754.565
10.8	0.45	720	1497.656	1008422	62096.37	4412736	101.302471	0.715327	0.178832	3.194471	0.718327	75.00979	145.8816	1754.715
11.0	0.46	720	1555.742	1135223	89431.29	5458528	125.310556	0.879492	0.219873	3.195497	0.882492	75.0102	198.7123	1754.879
11.2	0.47	720	1584.863	1202618	124053.8	6537092	150.070982	1.046592	0.261648	3.196541	1.049592	75.01062	257.8301	1755.047
11.4	0.48	720	1566.836	1206612	164355.3	7579348	173.997898	1.20591	0.301477	3.197537	1.20891	75.01101	318.8096	1755.206
11.6	0.48	720	1585.02	1170668	207590.3	8542426	196.107119	1.351217	0.337804	3.198445	1.354217	75.01138	378.093	1755.351
11.8	0.49	720	1462.908	1097203	250084.9	9388024	215.537741	1.477392	0.369348	3.199234	1.480392	75.01169	432.2551	1755.477
12.0	0.50	720	1325.703	1003929	291725.3	10101028	231.887637	1.582444	0.395611	3.19989	1.585444	75.01196	479.1725	1755.582
12.2	0.51	720	1205.059	911071.2	328113.9	10683988	245.270614	1.667665	0.416916	3.200423	1.670665	75.01217	518.4099	1755.668
12.4	0.52	720	1092.734	827205.5	359129.6	11152064	256.016156	1.735589	0.433897	3.200847	1.738589	75.01234	550.4186	1755.736
12.6	0.53	720	1003.984	754818.7	384778.3	11522104	264.511117	1.788968	0.447242	3.201181	1.791968	75.01247	576.0222	1755.789
12.8	0.53	720	926.3281	694912.5	405518.7	11811498	271.154684	1.830517	0.457629	3.201441	1.833517	75.01258	596.2206	1755.831
13.0	0.54	720	855.6055	641496.1	422007.4	12030987	276.193451	1.861914	0.465478	3.201637	1.864914	75.01265	611.6385	1755.862
13.2	0.55	720	800.1367	596067.2	434829.3	12192225	279.894965	1.884915	0.471229	3.201781	1.887915	75.01271	623.0171	1755.885
13.4	0.56	720	747.4414	557123.1	444476	12304877	282.481102	1.900952	0.475238	3.201881	1.903952	75.01275	630.9928	1755.901
13.6	0.57	720	707.2266	523680.5	451443.5	12377114	284.139433	1.911222	0.477806	3.201945	1.914222	75.01278	636.1101	1755.911
13.8	0.58	720	669.7852	495724.2	456159.9	12416678	285.047705	1.916843	0.479211	3.20198	1.919843	75.01279	638.9289	1755.917
14.0	0.58	720	639.2773	471262.5	459016.9	12428924	285.328826	1.918582	0.479645	3.201991	1.921582	75.0128	639.7993	1755.919
15.0	0.63	3600	522.793	2091727	2301711	12218939	280.50825	1.88872	0.47218	3.201805	1.89172	75.01272	624.9066	1755.889
16.0	0.67	3600	445.1367	1742273	2276471	11684742	268.244771	1.81234	0.453085	3.201327	1.81534	75.01253	587.3551	1755.812

Figure 16 - Displays calculation of height above weir for 75 ft. weir. Where: P= height from base of embankment to base of weir, L= length of weir, H is surface water height above weir, b is embankment width, and KL, Le, Ce, and He are coefficients determined by Figures 5-3a and 5-3b in Brater and King (1976). Highlighted row represents time of maximum surface water level.

Table 4– Displays calculation of 7 foot embankment volume (associated with a 75 ft. weir)

7 Foot Embankment	Length (ft.)	Top Width (ft.)	Bottom Width (ft.)	X - Sec Area (ft.^{2})	Volume (ft.^{3})	Volume (C.Y.)
West Side	210	12	54	231	24255	898
Middle	130	12	54	231	30030	1112
East Side	315	12	54	231	36382.5	1348
Total	655					3358

Table 5 – Displays calculation of 8 foot embankment volume (associated with weirs of 20, 30, 50 ft. lengths)

8 Foot Embankment	**Length (ft.)**	**Top Width (ft.)**	**Bottom Width (ft.)**	**X - Sec Area (ft.^{2})**	**Volume (ft.^{3})**	**Volume (C.Y.)**
West Side	225	12	60	288	32400	1200
Middle	125	12	60	288	36000	1333
East Side	345	12	60	288	49680	1840
Total	695					4373

Table 6 – Displays haul volume in C.Y. of embankment material for 7 ft. and 8ft. embankments.

Embankment Haul Volume	**7 Foot Height**	**8 Foot Height**
C.Y.	3,358	4,373
Volume in situ = C.Y. /.85	3,951	5,145
Total haul volume (swell factor = 1.35)	5,333	6,945

Table 7 – Displays daily cost assessment of excavation/construction of embankment utilizing 21 C.Y. Self propelled scrapers 1500 ft. haul and sheepsfoot rollers.

21 C.Y. Self propelled scrapers (5) 1500 ft. haul & sheepsfoot rollers (2)	Daily Output (C.Y.)	Cost/C.Y	Mobilization Costs/Unit	# of Units	Daily Cost
Sheepsfoot Rollers	3,225	$0.64	$300	2	$2,664
Self propelled Scrapers	3,225	$4.40	$300	5	$15,690
				Total Cost/Day	$18,354

Table 8 – Displays daily cost assessment of excavation/construction of embankment utilizing 60 C.Y. rear dump trucks 1 mi. haul, sheepsfoot rollers, and 5 C.Y. wheel mounted front end loaders.

3 60 C.Y. rear dump truck 1 mi. haul, 2 sheepsfoot, & 2 5 C.Y. mounted front end loaders	Daily Output (C.Y.)	Cost/C.Y	Mobilization Costs/Unit	# of Units	Daily Cost
60 C.Y. Rear Dump Truck	2960	$1.90	$150	3	$6,074
Sheepsfoot Rollers	2960	$0.76	$300	2	$2,850
Front End Loaders	2960	$0.64	$150	2	$2,194
				Total Cost/Day	$11,118

Table 9 – Displays total project costs associated with weirs of varying lengths. Costs determined using RS Means (2002)

Column1	20 Ft. Weir	30 Ft. Weir	50 Ft. Weir	75 Ft. weir
Volume Hauled (C.Y.)	6,945	6,945	6,945	5,333
Excavation/Haul/Compaction Daily Output (C.Y.)	2,960	2,960	2,960	2,960
Excavation/Haul/Compaction Costs/Day	$11,118	$11,118	$11,118	$11,118
Days Required for Excavation/Haul/Compaction	3.0	3.0	3.0	2.0
Sheet Pile Area (Ft.^{2})	552	672	912	1092
Sheet Pile Cost/Ft.^{2}	$40	$40	$40	$40
9 in. Gabion Area (S.Y.)	9	11	11	13
9 in. Gabion Cost/S.Y.	$33	$33	$33	$33
12 in. Gabion Area (S.Y.)	5	20	40	70
12 in. Gabion Cost/S.Y.	$37	$37	$37	$37
8 Foot Wide Bridge Area (S.Y.)	44	53	71	89
8 foot Wide Bridge Cost/S.Y.	$48.80	$47.56	$53.75	$74.56
Total Cost (2002)	$58,081.69	$63,863.23	$75,479.72	$75,529.06
Total Cost (2009)	$70,611	$77,639	$91,762	$91,821

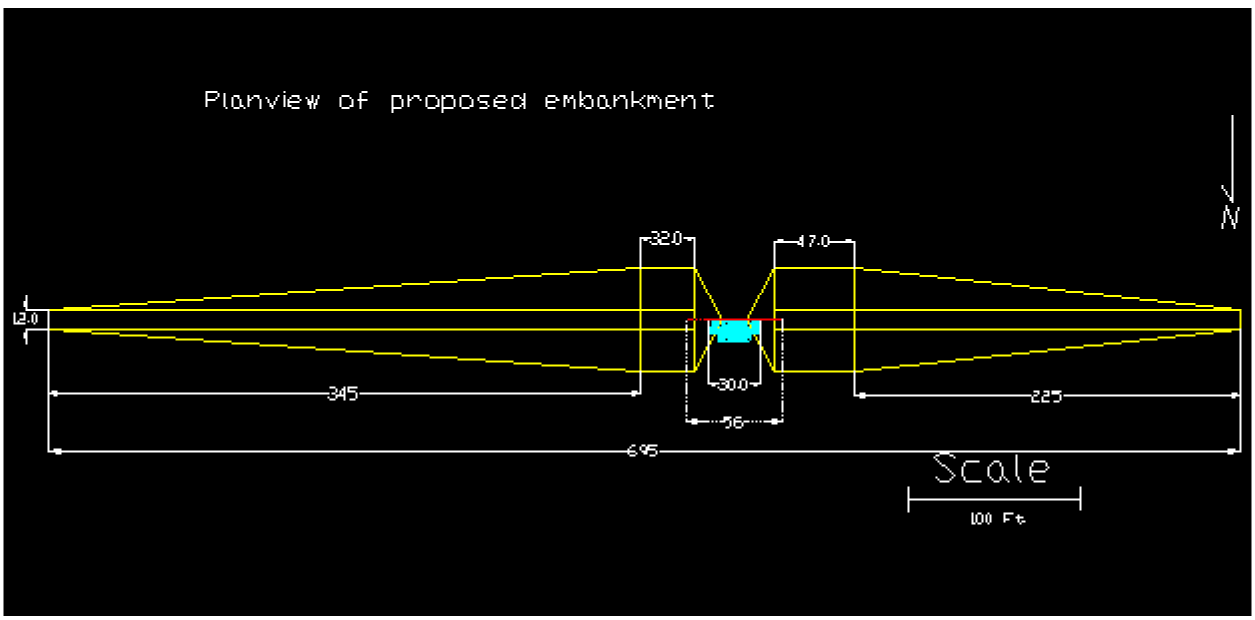

Figure 17- Displays Plan view of proposed embankment. Yellow lines signify embankment outline and blue circles represent gabions. All numbers represent distances in feet. Drawing does not include walk bridge.

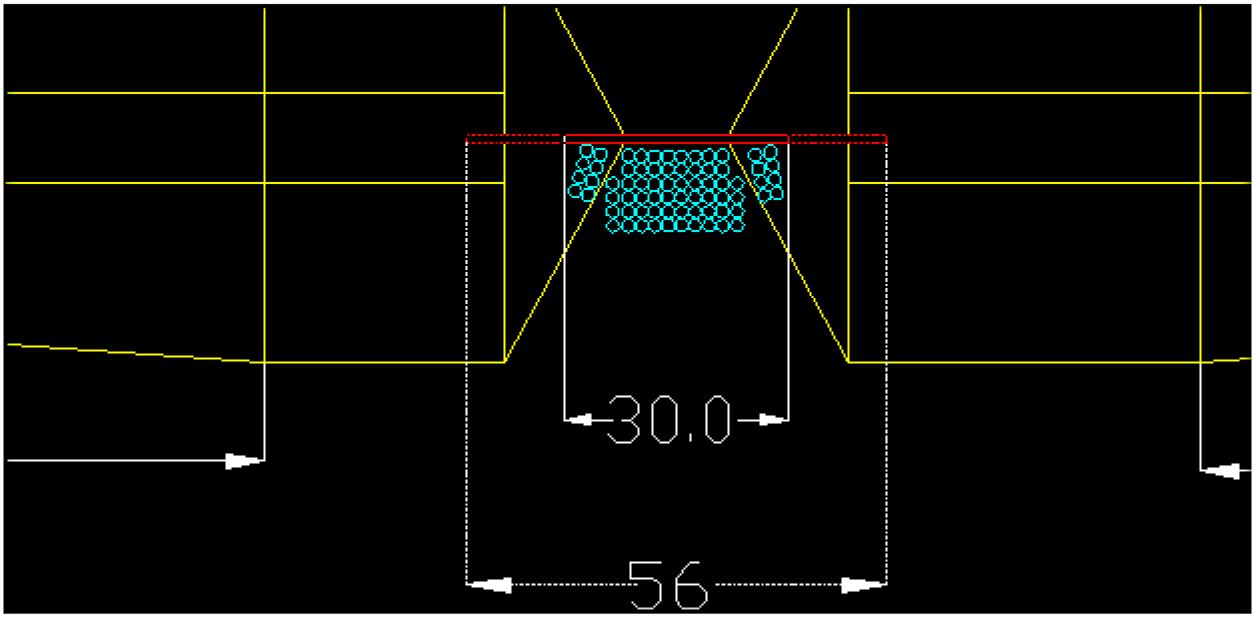

Figure 18- Displays close up of plan view near weir structure. All numbers represent distances in feet. Drawing does not include walk bridge.

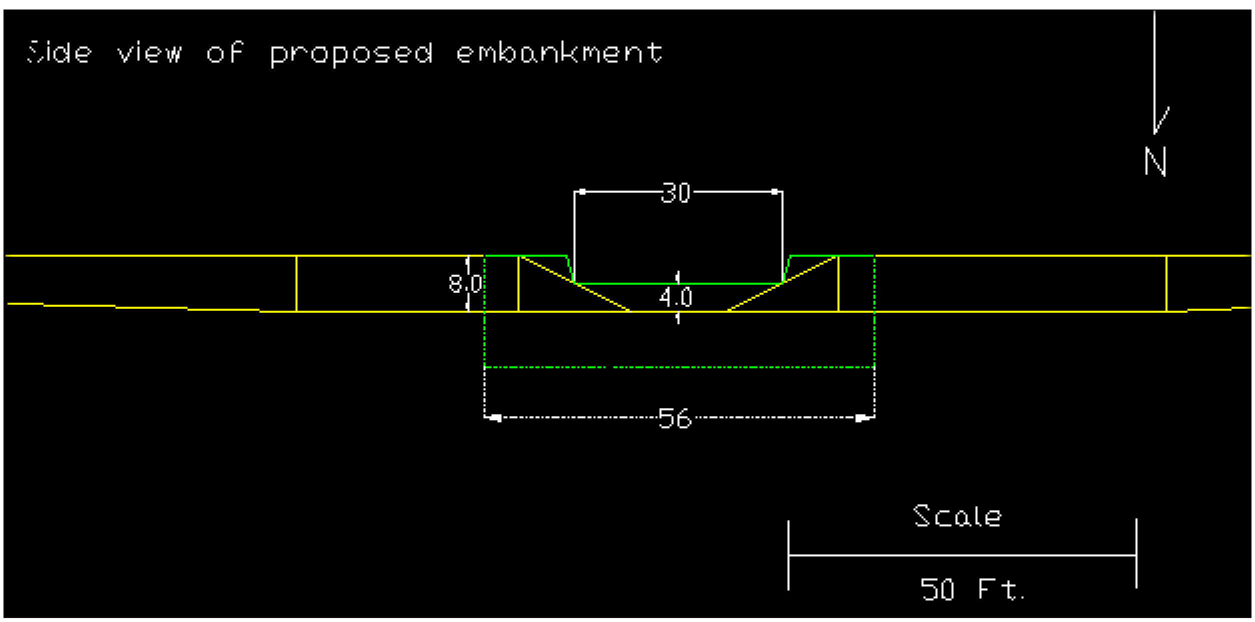

Figure 19- Displays side view of proposed embankment. Yellow lines represent embankment outline and green indicate weir outline. Dashed green lines are not exposed from this view. All numbers represent distances in feet. Drawing does not include walk bridge.

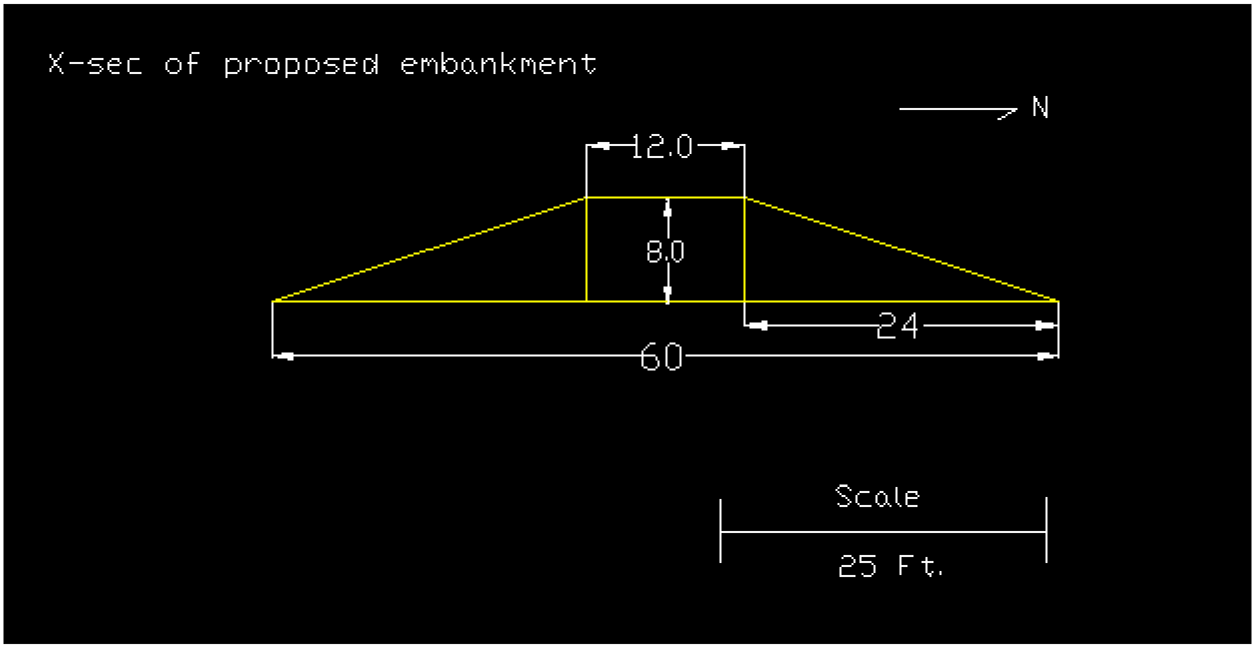

Figure 20 – Displays cross-sectional view of proposed embankment. Drawing represents Cross-sectional dimensions near weir, where the embankment is situated on level ground and is at its widest. All numbers represent distances in feet.