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2.4.7 Ice Effects

The potential impact of ice effects on the Clinch River Nuclear (CRN) Site is evaluated in this section. Because the site is located in a region of continental, humid subtropical climate, extreme ice conditions with potential adverse effects on safety-related and risk-significant structures, systems, and components (SSCs) are not typically present. Additionally, the small modular reactors (SMRs) under consideration for the CRN Site do not rely on an external, safety-related water source and therefore will not be affected by any potential loss of water supply due to ice conditions in the region.

2.4.7.1 Historical Ice Accumulation

Historical ice accumulations in the site region are evaluated by examining the U.S. Army Corps of Engineers (USACE) Ice Jam Database, weather records maintained by the National Oceanic and Atmospheric Administration (NOAA), and other available sources.

The USACE Ice Jam Database, which contains records of ice jam events from 1780 to the access date of February 7, 2014, documents one ice jam event on the Clinch River which took place near Clinton at Latitude: 36° 6' 12" N, Longitude: 84° 7' 55" W, in 1940 (Reference 2.4.7-1). This location is over 15 miles (mi) upstream of the CRN Site as shown in Figure 2.4.7-1. For this event, the Ice Jam Database states that the Clinch River was obstructed by rough ice at Clinton, TN from January 22 through February 6, 1940.

Prior to the closure of Watts Bar Dam, the most severe period of cold weather recorded was in January and early February of 1940. A maximum ice depth of five inches (in.) was recorded on the Tennessee River at Chattanooga. Except for one small ice jam on the lower French Broad River, there were no other ice jams recorded.

Records of icing near the CRN Site are limited. Newspaper records indicate that the earliest known freeze in the vicinity was at Knoxville in 1796. Newspaper accounts and U.S. Weather Bureau records for Knoxville provide a fairly complete history of icing for the period of 1840 to 1940. During this period, the Tennessee River at Knoxville has frozen more than 16 times, and floating ice has been observed 6 other times. The most severe event was in December of 1917 to January of 1918. During this time, ice jammed the Tennessee River at Knoxville for one to two weeks, reaching 10 feet (ft) high in some places. Rain and rising temperatures in late January produced flooding on the Clinch River in an event referred to by locals as the “ice tide”; however, there is no record of ice jamming during that period.

Historical weather data indicate that sub-freezing air temperatures can occur during the winter months in the area (Figure 2.4.7-2). For instance, according to NOAA National Weather Service (NWS), the all-time lowest temperature is -24°F recorded on January 21, 1985 for the Knoxville area, the records of which began in 1871 (Reference 2.4.7-2). Reference 2.4.7-3 also includes historical accounts of occurrences of freezing conditions in the region.

With regard to water temperature, the lowest water temperature observed in Watts Bar Reservoir at the dam, during the periods from 1942 to 1953 and from June 1967 to November 1973, was 39°F and occurred on January 30, 1970, the coldest January in the area since 1940. This water temperature is indicative of the lowest temperature released from Watts Bar Reservoir during the winter months.

Based on the climatic condition of the area and historical evidences, it can be established that the potential for ice formation and accumulation including ice jams exists in the area of the CRN Site. However, an ice jam sufficient to cause flooding at the CRN Site is not credible. This is

demonstrated by using conservative postulations which are not physically credible, consistent with the hierarchical hazard assessment (HHA) approach, as presented below.

2.4.7.2 High and Low Water Levels

The air temperatures near the CRN Site have historically fallen below freezing in the winter seasons as indicated by the mean daily temperatures measured at the Knoxville Municipal/McGhee Tyson Airport Station (Figure 2.4.7-2). This introduces the possibility of ice blockage of catch basins and drains causing storm water runoff to back up to the yard, creating a potential flood risk to the site. However, in evaluating the design basis flood hazard evaluation for the safety-related SSCs at the CRN Site, regarding in particular the local intense precipitation (LIP) flooding mechanism, it is assumed that all culverts, catch basins, and storm drains are blocked. With this assumption, the site is designed to pass the runoff from the LIP event without adversely impacting any safety-related facility as presented in Subsection 2.4.2. Therefore, flooding of any safety-related SSCs, as a result of LIP coincidental with ice formation, is precluded. Locating the site finish grade at elevation 821 ft North American Vertical Datum of 1988 (NAVD88) (821.4 ft National Geodetic Vertical Datum of 1929 [NGVD29]), which is above natural grade, creates a positive gradient to allow storm water runoff to gravity flow away from all safety-related SSCs and to prevent backwater flooding due to ice accumulation and ice jam formation in any of the natural water courses.

The breach of an upstream ice dam is one of the considerations in the flood hazard evaluation for the CRN Site. The flood risk to the site in a breach event would be most critical when the ice jam is formed just upstream of the site, at approximately Clinch River Mile (CRM) 16, maximizing the storage that can be impounded behind the jam. Given that the Melton Hill Dam is located at CRM 23.1, a 7.1-mi stretch of the river could hypothetically be impounded in a worst-case ice jam scenario. Because there are no natural or man-made features in this stretch of the river that particularly foster the formation of ice jams, a conservative assumption on the height of the ice jam is made to derive a bounding estimate of the impoundment volume, consistent with the HHA approach. It is assumed that the ice jam will build up to about 51 ft in height, extending from the river bed elevation near the site at approximately elevation 720 ft NAVD88 (720.4 ft NGVD29) to elevation 770.6 ft NAVD88 (771 ft NGVD29) which is the maximum design tailwater level at Melton Hill Dam (based on 124,000 cubic foot per second release) and also the maximum known flood level (occurring in March 1886). Conservatively using 1500 ft to represent the width of the impounded river, the bounding impoundment volume behind the hypothetical ice jam is computed to be about 66,000 acre-ft. This volume is insignificant in comparison with the combined storage capacities of the Norris Reservoir (about 2 million acre-ft at maximum operating water level of elevation 1019.6 ft NAVD88 (1020 ft NGVD29), and the Melton Hill Reservoir, which is approximately about 120,000 acre-ft at maximum pool level of elevation 794.6 ft NAVD88 (795 ft NGVD29). Combining with the higher available hydraulic heads for the flood waves during a breaching event of the two upstream dams, it is, therefore, concluded that the flooding impact on the CRN Site from the breach of any upstream ice dam will be bounded by the impact from the most limiting dam failure described in Subsection 2.4.4.

For high water concerns due to backwater caused by ice jams formed downstream of the CRN Site, a hypothetical worst case scenario, consistent with HHA approach, was conservatively assumed with ice buildup to a maximum possible elevation in the river downstream of the site. By reviewing the natural landscape and manmade structures in the river system, it was determined that the worst case backwater flooding at the site would occur when ice is built up at the Watts Bar Dam. The deck level of the dam is at elevation 751.6 ft NAVD88 (752 ft NGVD29) and the top of the earth embankment is at elevation 771.6 ft NAVD88 (772 ft NGVD29), with 20 ft of difference between the two levels. Assuming that an ice jam would build up to the top of the earth embankment, the backwater level behind the ice jam would be of the same order, i.e., about elevation 771.6 ft NAVD88 (772 ft NGVD29), which is 31 ft above the summer (higher) normal

operating level of elevation 740.6 ft NAVD88 (741 ft NGVD29) of the reservoir. As the site finish grade is at elevation 821 ft NAVD88, more than 49 ft above the hypothetical maximum ice buildup elevation, it is concluded that no safety-related or risk-significant SSCs will be affected by the backwater effect of a downstream ice jam.

Low water conditions resulting from ice formation or accumulations that may cause interruption of stream flow in Clinch River arm of the Watts Bar Reservoir will not impact the site, as SMRs being considered for the CRN Site do not rely on an external water source for safety-related and risk-significant water supply.

2.4.7.3 Ice Sheet Formation

The SMRs being considered for the CRN Site do not require external water sources for safety-related and risk-significant SSCs and do not rely on any open storage facilities or impoundments to supply or maintain the inventory for safety-related water use. Consequently, a reduction of stream flow in the river or storage volume in an impoundment due to ice sheet formation will not introduce any adverse impacts to safety-related or risk-significant SSCs.

The SMRs to be located at the CRN Site use cooling towers to dissipate the excess heat load from the main steam condensers. The three main water structures in the cooling system that would have hydrologic interfaces with ice sheet formation are the cooling tower basin, at the base of each cooling tower, the holding pond at the site for cooling tower blowdown and plant discharges, and the makeup water intake structure, located on Clinch River arm of the Watts Bar Reservoir, which supplies makeup water to the cooling water system.

Because subfreezing air temperatures can occur during the winter months, ice sheet formation is possible. The ice layer thickness was estimated to evaluate the impact of ice formation on the nonsafety-related cooling tower basins and intake structure.

Air temperature data from the nearby Knoxville Municipal/McGhee Tyson Airport meteorological station (Figure 2.4.7-1) was used for the ice thickness estimation (Reference 2.4.7-4). The station is located about 20 mi east of the site (Figure 2.4.7-1), and its temperature data is considered to be representative of the site and the nearby region. For this analysis, the station daily weather data from January 1, 1948, through September 1, 2013, (approximately 65 years of data) were used.

The examination of the daily average air temperature from the meteorological station, for the period of record from 1948 to 2013 (Figure 2.4.7-2), showed that there were several years in which the daily average temperature fell below freezing for consecutive days during the months of December through February. However, it appears that January and February were generally the months in which ice thickness reached its maximum (Table 2.4.7-1).

To predict the maximum ice thickness (t_i) that can form at the CRN Site, an analysis of the temperature data was made to determine the maximum accumulated freezing degree-days (AFDD) for the period of record, using the procedures in Reference 2.4.7-5, developed by the United States Army Corps of Engineers (USACE).

Following the methodology in Reference 2.4.7-5, freezing degree day (FDD) value for each day was determined by subtracting the daily average temperature from 32°F. The AFDD is then determined by summing the FDD values for each day during the winter. A negative freezing degree day value represents a temperature warmer than freezing, while a positive freezing degree day represents temperatures below freezing. The FDD values for each day of the winter were summed to determine the net AFDD. The AFDD point was reset to zero whenever the value

became negative. The peak AFDD value for the period analyzed was 182.4°F days, which occurred on February 16, 1985.

The ice thickness was then estimated using a conservative coefficient (C = 0.8), recommended for a windy lake with no snow condition (Reference 2.4.7-5). Figure 2.4.7-2 depicts the graph of air temperature (T_a) and AFDD for the period of record. Figure 2.4.7-3 depicts the temporal variation of the ice thickness (t_i). The maximum ice thickness was estimated to be approximately 11 in., occurring on February 16, 1985. This is also the year with the all-time lowest temperature (-24°F) recorded in Knoxville since 1871 (Reference 2.4.7-2). Figure 2.4.7-4 depicts the variations of T_a and AFDD for the winter of 1984/1985. Similarly, the variation of the estimated ice thickness (t_i) over the winter of 1984/1985 is shown in Figure 2.4.7-5. The yearly maximum ice thickness for the approximately 65-year period is plotted in Figure 2.4.7-6 and provided in Table 2.4.7-1.

As demonstrated above, ice could build up to a maximum thickness of approximately 11 in. at the CRN Site and vicinity for the worst winter on record. Being located in a relatively mild climatic region, the plant will not typically be subject to extreme ice conditions. Detailed design of the closed cycle cooling tower and intake structure was not performed to support the ESPA; however, detailed design of the closed-cycle cooling tower and intake structure would consider ice effects, consistent with standard industry practice, to protect against unplanned interruption of the operation of the cooling system.

2.4.7.4 Ice-Induced Forces and Blockages

The SMRs being considered for the CRN Site do not include safety-related or risk-significant SSCs that are subject to ice-induced forces or blockages from either sheet ice or frazil ice.

2.4.7.5 Consideration of Other Site-Related Evaluation Criteria

There is no additional site information that would indicate an icing scenario more severe than has been described above.

2.4.7.6 Consideration of Cold-Region Hydrology

The CRN Site is located in a region characterized as continental, humid subtropical climate; therefore, impacts associated with cold region hydrologic effects, including permafrost and significant frost, are not applicable to the site. The effect of rain-on-snow, ice and/or frozen soils is addressed, as applicable, in Subsection 2.4.2 for local intense precipitation flooding evaluation and in Subsection 2.4.3 for stream flooding evaluation.

2.4.7.7 Conclusion

Historical and postulated ice conditions applicable to the CRN Site are evaluated to determine the impact on the safety of the plant. Due to the relatively mild climatic condition at the CRN Site, and the elevated design plant grade above natural drainages, in combination with the SMR plant design that does not rely on external water sources for safety-related water use, it is concluded that ice effects will not cause flooding or water availability concerns for the safety-related and risk-significant SSCs.

2.4.7.8 References

2.4.7-1. USACE, Clinch River Historical Ice Jam Data, Cold Region Research and Engineering Laboratory (CRREL). Available at https://rsgisias.crrel.usace.army.mil/apex/f?p=273:2:519442794021001, accessed February 7, 2014.

2.4.7-2. NOAA, Knoxville Climate Normals and Records. Available at http://www.srh.noaa.gov/mrx/?n=tysclimate, accessed June 17, 2014.

2.4.7-3. Coggins, A.R., *Tennessee Tragedies, Natural Technological and Societal Disasters in the Volunteer State*. The University of Tennessee Press, 2011.

2.4.7-4. NOAA. Available at http://www1.ncdc.noaa.gov/pub/orders/CDO3843946306650.txt and http://www1.ncdc.noaa.gov/pub/orders/CDO8763406306656.txt, accessed June 17, 2014.

2.4.7-5. USACE, ERDC/CRREL, “Method to Estimate River Ice Thickness Based on Meteorological Data,” Technical Note 04-3, June 2004.

Table 2.4.7-1
Estimated Maximum Ice Thickness, t_i, (in) for Each Year for about 65-year Period of Record

Year	Date	t_i (in)	Year	Date	t_i (in)
1949	30-Jan	2.0	**1982**	19-Jan	9.1
1950	29-Nov	5.1	**1983**	31-Dec	8.2
1951	4-Feb	4.9	**1984**	2-Jan	8.4
1952	30-Jan	3.0	**1985**	16-Feb	10.8
1953	19-Dec	4.5	**1986**	29-Jan	5.4
1954	14-Jan	4.2	**1987**	29-Jan	4.6
1955	14-Feb	4.9	**1988**	16-Jan	7.5
1956	10-Jan	2.4	**1989**	27-Dec	9.0
1957	13-Dec	4.3	**1990**	2-Jan	7.3
1958	21-Feb	9.3	**1991**	16-Feb	3.8
1959	12-Jan	5.3	**1992**	20-Jan	3.5
1960	14-Mar	6.0	**1993**	15-Mar	3.9
1961	30-Jan	6.7	**1994**	23-Jan	9.0
1962	14-Jan	7.0	**1995**	13-Feb	5.8
1963	31-Dec	8.4	**1996**	7-Feb	7.8
1964	17-Jan	8.6	**1997**	19-Jan	6.5
1965	5-Feb	6.6	**1998**	13-Mar	2.7
1966	6-Feb	8.6	**1999**	6-Jan	4.5
1967	26-Feb	4.7	**2000**	31-Dec	7.1
1968	24-Feb	5.6	**2001**	4-Jan	8.2
1969	14-Jan	6.3	**2002**	5-Jan	4.2
1970	24-Jan	9.1	**2003**	28-Jan	6.8
1971	15-Feb	5.0	**2004**	11-Jan	4.0
1972	17-Jan	4.8	**2005**	19-Jan	3.7
1973	14-Jan	5.7	**2006**	9-Dec	3.1
1974	26-Feb	2.6	**2007**	6-Feb	4.2
1975	24-Dec	3.6	**2008**	4-Jan	3.9
1976	10-Jan	5.4	**2009**	22-Jan	5.4
1977	8-Feb	10.1	**2010**	14-Jan	8.4
1978	8-Feb	9.8	**2011**	15-Jan	5.1
1979	11-Feb	5.3	**2012**	4-Jan	2.6
1980	13-Feb	6.4	**2013**	2-Feb	2.0
1981	18-Jan	6.0			

Notes:

Year 1948 is not included because the data for part of 1947 winter is not available.

Year 2013 does not include data from Sept. 2 to Dec. 31 (a check of the 2013/2014 winter [until February 6] data showed that the temperature was not lower than the historical low temperature recorded in 1985).

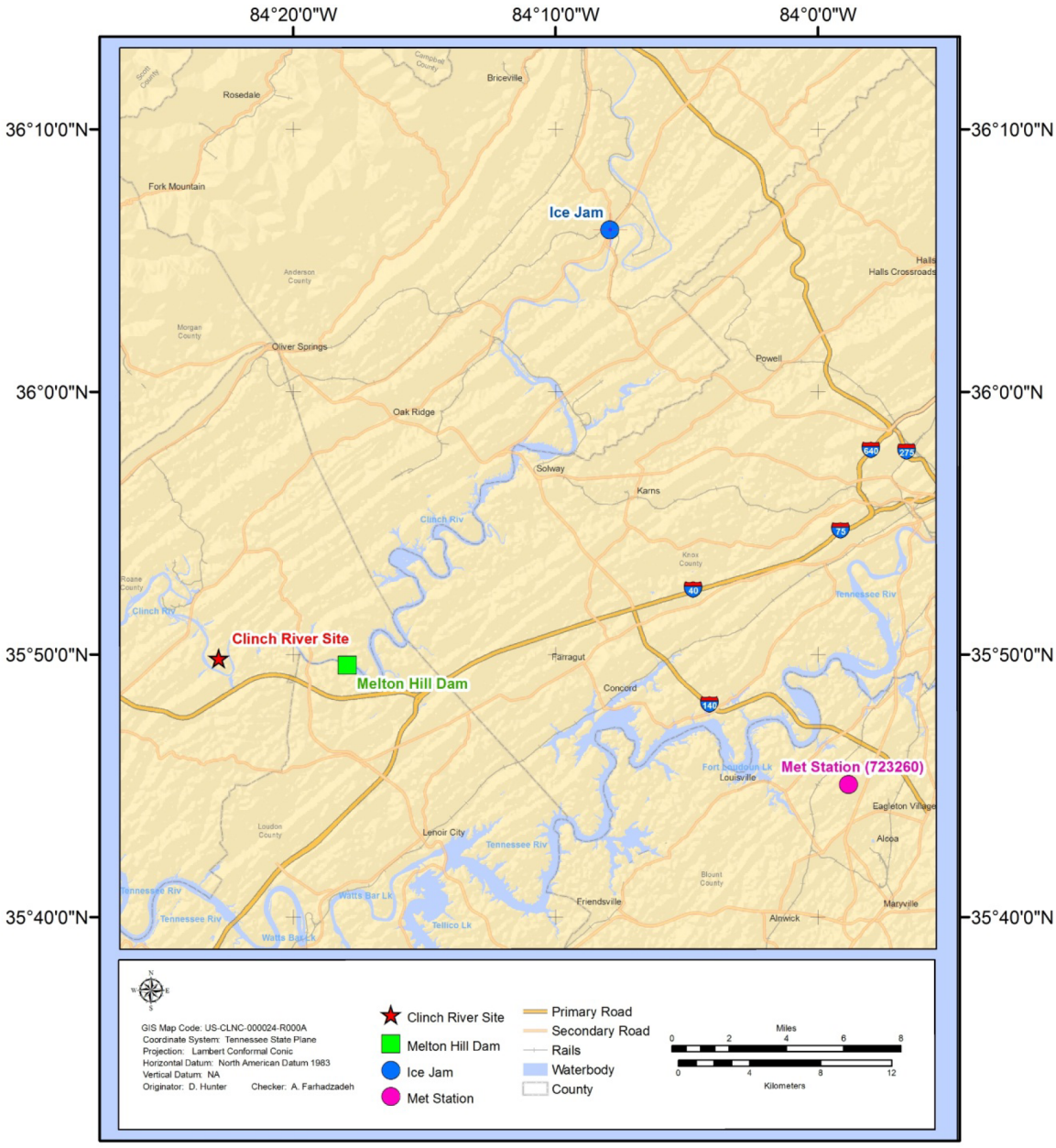

Figure 2.4.7-1. Locations of the Clinch River Project Site, Meteorological Station, and Historical Ice Jam

Figure 2.4.7-2. Temporal Variations of Daily Average Temperature and Accumulated Freezing Degree-Days for about 65-year Period of Record

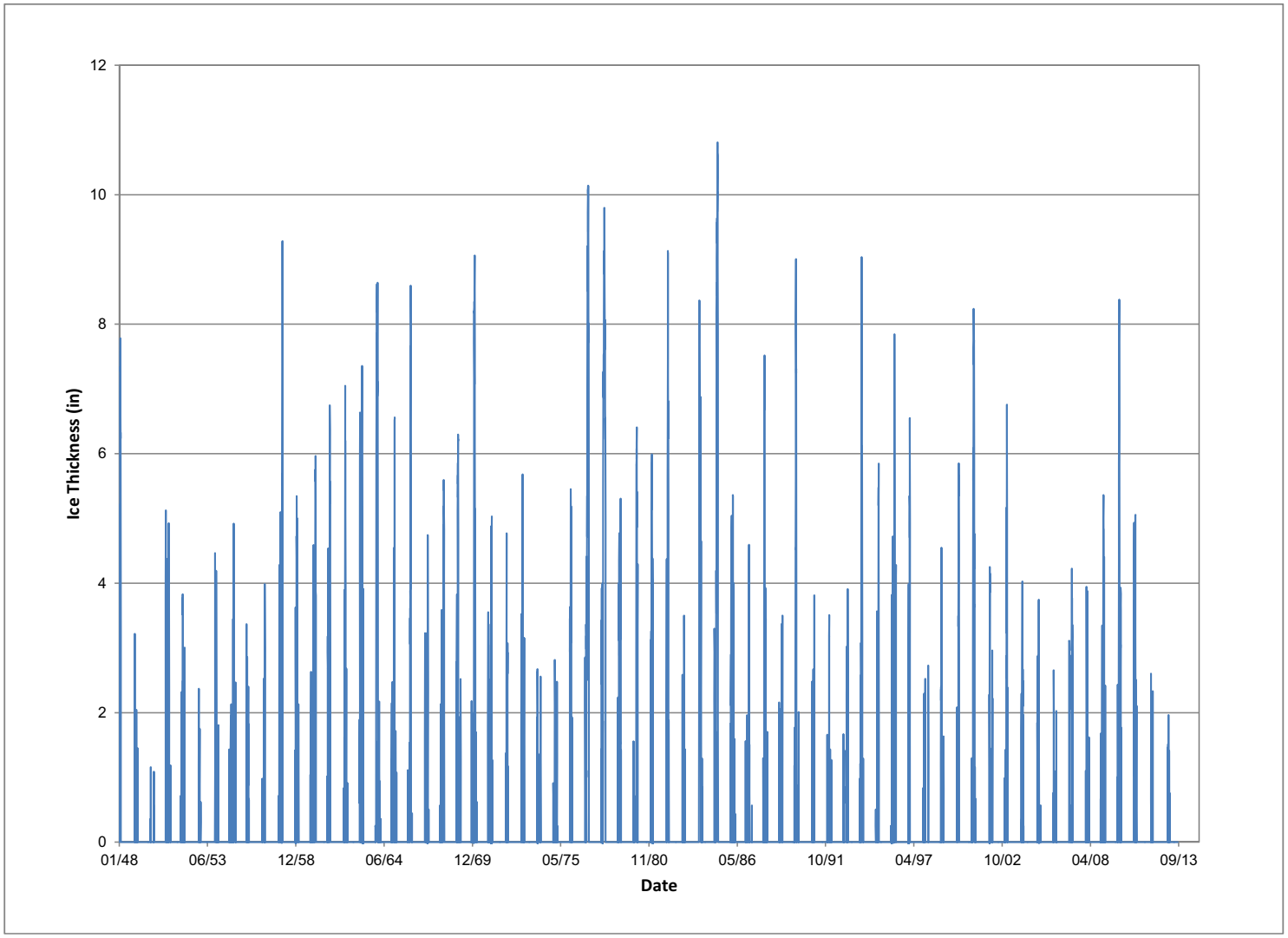

Figure 2.4.7-3. Temporal Variations of Estimated Ice Thickness for about 65-year Period of Record

Figure 2.4.7-4. Temporal Variations of Daily Average Temperature and Accumulated Freezing Degree-Days for Winter of 1984/1985

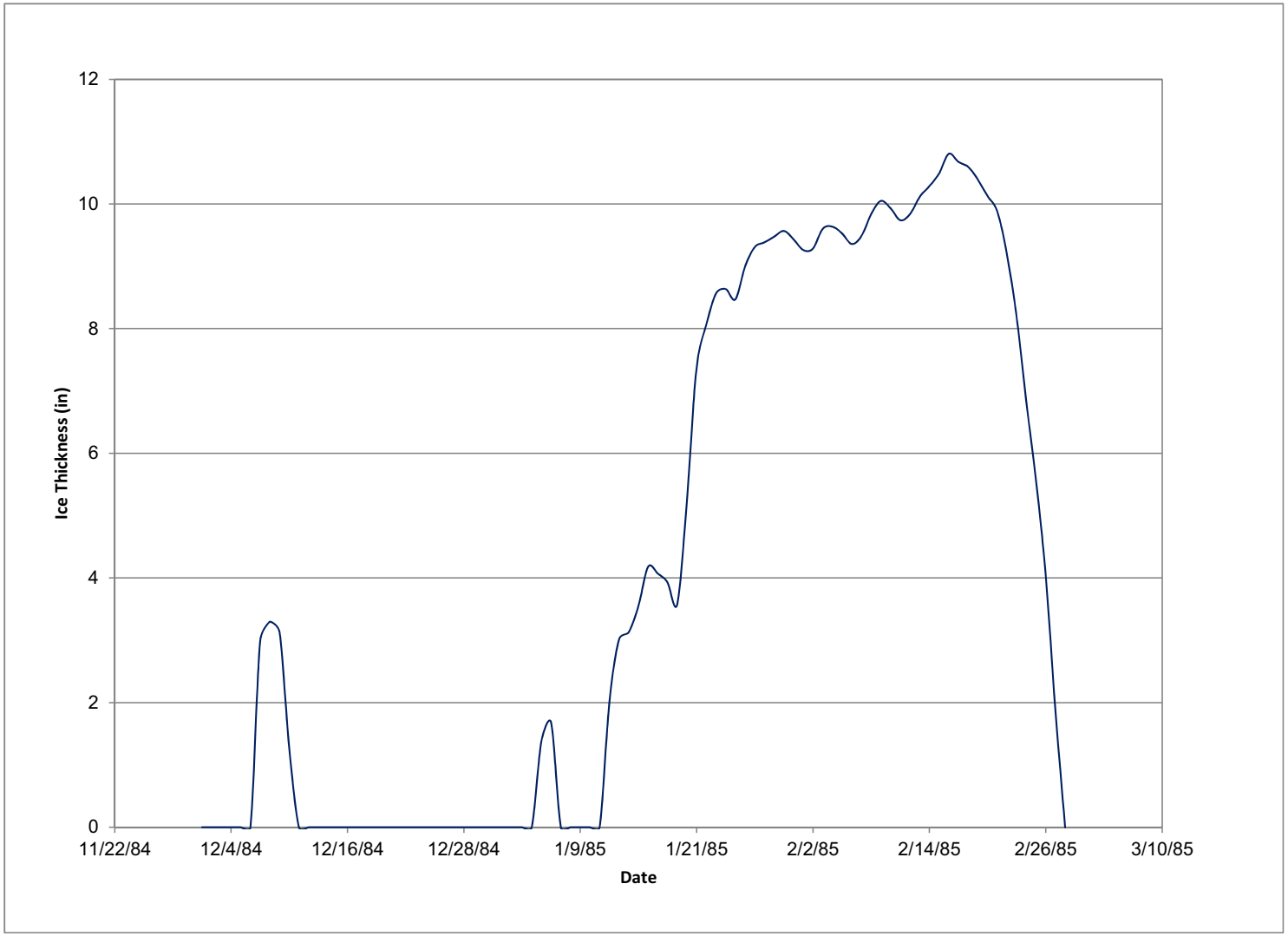

Figure 2.4.7-5. Temporal Variations of Estimated Maximum Ice Thickness for Winter of 1984/1985

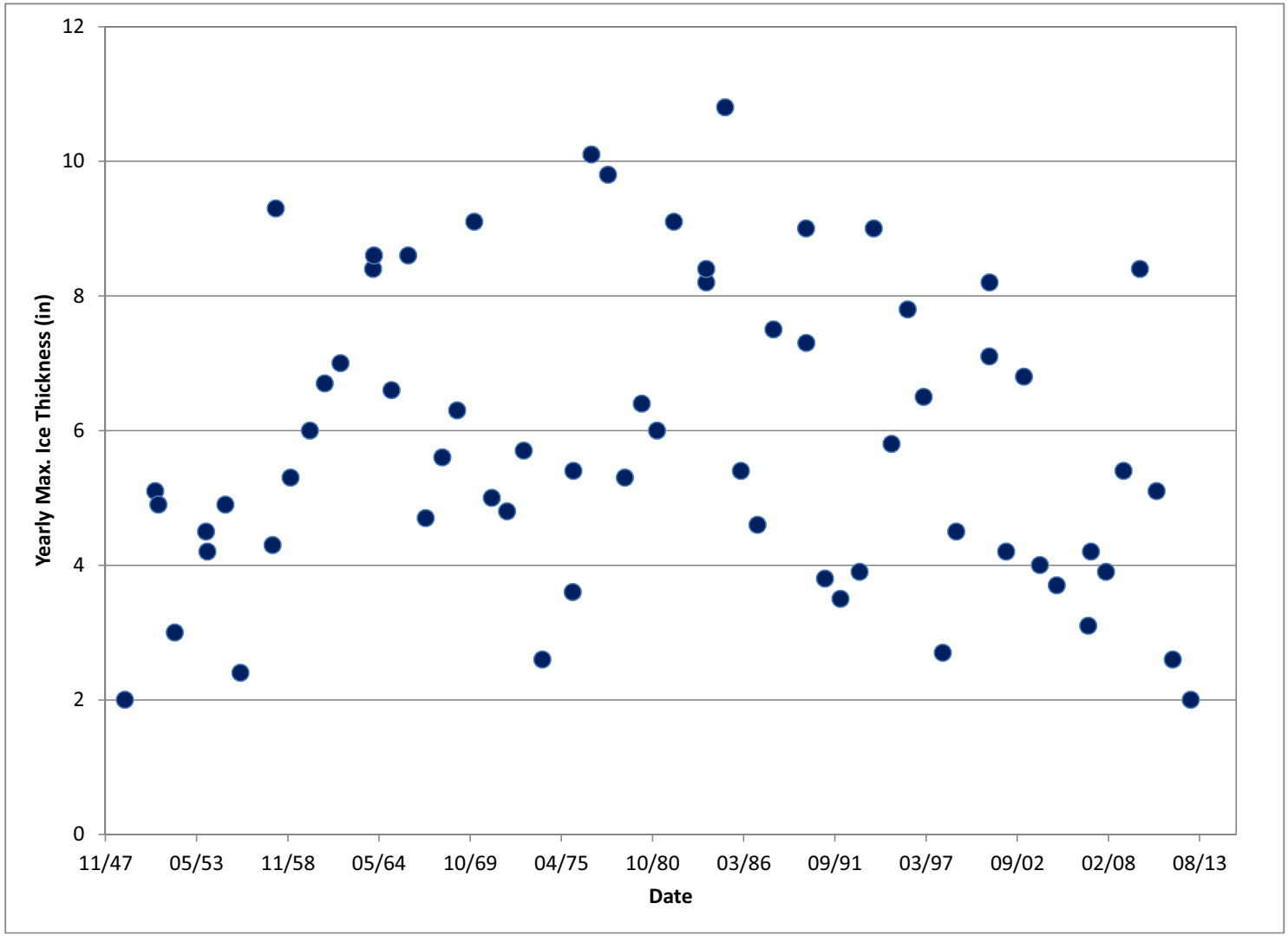

Figure 2.4.7-6. Estimated Yearly Maximum Ice Thickness for about 65-year Period of Record