5.4 Conclusions

If the OHB Ring Levee was set at 4 ft above the SWL of 922.5 ft and the exterior levee slope was constructed at 1V:4H, the maximum calculated wave overtopping for the most extreme event simulated (NNW Wind at 55.5 mi/hr) would be:

- *Maximum average overtopping rate = 0.00203 cfs/ft*
- *Maximum total average overtopping = 1.92 cfs for the entire length of levee*

The maximum average overtopping rate is well below the allowable overtopping (0.01 cfs/ft) and the total average overtopping is not a concern for interior flood control.

If the OHB Ring Levee was set at 3 ft above the SWL of 922.5 ft and the exterior levee slope was constructed at 1V:4H, the maximum calculated wave overtopping for the most extreme event simulated (NNW Wind at 55.5 mi/hr) would be:

- *Maximum average overtopping rate = 0.01 cfs/ft*
- *Maximum total average overtopping = 15.85 cfs for the entire length of levee*

The maximum average overtopping rate is right at the allowable overtopping (0.01 cfs/ft) and the total average overtopping could be accommodated by interior flood control (ditches, ponds, and pump stations).

If the design were just to satisfy the allowable overtopping criteria, a 3 ft levee height with 1V:4H slopes would be minimally adequate. A 4 ft levee height with 1V:4H would be more than adequate to limit wave overtopping, however, one location in the northeast corner of OHB would be exceeded by more than 4 ft of wave runup (see Figure 38). If the levee slope at this location were flattened to 1V:5H, the wave runup would not exceed 4 ft. Because the 4 ft levee height (with modified northeast levee slope) can accommodate both wave runup and wave overtopping criteria and because it exceeds the elevation of the overflow spillway by 3.5 ft rather than 2.5 ft, the preferred levee height for hydraulic criteria will be 4 ft.

5.5 Levee System Evaluation Considerations

The purpose of this analysis is to assess the top elevation of the OHB ring levee with regard to EC 1110-2-6067 requirements. All parties involved ultimately want assurance that the ring levee will be 'accredited' by the Federal Emergency Management Agency (FEMA). Two key definitions that are necessary for this discussion are:

- Annual Exceedance Probability (AEP) – the probability that a flood will equal or exceed a given elevation or discharge in any given year. A 1% AEP event has a 1 in 100 chance of being equaled or exceeded in any given year. A 1% AEP event is typically referred to as a "100-yr" event since the long-term expected value for the recurrence interval is 100 years. AEP is equivalent to "percent-annual-chance" and Annual Chance Exceedance (ACE).
- Conditional Non-Exceedance Probability (CNP) – the uncertainty about the AEP stage or discharge, due to the uncertainty in discharge-probability and stage-discharge estimates. The 1%

AEP typically refers to the 1% AEP at a 50% CNP as it has an equal chance of being exceeded or not exceeded based on uncertainties. Sometimes the word "assurance" is used instead of CNP.

EC 1110-2-6067 Top of Levee Elevation Critera:

1) The top of levee must be a minimum of 2 ft above the 1% AEP stage at a 50% CNP.
2) If the top of levee is *less* than 3 ft above the 1% AEP stage at a 50% CNP, the CNP for the top of the levee must be equal to or greater than **95%** for the 1% AEP stage.
3) If the top of levee is *greater* than 3 ft above the 1% AEP stage at a 50% CNP, the CNP for the top of the levee must be equal to or greater than **90%** for the 1% AEP stage.
4) If the top of levee height meets all three of the preceding criteria, it still must be higher than the wind-induced level for the 1% AEP stage with consideration for wave runup or allowable overtopping.

In typical riverine levees, there is uncertainty in the discharge-frequency curve and the stage discharge relationship, both having the potential to greatly reduce the CNP of the 1% AEP stage. Given the capacity and redundancy of outflow structures, it is known that a levee 2 ft above the 50% CNP 1% AEP stage has a CNP of at least 95% as long as waves are not considered. Therefore the wind/wave considerations outweigh hydrology/hydraulic considerations.

5.6 Flood-Side Erosion Resistance of the Levee

One additional concern for the performance of a levee in relation to wind and waves is the ability of the levee to resist erosion from wave attack. Results from full-scale testing of grass-covered clay levee slopes done by Seijffert and Verheij (1998) summarized in the ERDC/CHL Technical Report 10-7 (Hughes, 2010), states the following:

a) Waves up to 0.5 m (1.6 ft) caused no damage to grass covers
b) Waves in the range of 0.5 – 1.5 m (1.6 – 4.9 ft) with a duration between 6 and 24 hours generally did not cause severe damage
c) Waves greater than 1.5 m (4.9 ft) will likely cause severe erosion

Peak wave heights of around 3 ft, as modeled using STWAVE, would only be anticipated to last around one hour. Even if these peak wave heights lasted an order of magnitude longer than expected (~10 hours), the technical report states that they would "generally not cause severe damage." Additional checks using empirical equations developed by Seijffert and Verheij indicate that wave heights of 3 ft lasting for 6 hours or wave heights of 1.6 ft lasting for 24 hours would cause less than a few inches of erosion of the levee.

5.7 Wind Induced Ice Forces on the Levee

The use of the staging area will occur after the initial spring warm-up has melted enough snow to raise flows on the Red and Wild Rice Rivers to above flood stage. Historically, there are some instances where a cold-snap has occurred after a warm-up period, causing low temperature conditions that can lead to the re-formation of ice. The year 1997 is one of these instances, where five consecutive days with high temperatures below freezing occurred after an initial warm-up and ice formation occurred throughout

the basin. An analysis of potential ice growth and wind driven ice forces for the 1997 event has been performed as part of the design of the OHB levee.

By extracting the daily temperature data in 1997 from the weather station used for the wind data, an estimation of thermal ice growth can be made using the following equation from the Ice Engineering reference (USACE, 1999):

$$h_j = \alpha U_j^{1/2}$$

where:

h_j	=	calculated ice thickness on day j
U_j	=	Accumulated Freezing Degree-Days (AFDDs) recorded between the onset of freezeup (day 1) and day j
α	=	Ice cover condition, 0.47 used for other FMM analyses

A plot of the potential ice growth and recorded daily temperatures can be seen in the following figure, Figure 43.

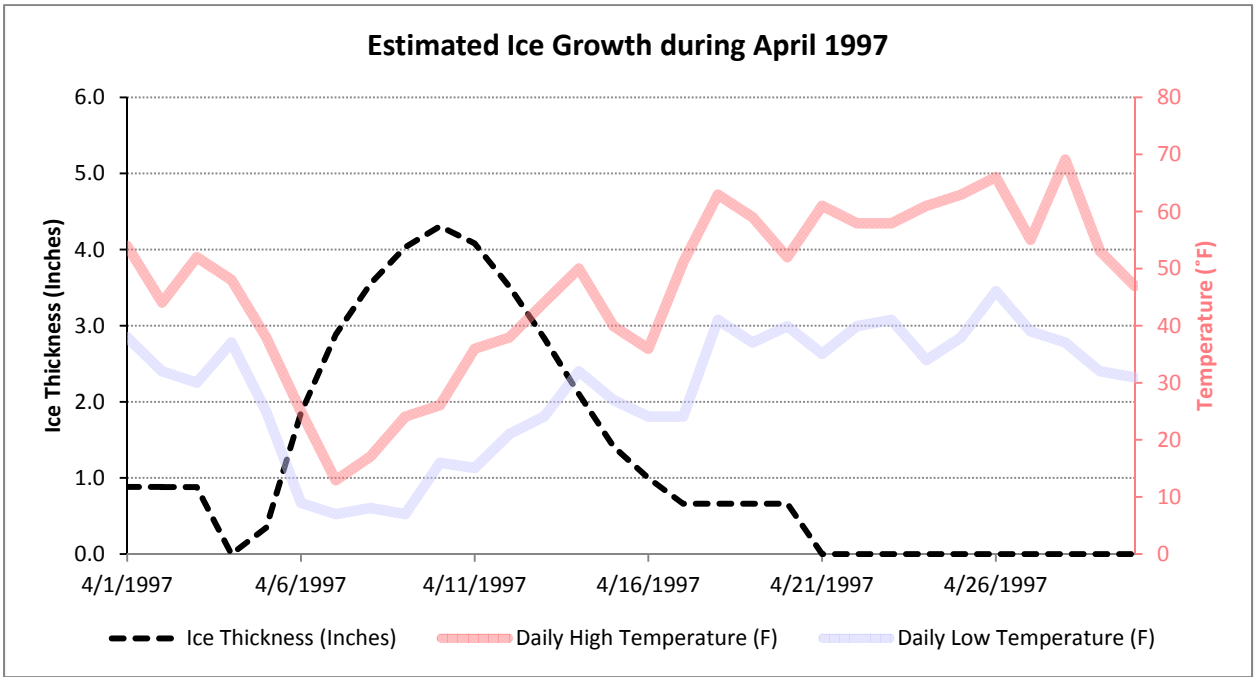

Figure 43 – Estimated Ice Growth during April 1997

The levee has a top width of 100 feet and will be at least 46 feet wide at the 922.5 water surface elevation. Ice that would form and be pushed by wind during project operation will not cause significant damage on an embankment of this size with 1V:4H or flatter slopes. Some turf damage may occur, but the ice will ride up the 1V:4H or flatter slope before it would remove a significant portion of the levee cross-section. It's possible that some ice could even make it to the top of the levee, but the volume of water in the ice would not be enough to cause flooding issues in the interior area, given the ditch that will exist at the interior toe of the levee. The infrequency of such an event warrants simply fixing any levee damage as needed. Interior drainage pipe outlets will not be allowed on the north side of the ring levee due to the wind-driven ice forces that could cause problems for unprotected culvert ends and flap gates.

5.8 Final Recommendations

- Top of Oxbow/Hickson/Bakke Ring Levee Elevation should be set 4 feet above pool elevation of 922.5. This elevation does not include required overbuild.
- Include an overtopping segment that would have controlled overtopping in a Probable Maximum Flood event. The height would be 3.5 feet above pool elevation of 922.5, or 0.5 ft lower than the Top of Levee elevation. The location and length of the segment is still to be determined.
- Erosion Protection: Topsoil and seed only with the intent of establishing and maintaining vegetation on the clay levee.
- Exterior Side Slopes of 1V:4H are acceptable with exception of the NE corner where wave heights would be greatest and the exterior slope should be flattened to 1V:5H.
- Interior Side Slopes of 1V:5H will be used per Local Sponsor request (1V:4H is acceptable from a COE perspective).
- Vegetation Free Zone (VFZ): Extends minimum of 15' from the toe of the levee. Local drainage ditches will be placed outside of the VFZ.
- Use EM 1110-2-1913, "Design and Construction of Levees".

6 REFERENCES

Adaptive Hydraulics Modeling (ADH). Accessed 2013. http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Links;139

EurOtop Manual. 2007. Overtopping Manual; Wave Overtopping of Sea Defences and Related Structures – Assessment Manual. UK: N.W.H. Allsop, T. Pullen, T. Bruce. NL: J.W. van der Meer. DE: H. Schüttrumpf, A. Kortenhaus. www.overtopping-manual.com.

Gumbel, Emil Julius. Statistical theory of extreme values and some practical applications. U.S. Govt. Print Office, 1954.

Holmes, J.D.. "Prediction of design wind speeds". Accessed 2013. www.hurricaneengineering.lsu.edu/CourseMat/03Lect4DesignWind.ppt

Hughes, Steven A.. "Flood-Side Wave Erosion of Earthen Levees: Present State of Knowledge and Assessment of Armoring Necessity". ERDC/CHL TR-10-7. U.S. Army Corps of Engineers, Coastal and Hydraulics Laboratory, Vicksburg, MS, August 2010.

Mapping of areas protected by levee systems, 44 CFR 65.10 (2010).

NOAA. National Climatic Data Center (NCDC). Daily Summaries Station Details. Fargo Hector International Airport, ND US. Accessed 2013. http://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00014914/detail

STWAVE – Steady State Spectral Wave. Accessed 2013. http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=software;9

U.S. Army Corps of Engineers. Coastal Engineering Manual (CEM). Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. 2002.

U.S. Army Corps of Engineers. Ice Engineering. Engineer Manual 1110-2-1612, U.S. Army Corps of Engineers, Washington, D.C. 1999.

U.S. Army Corps of Engineers. Engineering Circular No. 1110-2-6067 (EC-1110-2-6067). *USACE Process for the National Flood Insurance Program (NFIP) Levee System Evaluation.* Washington, DC. August 2010.