Vermont Agency of Natural Resources

Climate Change Adaptation Framework

May 31, 2013

Appendix 2

Appendix 2A

Data inventory for weather & climate

Available Data

Air Temperature and Precipitation

Future projections call for changing temperature and precipitation patterns. It is important that available monitoring data sufficiently capture different aspects of these climatic variables (annual, seasonal, extremes, frequency, variability, duration). We conducted an inventory of available air temperature and precipitation data from active and inactive weather stations in Vermont, using the sources listed in Table 2A-1. As of September 2012, there are more than 200 weather stations, over 100 of which are active. This includes data from the volunteer Community Collaborative Rain, Hail and Snow Network (CoCoRahs - http://www.cocorahs.org/). Various parameters are collected over different time periods at each station (Table 2A-1).

These stations belong to a number of different networks (some belong to multiple networks). A list of networks with descriptions can be found in Table 2A-2 and stations coded by network are shown in Figure 3. Most sites belong to the Global Historical Climatology Network (GHCN) network, which is an integrated database of daily climate summaries from land surface stations across the globe that recently superseded the Cooperative Data Network (COOP). Most of Vermont's airports belong to the Global Surface Summary of the Day (GSOD) network and provide hourly data for a multitude of parameters. Two sites, Mount Mansfield and Lye Brook, are part of the Soil Climate Analysis Network (SCAN) which is a nationwide soil moisture and climate information system.

In addition, we obtained locations of the VTrans Road Weather Information Stations (RWIS). There are 23 stations that are part of the VTrans Intelligent Transportation Systems (ITS) program, which includes 511 (VTrans 2012). Currently, RWIS data cannot be accessed from the 511 web page. VTrans is tentatively planning to have these data available online by mid- to late 2013.

The list of stations, along with spatial location (latitude/longitude), status and period of record, can be found in Table 2A-3, and locations of the weather stations are shown in Figure 2A-1. The 10 stations with the longest periods of record (over 100 years) are shown in Figure 2. Enosburg Falls is the oldest, with data collection starting in 1891, followed by Woodstock, which started collecting data in 1892.

As shown in Figure 2A-1, the spatial coverage across the state is fairly complete. There is a gap in south-central and southeastern Vermont, where several long-term stations have gone inactive (i.e. Vernon, which has a period of record from 1893-1998). Also, there is less coverage in mountains versus valleys, which is consistent with patterns seen nationwide (Gibson et al. 2002). Modeled data that account for these topographical differences are available from the PRISM Group, Oregon State University (http://www.prismclimate.org). These modeled data utilize a digital elevation model and point measurements of climate data to generate estimates of annual, monthly and event-based climatic elements with a 4-km resolution (Daly et al 1999, Gibson et al. 2002) (Table 2A-1).

Table 2A-1. Sources of climatic data used in the inventory (accessed in September 2012, subject to change).

Source	Year Start	Temporal scale	Type	Parameters	Format	Source
Climate Database Server, Utah State University	1883	daily, hourly	observed or auto	air temperature (min/max/mean), precipitation (rain, snow depth, snow amount), ref evapotranspiration, soil moisture (SCAN sites only); NOTE: these are station-specific, may include all or some, time periods for each can vary	tabular	http://climate.usurf.usu.edu/mapGUI/mapGUI.php
VTrans Road Weather Information Stations	2005?	daily	auto	air temperature, temperature-dewpoint, precipitation (rate, 24 hrs, intensity, type), relative humidity, wind (avg speed, gust speed and direction)	online interactive map	Robert.T.White@state.vt.us
Parameter-elevation Regressions on Independent Slopes Model (PRISM)	1819	annual, monthly	modeled	maximum and minimum air temperature, precipitation, standardized precipitation index (SPI), temperature-dewpoint, normals (avg 1971-2000)	GIS grid files (ASCII)	ftp://prism.oregonstate.edu/pub/prism/us/grids/ppt/

Table 2A-2. Description of climate networks (note that some sites are part of multiple networks).

Name	**Acronym**	**Description**
Global Historical Climatology Network	GHCN	An integrated database of daily climate summaries from land surface stations across the globe. As of April 2011, GHCN supercedes the COOP dataset. CoCoRAHS stations are included in this network.
Cooperative Data Network	COOP	Also referred to as the National Weather Service (NWS) Cooperative Observer Program. Administered through National Climatic Data Center (NCDC). More than 11,000 volunteers take observations of daily maximum and minimum temperatures, snowfall, and 24-hour precipitation totals in all areas of the nation. As of April 2011 COOP has been superceded by GHCN.
Global Surface Summary of the Day	GSOD	Produced by the National Climatic Data Center (NCDC). The input data used in building these daily summaries are the Integrated Surface Data (ISD), which includes global data obtained from the USAF Climatology Center. The data files begin with 1929 and are up to date normally 1-2 days after the observations.
Automated Surface Observing Systems	ASOS/AWOS	Automated Surface Observing Systems (name was recently changed from AWOS to ASOS) program is a joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). The ASOS systems serves as the nations primary surface weather observing network. ASOS is designed to support weather forecast activities and aviation operations and, at the same time, climatological research.
Integrated Surface Data	ISD-Lite	Data source is a subset derived from the full Integrated Surface Data (ISD) product provided by National Climatic Data Center (NCDC). ISD consists of global hourly and synoptic observations compiled from numerous sources and comprises over 20,000 stations worldwide with some having data as far back as 1901.
Soil Climate Analysis Network	SCAN	This is a nationwide soil moisture and climate information system. Administered by the United States Department of Agriculture Natural Resources Conservation Service (NRCS) through the National Water and Climate Center (NWCC), in cooperation with the NRCS National Soil Survey Center, the system focuses on agricultural areas of the U.S.
Road Weather Information Stations	RWIS	This is part of the VTrans Intelligent Transportation Systems (ITS) program, which includes 511. Currently, RWIS data cannot be accessed from the 511 web page; Vtrans is hoping to make these data available online by winter 2012.

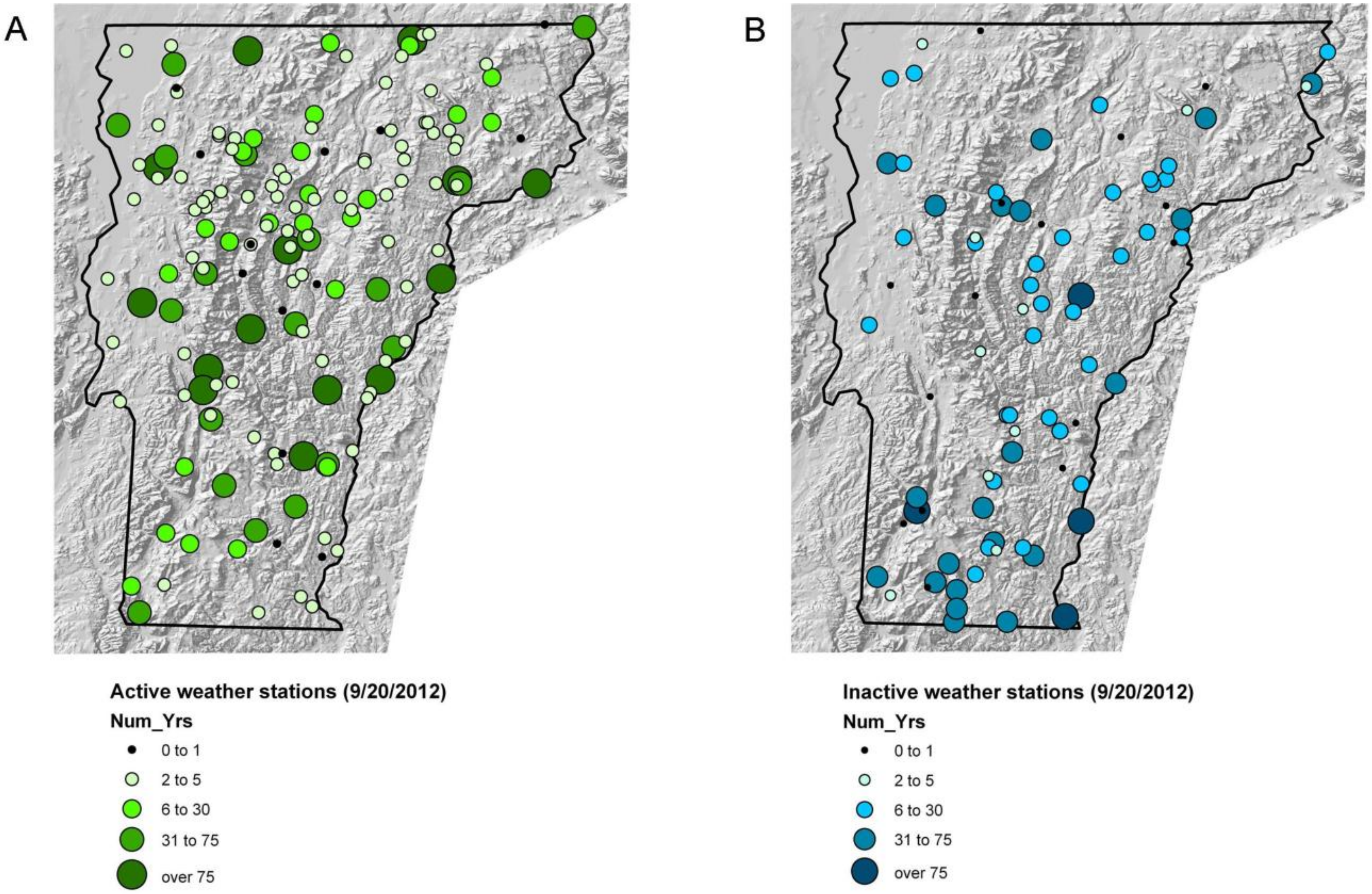

Figure 2A-1. Locations of A) active and B) inactive weather stations, coded by number of years of data. See Appendix A for list of stations.

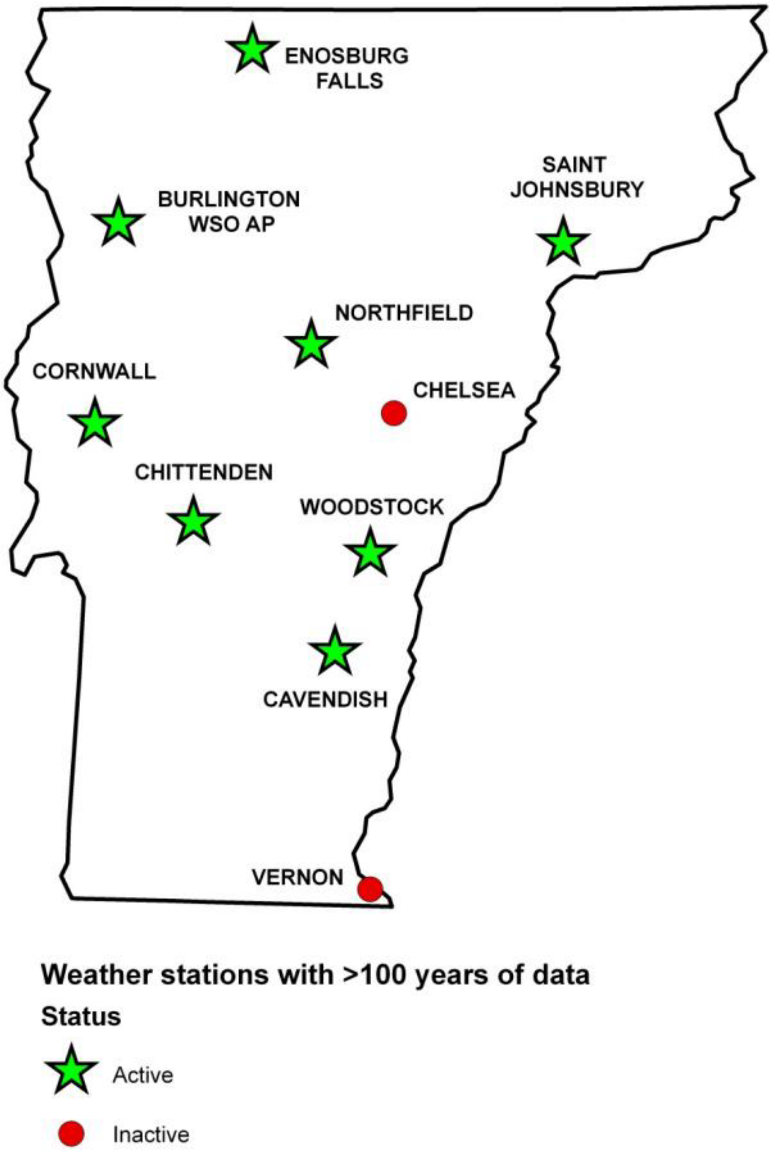

Figure 2A-2. Weather stations in Vermont with more than 100 years of data, coded by status (active/inactive).

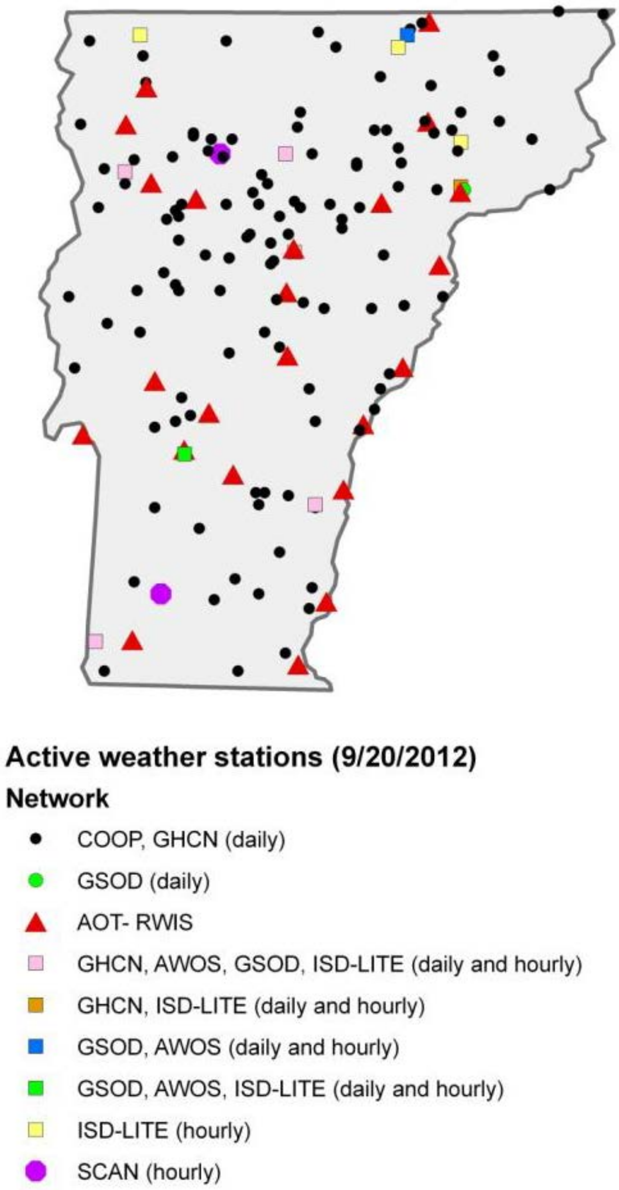

Figure 2A-3. Active weather stations in Vermont, coded by network.

Table 2A-1. VT weather stations as of 9/15/2012 (source: http://climate.usurf.usu.edu/mapGUI/mapGUI.php). Some stations have multiple StationIDs because they are part of different networks. They are listed in separate rows in this table. In the UniqueID_Tt field (which was assigned by Tetra Tech), these sites were given the same unique ID. Status – A=active, I=inactive. Yellow highlights = waiting for data.

Long	Lat	UniqueID_Tt	StationID	Station_Name	Network	Type	Status	POR (as of 9/15/2012)	Num_Yrs
-73.34000	44.05000	Addison_1	US1VTAD0001	ADDISON 3.6 SW	GHCN	Daily	A	2009-04-01 to 2011-09-30	2
-72.38000	44.70000	Albany_1	430134	ALBANY	COOP	Daily	I	1993-10-01 to 1999-04-30	6
-73.27000	44.91000	Alburgh_1	US1VTGI0003	ALBURGH 4.6 SSE	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-71.69000	45.01000	Averill_1	USC00430193	AVERILL	GHCN	Daily	A	2011-11-01 to 2012-06-30	1
-71.98000	44.77000	BaldMtn_1	430267	BALD MTN	COOP	Daily	I	1952-10-01 to 1952-10-31	0
-72.78000	43.10000	BallMtnLk_1	USC00430277	BALL MTN LAKE	GHCN	Daily	A	1969-05-01 to 2012-08-31	43
-72.52000	44.20000	Barre_1	430337	BARRE	COOP	Daily	I	1937-01-01 to 1960-02-29	23
-72.58000	44.20000	BarreMPV_1	USW00094705	BARRE MONTPELIER AP	GHCN	Daily	A	1948-06-01 to 2012-08-31	64
-72.58000	44.20000	BarreMPV_1	726145	BARRE-MONTPELIER	ISD-LITE	Hourly	A	1973-01-01 to 2012-09-07	39
-72.12000	44.76000	Barton_1	US1VTOL0002	BARTON 3.0 ENE	GHCN	Daily	A	2009-03-01 to 2012-08-31	3
-72.45000	43.13000	Bellows_1	430499	BELLOWS FALLS	COOP	Daily	I	1902-11-01 to 1997-01-31	95
-73.25000	42.88000	Bennington_1	KDDH	BENNINGTON	AWOS	Hourly	A	2005-09-14 to 2012-09-18	7
-73.17000	42.85000	Bennington_2	430558	BENNINGTON	COOP	Daily	I	1948-06-01 to 1950-09-30	2
-73.22000	42.92000	Bennington_3	430563	BENNINGTON 2 NNW	COOP	Daily	I	1896-11-01 to 1969-07-31	73
-73.23000	42.88000	Bennington_1	726166	BENNINGTON MORSE AR	GSOD	Daily	A	2001-08-15 to 2011-11-23	10
-73.25000	42.89000	Bennington_1	USW00054781	BENNINGTON MORSE ST AP	GHCN	Daily	A	1998-12-01 to 2012-08-31	14
-72.58335	44.21232	Berlin_2	707000	BERLIN	AOT_RWIS	Daily	A		
-72.66000	44.23000	Berlin_1	US1VTWS0005	BERLIN 4.3 WNW	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.60384	43.85176	Bethel_3	707002	BETHEL	AOT_RWIS	Daily	A		
-72.63000	43.83000	Bethel_2	430660	BETHEL	COOP	Daily	I	1928-11-01 to 1957-08-31	29
-72.63000	43.88000	Bethel_1	USC00430661	BETHEL 4 N	GHCN	Daily	A	1958-05-01 to 2012-08-31	54
-71.58000	44.78000	Bloom_1	430690	BLOOMFIELD	COOP	Daily	I	1906-08-01 to 1968-08-31	62
-72.91188	44.37945	Bolton_1	707001	BOLTON	AOT_RWIS	Daily	A		
-72.10000	44.18000	Bolton_1	430724	BOLTONVILLE	COOP	Daily	I	1948-11-01 to 1949-10-31	1
-72.21000	44.02000	Bradford_1	US1VTOG0003	BRADFORD 4.4 WNW	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-73.05025	43.76715	Brandon_1	707008	BRANDON	AOT_RWIS	Daily	A		
-72.61000	42.85000	Brattleboro_1	US1VTWH0001	BRATTLEBORO 2.0 SW	GHCN	Daily	A	2009-04-01 to 2011-12-31	2
-73.12000	44.20000	Bristol_1	430922	BRISTOL 5 NNW	COOP	Daily	I	1966-06-01 to 1981-01-31	15
-72.60655	44.06535	Brookfield_4	707007	BROOKFIELD	AOT_RWIS	Daily	A		
-72.64000	44.02000	Brookfield_3	430940	BROOKFIELD 2 SW	COOP	Daily	I	1989-09-01 to 2007-04-30	18
-72.64000	44.04000	Brookfield_1	430942	BROOKFIELD 2 WSW	COOP	Daily	A	2007-09-01 to 2011-04-16	4
-72.55000	44.03000	Brookfield_2	US1VTOG0007	BROOKFIELD 2.7 ESE	GHCN	Daily	A	2011-08-01 to 2012-08-31	1
-72.47000	43.50000	Browns_1	430949	BROWNSVILLE	COOP	Daily	I	1968-12-01 to 1969-02-28	1

Table 1 continued…

Long	Lat	UniqueID_Tt	StationID	Station_Name	Network	Type	Status	POR (as of 9/15/2012)	Num_Yrs
-73.15000	44.47000	Burlington_1	KBTV	BURLINGTON	AWOS	Hourly	A	2005-09-14 to 2012-09-18	7
-73.18000	44.48000	Burlington_3	431072	BURLINGTON	COOP	Daily	I	1883-12-01 to 1943-06-30	60
-73.22000	44.48000	Burlington_2	US1VTCH0020	BURLINGTON 0.4 W	GHCN	Daily	A	2012-01-01 to 2012-08-31	0
-73.22000	44.48000	Burlington_2	US1VTCH0005	BURLINGTON 0.5 NW	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-73.15000	44.46000	Burlington_1	726170	BURLINGTON INTERNAT	GSOD	Daily	A	1948-01-01 to 2011-11-29	63
-73.15000	44.47000	Burlington_1	726170	BURLINGTON INTL	ISD-LITE	Hourly	A	1948-01-01 to 2012-09-07	64
-73.15000	44.47000	Burlington_1	USW00014742	BURLINGTON INTL AP	GHCN	Daily	A	1940-12-01 to 2012-08-31	72
-73.15000	44.47000	Burlington_1	431081	BURLINGTON WSO AP	COOP	Daily	A	1893-01-01 to 2011-04-16	118
-72.28720	44.36637	Cabot_2	707018	CABOT	AOT_RWIS	Daily	A		
-72.23000	44.42000	Cabot_1	US1VTWS0012	CABOT 3.9 ENE	GHCN	Daily	A	2009-05-01 to 2012-08-31	3
-72.02000	44.57000	Caledonia_1	720492	CALEDONIA COUNTY AIR	ISD-LITE	Hourly	A	2008-04-22 to 2012-09-06	4
-72.86000	44.58000	Cambridge_1	US1VTLM0003	CAMBRIDGE 4.8 SSE	GHCN	Daily	A	2009-05-01 to 2012-08-31	3
-71.54000	45.00000	Canaan_1	USC00431213	CANAAN	GHCN	Daily	A	1938-03-01 to 2011-09-30	73
-72.60000	43.38000	Cavendish_1	USC00431243	CAVENDISH	GHCN	Daily	A	1903-02-01 to 2012-08-31	109
-73.02000	43.60000	CenterRut_1	431263	CENTER RUTLAND	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-73.24000	44.35000	Charlotte_1	US1VTCH0003	CHARLOTTE 2.9 NNE	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.45000	43.98000	Chelsea_2	431360	CHELSEA	COOP	Daily	I	1893-01-01 to 2000-01-31	107
-72.48000	44.01000	Chelsea_1	USC00431363	CHELSEA 2 NW	GHCN	Daily	A	2000-04-01 to 2012-08-31	12
-72.96000	43.71000	Chittenden_1	USC00431433	CHITTENDEN	GHCN	Daily	A	1904-01-01 to 2012-06-30	108
-72.32000	44.01000	Corinth_1	USC00431565	CORINTH	GHCN	Daily	A	1948-07-01 to 2012-08-31	64
-73.21000	43.96000	Cornwall_1	USC00431580	CORNWALL	GHCN	Daily	A	1893-01-01 to 2012-08-31	119
-73.05000	43.34000	Danby_1	USC00431705	DANBY FOUR CORNERS	GHCN	Daily	A	2002-05-01 to 2012-08-31	10
-72.13000	44.42000	Danville_2	431715	DANVILLE	COOP	Daily	I	1956-01-01 to 1984-10-31	28
-72.10000	44.41000	Danville_1	US1VTCL0006	DANVILLE 2.0	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.12638	44.97505	Derby_2	707010	DERBY	AOT_RWIS	Daily	A		
-72.15000	44.97000	Derby_1	US1VTOL0005	DERBY CENTER 1.8 NW	GHCN	Daily	A	2009-10-01 to 2012-08-31	3
-73.07000	43.22000	Dorset_1	431786	DORSET 2 SE	COOP	Daily	I	1940-11-01 to 1999-06-30	59
-72.46000	44.36000	EastCalais_1	US1VTWS0015	EAST CALAIS 1.5 SW	GHCN	Daily	A	2009-05-01 to 2012-08-31	3
-72.83000	44.98000	EastFrank_1	432269	EAST FRANKLIN	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-71.89000	44.64000	EastHaven_1	USC00432314	EAST HAVEN	GHCN	Daily	A	1993-09-01 to 2012-08-31	19
-72.07000	44.20000	EastRye_1	432578	EAST RYEGATE	COOP	Daily	I	1930-05-01 to 1949-06-30	19
-72.56000	44.67000	Eden_1	USC00432698	EDEN 2 S	GHCN	Daily	A	1997-12-01 to 2012-04-30	15
-72.52000	44.53000	Elmore_1	US1VTLM0008	ELMORE 0.8 SSE	GHCN	Daily	A	2011-07-01 to 2012-08-31	1
-72.81000	44.91000	Enosburg_1	USC00432769	ENOSBURG FALLS	GHCN	Daily	A	1891-08-01 to 2012-06-30	121

Table 1 continued…

Long	Lat	UniqueID_Tt	StationID	Station_Name	Network	Type	Status	POR (as of 9/15/2012)	Num_Yrs
-72.81000	44.91000	Enosburg_1	USC00432773	ENOSBURG FALLS 2	GHCN	Daily	A	1992-03-01 to 2012-08-31	20
-73.12000	44.48000	Essex_2	432828	ESSEX JUNCTION	COOP	Daily	I	1937-01-01 to 1960-09-30	23
-73.12000	44.51000	Essex_1	USC00432843	ESSEX JUNCTION 1 N	GHCN	Daily	A	1971-11-01 to 2012-08-31	41
-73.29290	43.58635	FairHaven_1	707003	FAIR HAVEN	AOT_RWIS	Daily	A		
-73.08000	44.77000	Fairfax_1	US1VTFR0007	FAIRFAX 7.7 NNW	GHCN	Daily	A	2011-08-01 to 2012-08-31	1
-73.10000	44.93000	Franklin_1	720494	FRANKLIN CO AIRPORT	ISD-LITE	Hourly	A	2008-04-01 to 2012-09-06	4
-71.78000	44.58000	Gallup_1	USC00433192	GALLUP MILLS	GHCN	Daily	A	2011-12-01 to 2012-06-30	1
-73.07803	44.75469	Georgia_1	707011	GEORGIA	AOT_RWIS	Daily	A		
-71.72000	44.41000	Gilman_1	USC0043334	GILMAN	GHCN	Daily	A	1930-05-01 to 2012-08-31	82
-72.63000	43.19000	Grafton_1	USC00433400	GRAFTON 1NW	GHCN	Daily	A	1948-06-01 to 2012-08-31	64
-72.85000	43.98000	Granville_1	433494	GRANVILLE	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-72.30000	44.58000	Greensboro_3	433556	GREENSBORO	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-72.31000	44.61000	Greensboro_1	US1VTOL0009	GREENSBORO 2.1 NNW	GHCN	Daily	A	2011-09-01 to 2012-08-31	1
-72.27000	44.61000	Greensboro_2	US1VTOL0004	GREENSBORO 2.3 NNE	GHCN	Daily	A	2009-02-01 to 2012-08-31	3
-72.20000	44.22000	Groton_2	433581	GROTON	COOP	Daily	I	1997-07-01 to 2003-08-31	6
-72.28000	44.19000	Groton_1	US1VTCL0003	GROTON 4.4 WSW	GHCN	Daily	A	2009-03-01 to 2012-08-31	3
-72.56773	42.81266	Guilford_1	707012	GUILFORD	AOT_RWIS	Daily	A		
-72.97000	44.24000	Hanksville_1	USC00433769	HANKSVILLE	GHCN	Daily	A	1997-12-01 to 2011-09-30	14
-72.37000	44.50000	Hardwick_1	US1VTCL0010	HARDWICK 0.1 ENE	GHCN	Daily	A	2009-05-01 to 2012-08-31	3
-72.37000	44.49000	Hardwick_2	US1VTCL0017	HARDWICK 0.8 S	GHCN	Daily	A	2010-11-01 to 2012-07-31	2
-72.34784	43.62101	Hartford_1	707017	HARTFORD	AOT_RWIS	Daily	A		
-73.05000	44.93000	Highgate_1	433914	HIGHGATE FALLS	COOP	Daily	I	1948-06-01 to 1951-09-30	3
-72.98000	44.34000	Huntington_1	US1VTCH0015	HUNTINGTON 0.7 NNE	GHCN	Daily	A	2010-08-01 to 2012-08-31	2
-72.97000	44.32000	Huntington_2	US1VTCH0007	HUNTINGTON 1.1 E	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-73.01000	44.31000	Huntington_3	US1VTCH0012	HUNTINGTON 1.6 SW	GHCN	Daily	A	2009-08-01 to 2012-08-31	3
-73.00000	44.32000	Huntington_4	434052	HUNTINGTON CTR	COOP	Daily	I	1955-11-01 to 1995-03-31	40
-72.57000	44.62000	Hyde_1	US1VTLM0007	HYDE PARK 2.9 NE	GHCN	Daily	A	2010-04-01 to 2012-08-31	2
-72.29000	44.79000	Irasburg_1	USC00434115	IRASBURG 1SW	GHCN	Daily	A	2009-12-01 to 2012-08-31	3
-71.89000	44.81000	Island_1	USC00434120	ISLAND POND	GHCN	Daily	A	1990-08-01 to 2012-08-31	22
-72.50000	44.94000	Jay_1	USC00434189	JAY PEAK	GHCN	Daily	A	1988-09-01 to 2012-08-31	24
-72.79000	44.58000	Jefferson_1	USC00434261	JEFFERSONVILLE	GHCN	Daily	A	1999-05-01 to 2012-08-31	13
-72.99000	44.52000	Jericho_1	US1VTCH0019	JERICHO 1.0 NNW	GHCN	Daily	A	2011-09-01 to 2012-08-31	1
-71.52000	44.90000	Leming_1	434603	LEMINGTON	COOP	Daily	I	1943-01-01 to 1958-10-31	15
-72.98000	44.09000	Lincoln_1	US1VTAD0007	LINCOLN 1.6 SE	GHCN	Daily	A	2009-08-01 to 2012-08-31	3

Table 1 continued…

Long	Lat	UniqueID_Tt	StationID	Station_Name	Network	Type	Status	POR (as of 9/15/2012)	Num_Yrs
-73.02000	44.13000	Lincoln_2	US1VTAD0002	LINCOLN 2.2 NW	GHCN	Daily	A	2009-04-01 to 2012-01-31	3
-72.71000	43.39000	Ludlow_2	434747	LUDLOW	COOP	Daily	I	1970-06-01 to 2005-02-28	35
-72.68000	43.39000	Ludlow_1	USC00434749	LUDLOW # 2	GHCN	Daily	A	2012-04-01 to 2012-06-30	0
-72.71000	43.39000	Ludlow_2	US1VTWR0003	LUDLOW 0.5 WSW	GHCN	Daily	A	2009-05-01 to 2012-08-31	3
-72.70000	43.35000	Ludlow_3	US1VTWR0006	LUDLOW 3.4 S	GHCN	Daily	A	2010-03-01 to 2012-08-31	2
-73.03000	43.05000	Lye_1	LBKV1	LYE BROOK	SCAN	Hourly	A	2009-10-07 to 2012-09-19	3
-73.03000	43.05000	Lye_1	2042	LYE BROOK	SCAN	Hourly	A	2000-09-15 to 2012-09-17	12
-71.60000	44.77000	Lyman_1	434765	LYMAN FALLS	COOP	Daily	I	1948-06-01 to 1951-01-31	3
-72.03000	44.54000	Lyndon_1	US1VTCL0014	LYNDONVILLE 1.1 W	GHCN	Daily	A	2010-01-01 to 2012-02-29	2
-73.07000	43.17000	Manchester_1	434882	MANCHESTER	COOP	Daily	I	1899-11-01 to 1988-12-31	89
-73.05000	43.17000	Manchester_2	434887	MANCHESTER DEPOT	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-72.36000	44.35000	Marshfield_1	USC00434999	MARSHFIELD	GHCN	Daily	A	1991-08-01 to 2012-08-31	21
-72.33000	44.37000	Marshfield_3	434985	MARSHFIELD	COOP	Daily	I	1936-12-01 to 1959-09-30	23
-72.42000	44.31000	Marshfield_2	US1VTWS0017	MARSHFIELD 4.5 SW	GHCN	Daily	A	2009-06-01 to 2012-08-31	3
-72.73000	42.75000	Mays_1	435029	MAYS MILL	COOP	Daily	I	1930-04-01 to 1975-02-28	45
-72.07000	44.27000	McIndoe_1	435044	MC INDOE FALLS	COOP	Daily	I	1932-03-01 to 1972-07-31	40
-72.86842	43.65966	Mendon_2	707006	MENDON	AOT_RWIS	Daily	A		
-72.93000	43.65000	Mendon_1	US1VTRT0003	MENDON 0.3 WSW	GHCN	Daily	A	2008-09-01 to 2012-08-31	4
-73.17000	44.02000	Middlebury_1	435066	MIDDLEBURY	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-72.68000	44.30000	Middlesex_3	435132	MIDDLESEX	COOP	Daily	I	1936-12-01 to 1968-12-31	32
-72.63000	44.32000	Middlesex_1	US1VTWS0007	MIDDLESEX 3.1 ENE	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.56000	44.35000	Middlesex_2	US1VTWS0013	MIDDLESEX 6.9 NE	GHCN	Daily	A	2009-06-01 to 2012-08-31	3
-73.14780	44.62955	Milton_1	707013	MILTON	AOT_RWIS	Daily	A		
-72.60000	44.25000	Montpelier_2	435270	MONTPELIER	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-72.60000	44.26000	Montpelier_1	USC00435273	MONTPELIER 2	GHCN	Daily	A	1999-05-01 to 2012-08-31	13
-72.56000	44.20000	BarreMPV_1	726145	MONTPELIER AP	GSOD	Daily	A	1973-01-01 to 2011-11-29	38
-72.57000	44.20000	BarreMPV_1	KMPV	MONTPELIER/BARRE	AWOS	Hourly	A	2005-09-14 to 2012-09-18	7
-72.74000	44.25000	Moretown_1	US1VTWS0004	MORETOWN 1.0 ESE	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.73000	44.26000	Moretown_2	US1VTWS0008	MORETOWN 1.7 ENE	GHCN	Daily	A	1998-06-01 to 2012-05-31	14
-71.91000	44.86000	Morgan_1	US1VTOL0006	MORGAN 6.7 SE	GHCN	Daily	A	2009-11-01 to 2012-08-31	3
-72.62000	44.50000	Morris_1	KMVL	MORRISVILLE	AWOS	Hourly	A	2005-09-14 to 2012-09-18	7
-72.60000	44.57000	Morris_2	435366	MORRISVILLE	COOP	Daily	I	1902-11-01 to 1951-09-30	49
-72.61000	44.53000	Morris_1	USW00054771	MORRISVILLE STOWE STATE AP	GHCN	Daily	A	1996-07-01 to 2012-08-31	16
-72.61000	44.53000	Morris_1	726114	MORRISVILLESTONE	ISD-LITE	Hourly	A	2006-01-01 to 2012-09-07	6
-72.61000	44.53000	Morris_1	726114	MORRISVILLESTONE	GSOD	Daily	A	1997-01-31 to 2011-11-29	14

Table 1 continued…

Long	Lat	UniqueID_Tt	StationID	Station_Name	Network	Type	Status	POR (as of 9/15/2012)	Num_Yrs
-72.78658	43.45176	MountHolly_1	707021	MOUNT HOLLY	AOT_RWIS	Daily	A		
-72.83000	44.53000	Mansfield_1	MMSV1	MOUNT MANSFIELD	SCAN	Hourly	A	2009-11-22 to 2012-09-19	3
-72.83000	44.53000	Mansfield_1	2041	MOUNT MANSFIELD	SCAN	Hourly	A	2000-09-13 to 2012-09-17	12
-72.82000	44.52000	Mansfield_2	435416	MT MANSFIELD	COOP	Daily	A	1954-11-01 to 2011-04-16	57
-72.82000	44.52000	Mansfield_2	USC00435416	MT MANSFIELD	GHCN	Daily	A	1954-11-01 to 2012-08-31	58
-72.51000	43.34000	NSpring_1	USC00435982	N SPRINGFIELD LAKE	GHCN	Daily	A	2006-09-01 to 2012-08-31	6
-73.11000	44.07000	NewHaven_1	435501	NEW HAVEN	COOP	Daily	A	2000-04-01 to 2010-08-03	10
-72.09172	44.15698	Newbury_1	707014	NEWBURY	AOT_RWIS	Daily	A		
-72.63000	43.00000	Newfane_1	435492	NEWFANE	COOP	Daily	I	1930-05-01 to 1981-06-30	51
-72.20000	44.93000	Newport_1	KEFK	NEWPORT	AWOS	Hourly	A	2008-04-01 to 2012-09-19	4
-72.20000	44.93000	Newport_1	726120	NEWPORT	GSOD	Daily	A	1973-01-02 to 1992-09-10	19
-72.19000	44.95000	Newport_2	USC00435542	NEWPORT	GHCN	Daily	A	1930-02-01 to 2012-08-31	82
-72.23000	44.89000	Newport_3	720493	NEWPORT STATE	ISD-LITE	Hourly	A	2008-04-23 to 2012-09-06	4
-72.12000	44.47000	NDanville_1	435632	NORTH DANVILLE	COOP	Daily	I	1958-03-01 to 1979-09-30	21
-72.36000	43.60000	NHartland_1	USC00435768	NORTH HARTLAND LAKE	GHCN	Daily	A	2010-05-01 to 2012-08-31	2
-72.52000	43.33000	NSpring_1	435977	NORTH SPRINGFIELD	COOP	Daily	I	1955-11-01 to 1956-06-30	1
-72.66000	44.16000	Northfield_1	USC00435733	NORTHFIELD	GHCN	Daily	A	1901-11-01 to 2012-08-31	111
-72.65000	44.17000	Northfield_2	US1VTWS0010	NORTHFIELD 1.5 N	GHCN	Daily	A	2009-05-01 to 2012-08-31	3
-72.62000	44.10000	Northfield_3	435740	NORTHFIELD 3 SSE	COOP	Daily	I	1974-06-01 to 1994-05-31	20
-72.29000	43.74000	Norwich_1	US1VTWR0004	NORWICH 1.6 NNE	GHCN	Daily	A	2009-07-01 to 2012-08-31	3
-73.32000	43.81000	Orwell_1	US1VTAD0005	ORWELL 1.2 WNW	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.90000	43.27000	Peru_1	USC00436335	PERU	GHCN	Daily	A	1940-11-01 to 2012-08-31	72
-72.42000	44.28000	Plainfield_1	USC00436391	PLAINFIELD	GHCN	Daily	A	1999-10-01 to 2012-08-31	13
-72.72000	43.53000	Plymouth_1	436438	PLYMOUTH	COOP	Daily	I	1941-05-01 to 1953-02-28	12
-72.73000	43.53000	Plymouth_2	436446	PLYMOUTH UNION	COOP	Daily	I	1955-11-01 to 1970-04-30	15
-72.53000	43.74000	Pomfret_1	US1VTWR0002	POMFRET 2.6 N	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-73.22000	42.79000	Pownal_1	USC00436500	POWNAL 1 NE	GHCN	Daily	A	1975-01-01 to 2012-08-31	37
-72.53000	43.00000	Putney_1	US1VTWH0012	PUTNEY 2.0 WNW	GHCN	Daily	A	2011-10-01 to 2012-08-31	1
-72.67000	43.93000	Randolph_2	436712	RANDOLPH	COOP	Daily	I	1952-11-01 to 1957-01-31	5
-72.68000	43.93000	Randolph_1	US1VTOG0006	RANDOLPH 0.7 WNW	GHCN	Daily	A	2011-07-01 to 2012-08-31	1
-72.60000	43.95000	Randolph_3	436717	RANDOLPH CTR	COOP	Daily	I	1941-06-01 to 1957-09-30	16
-72.57000	43.52000	Reading_1	436746	READING HILL	COOP	Daily	I	1948-06-01 to 1967-12-31	19
-72.93000	42.75000	Readsboro_1	436761	READSBORO 1 SE	COOP	Daily	I	1930-12-01 to 1998-03-31	68
-72.96000	44.36000	Richmond_1	US1VTCH0013	RICHMOND 3.4 SSE	GHCN	Daily	A	2009-01-01 to 2012-08-31	3

Table 1 continued…

Long	Lat	UniqueID_Tt	StationID	Station_Name	Network	Type	Status	POR (as of 9/15/2012)	Num_Yrs
-72.80000	43.86000	Rochester_1	USC00436893	ROCHESTER	GHCN	Daily	A	1928-11-01 to 2012-08-31	84
-72.98000	43.63000	Rutland_1	USC00436995	RUTLAND	GHCN	Daily	A	1916-08-01 to 2012-08-31	96
-72.95127	43.53510	Rutland_3	707005	RUTLAND	AOT_RWIS	Daily	A		
-72.93000	43.53000	Rutland_2	725165	RUTLAND STATE	ISD-LITE	Hourly	A	2006-01-01 to 2012-09-07	6
-72.95000	43.52000	Rutland_2	KRUT	RUTLAND STATE	AWOS	Hourly	A	2005-09-14 to 2012-09-19	7
-72.95000	43.53000	Rutland_2	725165	RUTLAND STATE(AWOS)	GSOD	Daily	A	1973-02-02 to 2011-11-29	38
-72.01000	44.41000	StJay_1	726140	SAINT JOHNSBURY	GSOD	Daily	A	1978-11-29 to 2011-11-29	33
-72.02000	44.42000	StJay_2	USW00054742	SAINT JOHNSBURY	GHCN	Daily	A	1894-03-01 to 2012-08-31	118
-73.10000	43.93000	Salisbury_1	USC00437098	SALISBURY 2 N	GHCN	Daily	A	1947-10-01 to 2012-08-31	65
-73.00000	42.90000	Searsburg_1	437142	SEARSBURG PWR PLT	COOP	Daily	I	1930-04-01 to 1965-09-30	35
-72.92000	42.87000	Searsburg_2	437152	SEARSBURG STN	COOP	Daily	I	1930-05-01 to 1998-07-31	68
-72.13076	44.63892	Sheffield_3		SHEFFIELD	AOT_RWIS	Daily	A		
-72.11000	44.60000	Sheffield_1	US1VTCL0011	SHEFFIELD 0.1 SE	GHCN	Daily	A	2009-07-01 to 2012-01-31	3
-72.14000	44.64000	Sheffield_2	US1VTCL0001	SHEFFIELD 2.8 NNW	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-73.25000	43.87000	Shoreham_1	437217	SHOREHAM	COOP	Daily	I	1992-03-01 to 1999-07-31	7
-72.95000	42.97000	Somerset_1	437401	SOMERSET	COOP	Daily	I	1911-12-01 to 1968-08-31	57
-73.15000	44.43000	SBurlington_1	US1VTCH0006	SOUTH BURLINGTON 2.5 SE	GHCN	Daily	A	2009-05-01 to 2012-05-31	3
-73.30000	44.63000	SHero_1	USC00437607	SOUTH HERO	GHCN	Daily	A	1969-07-01 to 2012-07-31	43
-72.97000	44.07000	SLincoln_1	USC00437612	SOUTH LINCOLN	GHCN	Daily	A	1981-03-01 to 2012-08-31	31
-72.82000	43.18000	SLondon_1	437617	SOUTH LONDONDERRY	COOP	Daily	I	1930-05-01 to 1984-03-31	54
-72.08000	44.05000	SNewbury_1	USC00437646	SOUTH NEWBURY	GHCN	Daily	A	1936-10-01 to 2012-03-31	76
-72.52000	43.35000	Springfield_1	KVSF	SPRINGFIELD	AWOS	Hourly	A	2005-09-14 to 2012-09-18	7
-72.45000	43.27000	Springfield_2	437954	SPRINGFIELD 2 SE	COOP	Daily	I	1940-10-01 to 1956-06-30	16
-72.52000	43.34000	Springfield_1	USW00054740	SPRINGFIELD HARTNESS AP	GHCN	Daily	A	1996-07-01 to 2012-08-31	16
-72.52000	43.34000	Springfield_1	726115	SPRINGFIELD/HARTNES	ISD-LITE	Hourly	A	2006-01-01 to 2012-09-07	6
-72.51000	43.35000	Springfield_1	726115	SPRINGFIELD/HARTNES	GSOD	Daily	A	1976-03-21 to 2011-11-29	35
-73.08000	44.82000	StAlbans_2	437025	ST ALBANS	COOP	Daily	I	1929-04-01 to 1956-05-31	27
-73.17000	44.80000	StAlbans_3	437026	ST ALBANS BAY	COOP	Daily	I	1956-06-01 to 1977-09-30	21
-73.09000	44.86000	StAlbans_1	437032	ST ALBANS RADIO	COOP	Daily	A	1978-01-01 to 2010-09-30	32
-72.02000	44.42000	StJay_2	726140	ST. JOHNSBURY(AMOS)	ISD-LITE	Hourly	A	1973-01-01 to 2012-09-07	39
-72.02155	44.40221	StJay_3	707016	ST.JOHNSBURY	AOT_RWIS	Daily	A		
-72.23000	44.55000	Stannard_1	US1VTCL0005	STANNARD 0.9 WNW	GHCN	Daily	A	2009-05-01 to 2012-08-31	3
-72.83000	43.77000	Stockbridge_1	438057	STOCKBRIDGE 3 WSW	COOP	Daily	I	1948-06-01 to 1951-09-30	3
-72.69000	44.46000	Stowe_1	US1VTLM0001	STOWE 0.2 SW	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.67000	44.43000	Stowe_2	US1VTLM0006	STOWE 2.8 SSE	GHCN	Daily	A	2009-06-01 to 2012-08-31	3
-73.12000	43.12000	Sunder_2	438150	SUNDERLAND	COOP	Daily	I	1989-04-01 to 1989-10-31	0

Table 1 continued…

Long	Lat	UniqueID_Tt	StationID	Station_Name	Network	Type	Status	POR (as of 9/15/2012)	Num_Yrs
-73.12000	43.09000	Sunder_1	USC00438160	SUNDERLAND 2	GHCN	Daily	A	1990-01-01 to 2012-08-31	22
-72.05000	44.61000	Sutton_1	USC00438169	SUTTON	GHCN	Daily	A	2007-10-01 to 2012-08-31	5
-72.02000	44.67000	Sutton_2	USC00438172	SUTTON 2NE	GHCN	Daily	A	1999-05-01 to 2012-08-31	13
-72.21546	43.81306	Thetford_1	707015	THETFORD	AOT_RWIS	Daily	A		
-72.67000	43.03000	Townshend_2	438438	TOWNSHEND	COOP	Daily	I	1947-10-01 to 1957-01-31	10
-72.70000	43.05000	Townshend_1	USC00438428	TOWNSHEND LAKE	GHCN	Daily	A	2011-01-01 to 2011-10-31	0
-72.48000	43.92000	Tunbridge_1	438483	TUNBRIDGE	COOP	Daily	I	1941-06-01 to 1952-05-31	11
-72.70000	43.47000	Tyson_1	438512	TYSON	COOP	Daily	I	1948-06-01 to 1951-09-30	3
-72.92000	44.59000	Underhill_1	US1VTCH0004	UNDERHILL 4.4 NNE	GHCN	Daily	A	2009-03-01 to 2012-08-31	3
-72.92000	44.60000	Underhill_2	US1VTCH0011	UNDERHILL 5.1 NNE	GHCN	Daily	A	2009-06-01 to 2012-08-31	3
-72.87000	44.54000	Underhill_3	US1VTCH0009	UNDERHILL CENTER 2.8 NE	GHCN	Daily	A	2009-05-01 to 2012-06-30	3
-72.26000	43.79000	Union_1	USC00438556	UNION VILLAGE DAM	GHCN	Daily	A	1950-04-01 to 2012-08-31	62
-72.51000	42.77000	Vernon_1	438600	VERNON	COOP	Daily	I	1893-01-01 to 1998-07-31	105
-73.25000	42.89000	Bennington_1	726166	W H MORSE STATE	ISD-LITE	Hourly	A	2006-01-01 to 2012-09-07	6
-72.85000	44.20000	Waits_3	438633	WAITSFIELD 1 W	COOP	Daily	I	1983-08-01 to 1985-06-30	2
-72.80000	44.18000	Waits_1	US1VTWS0011	WAITSFIELD 1.8 SE	GHCN	Daily	A	2009-04-01 to 2012-04-30	3
-72.80000	44.18000	Waits_1	USC00438640	WAITSFIELD 2 SE	GHCN	Daily	A	2011-06-01 to 2012-08-31	1
-72.88000	44.19000	Waits_2	438637	WAITSFIELD 2 W	COOP	Daily	A	1985-07-01 to 2011-02-28	26
-72.85000	44.18000	Waits_4	438644	WAITSFIELD 2 WSW	COOP	Daily	I	1955-11-01 to 1983-07-31	28
-72.22000	44.50000	Walden_1	USC00438652	WALDEN 4N	GHCN	Daily	A	2009-09-01 to 2012-08-31	3
-72.78000	43.05000	Wards_1	438747	WARDSBORO	COOP	Daily	I	1940-10-01 to 1973-12-31	33
-72.80000	43.03000	Wards_2	438755	WARDSBORO 1 SW	COOP	Daily	I	1978-09-01 to 1984-11-30	6
-72.77000	43.02000	Wards_3	438750	WARDSBORO 3 SE	COOP	Daily	I	1974-05-01 to 1978-08-31	4
-72.83000	44.07000	Warren_1	US1VTWS0022	WARREN 3.3 SSE	GHCN	Daily	A	2011-07-01 to 2012-08-31	1
-72.75000	44.33000	Waterbury_4	438810	WATERBURY 2	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-72.75000	44.32000	Waterbury_5	438815	WATERBURY 2 SSE	COOP	Daily	I	1958-06-01 to 1992-03-31	34
-72.77000	44.37000	Waterbury_6	438805	WATERBURY 3 NNW	COOP	Daily	I	1941-06-01 to 1958-06-30	17
-72.81000	44.36000	Waterbury_1	US1VTWS0019	WATERBURY 3.0 NW	GHCN	Daily	A	2010-01-01 to 2012-08-31	2
-72.70000	44.36000	Waterbury_2	US1VTWS0018	WATERBURY 3.3 NE	GHCN	Daily	A	2009-07-01 to 2012-08-3	3
-72.72000	44.40000	Waterbury_3	US1VTWS0003	WATERBURY 4.6 NNE	GHCN	Daily	A	2009-05-01 to 2012-08-31	3
-72.41499	43.40140	Weatherfie_1	707019	WEATHERSFIE	AOT_RWIS	Daily	A		
-72.13000	44.32000	WBarnet_1	438959	WEST BARNET	COOP	Daily	I	1993-09-01 to 1994-04-30	1
-71.98000	44.65000	WBurke_1	439099	WEST BURKE	COOP	Daily	I	1930-07-01 to 1998-12-31	68
-72.05000	44.68000	WBurke_2	439109	WEST BURKE 5 NW	COOP	Daily	I	1945-07-01 to 1950-09-30	5
-72.18000	44.40000	WDanville_1	439182	WEST DANVILLE	COOP	Daily	I	1941-07-01 to 1955-12-31	14
-72.19000	44.42000	WDanville_2	439184	WEST DANVILLE 2	COOP	Daily	I	1989-05-01 to 2002-12-31	13

Table 1 continued…

Long	Lat	UniqueID_Tt	StationID	Station_Name	Network	Type	Status	POR (as of 9/15/2012)	Num_Yrs
-72.85000	42.93000	WDover_1	439190	WEST DOVER	COOP	Daily	I	1989-09-01 to 1996-05-31	7
-72.77000	42.79000	WHalifax_1	US1VTWH0009	WEST HALIFAX 0.2 SE	GHCN	Daily	A	2009-08-01 to 2012-08-31	3
-72.42000	43.72000	WHartford_1	439329	WEST HARTFORD	COOP	Daily	I	1930-05-01 to 1957-09-30	27
-72.42000	43.72000	WHartford_1	439339	WEST HARTFORD 2	COOP	Daily	I	1948-06-01 to 1948-12-31	0
-73.05000	43.61000	WRutland_1	US1VTRT0001	WEST RUTLAND 1.2 N	GHCN	Daily	A	2010-10-01 to 2012-08-31	2
-72.30000	44.13000	WTopsham_1	439588	WEST TOPSHAM	COOP	Daily	I	1940-10-01 to 1957-06-30	17
-72.85000	43.03000	WWards_1	USC00439591	WEST WARDSBORO	GHCN	Daily	A	1985-06-01 to 2012-03-31	27
-72.53000	43.47000	WWindsor_1	439600	WEST WINDSOR	COOP	Daily	I	1969-12-01 to 1977-04-30	8
-72.44000	44.89000	Westfield_1	US1VTOL0001	WESTFIELD 0.7 WNW	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.47271	43.02414	Westminster_2	707020	WESTMINSTER	AOT_RWIS	Daily	A		
-72.52000	43.07000	Westminster_1	US1VTWH0006	WESTMINSTER WEST 0.9 E	GHCN	Daily	A	2009-04-01 to 2012-08-31	3
-72.80000	43.30000	Weston_1	439476	WESTON	COOP	Daily	I	1948-06-01 to 1950-09-30	2
-72.78000	43.28000	Weston_2	439477	WESTON 1 S	COOP	Daily	I	1940-10-01 to 1955-10-31	15
-72.32000	43.65000	WRJ_1	439691	WHITE RIVER JUNCTION	COOP	Daily	I	1902-11-01 to 1959-11-30	57
-72.92000	42.80000	Whiting_1	439735	WHITINGHAM 1 W	COOP	Daily	I	1930-05-01 to 1998-07-31	68
-72.31000	43.67000	Wilder_1	439764	WILDER	COOP	Daily	A	1930-01-01 to 2010-01-31	80
-73.06287	44.43389	Williston_1	707004	WILLISTON	AOT_RWIS	Daily	A		
-73.12630	42.89471	Woodford_2	707009	WOODFORD	AOT_RWIS	Daily	A		
-73.03000	42.88000	Woodford_1	439953	WOODFORD	COOP	Daily	I	1966-05-01 to 1966-08-31	0
-72.51000	43.63000	Woodstock_1	USC00439984	WOODSTOCK	GHCN	Daily	A	1892-10-01 to 2012-08-31	120
-72.58000	44.37000	Worcester_1	USC00439988	WORCESTER 2 W	GHCN	Daily	A	2000-04-01 to 2012-08-31	12

Appendix 2B

Temperature and Precipitation Trends on Mount Mansfield Summit (Wright 2009)

Rising Temperature and Precipitation Trends on Mount Mansfield Summit

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Vermont Monitoring Cooperative 2009 Annual Meeting

Abstract:

A simple Mann-Kendall trend test was applied to the Mount Mansfield Summit weather data. The data set includes the daily maximum and minimum temperatures, precipitation, new snow fall, and total snow depth. The mean annual maximum and minimum temperature, precipitation, and snow depth measurements were calculated for each year, and the results were analyzed by a simple Mann-Kendall trend test. Results suggest that over a 50+ year period the minimum daily temperature, precipitation, and snow depth have risen, while the maximum daily temperature has remained steady.

Materials and Methods:

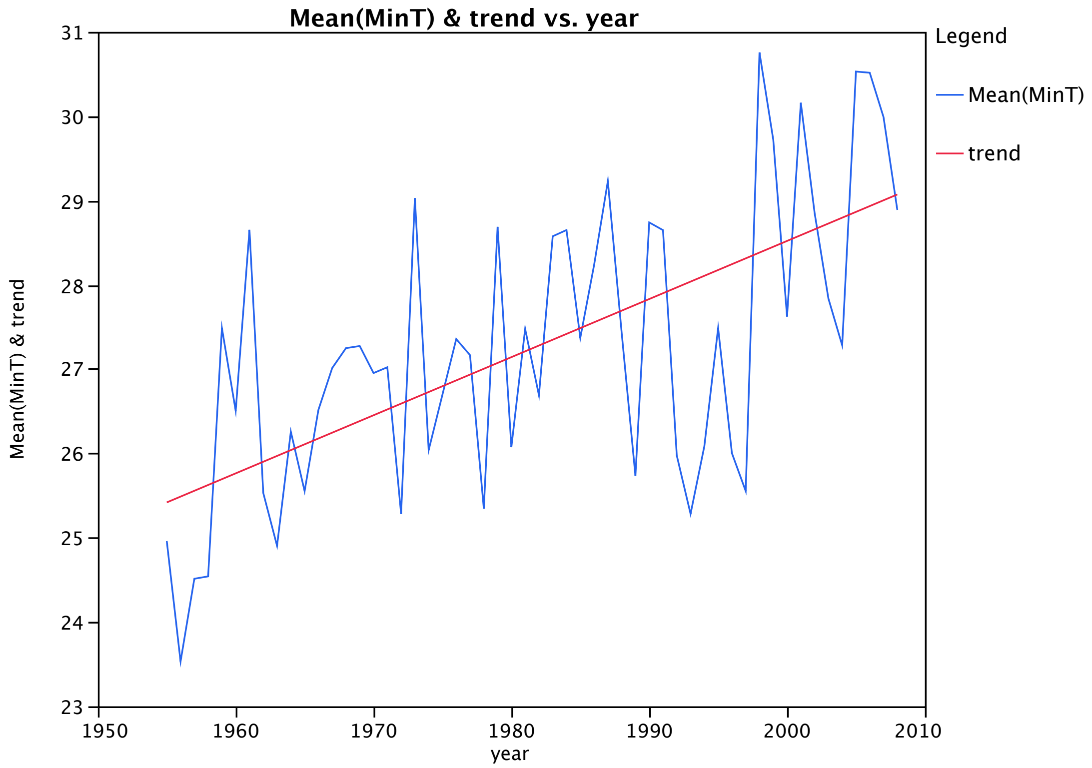
Each day around 5 PM during shift change, WCAX engineers record data at the Summit Snow Stake and related weather instruments at the summit of Mount Mansfield and radio it to the NWS in Burlington, who then release it in their "DAILY HYDROMETEOROLOGICAL DATA" report at http://www.srh.noaa.gov/data/BTV/HYDBTV . Once each day a script is launched on a UVM server which looks for the report, parses the data, and inserts it into a mySQL database housed on an university server. The database was pre-populated with historic data obtained from the NOAA National Data Center. The result is data set spanning over 50 years of measurements.

Four annual summary statistics where chosen for analysis: mean daily minimum temperature; mean daily maximum temperature, mean daily precipitation, and mean snow depth. Trend significance was determined using the non-parametric Mann-Kendall test (Helsel et al, 2005 “Computer Program for the Kendall Family of Trend Tests”, USGS Scientific Investigations Report 2005-5275 http://pubs.usgs.gov/sir/2005/5275/pdf/sir2005-5275.pdf).

Results:

Data set: Mean(MinT) The tau correlation coefficient is 0.433 S = 597. **z = 4.572 Increasing Trend** **p < 0.0001 Significantly different from 0** The relation may be described by the equation: MinT = -109.32 +0.6892E-01 * Year	**Data set: Mean(MaxT)** The tau correlation coefficient is 0.051 S = 70. **z = 0.529 No Trend** **p = 0.5966 Not significantly different from 0** The relation may be described by the equation: MaxT = 30.517 + 0.5756E-02 * Year
Data set: Mean(Precip) The tau correlation coefficient is 0.553 S = 762. **z = 5.837 Increasing Trend** **p < 0.0001 Significantly different from 0** The relation may be described by the equation: Precip = -3.7121 + 0.1973E-02 * Year	**Data set: Mean(SnowDepth)** The tau correlation coefficient is 0.266 S = 366. **z = 2.800 Increasing Trend** **p = 0.0051 Significantly different from 0** The relation may be described by the equation: Depth = -326.09 + 0.1764 * Year

For all measures, except MaxT, a significant increasing trend is detected.


Mean(MinT) & trend vs. year
Legend
Mean(MinT)
trend
Mean(MinT) & trend
year
31
30
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1950
1960
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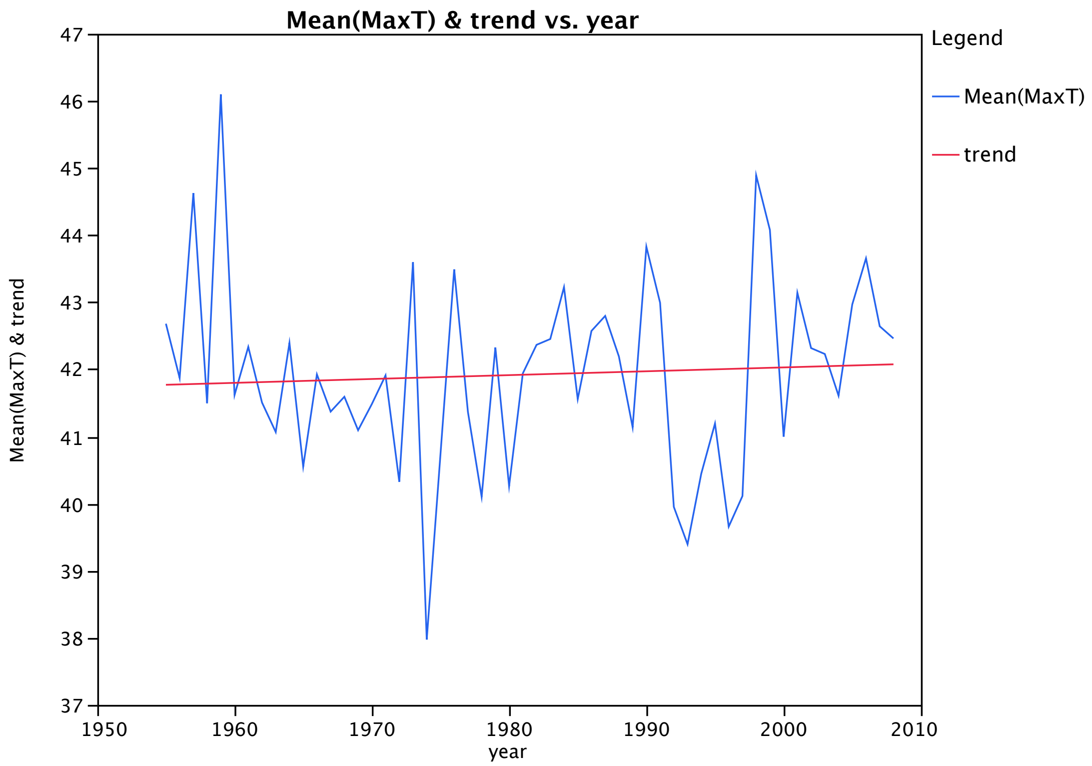
2000
2010


Mean(MaxT) & trend vs. year
Legend
Mean(MaxT)
trend
Mean(MaxT) & trend
year
47
46
45
44
43
42
41
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1950
1960
1970
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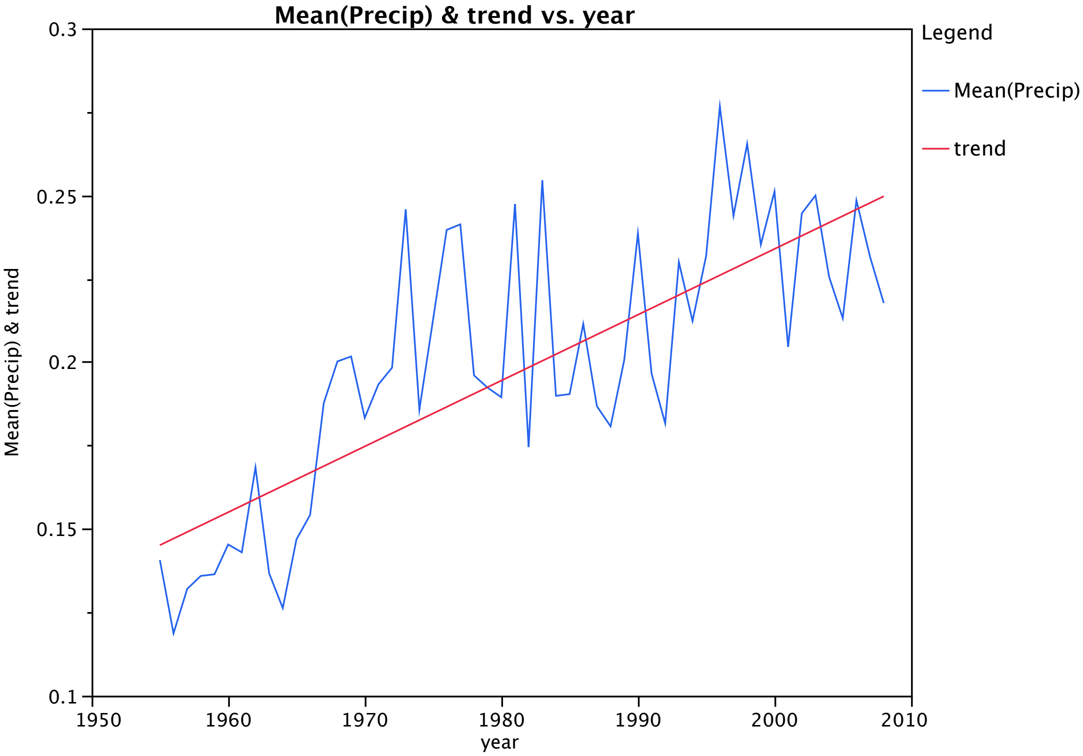
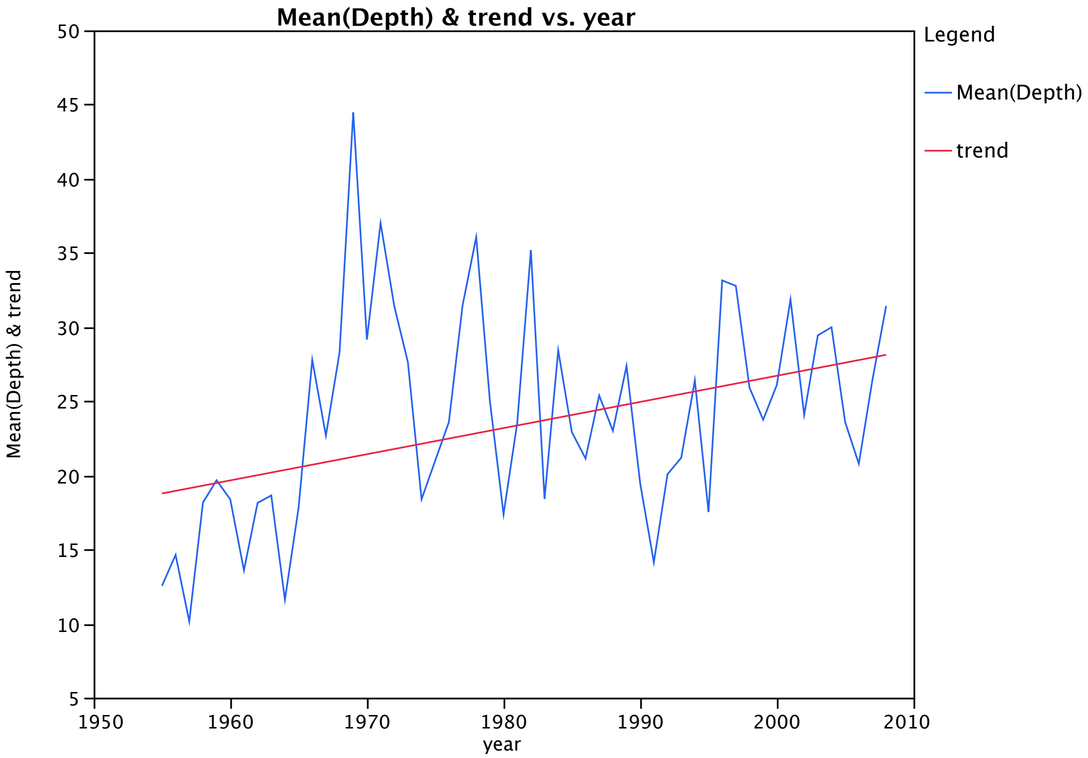

Mean(Precip) & trend vs. year
Mean(Precip) & trend
0.3
0.25
0.2
0.15
0.1
1950
1960
1970
1980
1990
2000
2010
year
Legend
Mean(Precip)
trend


Mean(Depth) & trend vs. year
Mean(Depth) & trend
year
50
45
40
35
30
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20
15
10
5
1950
1960
1970
1980
1990
2000
2010
Legend
Mean(Depth)
trend

Conclusions:

The results present strong evidence that while daytime temperatures on Mount Mansfield have remained consistent over the last half century, night time temperatures, precipitation, and summit snow depth are all on the rise. However, snow depth is not increasing as quickly as precipitation. This may suggest that the rising temperatures will spell more rain rather than snow events in coming years.

Appendix 2C

Data inventory for USGS gages located in Vermont

Stream flow and Water Temperature

We inventoried USGS stream gages in Vermont with assistance from USGS (USGS 2012a, Jeff Deacon, personal communication, 2012). A full list of USGS gages in Vermont, with spatial location (latitude/longitude), status (active/inactive) and period of record can be found in Table 2C-1 and gage locations are shown in Figure 2C-1. Most are stream gages with discharge measurements, but some are located on lakes and reservoirs and only measure level (not flow). The current status of some gages is uncertain due to funding issues, but as of fall 2012, there are about 50 active gages in Vermont. If inactive gages are included in the count, data are available for 107 sites. Thirty-one of these gages have over 50 years of data, and 13 have 80 or more years of data. The gage site with the longest-term flow data is the White River at West Hartford, which dates back to 1910, followed by Otter Creek at Middlebury and the Winooski River in Montpelier. Parameters include daily flow measurements, as well as various measures of water quality.

Based on the recently released USGS water quality watch website, none of the real-time USGS Daily Streamflow Network gages are currently reporting water temperature data (USGS 2012b). There is, however, one ‘unofficial’ site (Sleepers W-9 gage) with 21 years of water temperature data (Jamie Shanley, personal communication 2012). Limited water temperature data are also available from the Vermont Division of Fisheries and the Biomonitoring and Aquatic Studies (BASS). Traditionally these groups have collected instantaneous measurements at the time of the sampling event, but now that continuous temperature loggers are more affordable and reliable, they are being deployed at more and more sites. Continuous data are preferable over instantaneous measures because they capture more aspects of the true thermal regime, such as timing, duration and frequency of extremes. Fisheries has several years of continuous summer data for sites on the Dog River (Rich Kirn, personal communication) and BASS currently deploys the loggers at 10 to 20 sites per year. Most of these data are being collected during the summer when temperatures are warmest and access is easiest. If resources permit, year-round deployment is recommended, as ecologically relevant information about the date of spring onset, growing season length, overall variability, and total annual thermal units are missed when measurements are restricted to summer only (Isaac 2012). A regional effort is currently underway to compile water temperature records in the Northeast and put the locations in an interactive Google Earth map interface (Dave Armstrong USGS, personal communication 2012). This is modeled after a mapping tool that has been created in the Pacific Northwest (Rocky Mountain Research Station 2012).

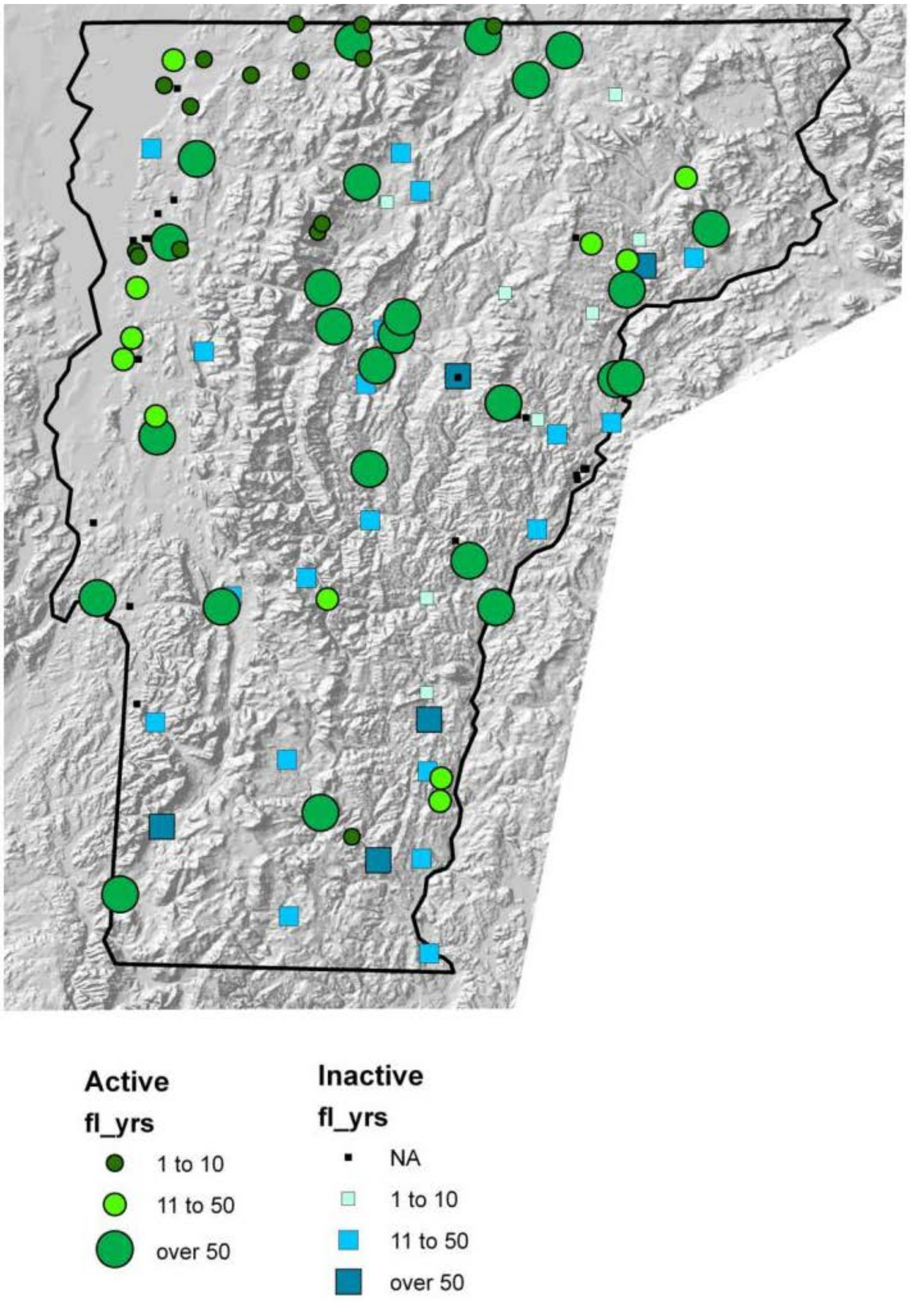


Figure 2C-1. Locations of active and inactive USGS gages in Vermont, coded by number of years of data. See Appendix B for list of gages.

Table 2C-1. USG gages located in Vermont (June 2012 output provided by Jeff Deacon, USGS (jrdeacon@usgs.gov). Site_Type – S=stream, LRI= Lake, Reservoir, Impoundment.

Long	Lat	Site_No	Station_name	Site_Type	DrainArea (sq mile)	Flow_Year Start	Flow_Year End	# Flow Years
-73.11263	44.46172	04290335	ALLEN BROOK AT VT 2A, NEAR ESSEX JUNCTION, VT	S	9.85	2006	2010	5
-72.65788	43.93451	01142500	AYERS BROOK AT RANDOLPH, VT	S	31.72	1940	2009	69
-73.15677	43.07619	01329000	BATTEN KILL AT ARLINGTON, VT	S	150.34	1929	1983	55
-72.85121	42.86064	01167800	BEAVER BROOK AT WILMINGTON, VT	S		1964	1977	14
-72.14203	43.93479	01140580	BIG BROOK (LAKE MOREY TRIBUTARY #4) NR FAIRLEE, VT	S	1.42	1982	1982	1
-72.94278	44.88056	04293795	BLACK CREEK ABOVE BRIDGE STREET, AT SHELDON, VT	S	119	2010	2010	1
-72.52009	43.39785	01152800	BLACK R AT COVERED BRIDGE, AT WEATHERSFIELD, VT	S	114	1977	1981	5
-72.27010	44.86894	04296000	BLACK RIVER AT COVENTRY, VT	S	116.68	1952	2010	59
-72.51481	43.33341	01153000	BLACK RIVER AT NORTH SPRINGFIELD, VT	S	158.91	1931	1989	59
-72.06621	44.83394	04296200	BROWNINGTON BRANCH NEAR EVANSVILLE, VT	S	2.15	1964	1973	10
-72.18927	44.94032	04296500	CLYDE RIVER AT NEWPORT, VT	S	144.79	1910	2010	90
-72.07565	44.04562	01139500	CONNECTICUT RIVER AT SOUTH NEWBURY, VT	S	2825	1919	1950	31
-72.51426	42.77147	01156500	CONNECTICUT RIVER AT VERNON, VT	S	6259.98	1945	1973	29
-72.04231	44.15367	01138500	CONNECTICUT RIVER AT WELLS RIVER, VT	S	2644	1951	2009	59
-72.64039	44.18284	04287000	DOG RIVER AT NORTHFIELD FALLS, VT	S	76.65	1936	2010	75
-72.66678	44.13867	04286500	DOG RIVER AT NORTHFIELD, VT	S	52	1913	1934	12
-72.44455	44.15506	04283500	EAST BARRE DETENTION RESERVOIR AT EAST BARRE, VT	LRI	38.8			
-71.89759	44.63394	01133000	EAST BRANCH PASSUMPSIC RIVER NEAR EAST HAVEN, VT	S	53.4	1940	2009	49
-72.98900	43.62868	04281500	EAST CREEK AT RUTLAND, VT	S	53.75	1941	1977	37
-72.33565	44.09284	01139800	EAST ORANGE BRANCH AT EAST ORANGE, VT	S	8.8	1959	2009	51
-73.21929	44.45783	04282815	ENGLESBY BROOK AT BURLINGTON, VT	S	0.9	2000	2009	10
-72.85593	43.23646	01155300	FLOOD BROOK NEAR LONDONDERRY, VT	S	9.25	1964	1974	11
-72.15981	43.92035	01140590	GLENN FALLS BK (LAKE MOREY TR #3) NEAR FAIRLEE, VT	S	1.64	1982	1982	1
-72.53511	44.60283	04291000	GREEN RIVER AT GARFIELD, VT	S	18	1916	1931	13

Table 2C-1. continued…

Long	Lat	Site_No	Station_name	Site_Type	DrainArea (sq mile)	Flow_Year Start	Flow_Year End	# Flow Years
-73.05556	44.91833	04293900	HUNGERFORD BR @ HIGHGATE RD NR HIGHGATE CENTER, VT	S	18.6	2010	2010	1
-73.16541	44.54810	04290580	INDIAN BROOK NEAR COLCHESTER, VT	S	10.8	1991	1991	1
-72.44510	44.15840	04284000	JAIL BRANCH AT EAST BARRE, VT	S	38.91	1921	1992	61
-73.15083	44.85611	04292810	JEWETT BROOK AT VT 38, NEAR ST. ALBANS, VT	S	4.74	2009	2009	1
-72.80871	43.67340	01150800	KENT BROOK NEAR KILLINGTON, VT	S	3.31	1964	1974	11
-71.87815	44.44200	01134800	KIRBY BROOK AT CONCORD, VT	S	8.05	1964	1974	11
-73.23317	43.60507	04279490	LAKE BOMOSEEN AT OUTLET, NEAR FAIR HAVEN, VT	LRI	37.5			
-73.22513	44.48394	04294500	LAKE CHAMPLAIN AT BURLINGTON, VT	LRI				
-72.20538	44.93755	04295500	LAKE MEMPHREMAGOG AT NEWPORT, VT	LRI				
-72.13787	43.93507	01140599	LAKE MOREY NEAR FAIRLEE, VT					
-72.15759	43.90979	01140600	LAKE MOREY OUTLET AT FAIRLEE, VT	S	8.2	1982	1982	1
-72.14092	43.93618	01140575	LAKE MOREY TRIBUTARY #5 NEAR FAIRLEE, VT	S	0.37	1982	1982	1
-72.13676	43.93618	01140570	LAKE MOREY TRIBUTARY #6 NEAR FAIRLEE, VT	S	0.58	1982	1982	1
-72.61567	44.57589	04291500	LAMOILLE RIVER AT CADYS FALLS, VT	S	268	1914	1923	10
-73.07264	44.67921	04292500	LAMOILLE RIVER AT EAST GEORGIA, VT	S	690.18	1930	2010	81
-72.67623	44.62283	04292000	LAMOILLE RIVER AT JOHNSON, VT	S	314.77	1929	2010	82
-73.21624	44.37005	04282795	LAPLATTE RIVER AT SHELBURNE FALLS, VT.	S	44.82	1991	2010	20
-73.22846	44.24922	04282780	LEWIS CREEK AT NORTH FERRISBURG, VT.	S	76.79	1991	2009	19
-73.05540	44.21672	04282700	LEWIS CREEK TRIBUTARY AT STARKSBORO, VT	S	5.31	1964	1974	11
-73.21207	44.19894	04282636	LITTLE OTTER CR @ MIDDLE BR RD, NR FERRISBURG, VT	S	43.4			
-73.24901	44.19811	04282650	LITTLE OTTER CREEK AT FERRISBURG, VT.	S	58.26	1991	2009	19
-72.76929	44.37006	04289000	LITTLE RIVER NEAR WATERBURY, VT	S	110.76	1938	2009	72
-72.74262	44.27728	04288000	MAD RIVER NEAR MORETOWN, VT	S	140.56	1929	2009	81
-73.12735	44.58116	04290610	MALLETTS CREEK NEAR COLCHESTER, VT	S		1991	1991	1
-73.21622	43.37063	04280350	METTAWEE RIVER NEAR PAWLET, VT	S	69.8			
-73.17177	43.32646	04280300	METTAWEE RIVER TRIBUTARY NEAR PAWLET, VT	S	2.95	1964	1974	11
-73.12846	44.91671	04294000	MISSISQUOI RIVER AT SWANTON, VT	S	850	1991	2010	20

Table 2C-1. continued…

Long	Lat	Site_No	Station_name	Site_Type	DrainArea (sq mile)	Flow_Year Start	Flow_Year End	# Flow Years
-72.69652	44.96005	04293500	MISSISQUOI RIVER NEAR EAST BERKSHIRE, VT	S	479	1917	2009	86
-72.38539	44.97282	04293000	MISSISQUOI RIVER NEAR NORTH TROY, VT	S	131	1932	2010	79
-72.33177	44.35784	04283000	MOLLYS BROOK NEAR MARSHFIELD, VT	S	24	1921	1923	3
-72.00009	44.42284	01135000	MOOSE RIVER AT ST. JOHNSBURY, VT	S	129.08	1929	1983	55
-71.83731	44.51172	01134500	MOOSE RIVER AT VICTORY, VT	S	75.34	1948	2010	63
-72.35917	44.99833	04293200	MUD CREEK AT BEAR MOUNTAIN RD, NEAR NORTH TROY, VT	S	37.1	2010	2010	1
-73.17067	44.06173	04282525	NEW HAVEN RIVER @ BROOKSVILLE, NR MIDDLEBURY, VT	S	116.21	1991	2010	20
-72.67556	45.00194	04293430	NORTH BRANCH ABOVE RIVER STREET, AT RICHFORD, VT	S	64.8	2010	2010	1
-72.57872	44.29950	04285500	NORTH BRANCH WINOOSKI RIVER AT WRIGHTSVILLE, VT	S	70.23	1934	2010	77
-72.25481	43.79007	01141500	OMPOMPANOOSUC RIVER AT UNION VILLAGE, VT	S	130.68	1941	1989	49
-72.35426	43.60257	01151500	OTTAUQUECHEE RIVER AT NORTH HARTLAND, VT	S	222.45	1931	2010	80
-72.52009	43.62479	01151000	OTTAUQUECHEE RIVER AT WOODSTOCK, VT	S	126	1929	1930	2
-72.75899	43.62229	01150900	OTTAUQUECHEE RIVER NEAR WEST BRIDGEWATER, VT	S	23.62	1985	2009	25
-73.01316	43.60368	04282000	OTTER CREEK AT CENTER RUTLAND, VT	S	308.16	1929	2009	81
-73.16790	44.01312	04282500	OTTER CREEK AT MIDDLEBURY, VT	S	630.45	1911	2010	91
-72.03926	44.36561	01135500	PASSUMPSIC RIVER AT PASSUMPSIC, VT	S	434.32	1930	2010	81
-72.00926	44.48617	01133500	PASSUMPSIC RIVER NEAR ST. JOHNSBURY, VT	S	237	1916	1918	3
-72.28121	44.05784	01139833	PIKE HILL BR @ PIKE HILL RD W X, NR BRADFORD, VT	S		2006	2006	1
-72.30149	44.06395	01139830	PIKE HILL BR AB RICHARDSON RD, NR BRADFORD, VT	S		2006	2006	1
-72.25287	44.05340	01139838	PIKE HILL BROOK @ PIKE HILL ROAD, NR BRADFORD, VT	S		2005	2006	2
-72.83347	45.00282	04294300	PIKE RIVER AT EAST FRANKLIN, NR ENOSBURG FALLS, VT	S	34.5	2002	2010	9
-72.12454	44.47617	01135150	POPE BROOK (SITE W-3) NEAR NORTH DANVILLE, VT	S	3.9	1992	2009	18
-73.21346	44.44588	04282813	POTASH BR @ QUEEN CITY PARK RD, NR BURLINGTON, VT	S	6.84	2005	2009	5
-73.31150	43.62423	04280000	POULTNEY RIVER BELOW FAIR HAVEN, VT	S	188.26	1929	2010	82
-72.78179	44.50394	04288230	RANCH BROOK AT RANCH CAMP, NEAR STOWE, VT	S	3.83	2001	2009	9

Table 2C-1. continued…

Long	Lat	Site_No	Station_name	Site_Type	DrainArea (sq mile)	Flow_Year Start	Flow_Year End	# Flow Years
-72.53259	42.99925	01155200	SACKETS BROOK NEAR PUTNEY, VT	S	10	1964	1974	11
-72.48814	43.13758	01154000	SAXTONS RIVER AT SAXTONS RIVER, VT	S	72.33	1941	2009	50
-72.03843	44.43534	01135300	SLEEPERS RIVER (SITE W-5) NEAR ST. JOHNSBURY, VT	S	42.9	1991	2009	19
-72.16204	44.49061	01135100	SLEEPERS RIVER TRIB. W-9, AT N. DANVILLE, VT	S	0.18			
-72.20732	44.01812	01140000	SOUTH BRANCH WAITS RIVER NEAR BRADFORD, VT	S	43.8	1941	1951	11
-73.32067	43.80562	04280800	SOUTH FORK NEAR ORWELL, VT	S	13.4	1991	1991	1
-73.08792	44.80560	04292770	STEVENS BROOK AT LEMNAH DRIVE, AT ST ALBANS, VT	S	1.28	2007	2009	3
-73.11930	44.84893	04292800	STEVENS BROOK NEAR ST ALBANS, VT	S	10.2	1991	1991	1
-72.12176	44.31006	01136000	STEVENS RIVER AT WEST BARNET, VT	S	22.2	1940	1945	6
-73.18152	44.70393	04292700	STONE BRIDGE BROOK NEAR GEORGIA PLAINS, VT	S	8.46	1964	2000	21
-72.58234	44.69366	04292100	STONY BROOK NEAR EDEN, VT	S	4.21	1964	1974	11
-72.62400	44.26811	04287300	SUNNY BROOK NEAR MONTPELIER, VT	S	2.31	1964	1974	11
-72.67250	44.92028	04293600	TROUT RIVER AT HOPKINS BR, NR ENOSBURG FALLS, VT	S	78.6	2010	2010	1
-72.82194	44.89083	04293700	TYLER BRANCH @ DUFFY HILL RD NR ENOSBURG FALLS, VT	S	55.1	2010	2010	1
-72.77179	44.52339	04288225	W BRANCH LITTLE R ABV BINGHAM FALLS NEAR STOWE, VT	S	4.6	2008	2009	2
-73.25650	42.91286	01334000	WALLOOMSAC RIVER NEAR NORTH BENNINGTON, VT	S	115.66	1932	2010	79
-72.76984	44.38172	04288500	WATERBURY RESERVOIR NEAR WATERBURY, VT	LRI	109			
-72.06509	44.15034	01139000	WELLS RIVER AT WELLS RIVER, VT	S	95.11	1941	2009	69
-72.77537	43.10897	01155500	WEST RIVER AT JAMAICA, VT	S	177.53	1947	2009	57
-72.63648	42.99536	01156000	WEST RIVER AT NEWFANE, VT	S	305.82	1920	1989	65
-72.70009	43.05119	01155910	WEST RIVER BELOW TOWNSHEND DAM NEAR TOWNSHEND, VT	S	279.26	1995	2000	6
-72.45093	43.76257	01143500	WHITE RIVER AT SHARON, VT	S	654			
-72.41815	43.71424	01144000	WHITE RIVER AT WEST HARTFORD, VT	S	691.21	1916	2009	93
-72.65621	43.81146	01142000	WHITE RIVER NEAR BETHEL, VT	S	241	1932	1955	24
-72.51759	43.20869	01153500	WILLIAMS RIVER AT BROCKWAYS MILLS, VT	S	101.67	1941	1984	44
-72.48509	43.19174	01153550	WILLIAMS RIVER NEAR ROCKINGHAM VT	S	111.8	1987	2010	24

Table 2C-1. continued…

Long	Lat	Site_No	Station_name	Site_Type	DrainArea (sq mile)	Flow_Year Start	Flow_Year End	# Flow Years
-73.18235	44.48810	04290550	WINOOSKI RIVER ABOVE CHASE MILL, AT BURLINGTON, VT					
-72.59289	44.25645	04286000	WINOOSKI RIVER AT MONTPELIER, VT	S	394.98	1915	2010	91
-73.19596	44.48866	04290560	WINOOSKI RIVER BELOW CHASE MILL, AT BURLINGTON, VT					
-73.13874	44.47894	04290500	WINOOSKI RIVER NEAR ESSEX JUNCTION, VT	S	1013.51	1929	2009	81
-72.57483	44.31061	04285000	WRIGHTSVILLE DETENTION RESERVOIR @ WRIGHTSVILLE VT	LRI	66.5			

Appendix 2D

Lake and pond ice out data collected by citizen scientists (contacts: Jeff Merrell and Amy Picotte, VT DEC)

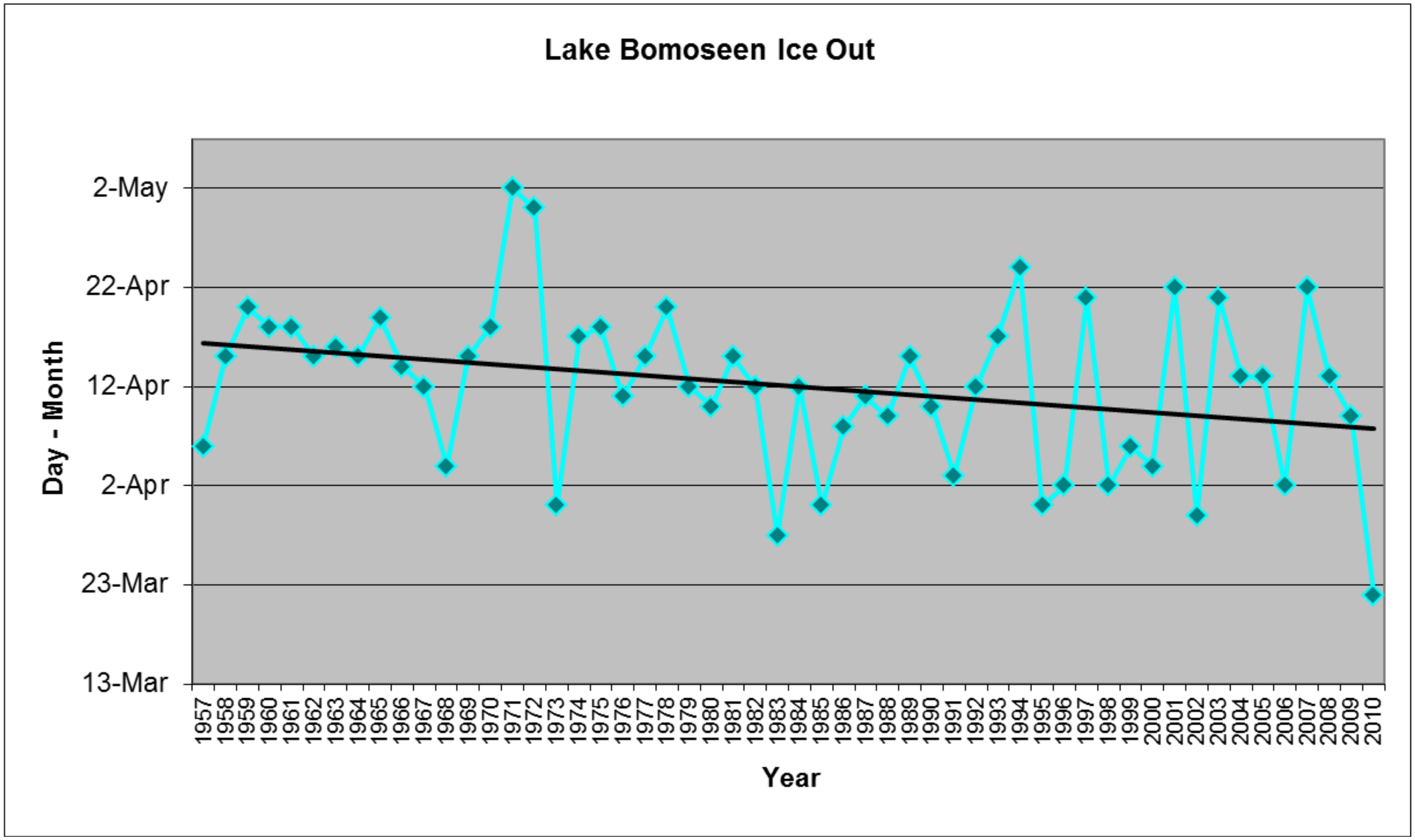

Lakes or ponds with citizen ice-out data

Table 1. Sentinel lake/pond and stream monitoring sites in Vermont.

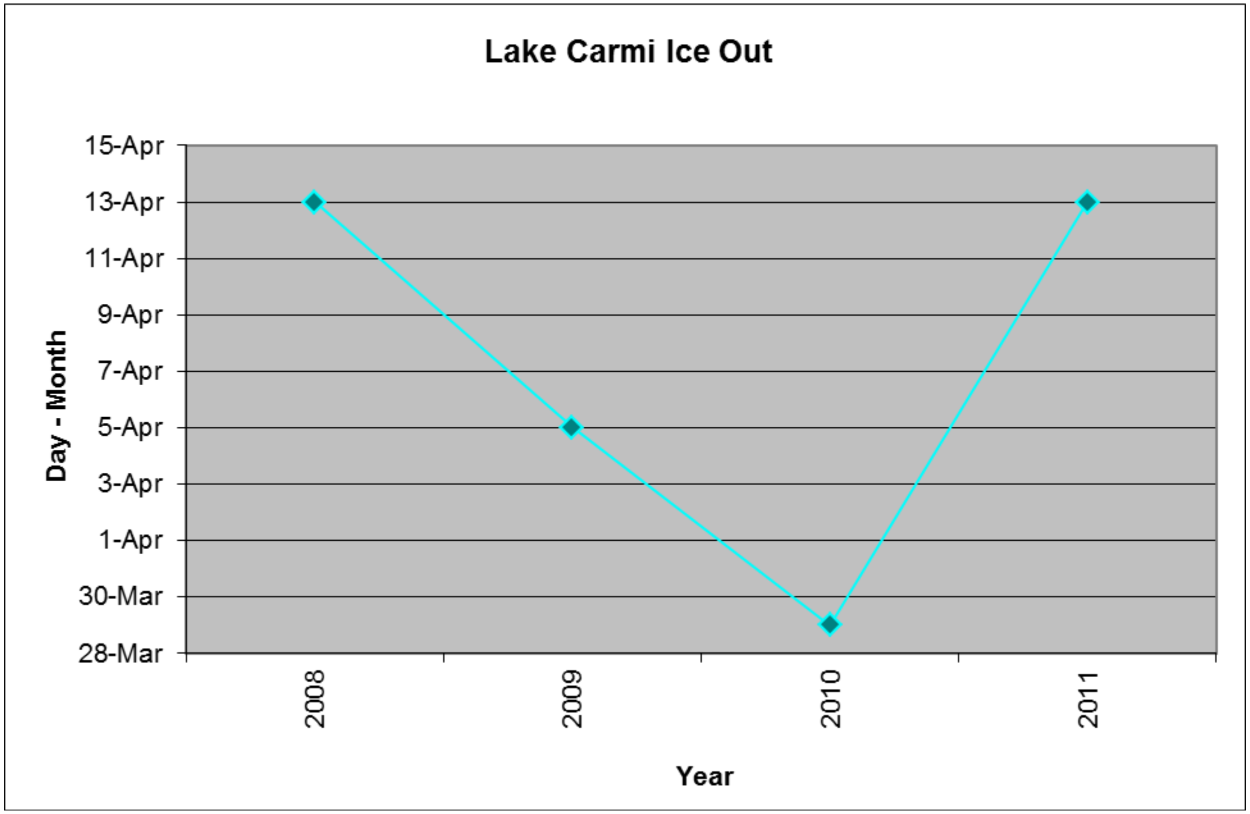
Longitude	Latitude	Station Name	Site Type	Program	Year_Start	Contact
-72.21480	43.64347	Lake Bomoseen	Lakes	Ice out	1957	Amy Picotte
-72.87601	44.97507	Lake Carmi	Lakes	Ice out	2008	Amy Picotte
-71.99277	44.85926	Echo Lake (Charleston, VT)	Lakes	Ice out	1970	Amy Picotte
-72.22886	43.88605	Lake Fairlee	Lakes	Ice out	1975	Amy Picotte
-72.12265	44.08582	Halls Lake	Lakes	Ice out	1987	Amy Picotte
-72.13834	44.29212	Lake Harvey (Harvey's Lake)	Lakes	Ice out	1946 (with gaps)	Amy Picotte
-73.08383	44.36787	Lake Iroquois	Lakes	Ice out	1994	Amy Picotte
-72.22167	44.40851	Joe's Pond	Lakes	Ice out	1988	Amy Picotte
-71.64599	44.65405	Maidstone	Lakes	Ice out	1973	Amy Picotte
-72.70232	43.45146	Lake Rescue	Lakes	Ice out	1995	Amy Picotte
-71.98840	44.89694	Lake Seymour	Lakes	Ice out	1983	Amy Picotte
-73.03019	43.40850	Chipman - Tinmouth Pond	Lakes	Ice out	2005	Amy Picotte
-72.15448	43.91759	Lake Morey	Lakes	Ice out	1977	Amy Picotte
-73.21320	43.46902	Lake St Catherine	Lakes	Ice out	1933	Amy Picotte
-72.21344	44.97429	Lake Memphremagog	Lakes	Ice out	1992	Amy Picotte
-71.93950	44.41687	Stile's Pond	Lakes	Ice out	1970	Amy Picotte
-72.60499	44.04218	Colts Pond/Sunset Lake	Lakes	Ice out	1933	Amy Picotte

These plots were provided by Jeff Merrell and Amy Picotte from VT DEC.

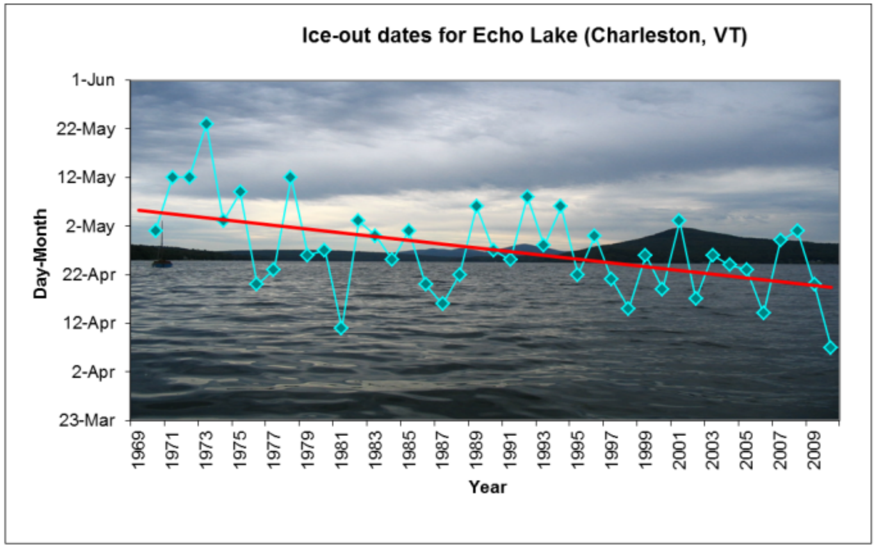
Lake Bomoseen

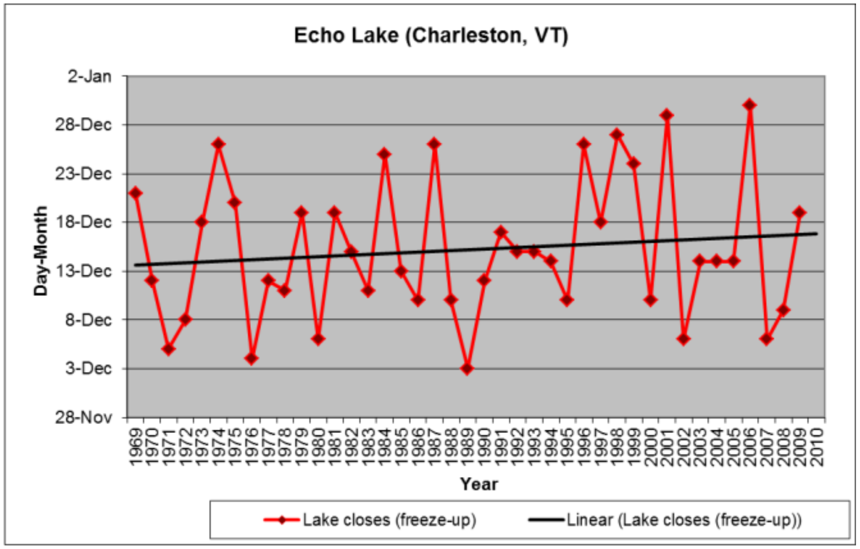


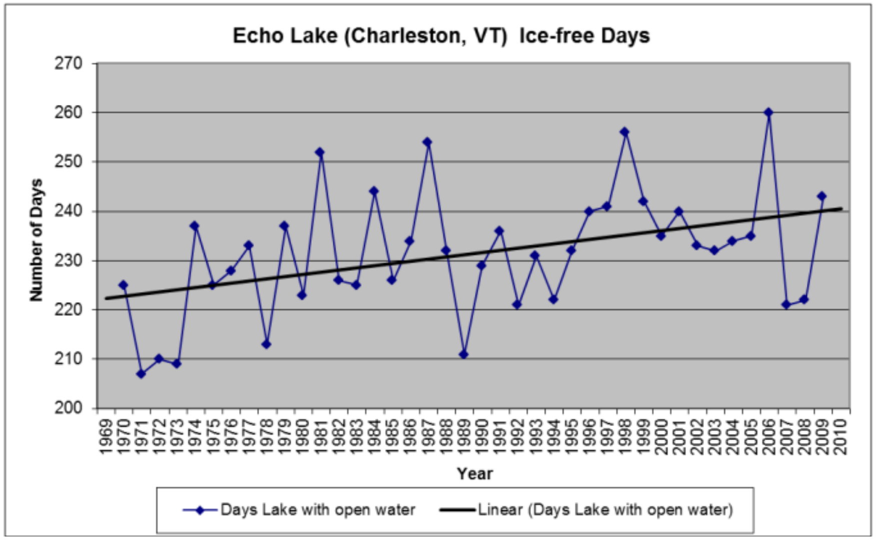
Lake Carmi


Lake Carmi Ice Out
Day - Month
15-Apr
13-Apr
11-Apr
9-Apr
7-Apr
5-Apr
3-Apr
1-Apr
30-Mar
28-Mar
2008
2009
2010
2011
Year

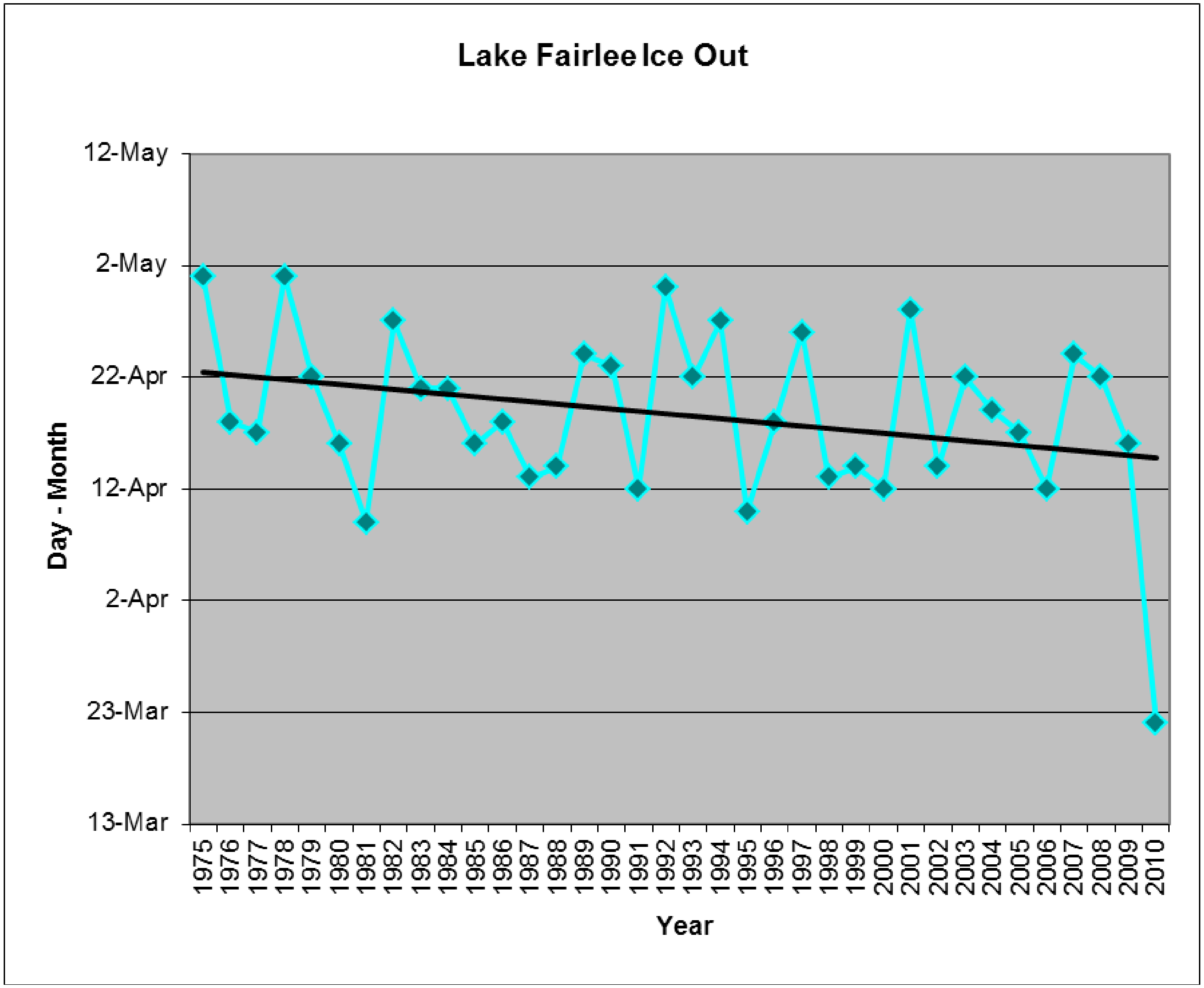
Echo Lake (Charleston, VT)



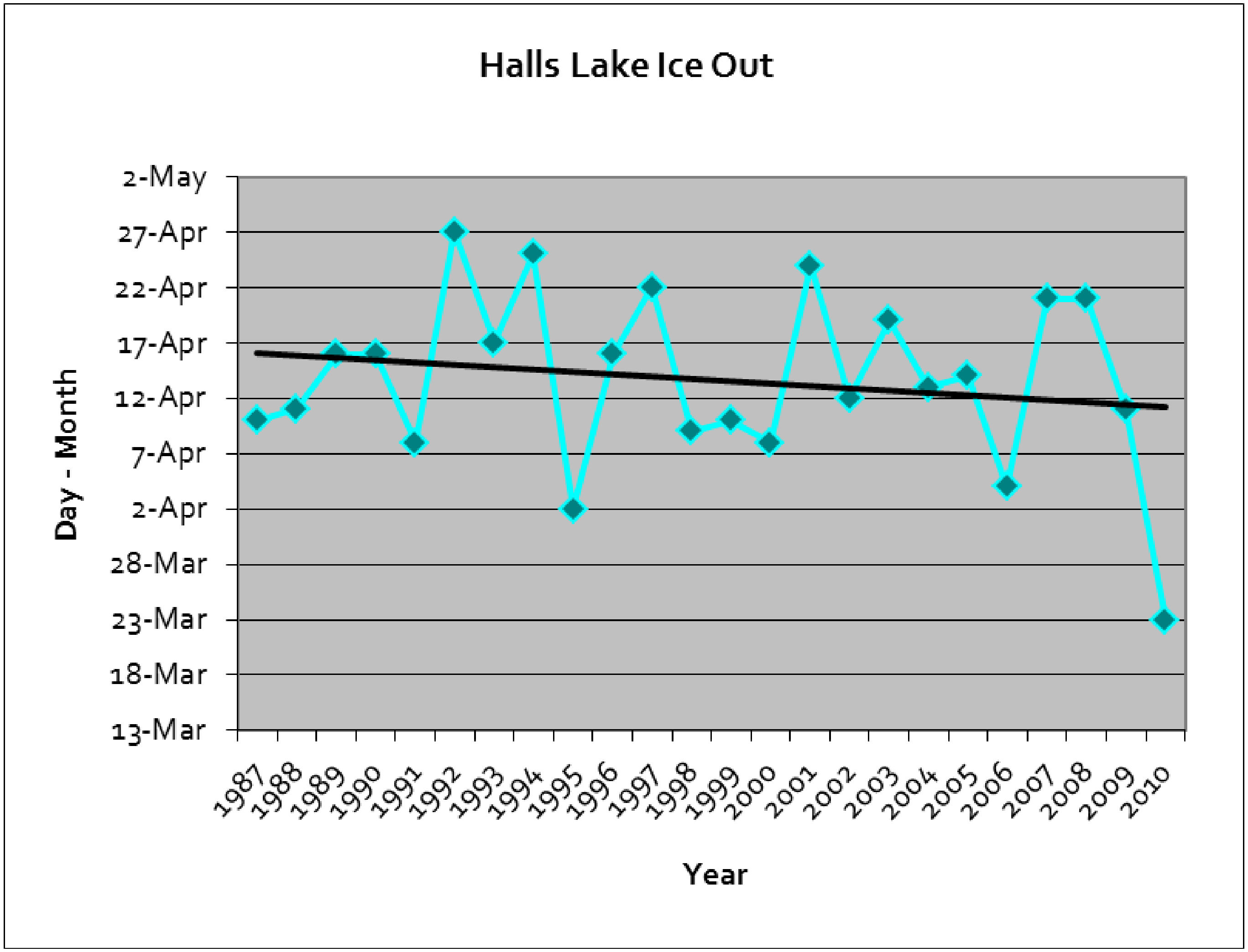




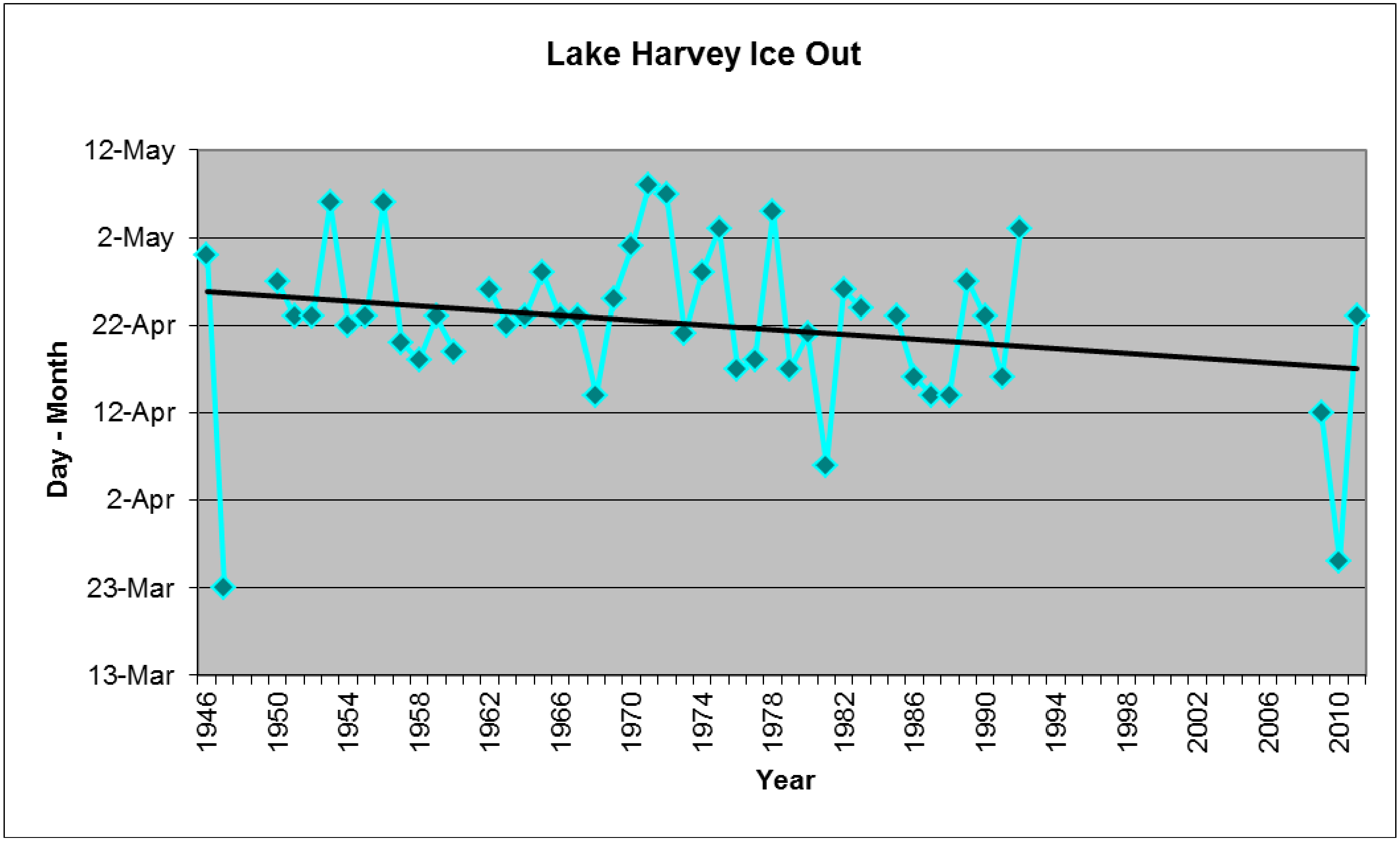
Lake Fairlee



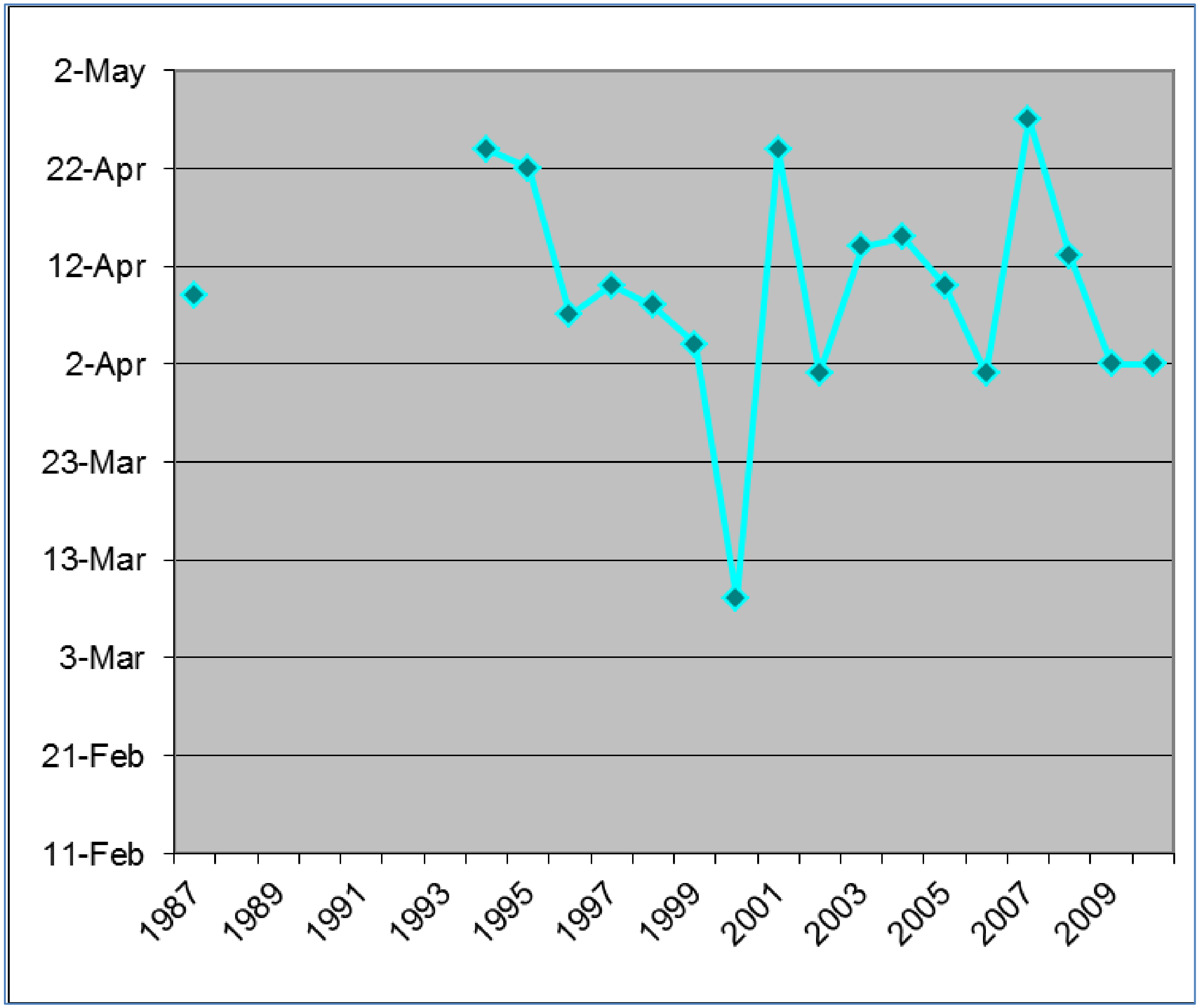
Halls Lake


Halls Lake Ice Out
Day - Month
2-May
27-Apr
22-Apr
17-Apr
12-Apr
7-Apr
2-Apr
28-Mar
23-Mar
18-Mar
13-Mar
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year

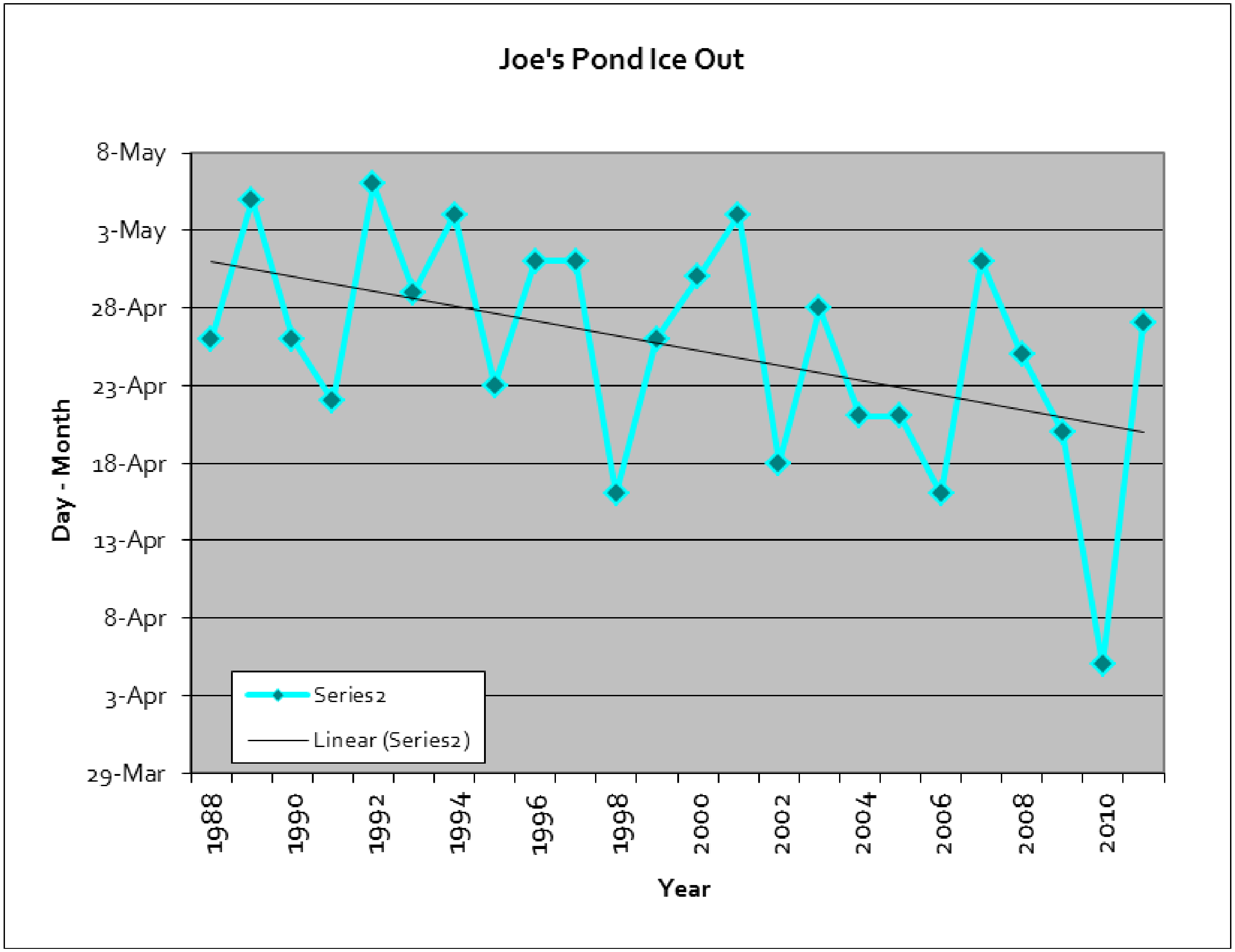
Lake Harvey (Harvey's Lake)



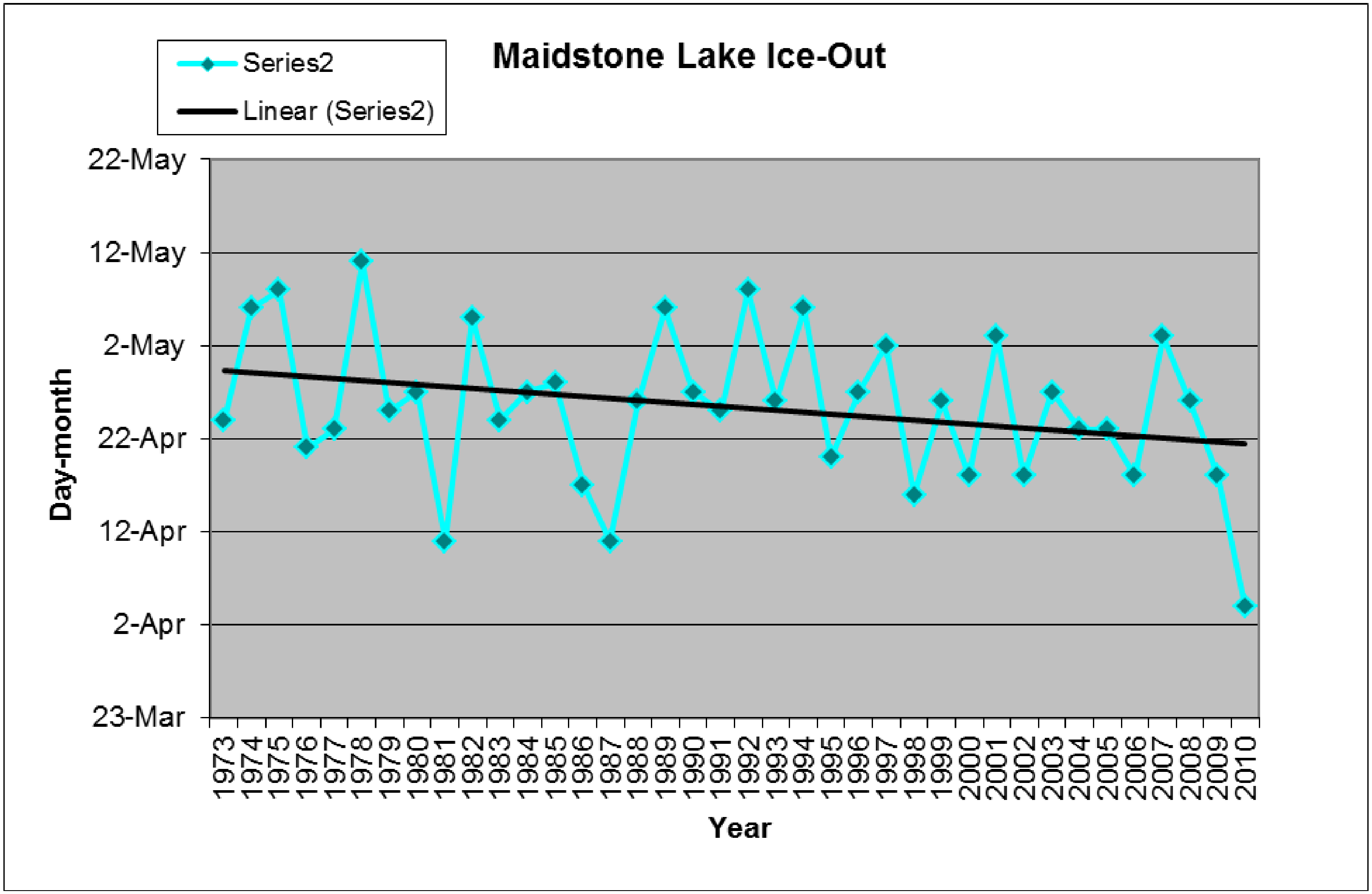
Lake Iroquois



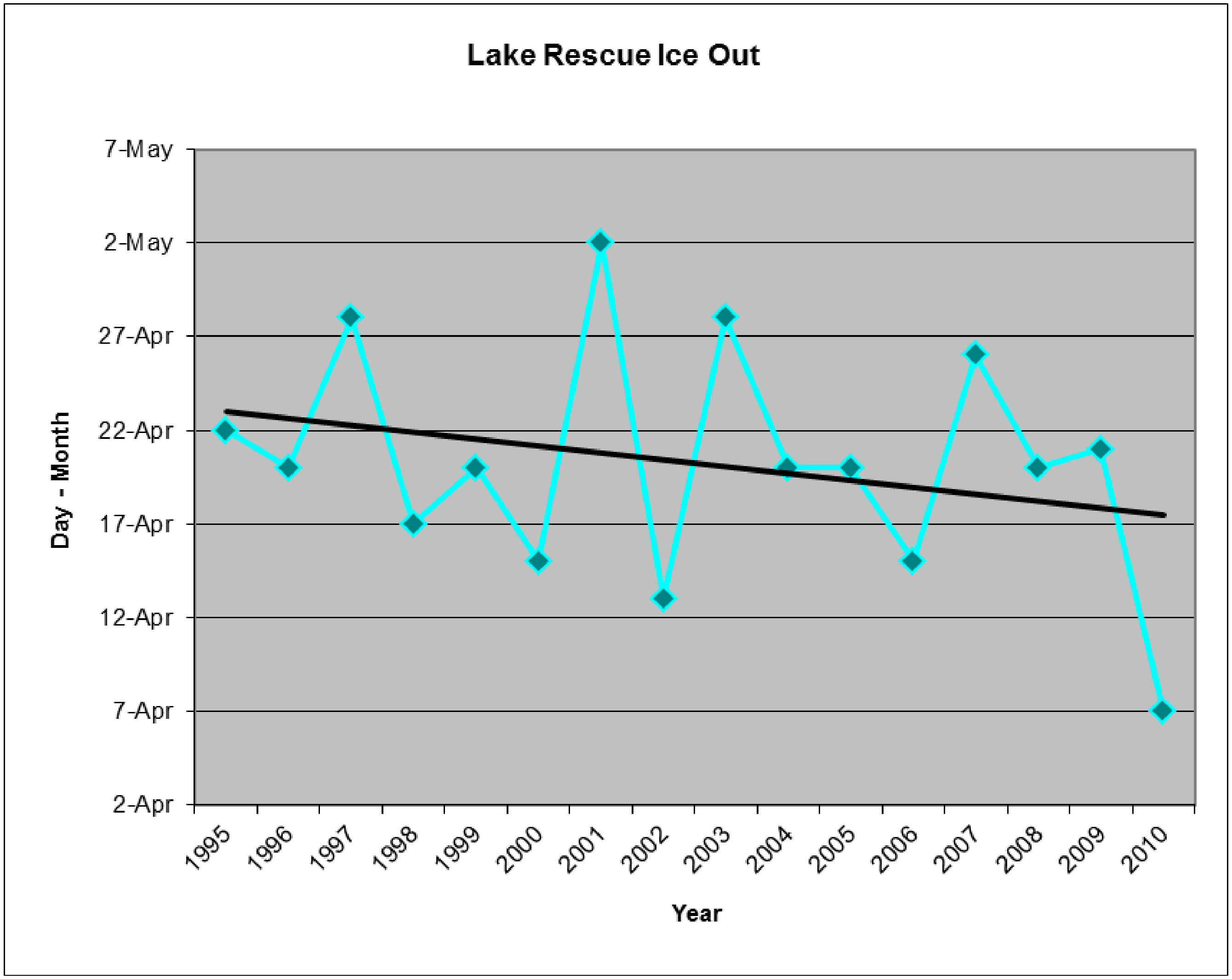
Joe's Pond


Joe's Pond Ice Out
8-May
3-May
28-Apr
23-Apr
18-Apr
13-Apr
8-Apr
3-Apr
29-Mar
Day - Month
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Year
Series2
Linear (Series2)

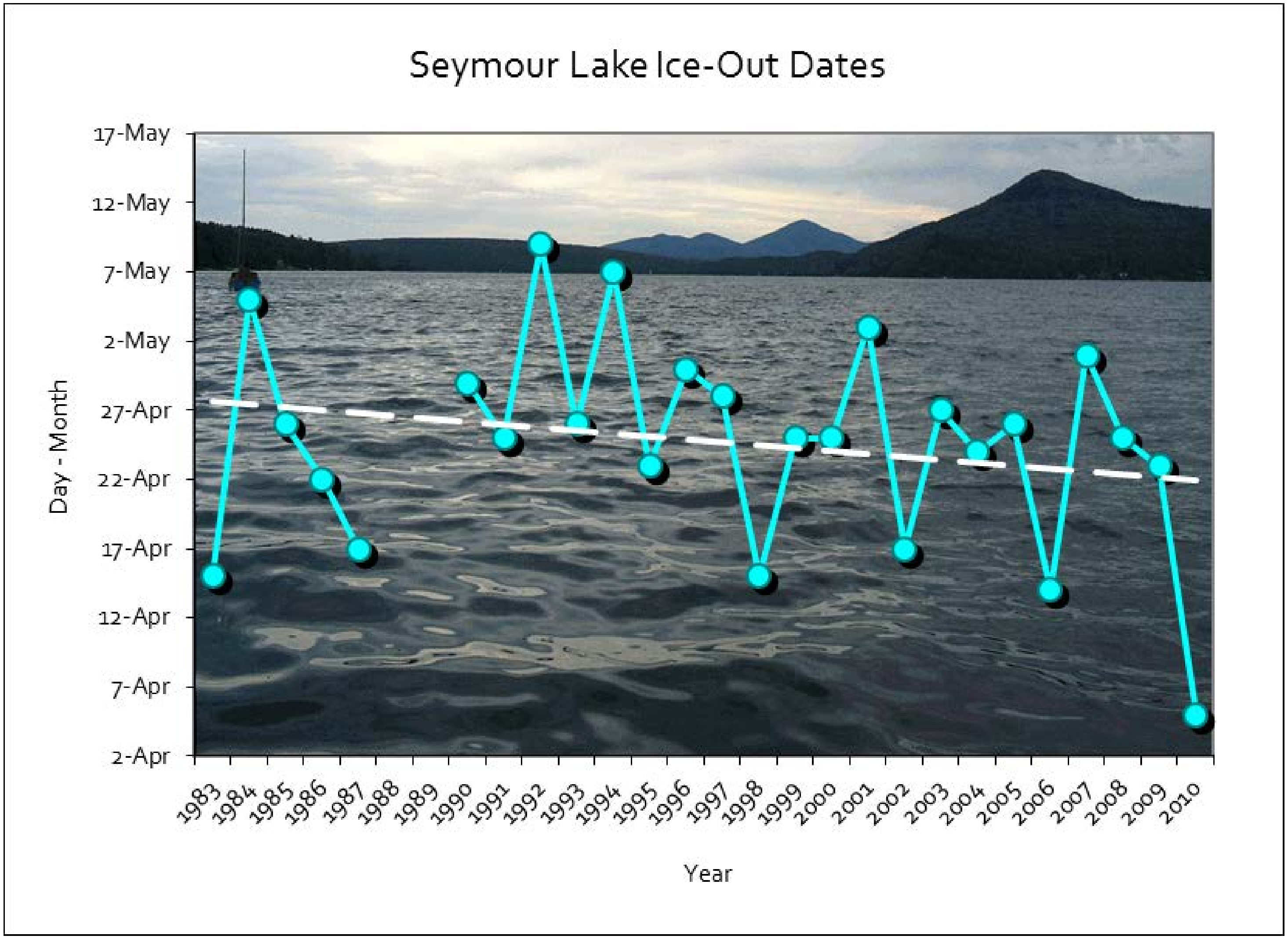
Maidstone Lake



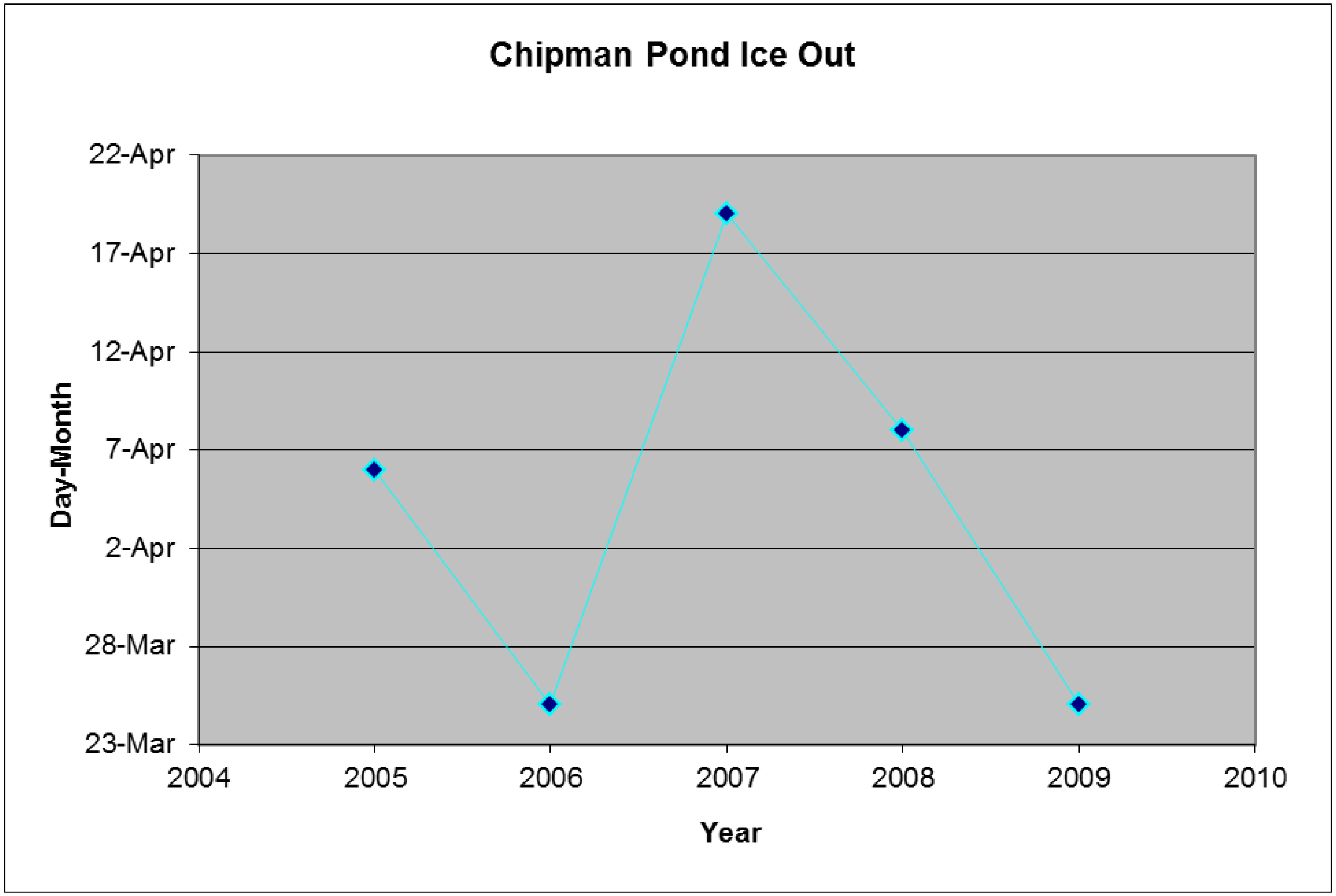
Lake Rescue


Lake Rescue Ice Out
Day - Month
7-May
2-May
27-Apr
22-Apr
17-Apr
12-Apr
7-Apr
2-Apr
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year

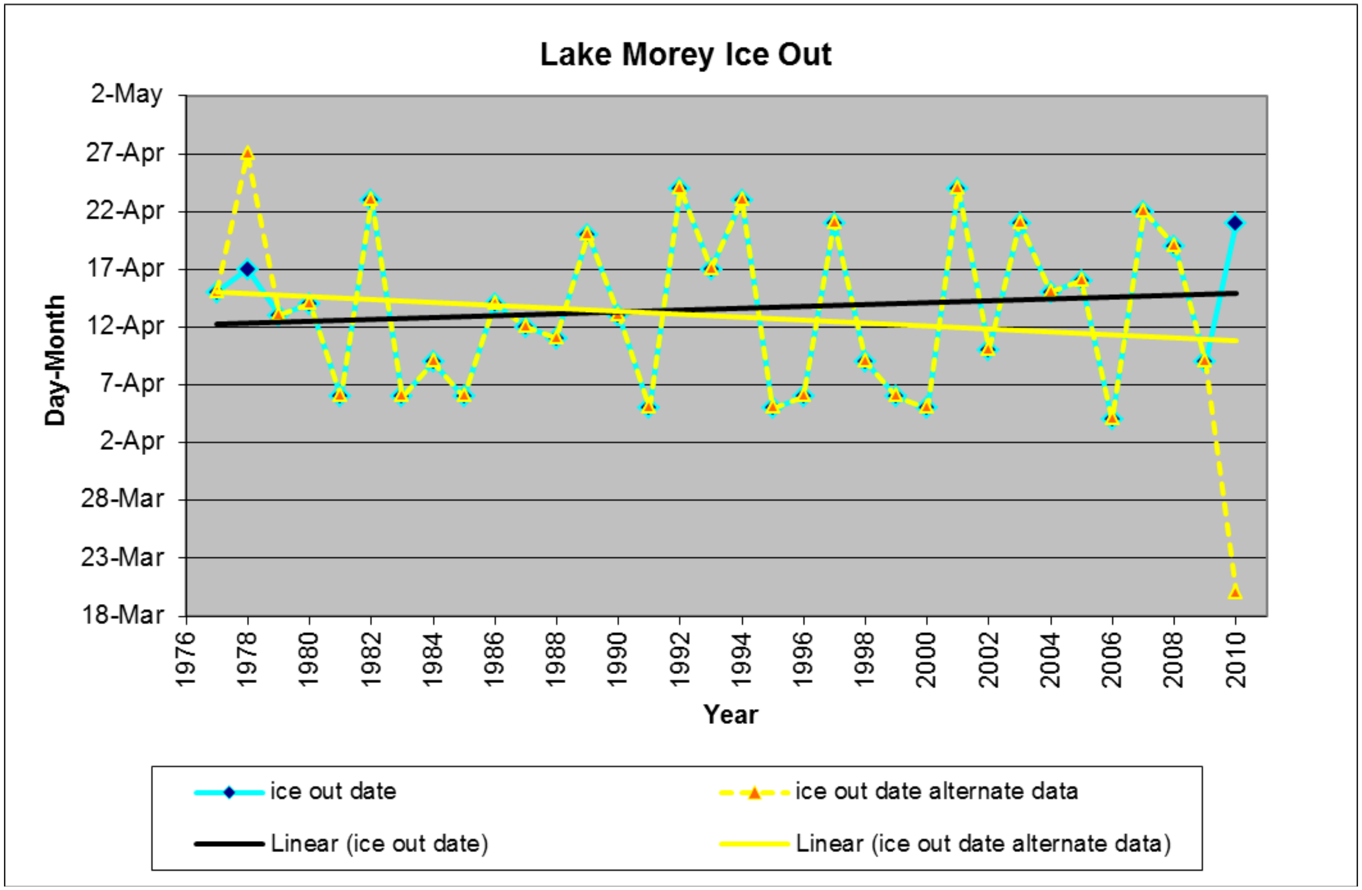
Lake Seymour



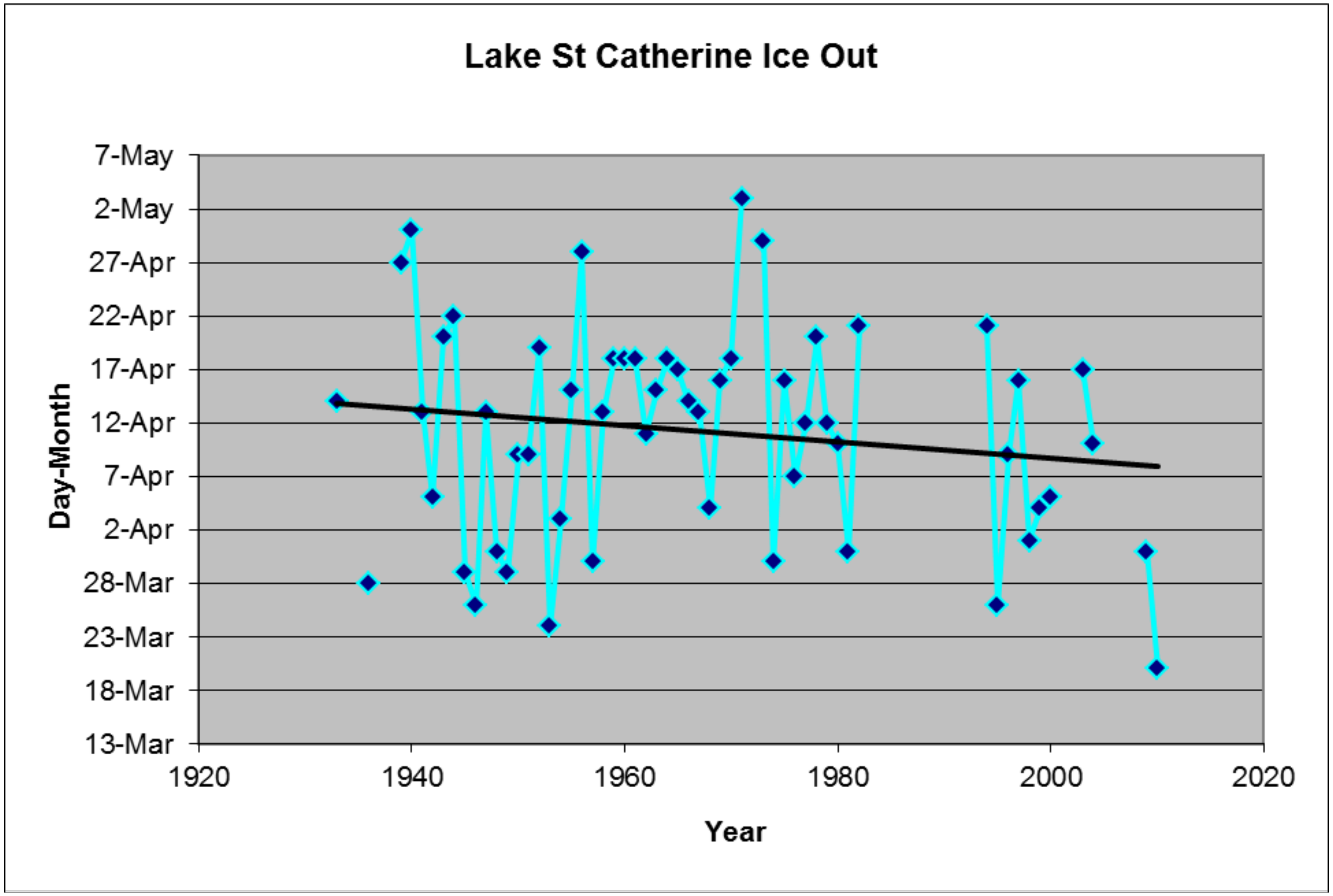
Chipman-Tinmouth Pond



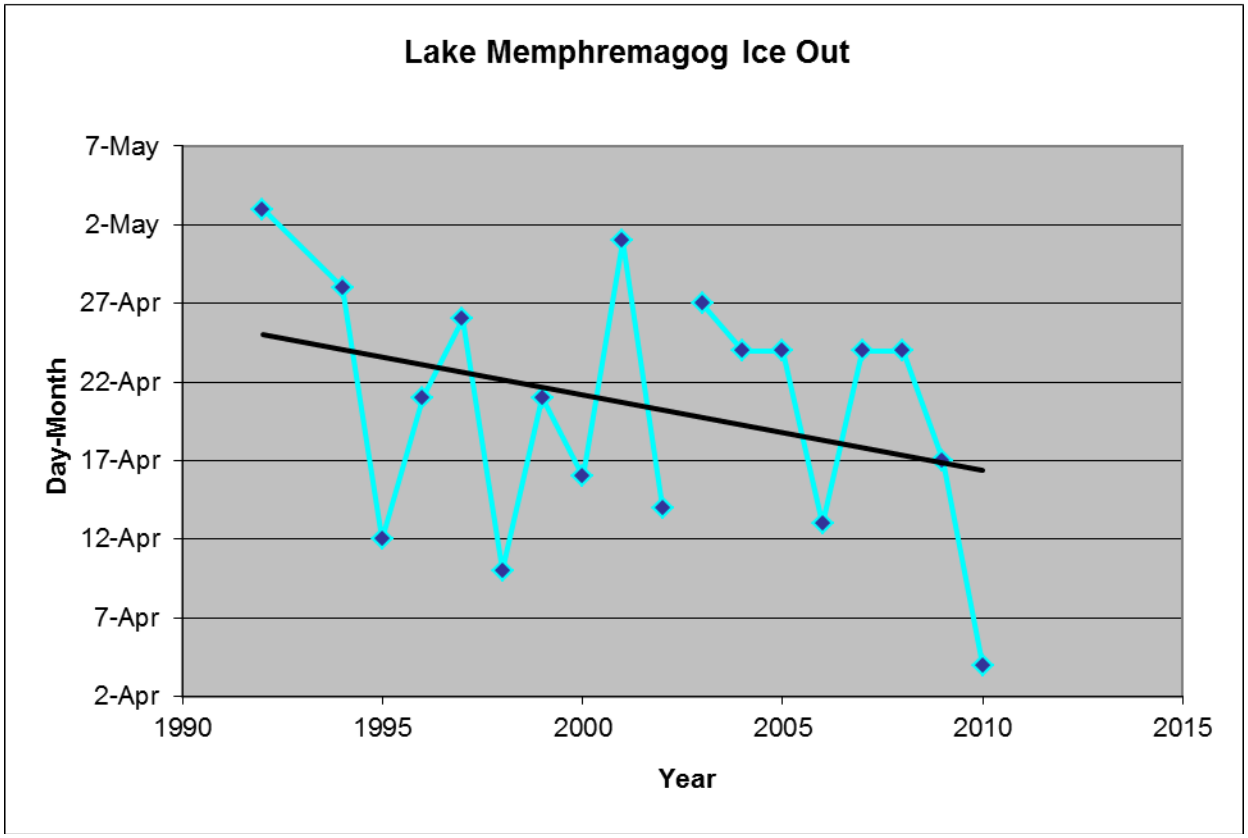
Lake Morey


Lake Morey Ice Out
2-May
27-Apr
22-Apr
17-Apr
12-Apr
7-Apr
2-Apr
28-Mar
23-Mar
18-Mar
Day-Month
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Year
ice out date
ice out date alternate data
Linear (ice out date)
Linear (ice out date alternate data)

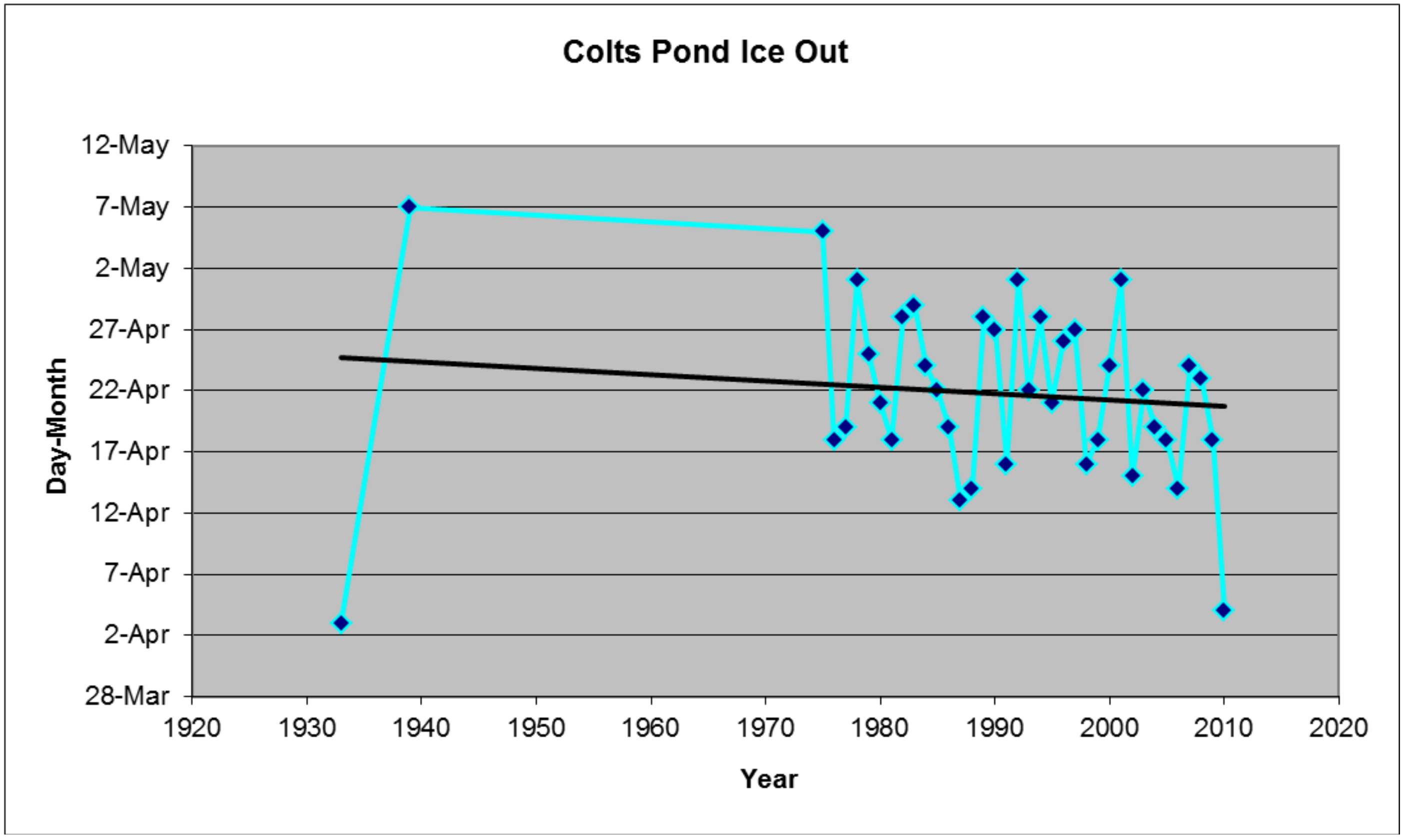
Lake St Catherine



Lake Memphremagog



Colts Pond



Colts Pond Ice Out
Day-Month
12-May
7-May
2-May
27-Apr
22-Apr
17-Apr
12-Apr
7-Apr
2-Apr
28-Mar
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

Appendix 2E

List of additional resources on climate trends

EXPOSURES

The following resources related to **climatic exposures** were compiled through desktop research and consultations. The list is not intended to be exhaustive and is continually being updated as new information becomes available.

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Historical trends

Historical trends for climate factors	**Location**	**Time Period**	**Citation**
AIR TEMPERATURE ANNUAL			
Mean annual air temperature increasing at 0.28 °C (0.5 °F) per decade	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
Long-term temperature records show considerable variability over the past century, with steeper upward temperature trends in recent decades of 0.5°F per decade	Lake Champlain basin	long-term and recent decades	Stager and Thill 2010
Annual temperatures have risen an average of +0.08 ± 0.01_C/decade. This rate has increased significantly over the recent three decades to a rate of +0.25 ± 0.01 C/decade. On average, observed annual temperatures in the 1990s were 0.6_C warmer than the 1900–1999 long-term mean.	Northeast	last century	Hayhoe et al. 2007
The region has been warming at a rate of nearly 0.5 F per decade; Average annual temperatures have risen more than 1.5 degrees Fahrenheit (°F) between 1970 and 2000	Northeast	1970-2000	UCS 2006 - Vermont summary
Average land temperature has risen 1 degree Celsius — or about 1.8 degrees Fahrenheit	Global	mid-1950s to present	Berkeley Earth Surface Temperature project
AIR TEMPERATURE SEASONAL			
Summer trend is 0.23±0.07 °C (0.4±0.12 °F) per decade	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
Winter trend is 0.5±0.16 °C (0.91±028 °F) per decade	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)

Historical trends for climate factors	Location	Time Period	Citation
The trend in winter is about twice as large as in summer. In fifty years, mean winter temperatures in Vermont have risen about 2.5 °C (4.5 °F); while in summer, mean temperatures have risen about 1.1 °C (2 °F). There is an uncertainty in the trends of about 30%, because of the large variability from year to year. There is larger uncertainty bars in winter. For these linear regression fits, the explained variance is small (R2 ≈ 0.18), because the interannual variability is large	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
The smallest trends are in May and October.	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
The greatest changes over the last 35 years have been seen in winter, which has warmed at 0.70 ± 0.05_C/decade, almost a degree per decade (see also Keim et al. 2003; Trombulak and Wolfson 2004)	Northeast		Hayhoe et al. 2007; see also Keim et al. 2003; Trombulak and Wolfson 2004)
In the 1990s, temperatures were also greater in winter (1.1_C) than summer (0.4_C) relative to the long-term mean	Northeast		Hayhoe et al. 2007
Average winter temperatures have been rising most rapidly—4°F between 1970 and 2000	Northeast	1970-2000	UCS 2006 - Vermont summary
Winter temperatures have risen even faster, at a rate of 1.3 F per decade	Northeast	1970 to 2000	UCS 2006 - Northeast
winter temperatures over the northern latitude continents have generally been rising faster than summer temperatures	northern latitude continents		Hansen et al. 2010 in Betts 2011
EXTREME HEAT DAYS			
More frequent days with temperatures above 90°F			Betts 2011 white paper
Vermont has gone from mostly USDA winter hardiness zones Zone 4 to mostly zone 5 between 1990 and 2006			

Historical trends for climate factors	Location	Time Period	Citation
the number of extremely hot days in summer has been increasing	Northeast	1970 to 2000	DeGaetano, A.T., and R.J. Allen. 2002. Trends in twentieth-century temperature extremes across the United States. Journal of Climate 15:3188–3205. (in UCS 2006)
More frequent extreme-heat days (maximum temperatures greater than 90°F)	Northeast	1970 to 2000	UCS 2006 - Northeast
The number of days that exceed the 95th percentile threshold for daily maximum temperature at northeastern US stations has increased by nearly 1.7 occurrences per decade over the last 45 years (DeGaetano and Allen 2002)	Northeast		Hayhoe et al. 2007; DeGaetano and Allen 2002
MINIMUM TEMPERATURES			
Warm minimum temperature extremes (i.e., nights that remain above the daily 95th percentile) have increased at almost double this rate (2.9 occurrences per decade) and more than twice the rate observed in other regions of the US	Northeast		Hayhoe et al. 2007; DeGaetano and Allen 2002
Extremely cold temperature days also have decreased since 1960, although they have typically decreased at a rate of less than one occurrence per decade (DeGaetano and Allen 2002).			Hayhoe et al. 2007; DeGaetano and Allen 2002
WATER TEMPERATURE WATER			
increasing water temperature in lakes and streams	uncertain, likely global		Bates et al. 2008 in EPA GCRP 2009
PRECIPITATION ANNUAL			
Precipitation has increased in Vermont by 15-20% in the past fifty years, with increasing trends throughout much of the year.	Vermont	past 50 years	Betts 2011 white paper

Historical trends for climate factors	Location	Time Period	Citation
Despite uncertainty in determining long-term trends, historical records do show a consistent long-term trend in annual precipitation of +9.5 ± 2 mm/decade over the last century (as also found by Keim et al. 2005).			Hayhoe et al. 2007; Keim et al. 2005
Changes have been observed in the amount, intensity, frequency, and type of precipitation	global		EPA GCRP 2009
Precipitation has increased an average of about 5 percent over the past 50 years			EPA GCRP 2009
PRECIPITATION SEASONAL			
changes are split between spring, summer and fall, with seasonal trends of +2.4 ± 0.3 mm/decade for spring and fall, 1.2 ± 0.5 mm/decade for summer, but little change (–0.5 ± 1 mm/decade) in winter.			Hayhoe et al. 2007; Keim et al. 2005
INTENSITY			
Increased heavy precipitation			Betts 2011 white paper
Heavy downpours have increased in frequency and intensity; in the Northeast there has been a 67% increase in the amount falling during very heavy precipitation events	Northeast	past 50 years	Betts 2011 white paper
Heavy, damaging rainfall events have increased measurably	Northeast	recent decades	UCS 2006
An increase in heavy rainfall events (as measured by the number of 48-hour periods with more than two inches of rain)	Northeast	recent decades	UCS 2006, Wolfe et al. 2005
The amount of rain falling in the heaviest downpours has increased approximately 20 percent on average in the past century; this trend is very likely to continue, with the largest increases in the wettest places			EPA GCRP 2009
Increases in heavy precipitation (greater than 2 in. in less than 48 h) have already been observed across much of the NE, particularly during the 1980s and 1990s relative to earlier in the century	NE	1980s and 1990s relative to earlier in the century	Wake and Markham 2005
RAIN VS. SNOW			
ratio of snow to rain in winter falls			Feng and Hu 2007

Historical trends for climate factors	Location	Time Period	Citation
Less precipitation falling as snow and more as rain			UCS 2006, Huntington et al. 2004
The S/P ratio decreased at 11 of 21 United States Historical Climatology Network (USHCN) sites in New England from 1948 through 2000. The four sites in northernmost New England with the strongest and most coherent trends showed an average decrease in annual S/P ratio from about 30% in 1949 to 23% in 2000.			Huntington et al. 2004
over the last few decades more winter precipitation has been falling as rain and less as snow, particularly at the more northern sites (Huntington et al. 2004).		over the last few decades	Huntington et al. 2004
SNOW			
Rising temperatures over the past few decades have caused snow to become wetter, or more “slushy,” and decreased the average number of snow-covered days across the state.			UCS 2006 - VT
Snow cover is decreasing	Northeast		UCS 2006
Reduced snowpack and increased snow density	Northeast		UCS 2006, Hodgkins and Dudley 2006a
decreasing snowfall amounts at most of the 21 USHCN sites over this period	Northeast	1948 through 2000	Huntington et al. 2004
18 of 23 snow course sites in Maine with records spanning at least 50 years through 2004 had decreases in snowpack depth or increases in snow density	Maine	mid-1900's -2004	Hodgkins and Dudley 2006a
four sites with the longest (1926–2004) and most complete records indicate an average decrease in March/April snowpack depth of 16% and an 11% increase in snow density	Maine	1926-2004	Hodgkins and Dudley 2006a
trends of decreasing snow cover but increasing density			Huntington et al. 2004, Hodgkins and Dudley 2006a
decreasing trends in SWE and snow days			Hayhoe et al. 2007

Historical trends for climate factors	Location	Time Period	Citation
longest, most complete snow records in coastal Maine indicate an increase in snow density for the March 1 snow-survey date during the last 60 years	coastal river basins in Maine		Dudley and Hodgkins 2002
Snow density has increased as the snow has become wetter and heavier (i.e., more "slushy").	Northeast		UCS 2006
MEAN ANNUAL STREAMFLOW			
Preliminary results for Vermont show increases in annual mean stream flow have occurred in the past fifty years, with significant increases in monthly mean flows in the period July through December	Vermont	past 50 yrs	Betts 2011 white paper, cites Hodgkins et al. (2010): Trends in Streamflow Characteristics at Selected Streamgages in Vermont. Draft manuscript
Only one of the six coastal rivers in the study analyzed for trends in cumulative runoff had a significant change in total annual runoff volume	coastal river basins in Maine	1906-21 and 1929-2000	Dudley and Hodgkins. 2002
TIMING OF SPRING RUNOFF			
Earlier snowmelt runoff in the late winter and early spring			Dudley and Hodgkins 2002, Hodgkins et al. 2002, Hodgkins and Dudley 2006a, Hodgkins and Dudley 2006b, Huntington et al. 2004, Hodgkins et al. 2005
Reduced snow cover and warmer winter and spring temperatures also change the hydrologic response, giving earlier spring runoff (Hodgkins et al. 2009)			Hodgkins et al. 2009
Earlier spring snowmelt resulting in earlier peak river flows			Betts 2011 white paper
Earlier spring snowmelt resulting in earlier high spring river flows			UCS 2006, Hodgkins et al. 2003

Historical trends for climate factors	Location	Time Period	Citation
Significant trends toward earlier spring peak flow and earlier center-of-volume runoff dates	coastal river basins in Maine	1906-21 and 1929-2000	Dudley and Hodgkins 2002
historical stream flow records indicate an advance in the timing of high river flows during the twentieth century over the northern part of the NE, where snowmelt dominates the annual hydrological cycle. Most of the observed change occurred during the period 1970 through 2000—when winters in the NE were warming at ~0.7 C/decade—with the dates of high flow advancing by 7–14 days	northern New England	twentieth century, 1970-2000	Hodgkins et al. 2003; Hodgkins and Dudley 2006a
Increasing trends in late winter and early spring streamflow, and advances of 1–2 weeks in the date of peak streamflow have been observed over the northern part of the NE, with most of the change occurring from 1970 to 2000 (Hodgkins et al. 2003, 2005a). These changes are positively correlated with March–April air temperature, which determines the date at which ice ceases to affect flow5 as well as the timing of snow melt	northern part of the NE	1970 to 2000	Hodgkins et al. 2003, 2005a in Hayhoe et al. 2007
69, 75, and 94% of all stations had increasing mean monthly runoff for January, February, and March, respectively (Hodgkins and Dudley 2006b). In contrast, about two-thirds of all stations had trends toward decreasing streamflow for the month of May.	80 stations north of 44 N latitude	1953 - 2002	Hodgkins and Dudley 2006b
late spring streamflow has been decreasing (Hodgkins and Dudley 2006b)			Hodgkins and Dudley 2006b
LOW FLOWS AND DROUGHT			
Few significant changes during the last century in the magnitude, timing, or duration of low streamflows in Maine	Maine		Hodgkins and Dudley 2005, Hodgkins et al. 2005b
The timing and magnitude of low flows were much more highly correlated with summer precipitation than with air temperature	Maine		Hodgkins and Dudley 2005, Hodgkins et al. 2005b
Weak evidence of historical summer or fall hydrologic changes in Maine	Maine		Hodgkins and Dudley 2005, Hodgkins et al. 2005b

Historical trends for climate factors	Location	Time Period	Citation
on average, historically, short-term droughts have occurred once every two years	Vermont		UCS 2006 - NECIA VT
EXTREME EVENTS			
Many types of extreme weather events, such as heat waves and regional droughts, have become more frequent and intense during the past 40 to 50 years			EPA GCRP 2009
The destructive energy of Atlantic hurricanes has increased in recent decades. The intensity of these storms is likely to increase in this century.			EPA GCRP 2009
BASEFLOW/ GROUNDWATER			
The contribution and timing of spring snowmelt to groundwater recharge is particularly important to groundwater resources in the northeastern United States where aquifers typically consist of thin sediments overlying crystalline bedrock with relatively little storage capacity (Mack, 2009)…This groundwater flow is a source of cool water during the summer and accounts for a large proportion of the streamflow during summer low-flow periods.			Dudley and Hodgkins 2002
The USGS is currently investigating whether or not groundwater recharge from snowmelt and precipitation exhibits historical trends			Dudley et al. 2010
PEAK FLOWS			
Annual peak flows have increased significantly ($p < 0.1$) during the last 50 to 100 years at some streamflow-gaging stations in Maine			Hodgkins and Dudley, 2005; Collins, 2009
The 1967–1996 sub-period had the highest 100- and 5-year peak flows overall when compared to 100- and 5-year peak flows based on the full period of record; the median difference for all 28 streamgages is 8 percent for both the 100- and 5-year peak flows			Hodgkins 2010

Historical trends for climate factors	Location	Time Period	Citation
Because large floods in Maine typically result from a combination of snowmelt and rainfall, and in the future may be affected by global warming and by climatic variability (related to sea surface temperature variability or large scale atmospheric patterns), future patterns of change are likely to be complex over both space and time			Hodgkins 2010
ICE COVER			
trends towards later freezing (5.8 days per century) and earlier breakup (6.5 days per century) of ice on lakes and rivers, as temperatures have increased about 1.2°C (2.16°F) per century	northern hemisphere	1846-1995	Magnusson 2000
substantial change in ice cover. On average, the main body of the lake now freezes roughly two weeks later than during the early 1800s and about nine days later on average than in 1900. During the 19th century the main lake remained open in winter only three times, but it remained open almost half the years between 1970 and 2007.	Lake Champlain	long-term	Betts 2011 - Vermont Climate Change Indicators (in press)
Freeze-up has occurred later by 3.9 (±1.1) days per decade	Joe's Pond in West Danville, VT and Stile's Pond in Waterford, VT (same latitude but a lower elevation than Joe's Pond)	Joe's (1988-present) and Stile's (1971-present)	Betts 2011 - Vermont Climate Change Indicators (in press)
Ice-out has come earlier by 2.9 (±1.0) days per decade			Betts 2011 - Vermont Climate Change Indicators (in press)
Lake frozen duration has decreased by 6.9 (±1.5) days per decade			Betts 2011 - Vermont Climate Change Indicators (in press)
Stile's Pond is frozen for 4 weeks less on average than forty years ago			

Historical trends for climate factors	Location	Time Period	Citation
Earlier breakup of winter ice on lakes and rivers	Northeast	recent decades	UCS 2006, Hodgkins et al. 2002, Hodgkins et al. 2005
Freeze-up on Lake Champlain is happening two weeks later than in the early 1800s—that is, in the increasingly rare winters when ice covers the main body of the lake at all.	Lake Champlain	1800's	Stager and Thill 2010
shrinking of the cold season seen in Vermont is part of the much larger warming trend at northern latitudes, driven by the same climate feedback processes			Screen and Simmons 2010
Last spring river-ice-off dates at most coastal streamflow-gaging stations examined are trending to earlier dates	coastal river basins in Maine	1906-21 and 1929-2000	Dudley, and Hodgkins 2002
Trends in later fall initial onset of ice also are evident, although these trends are significant at fewer stations than that observed for ice-off dates	coastal river basins in Maine	1906-21 and 1929-2000	Dudley, and Hodgkins 2002
statistically significant decrease over time in the total number of days of ice occurrence at most gaging stations on coastal rivers in Maine.	coastal river basins in Maine	1906-21 and 1929-2000	Dudley, and Hodgkins 2002
Records of spring ice-out on lakes in the NE between 1850 and 2000 indicate an advancement of 9 days for lakes in northern and mountainous regions and 16 days for lakes in more southerly regions	NE	1850-2000	Hodgkins et al. 2002
on average, the last dates of ice-affected flow occurred 11 days earlier in the spring in 12 of 16 rural unregulated streams studied		1936 to 2000	Hodgkins et al. 2005a
FREEZE DATES			
Freeze-period has decreased 3.9 (±1.1) days per decade	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
Last spring freeze has come earlier by 2.3 (±0.7) days per decade	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)

Historical trends for climate factors	Location	Time Period	Citation
First autumn freeze has come later by 1.5 (±0.8) days per decade	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
despite the large variability from year to year, on average the last spring freeze has come earlier and the first fall freeze has come later, so that the freeze period has got shorter and the growing season longer in Vermont	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
first and last frosts are sensitive to the local topography as well as to specific daily weather events, some colder locations in Vermont, such as mountain valley floors and elevated terrain, will on average have a shorter growing season than this four-station mean		1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
LENGTH OF THE GROWING SEASON			
Growing season has increased 3.7 (±1.1) days per decade	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
growing season for frost-sensitive plants has increased by 2 weeks; interannual variability is large (±6 to 9 days)	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
growing season for frost-hardy plants may have increased more	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
Spring is coming earlier and fall later, so the summer growing season is lengthening	Vermont	1960-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
spring is arriving earlier in the year	Northeast		UCS 2006 - NECIA
The growing season in the Northeast has been getting longer by 2.5 days per decade since 1970.	Northeast	1970-present	UCS 2006 - NECIA
length of the winter freeze period has already been decreasing over the last half of the past century			Kunkel et al. 2004; Schwartz et al. 2006 in Hayhoe

Historical trends for climate factors	Location	Time Period	Citation
Over the period of record (1915–2003), the length of the growing or frost-free season has been increasing at an average of +0.7 days/decade. Over the last 30 years (1970–2000), the observed trend based on daily station data across the NE has increased to +2.4 days/decade. This is being driven primarily by earlier last freeze dates in spring (Schwartz et al. 2006)			Hayhoe et al. 2007; Schwartz et al. 2006
by mid-century the growing season may be 2–4 weeks longer than during the 1961–1990 reference period. By end-ofcentury (2080–2099), the growing season may be extended by an average of 4 weeks under the lower B1 scenario and 6 weeks under the higher A1FI and A2 scenarios.			Hayhoe et al. 2007
For relatively small temperature changes (B1 mid-century), model simulations suggest that the retreat of spring freeze dates continues to be the primary cause of the lengthening growing season, as observed over the past few decades. On average, under B1 the mid-century spring last freeze is coming 9 days earlier and the autumn first freeze only 0.6 days later			Hayhoe et al. 2007
LENGTH AND SEVERITY OF THE COLD SEASON			
Winter temperatures are rising fastest, so the winter season is shrinking and becoming less severe			Betts 2011 white paper
frozen period for small lakes has decreased by 6.9 (±1.5) days per decade	Vermont	1960-present	Betts 2011 - Vermont Climate Change Indicators (in press)
Lake freeze-up has occurred later by 3.9 (±1.1) days per decade	Vermont	1960-present	
ice-out has come earlier by 2.9 (±1.0) days per decade	Vermont	1960-present	
ONSET OF SPRING			
Four Vermont climate stations preprocessed by Schwartz et al. (2006), and extended to 2008	Burlington, Cavendish, Enosburg Falls and St Johnsbury	1960-present	Betts 2011 - Vermont Climate Change Indicators (in press)
earlier onset of spring in the northern hemisphere since 1961	larger dataset		Schwartz et al. 2006

Historical trends for climate factors	Location	Time Period	Citation
large variability from year to year	six Vermont sites	1965-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
date of lilac first leaf in spring has advanced about 2.9 (±0.8) days per decade		1965-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
the later date of lilac first bloom has advanced more slowly by 1.6 (±0.6) days per decade		1965-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
the mean time between first leaf and first bloom has increased from about 24 to about 30 days over the 45-year period		1965-2008	Betts 2011 - Vermont Climate Change Indicators (in press)
A comprehensive analysis of historical records from 72 sites across the NE, where the first flower date for the same clone of lilac has been monitored since the 1960s, shows an advance of 4 days	NE	1960-	Wolfe et al. 2005
The same study also examined first flower data from 1960 to 2000 for grape and apple trees in NY only, and found an advance of 6–8 days for these woody perennials.	NE	1960-2000	Wolfe et al. 2005
Using herbarium specimens at the Harvard University Arnold Arboretum (Cambridge, MA, USA), Primack et al. (2004) found that flowering was occurring on average 8 days earlier from 1980 to 2002 than it did from 1900 to 1920.		1900-1920 vs 1980-2002	Primack et al. (2004)
Gibbs and Breisch (2001) documented an advance of 10–13 days in first date of spring mating calls in upstate NY since the beginning of the century, for four of six frog species studied			Gibbs and Breisch (2001)
Advances in the timing of migration of anadromous fish (Atlantic salmon and alewives) in NE rivers during the last few decades have also been recently reported (Huntington et al. 2003; Juanes et al. 2004)			Huntington et al. 2003; Juanes et al. 2004

Appendix 2F

Annual and seasonal temperature and precipitation trend plots generated using the Climate Wizard

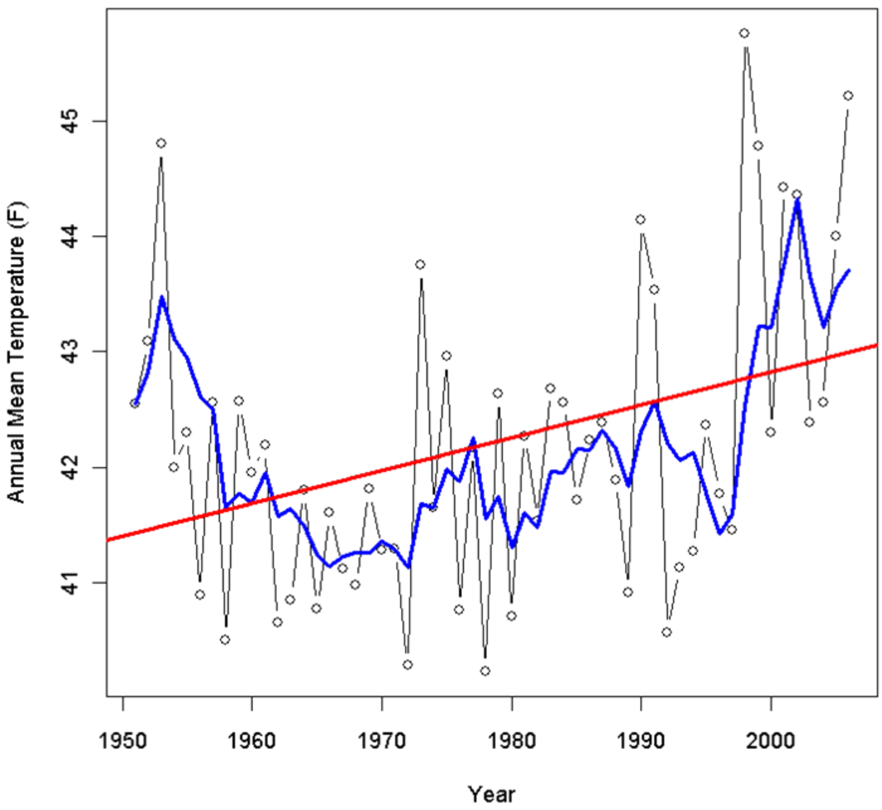

Figure 2F-1. Trends in annual mean air temperature in Vermont from 1951-2006. Blue lines are a 5-year moving average going back in time 4-years (for 1999 the average would be for 1995-1999); gray lines connect actual values. Change rate = 0.029 °F/yr, p-value = 0.027. Maps produced by ClimateWizard © University of Washington and The Nature Conservancy, 2009. Base climate data from the PRISM Group, Oregon State University, http://www.prismclimate.org.

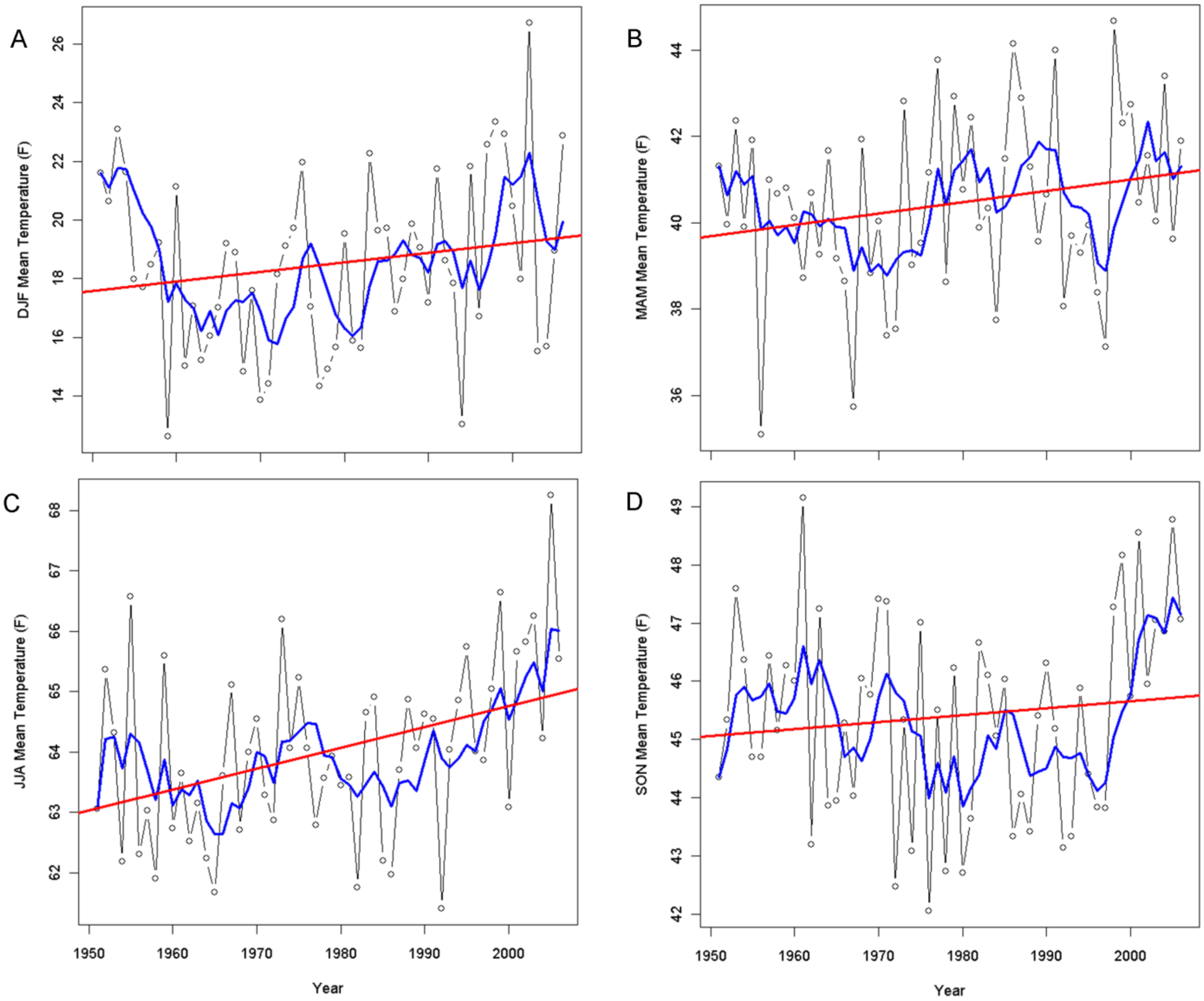

Figure 2F-2. Trends in seasonal mean air temperature in Vermont from 1951-2006. A) DJF=December, January & February, change rate= 0.033 F/yr, p-value= 0.265; B) MAM= March, April & May, change rate = 0.026 F/yr, p-value = 0.096; C) JJA = June, July & August, change rate = 0.035 F/yr, p-value = 0.0026; D) SON= September, October & November, change rate = 0.012 F/yr, p-value = 0.454. Blue lines are a 5-year moving average going back in time 4-years (for 1999 the average would be for 1995-1999); gray lines connect actual values. Maps produced by ClimateWizard © University of Washington and The Nature Conservancy, 2009. Base climate data from the PRISM Group, Oregon State University, http://www.prismclimate.org

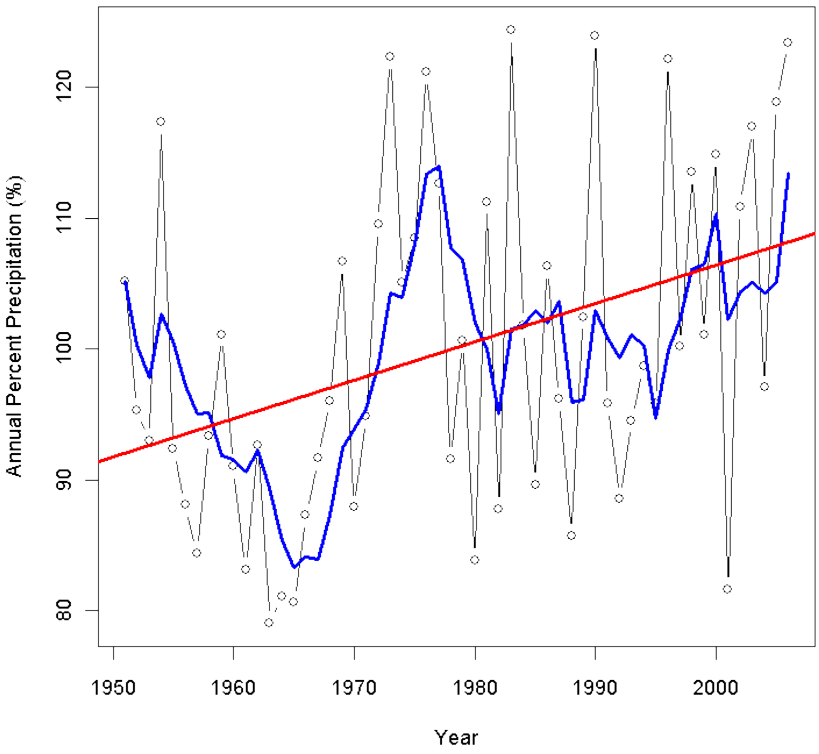

Figure 2F-3. Trends in rate of change of annual percent precipitation in Vermont from 1951-2006. Change rate = 0.294 %/yr, p-value = 0.011. Blue lines are a 5-year moving average going back in time 4-years (for 1999 the average would be for 1995-1999); gray lines connect actual values. Maps produced by ClimateWizard © University of Washington and The Nature Conservancy, 2009. Base climate data from the PRISM Group, Oregon State University, http://www.prismclimate.org.

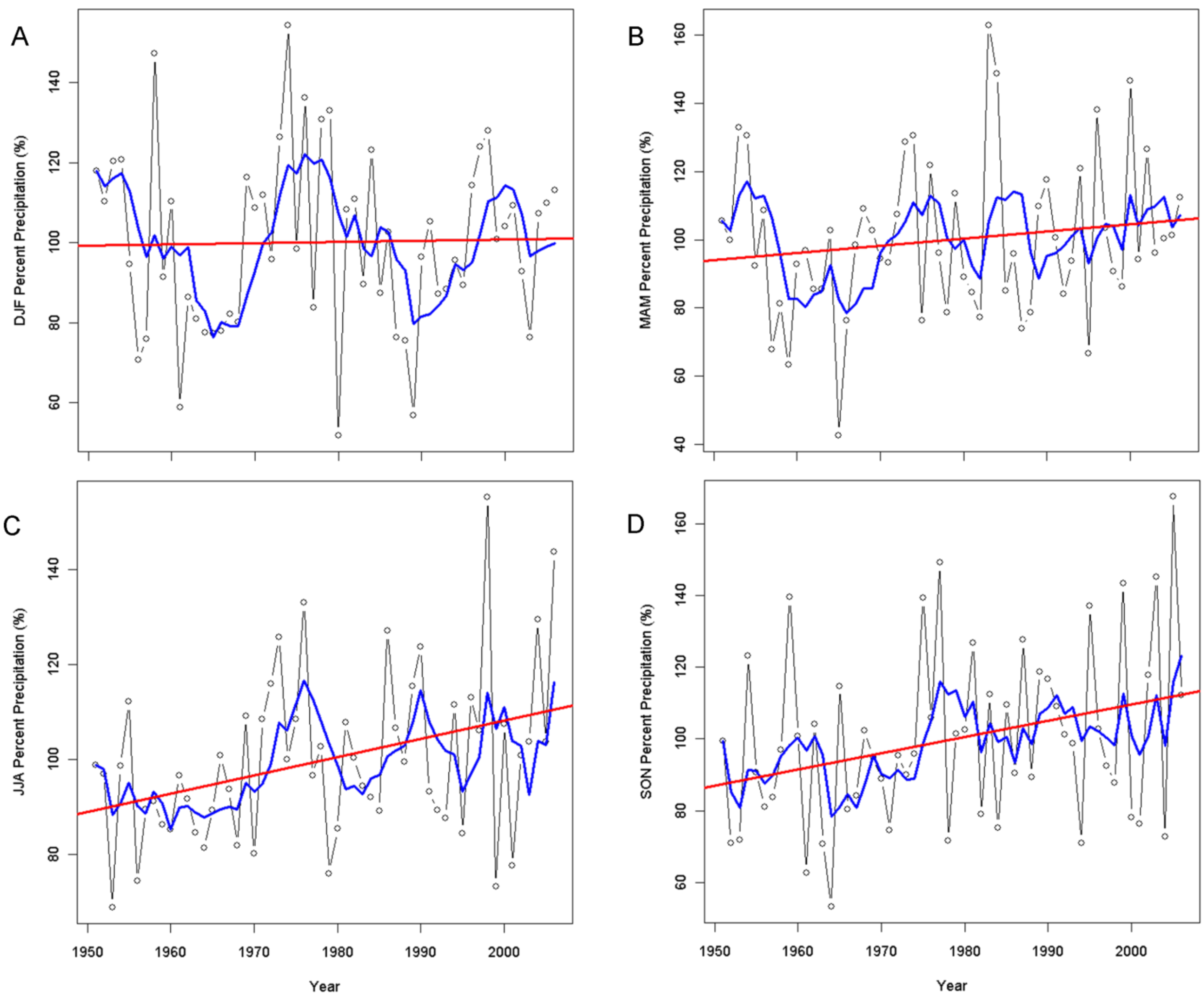

Figure 2F-4. Trends in seasonal rate of change of precipitation in Vermont from 1951-2006. A) DJF=December, January & February, change rate= 0.031 %/yr, p-value= 0.888; B) MAM= March, April & May, change rate = 0.212 %/yr, p-value = 0.305; C) JJA = June, July & August, change rate = 0.386 %/yr, p-value = 0.004; D) SON= September, October & November, change rate = 0.453 %/yr, p-value = 0.004. Blue lines are a 5-year moving average going back in time 4-years (for 1999 the average would be for 1995-1999); gray lines connect actual values. Maps produced by ClimateWizard © University of Washington and The Nature Conservancy, 2009. Base climate data from the PRISM Group, Oregon State University, http://www.prismclimate.org.

Appendix 2G

Additional climate projection data

Projected Trends

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
TEMPERATURE				
about 3°F increase in annual mean; the northeast is likely to see larger temperature increases in winter than summer	lower emissions	Vermont	mid-century (2050)	EPA GCRP 2009
temperatures across the region are likely to rise by 2.5 to 4 degrees Fahrenheit (°F) in winter and 1 to 3°F in summer, regardless of the emissions during that period	either	Northeast	next few decades	UCS 2006
Under the lower-emissions scenario, annual temperatures are projected to increase 3.5 to 6.5 F by 2100	lower emissions	Northeast	2100	UCS 2006
Under the higher-emissions scenario, annual temperatures are projected to increase 6.5 to 12.5 F	higher emissions	Northeast		UCS 2006
winters could warm by 8 to 12°F and summers by 6 to 14°F	higher emissions	Northeast	end of century	UCS 2006
temperature increases of 5 to 7.5°F in winter and 3 to 7°F in summer	lower emissions	Northeast	end of century	UCS 2006
about 5°F increase (annual)	lower emissions	Vermont	late-century	EPA GCRP 2009 in Betts 2011 white paper
about 4°F increase (annual)	higher emissions	Vermont	mid-century (2050)	EPA GCRP 2009 in Betts 2011 white paper
about 8°F increase (annual)	higher emissions	Vermont	late-century	EPA GCRP 2009 in Betts 2011 white paper
If we extrapolate the observed mean annual warming trend for Vermont of 0.5°F per decade from 1970 out to 2050, we get a 4°F warming, which is consistent with the model projections shown earlier				Betts 2011 white paper

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
Warmer fall temperatures				Betts 2011 white paper
seasonal average temperatures across Vermont are projected to rise 9°F to 13°F above historic levels in winter and 7°F to 14°F in summer by late-century	higher emissions	Vermont	late-century	UCS 2006 - VT
roughly half what is cited above	lower emissions	Vermont	late-century	UCS 2006 - VT
All models consistently indicate increases in temperature over all seasons				Hayhoe et al. 2007
HEAT INDEX				
large increase in the frequency of days over 90°F over the course of this century, with steep increases	higher emissions			
Currently, northeastern cities experience one or two days per summer over 100 F. This number could increase by late century to between 14 and 28 days under higher emissions	higher emissions	Vermont		
Currently, northeastern cities experience one or two days per summer over 100 F. This number could increase by late century to between three and nine days under lower emissions	lower emissions	Vermont		
Vermont's summer climate by 2080 will feel similar to the climate of northwest Georgia for the period 1961-1990.	higher emissions	Vermont	2080	UCS 2006 - VT
the climate of Vermont will more closely resemble the climate of southeastern Ohio	low emissions	Vermont	2080	UCS 2006 - VT
models project there will be an increased risk of more intense, more frequent, and longer-lasting heat waves		global		EPA GCRP 2009, Meehl et al. 2007
PRECIPITATION				
projected increases are about 15% in winter, 10% in spring, 5% in fall, and no change in summer	higher emissions	Vermont	late-century	EPA GCRP 2009

Projected trend for climate factors	**Emissions Scenario**	**Location**	**Time Period**	**Citation**
The lightest precipitation is projected to decrease, while the heaviest precipitation will increase	higher emissions	Vermont	late-century	EPA GCRP 2009
total precipitation in Vermont is expected to increase in all seasons except summer				Betts 2011 white paper
frequency of heavy precipitation events is likely to increase in all seasons, with the heaviest precipitation events occurring in the summer season				Betts 2011 white paper
More wet snow and freezing rain				Betts 2011 white paper
Multiple melt events in the winter with possible flooding				Betts 2011 white paper
More heavy rain events in summer				Betts 2011 white paper
Increased fall precipitation and stream flow				Betts 2011 white paper
An increase in winter precipitation on the order of 20 to 30 percent		Northeast		UCS 2006 - VT
less winter precipitation falling as snow and more as rain				UCS 2006 - VT
The frequency and severity of heavy rainfall events is expected to rise further under either emissions scenario	higher or lower			UCS 2006 - VT
As winter temperatures rise, more precipitation will fall as rain and less as snow. By the end of the century, the length of the winter snow season could be cut in half	higher	Northeast		UCS 2006
A 25 percent loss of the winter snow season	lower emissions	Northeast		UCS 2006
Increases in the likelihood and severity of heavy rainfall events, including more than a 10 percent increase in the number of annual extreme rainfall events and a 20 percent increase in the maximum amount of rain that falls in a five-day period each year.	either scenario	Northeast		UCS 2006

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
Increases in winter precipitation on the order of 20 to 30 percent, with slightly greater increases under the higher-emissions scenario	either scenario	Northeast		UCS 2006
Winter precipitation (in the form of both snow and rain falling in winter months) has been increasing over the past few decades, and is projected to continue increasing, with slightly larger changes under the higher-emissions scenario than the lower-emissions scenario	higher	Northeast		UCS 2006
Winter precipitation (in the form of both snow and rain falling in winter months) has been increasing over the past few decades, and is projected to continue increasing, with slightly larger changes under the higher-emissions scenario than the lower-emissions scenario	lower emissions	Northeast		UCS 2006
Little change is expected in summer rainfall, although projections are highly variable	either scenario	Northeast		UCS 2006
frequency of heavy rainfall events is increasing across the Northeast	either scenario	Northeast		UCS 2006
Under both emissions scenarios, rainfall is expected to become more intense. In addition, periods of heavy rainfall are expected to become more frequent	either scenario	Northeast		UCS 2006
Confidence in projected changes is higher for winter and spring than for summer and fall. In winter and spring, northern areas are expected to receive significantly more precipitation than they do now, because the interaction of warm and moist air coming from the south with colder air from the north is projected to occur farther north than it did on average in the last century.				EPA GCRP 2009

Projected trend for climate factors	**Emissions Scenario**	**Location**	**Time Period**	**Citation**
Climate models project continued increases in the heaviest downpours during this century, while the lightest precipitation is projected to decrease. Heavy downpours that are now 1-in-20-year occurrences are projected to occur about every 4 to 15 years by the end of this century, depending on location, and the intensity of heavy downpours is also expected to increase. The 1-in-20-year heavy downpour is expected to be between 10 and 25 percent heavier by the end of the century than it is now.				EPA GCRP 2009, Kunkel et al. 2008
Projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier				EPA GCRP 2009
increases in annual and winter precipitation that become greater over time				Hayhoe et al. 2007
Future projections from almost all model simulations show consistent increases in winter precipitation and no change to a decrease in summer rainfall. Specifically, by end-of-century, winter precipitation is projected to increase an average of 11%under B1 and 14% under A2, but show small decreases (on the order of a few percent) in summer precipitation				Hayhoe et al. 2007
Further increases in heavy precipitation are expected in many locations around the world, including the NE (Wehner 2004; Tebaldi et al. 2006)				Wehner 2004; Tebaldi et al. 2006
precipitation and runoff are likely to increase	Northeast			EPA GCRP 2009
increasing precipitation during the cold season				Schoof et al. 2010
changes in occurrences and intensity of precipitation; disproportionate increases in large precipitation events				Schoof et al. 2010
EXTREME WEATHER				
Some East Coast winter storms are projected to shift from earlier to later in the winter season as temperatures rise, and more storms are expected to travel further up the coast and affect the Northeast				

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
increased frequency and altered timing of flooding				EPA GCRP 2009
floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change and rainfall becomes more concentrated into heavy events (with longer, hotter dry periods in between)				EPA GCRP 2009
DROUGHT				
Evaporation increases with temperature; therefore in regions where precipitation decreases, an increase in drought frequency is likely		global		Dai, A. 2011
earlier snowmelt, and more runoff from heavier summer rainfall, coupled with increased evaporation, are expected to increase the frequency of summer droughts	higher emissions	New England		Frumhoff et al. 2007
Greater frequency of 1-2 month droughts in summer				Betts 2011 white paper
rising summer temperatures coupled with little change in summer rainfall are projected to increase the frequency of short-term (one- to three month) droughts, particularly if higher emissions prevail	higher emissions	Vermont		UCS 2006 - VT
short-term droughts are projected to occur annually under the higher emissions scenario (compared with once every two years, on average, historically)	higher emissions	Vermont		UCS 2006 - VT
little change in drought is expected	lower emissions	Vermont		UCS 2006 - VT
The frequency of late summer and fall droughts is projected to increase significantly, with short term droughts (lasting one to three months) becoming as frequent as once per year over much of the Northeast by the end of the century	higher emissions	Northeast		UCS 2006
A likelihood of short-term drought only slightly higher than today.	lower emissions	Northeast		UCS 2006

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
A combination of higher temperatures, increased evaporation, expanded growing season, and other factors that will cause summer and fall to become drier, with extended periods of low streamflow.	either scenario	Northeast		UCS 2006
more frequent droughts		Northeast		Hayhoe et al. 2007
extended low-flow periods in summer		Northeast		Hayhoe et al. 2007
A general increase in drought frequency is projected in the future, especially under the A1FI scenario. This is driven by reductions in mean monthly soil moisture during summer and autumn as a result of increased evapotranspiration and reduced precipitation; changes are highly variable both spatially as well as between scenarios.		Northeast		Hayhoe et al. 2007
projections of drier, hotter summers and more frequent short- and medium-term droughts		Northeast		Hayhoe et al. 2007
in areas where snowpack dominates, the timing of runoff will continue to shift to earlier in the spring and flows will be lower in late summer				
Rising temperatures will increase evaporation rates and reduce soil moisture in summer		Northeast		UCS 2006
By mid-century, these changes are projected to lead to more frequent short-term droughts (an average of two every three years) under both scenarios, with a slightly higher frequency under the higher-emissions scenario		Northeast		UCS 2006
By the end of the century, short-term droughts under the higher-emissions scenario may be as frequent as once per year in parts of the Northeast. Only a slight increase in drought risk is expected under the lower-emissions scenario		Northeast		UCS 2006
As soil moisture is further depleted and vegetation becomes increasingly water stressed, the risk of wildfires also rises		Northeast		UCS 2006, Brown et al. 2004, Amiro et al. 2001

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
Warming temperatures will also cause more water to evaporate in the summer months, extending the summer low-flow period by nearly a month under the higher-emissions scenario and increasing the risk of water shortages and drought	higher emissions	Northeast		UCS 2006 - NECIA
WILDFIRE				
hardwoods could become more vulnerable to a number of threats under the higher-emissions scenario, including disease, pests, drought, wildfire, and severe storm damage				Frumhoff et al. 2007
EVAPOTRANSPIRATION				
Rising temperatures are projected to increase evaporation across the NE. In general, changes are in general evenly distributed across the region. Most increases are projected to occur in the spring and summer for all scenarios and appear to be primarily driven by increasing temperatures and available soil moisture from increased precipitation. Winter evapotranspiration is relatively small in comparison but does show a decrease, especially in the east, because the decrease in snow pack (caused by increased temperatures) reduces the total amount of sublimation.				Hayhoe et al. 2007
SOIL MOISTURE				
Increased evapotranspiration combined with low early fall precipitation produces a late summer decrease in soil moisture				Hayhoe et al. 2007
soil moisture projections presented here, although highly variable, suggest a general increase in dry conditions				Hayhoe et al. 2007
STREAM FLOW				
Stream flow is likely to increase				Betts 2011 white paper
Earlier spring melt and run-off; possibly larger stream flows				Betts 2011 white paper

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
More frequent floods and associated flood damage in summer				Betts 2011 white paper
As temperatures continue to rise, snow and ice will melt even earlier, advancing spring streamflow 10 days earlier	lower emissions	Northeast		UCS 2006
As temperatures continue to rise, snow and ice will melt even earlier, advancing spring streamflow more than two weeks earlier	higher emissions	Northeast		UCS 2006
Global warming is also expected to increase the likelihood of high flow events in the winter, particularly under the higher-emissions scenario, which implies a greater risk of flooding	higher emissions	Northeast		UCS 2006
As soil moisture is further depleted and vegetation becomes increasingly water stressed, the risk of wildfires also rises.		Northeast		UCS 2006
general tendency toward more streamflow in winter and spring, and less in summer and fall. This translates into higher winter highflow events and lower summer low flows.		Northeast		Hayhoe et al. 2007
increased variability: both more high-flow events and more low-flow events over the course of the year; this is consistent with increases in precipitation projected during the late fall, winter, and spring as compared with little to no changes in summer, and with increasing summertime drying due to higher evapotranspiration.		Northeast		Hayhoe et al. 2007
peak streamflow in spring is projected to continue to occur earlier in the year, with further advances of 5–8 days by mid-century. End-ofcentury changes are larger under the higher emissions scenario (+15 days under A1FI as compared to +10 days under B1).	mid- and late-century	Northeast		Hayhoe et al. 2007
In the summer and autumn, streamflow tends to drop as temperatures and evaporation rise		Northeast		Hayhoe et al. 2007
During the twentieth century, no significant decrease in summer/fall low flows or change in the timing of those low-flow events has been observed (Hodgkins et al. 2005b)	twentieth century	Northeast		Hodgkins et al. 2005b

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
Projected future changes in low-flow amounts and duration differ significantly between the higher A1FI and lower B1 scenarios. Under A1FI, the 7-day consecutive low-flow amounts from every year are projected to decrease on the order of 10% or more for 51 unmanaged rivers in the NE (Fig. 11). Changes under B1 are smaller, <10% for HadCM3 and little net change for PCM. even under the B1 scenario, streamflow remains significantly below the historical mean during early to mid fall.		Northeast		Hayhoe et al. 2007
more variability in flow		Northeast		Hayhoe et al. 2007
declining springtime snowpack, which will lead to reduced summer streamflows				EPA GCRP 2009
SNOW				
Vermont's snow season could be cut by more than half by late-century.	higher emissions	Vermont		UCS 2006 - VT
Under the lower emissions scenario, this change would be more modest—a decrease of roughly one-third	lower emissions	Vermont		
By the end of the century, the northern part of the Northeast, currently snow-covered for almost the entire winter season, could lose up to one-quarter of its snow-covered days under the lower-emissions scenario	lower emissions	Northeast	end of century	UCS 2006
By the end of the century, the northern part of the Northeast, currently snow-covered for almost the entire winter season, could lose more than half of its snow-covered days under the higher emissions scenario.	higher emissions	Northeast	end of century	UCS 2006
shrinking snow cover				Hayhoe et al. 2007
a general decrease in the number of snow days, most notably across the central part of the domain and southern Maine; These decreases occur mainly at the edge of the snowline where the threshold between snow and no snow is most sensitive; primarily driven by increasing temperatures, especially in February and March				Hayhoe et al. 2007

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
the winter snow season is shortened in all regions, with snow appearing later in the winter and disappearing earlier in the spring; most evident in northern regions				Hayhoe et al. 2007
Both scenarios show large reductions in the length of the snow season in winter/early spring with greater than 50 and 25% reductions in the number of snow days by 2070–2099 under scenarios A1FI and B1, respectively.				Hayhoe et al. 2007
Because of the warming, there will be less lake and river ice in winter and less snowpack in the watershed		Lake Champlain		Stager and Thill 2010
SEASONS				
character of the seasons will change significantly, with spring arriving three weeks earlier by the end of the century, summer lengthening by about three weeks at both its beginning and end, fall becoming warmer and drier, and winter becoming shorter and milder	higher emissions	Northeast		UCS 2006
Arrival of spring one to two weeks earlier by century's end; summer would arrive only one week earlier and extend a week and a half longer into the fall.	lower emissions	Northeast		UCS 2006
key harbingers of spring are expected to arrive almost three weeks earlier under a higher emissions scenario	higher emissions	Northeast	end of century	UCS 2006
key harbingers of spring are expected to arrive one to two weeks earlier under a lower-emissions scenario	lower emissions	Northeast	end of century	UCS 2006
By the end of the century, the growing season is projected to be six weeks longer (under higher emissions) compared with the 1961 to 1990 average	higher emissions	Northeast		UCS 2006
By the end of the century, the growing season is projected to be four weeks longer (under lower emissions) compared with the 1961 to 1990 average	lower emissions	Northeast		UCS 2006

Projected trend for climate factors	Emissions Scenario	Location	Time Period	Citation
Summer is expected to arrive three weeks earlier in the spring and stay three weeks later in the fall under a higher-emissions scenario	higher emissions	Northeast		UCS 2006
under a lower-emissions scenario, summer could arrive 1 to 1.5 weeks earlier in the spring and stay almost two weeks longer in the fall.	lower emissions	Northeast		UCS 2006
Cold-season storm tracks are shifting northward and the strongest storms are likely to become stronger and more frequent				EPA GCRP 2009
number of frost days is expected to continue to decline in the future across the entire Northern Hemisphere, while the growing season will expand (Tebaldi et al. 2006)				Tebaldi et al. 2006
trend toward earlier dates, with changes of –2.1 and –2.3 days/decade or almost 3 weeks earlier by end-of-century under A1FI/A2 and –1.0 and –0.9 days/decade or 1–2 weeks earlier by end of- century under B1 for SI first leaf and first bloom dates, respectively				Hayhoe et al. 2007
in areas where snowpack dominates, the timing of runoff will continue to shift to earlier in the spring and flows will be lower in late summer				EPA GCRP 2009

Appendix 2H

Early, mid and late-century projections for Vermont, based on Climate Wizard data

These data were derived from Climate Wizard (http://climatewizardcustom.org/), using the custom data download function (limited to Vermont only). They are for projected changes in annual and seasonal air temperature and precipitation for high (a2) and low (b1) emissions scenarios for early (2010-2039), mid (2040-2069) and late (2070-2099) century compared to a historic (1961-1990) time period. Data from 15 different General Circulation Models (GCM) were evaluated (Table 2G-1). We used these data to calculate ensemble minimum, maximum and average values. In addition, we calculated standard deviations to assess levels of uncertainty across models. We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.

Table2 H-1. Future projection data from 15 General Circulation Models (GCM) were evaluated. These data were obtained from the Climate Wizard website (University of Washington and The Nature Conservancy 2009).

General Circulation Models (GCM)	Country	Institution
BCCR-BCM2.0	Norway	Bjerknes Centre for Climate Research
CGCM3.1(T47)	Canada	Canadian Centre for Climate Modelling & Analysis
CNRM-CM3	France	Météo-France / Centre National de Recherches Météorologiques
CSIRO-Mk3.0	Australia	CSIRO Atmospheric Research
GFDL-CM2.0	USA	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory
GFDL-CM2.1	USA	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory
GISS-ER	USA	NASA / Goddard Institute for Space Studies
INM-CM3.0	Russia	Institute for Numerical Mathematics
IPSL-CM4	France	Institut Pierre Simon Laplace
MIROC3.2(medres)	Japan	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)
ECHO-G	Germany / Korea	Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group.
ECHAM5/MPI-OM	Germany	Max Planck Institute for Meteorology
MRI-CGCM2.3.2	Japan	Meteorological Research Institute
CCSM3	USA	National Center for Atmospheric Research
PCM	USA	National Center for Atmospheric Research
UKMO-HadCM3	UK	Hadley Centre for Climate Prediction and Research / Met Office

Table2 H-2. Projected changes in annual and seasonal air temperature (˚C) in Vermont for high (a2) and low (b1) emissions scenarios for early (2010-2039) century compared to a historic (1961-1990) time period. See Table 2G-1 for information on the 15 General Circulation Models (GCM). These data were obtained from the Climate Wizard website (University of Washington and The Nature Conservancy 2009).

Departure Analysis - Early-Century (2010-2039) vs. Historic (1961-1990)												
	a2 (high) emissions scenario							b1 (low) emissions scenario				
Model	**Annual**	**DJF**	**MAM**	**JJA**	**SON**		**Model**	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
bccr_bcm2_0.1	1.0	1.3	0.7	1.0	0.5		bccr_bcm2_0.1	1.0	1.6	0.8	0.7	0.9
cccma_cgcm3_1.1	1.7	1.7	1.6	1.7	1.7		cccma_cgcm3_1.1	1.5	1.5	1.2	1.8	1.4
cnrm_cm3.1	1.1	1.4	0.6	1.1	1.4		cnrm_cm3.1	1.2	1.7	0.8	1.1	1.3
csiro_mk3_0.1	1.3	2.6	1.8	0.8	1.0		csiro_mk3_0.1	1.2	2.5	0.7	0.6	0.9
gfdl_cm2_0.1	1.5	1.5	0.9	1.5	1.4		gfdl_cm2_0.1	1.5	1.1	1.7	1.7	1.5
gfdl_cm2_1.1	1.2	1.8	1.0	1.2	1.1		gfdl_cm2_1.1	1.5	2.3	1.2	1.3	1.1
giss_model_e_r.1	0.8	0.1	0.1	1.1	1.1		giss_model_e_r.1	1.1	0.9	0.9	1.1	1.5
inmcm3_0.1	1.9	2.6	2.1	1.2	1.7		inmcm3_0.1	1.5	1.9	1.0	1.3	1.7
ipsl_cm4.1	2.0	2.6	2.3	1.6	1.8		ipsl_cm4.1	2.1	2.6	2.2	1.4	2.3
miroc3_2_medres.1	2.0	2.2	2.1	1.5	2.0		miroc3_2_medres.1	2.0	2.3	2.0	1.5	2.3
miub_echo_g.1	1.9	2.4	1.0	1.8	2.2		miub_echo_g.1	1.7	1.7	1.5	1.7	1.8
mpi_echam5.1	1.1	1.0	0.8	1.1	1.2		mpi_echam5.1	1.2	1.3	1.5	1.2	0.9
ncar_ccsm3_0.1	1.5	1.4	1.3	1.6	1.7		ncar_ccsm3_0.1	1.7	1.9	1.5	1.6	1.6
ncar_pcm1.1	0.6	0.8	0.6	0.4	1.0		ncar_pcm1.1	1.2	2.1	0.8	1.1	0.8
ukmo_hadcm3.1	1.3	0.6	1.0	1.4	1.6		ukmo_hadcm3.1	1.4	2.0	1.3	1.3	1.1
Ensemble Low	***0.6***	***0.1***	***0.1***	***0.4***	***0.5***		***Ensemble Low***	***1.0***	***0.9***	***0.7***	***0.6***	***0.8***
Ensemble Average	***1.4***	***1.6***	***1.2***	***1.3***	***1.4***		***Ensemble Average***	***1.4***	***1.8***	***1.3***	***1.3***	***1.4***
Ensemble High	***2.0***	***2.6***	***2.3***	***1.8***	***2.2***		***Ensemble High***	***2.1***	***2.6***	***2.2***	***1.8***	***2.3***
St Dev	***0.4***	***0.8***	***0.6***	***0.4***	***0.5***		***St Dev***	***0.3***	***0.5***	***0.5***	***0.4***	***0.5***

Table2 H-3. Projected changes in annual and seasonal air temperature (˚C) in Vermont for high (a2) and low (b1) emissions scenarios for mid (2040-2069) century compared to a historic (1961-1990) time period. See Table 2G-1 for information on the 15 General Circulation Models (GCM). These data were obtained from the Climate Wizard website (University of Washington and The Nature Conservancy 2009).

Departure Analysis - Mid-Century (2040-2069) vs. Historic (1961-1990)												
	a2 (high) emissions scenario							b1 (low) emissions scenario				
Model	**Annual**	**DJF**	**MAM**	**JJA**	**SON**		**Model**	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
bccr_bcm2_0.1	2.2	3.0	2.2	2.3	1.5		bccr_bcm2_0.1	1.6	2.2	1.2	1.5	1.2
cccma_cgcm3_1.1	3.2	3.4	3.5	3.1	3.0		cccma_cgcm3_1.1	2.5	2.9	3.2	2.3	2.1
cnrm_cm3.1	2.4	2.9	2.0	2.2	2.7		cnrm_cm3.1	1.9	2.2	1.6	1.8	2.0
csiro_mk3_0.1	2.5	4.5	3.2	1.6	1.9		csiro_mk3_0.1	1.5	2.6	1.3	1.1	0.9
gfdl_cm2_0.1	3.1	3.4	3.2	2.5	3.3		gfdl_cm2_0.1	2.4	2.4	2.0	2.8	2.3
gfdl_cm2_1.1	2.4	3.4	2.1	1.9	2.6		gfdl_cm2_1.1	2.1	2.8	1.3	2.1	2.1
giss_model_e_r.1	1.8	1.6	1.5	1.8	1.9		giss_model_e_r.1	1.3	0.9	1.6	1.2	1.4
inmcm3_0.1	2.8	3.9	2.8	2.0	2.5		inmcm3_0.1	2.2	2.7	1.8	2.0	2.2
ipsl_cm4.1	3.8	4.3	4.0	3.3	3.6		ipsl_cm4.1	3.1	3.5	3.3	2.5	3.1
miroc3_2_medres.1	3.5	3.6	4.0	3.1	3.2		miroc3_2_medres.1	2.9	2.9	3.0	2.6	3.2
miub_echo_g.1	3.4	3.9	2.9	3.2	3.6		miub_echo_g.1	2.7	3.2	2.1	2.7	2.8
mpi_echam5.1	2.6	2.9	1.9	2.4	2.8		mpi_echam5.1	2.2	2.2	1.9	2.0	2.5
ncar_ccsm3_0.1	3.2	3.1	2.9	3.0	3.4		ncar_ccsm3_0.1	2.3	2.7	2.1	2.1	2.3
ncar_pcm1.1	1.8	2.8	2.1	1.4	1.5		ncar_pcm1.1	1.6	2.3	1.5	1.5	1.2
ukmo_hadcm3.1	2.8	2.3	1.9	3.3	3.5		ukmo_hadcm3.1	2.7	2.6	2.7	2.7	2.7
Ensemble Low	***1.8***	***1.6***	***1.5***	***1.4***	***1.5***		***Ensemble Low***	***1.3***	***0.9***	***1.2***	***1.1***	***0.9***
Ensemble Average	***2.8***	***3.3***	***2.7***	***2.5***	***2.7***		***Ensemble Average***	***2.2***	***2.5***	***2.0***	***2.1***	***2.1***
Ensemble High	***3.8***	***4.5***	***4.0***	***3.3***	***3.6***		***Ensemble High***	***3.1***	***3.5***	***3.3***	***2.8***	***3.2***
St Dev	***0.6***	***0.8***	***0.8***	***0.6***	***0.7***		***St Dev***	***0.6***	***0.6***	***0.7***	***0.6***	***0.7***

Table2 H-4. Projected changes in annual and seasonal air temperature (˚C) in Vermont for high (a2) and low (b1) emissions scenarios for late (2070-2099) century compared to a historic (1961-1990) time period. See Table 2G-1 for information on the 15 General Circulation Models (GCM). These data were obtained from the Climate Wizard website (University of Washington and The Nature Conservancy 2009).

Departure Analysis - Late-Century (2070-2099) vs. Historic (1961-1990)												
	a2 (high) emissions scenario							**b1 (low) emissions scenario**				
Model	**Annual**	**DJF**	**MAM**	**JJA**	**SON**		**Model**	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
bccr_bcm2_0.1	3.6	4.2	2.8	3.5	3.6		bccr_bcm2_0.1	2.2	2.8	1.8	2.5	1.9
cccma_cgcm3_1.1	5.2	5.8	5.7	5.1	4.8		cccma_cgcm3_1.1	3.0	3.4	2.7	3.0	3.1
cnrm_cm3.1	4.1	4.6	2.9	3.8	4.6		cnrm_cm3.1	2.4	2.9	1.9	2.4	2.1
csiro_mk3_0.1	4.0	6.8	5.1	2.6	3.4		csiro_mk3_0.1	2.3	4.0	1.8	1.6	1.8
gfdl_cm2_0.1	5.1	5.6	4.9	4.5	5.7		gfdl_cm2_0.1	3.1	3.7	3.0	3.1	2.5
gfdl_cm2_1.1	4.0	4.8	4.1	3.2	4.4		gfdl_cm2_1.1	2.6	3.2	2.1	2.8	2.5
giss_model_e_r.1	3.1	3.1	2.8	3.2	3.0		giss_model_e_r.1	1.4	0.8	1.4	1.6	1.7
inmcm3_0.1	4.6	5.5	4.8	3.5	4.5		inmcm3_0.1	2.6	3.4	2.0	2.2	3.0
ipsl_cm4.1	6.1	6.8	6.1	5.1	5.9		ipsl_cm4.1	4.3	4.5	4.4	3.6	4.5
miroc3_2_medres.1	6.0	6.7	6.8	5.0	5.7		miroc3_2_medres.1	3.8	4.3	3.8	3.6	3.7
miub_echo_g.1	5.2	5.9	4.2	4.8	5.8		miub_echo_g.1	3.7	4.4	3.1	3.5	4.0
mpi_echam5.1	4.3	4.5	4.0	4.1	4.5		mpi_echam5.1	3.2	3.5	2.9	3.3	3.2
ncar_ccsm3_0.1	4.8	5.0	4.8	4.9	4.7		ncar_ccsm3_0.1	2.2	2.1	2.5	2.0	2.1
ncar_pcm1.1	3.0	3.9	3.1	2.5	3.4		ncar_pcm1.1	2.2	3.1	1.9	1.9	1.8
ukmo_hadcm3.1	5.0	4.0	4.3	5.6	5.7		ukmo_hadcm3.1	3.6	4.0	3.2	3.8	3.4
Ensemble Low	***3.0***	***3.1***	***2.8***	***2.5***	***3.0***		***Ensemble Low***	***1.4***	***0.8***	***1.4***	***1.6***	***1.7***
Ensemble Average	***4.5***	***5.1***	***4.4***	***4.1***	***4.7***		***Ensemble Average***	***2.8***	***3.3***	***2.6***	***2.7***	***2.8***
Ensemble High	***6.1***	***6.8***	***6.8***	***5.6***	***5.9***		***Ensemble High***	***4.3***	***4.5***	***4.4***	***3.8***	***4.5***
St Dev	***0.9***	***1.1***	***1.2***	***1.0***	***1.0***		***St Dev***	***0.8***	***1.0***	***0.8***	***0.8***	***0.9***

Table2 H-5. Projected changes in annual and seasonal precipitation (mm) in Vermont for high (a2) and low (b1) emissions scenarios for early (2010-2039) century compared to a historic (1961-1990) time period. See Table 2G-1 for information on the 15 General Circulation Models (GCM). These data were obtained from the Climate Wizard website (University of Washington and The Nature Conservancy 2009).

Departure Analysis - Early-Century (2010-2039) vs. Historic (1961-1990)												
	a2 (high) emissions scenario								**b1 (low) emissions scenario**			
Model	**Annual**	**DJF**	**MAM**	**JJA**	**SON**		**Model**	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
bccr_bcm2_0.1	16.7	19.0	1.9	3.9	-7.3		bccr_bcm2_0.1	61.4	35.4	-5.3	17.0	13.0
cccma_cgcm3_1.1	57.7	24.5	38.8	-17.3	12.5		cccma_cgcm3_1.1	60.0	28.2	33.7	-13.0	12.3
cnrm_cm3.1	101.2	35.9	11.5	24.2	25.7		cnrm_cm3.1	91.1	38.8	16.3	14.7	18.4
csiro_mk3_0.1	27.7	23.0	1.6	7.0	-4.5		csiro_mk3_0.1	8.6	19.5	-4.2	3.3	-5.7
gfdl_cm2_0.1	68.7	21.3	11.2	14.4	22.3		gfdl_cm2_0.1	39.1	10.0	7.4	25.8	-5.7
gfdl_cm2_1.1	71.5	38.2	43.2	-8.3	0.7		gfdl_cm2_1.1	94.8	34.5	39.1	11.6	9.3
giss_model_e_r.1	81.0	7.7	33.4	37.4	3.1		giss_model_e_r.1	87.7	10.2	29.2	31.7	16.0
inmcm3_0.1	42.3	25.5	-9.7	27.7	-4.0		inmcm3_0.1	55.1	27.1	-16.6	37.3	4.9
ipsl_cm4.1	89.3	46.6	0.4	18.2	24.8		ipsl_cm4.1	86.1	24.8	8.1	36.7	14.9
miroc3_2_medres.1	85.9	31.3	34.6	6.4	9.7		miroc3_2_medres.1	43.7	17.1	11.3	-0.4	11.3
miub_echo_g.1	-20.3	19.6	-6.9	-24.8	-9.2		miub_echo_g.1	-24.7	14.0	-2.8	-1.3	-34.4
mpi_echam5.1	42.4	26.9	16.0	16.5	-19.0		mpi_echam5.1	30.5	22.2	17.4	3.6	-12.3
ncar_ccsm3_0.1	17.8	-13.7	-1.2	25.7	3.4		ncar_ccsm3_0.1	-12.3	-17.1	-15.2	-42.5	-58.1
ncar_pcm1.1	46.5	15.8	15.0	18.4	-1.1		ncar_pcm1.1	48.8	6.8	6.8	13.3	20.9
ukmo_hadcm3.1	20.6	-5.0	13.5	3.8	2.3		ukmo_hadcm3.1	97.0	41.8	13.4	44.9	-1.4
Ensemble Low	***-20.3***	***-13.7***	***-9.7***	***-24.8***	***-19.0***		***Ensemble Low***	***-24.7***	***-17.1***	***-16.6***	***-42.5***	***-58.1***
Ensemble Average	***49.9***	***21.1***	***13.5***	***10.2***	***4.0***		***Ensemble Average***	***51.1***	***20.9***	***9.2***	***12.2***	***0.2***
Ensemble High	***101.2***	***46.6***	***43.2***	***37.4***	***25.7***		***Ensemble High***	***97.0***	***41.8***	***39.1***	***44.9***	***20.9***
St Dev	***33.7***	***15.7***	***16.9***	***17.1***	***13.0***		***St Dev***	***38.4***	***15.1***	***16.6***	***22.4***	***21.7***

Table2 H-6. Projected changes in annual and seasonal precipitation (mm) in Vermont for high (a2) and low (b1) emissions scenarios for mid (2040-2069) century compared to a historic (1961-1990) time period. See Table 2G-1 for information on the 15 General Circulation Models (GCM). These data were obtained from the Climate Wizard website (University of Washington and The Nature Conservancy 2009).

Departure Analysis - Mid-Century (2040-2069) vs. Historic (1961-1990)												
	a2 (high) emissions scenario							**b1 (low) emissions scenario**				
Model	**Annual**	**DJF**	**MAM**	**JJA**	**SON**		**Model**	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
bccr_bcm2_0.1	89.2	35.7	21.8	20.4	8.2		bccr_bcm2_0.1	30.4	24.8	3.6	-3.9	6.5
cccma_cgcm3_1.1	94.9	52.2	38.7	-31.1	36.1		cccma_cgcm3_1.1	73.5	37.7	52.4	-27.3	11.4
cnrm_cm3.1	126.5	27.6	15.4	24.5	55.6		cnrm_cm3.1	163.9	39.8	34.8	28.0	56.1
csiro_mk3_0.1	63.9	26.7	18.4	17.4	3.8		csiro_mk3_0.1	-135.9	9.0	-28.4	-67.1	-47.5
gfdl_cm2_0.1	82.5	54.9	27.1	-11.1	10.0		gfdl_cm2_0.1	73.6	27.5	25.9	9.6	9.9
gfdl_cm2_1.1	106.2	56.3	47.4	-5.6	5.1		gfdl_cm2_1.1	76.0	27.0	39.4	-7.8	14.9
giss_model_e_r.1	209.5	52.5	59.1	56.0	40.4		giss_model_e_r.1	121.0	7.7	41.8	38.7	32.2
inmcm3_0.1	11.7	1.2	-23.0	51.1	-14.5		inmcm3_0.1	40.6	4.8	-1.9	50.7	-12.0
ipsl_cm4.1	49.4	38.5	-10.2	-7.1	27.9		ipsl_cm4.1	112.8	26.5	17.5	33.4	32.4
miroc3_2_medres.1	43.2	25.7	25.1	3.6	-16.5		miroc3_2_medres.1	95.8	17.6	43.2	38.7	-7.4
miub_echo_g.1	12.1	29.0	0.9	-11.2	-5.4		miub_echo_g.1	7.0	15.6	11.9	-22.5	0.0
mpi_echam5.1	84.4	55.0	33.3	0.7	-4.2		mpi_echam5.1	93.2	42.5	13.5	24.6	13.3
ncar_ccsm3_0.1	29.6	19.7	3.5	34.0	-31.6		ncar_ccsm3_0.1	39.0	-52.8	-118.1	-267.2	-171.4
ncar_pcm1.1	95.8	17.9	33.5	18.3	24.9		ncar_pcm1.1	-387.8	27.3	27.1	0.4	34.7
ukmo_hadcm3.1	125.9	23.3	9.7	46.9	45.1		ukmo_hadcm3.1	103.6	24.2	27.2	43.6	6.7
Ensemble Low	***11.7***	***1.2***	***-23.0***	***-31.1***	***-31.6***		***Ensemble Low***	***-387.8***	***-52.8***	***-118.1***	***-267.2***	***-171.4***
Ensemble Average	***81.7***	***34.4***	***20.1***	***13.8***	***12.3***		***Ensemble Average***	***33.8***	***18.6***	***12.6***	***-8.5***	***-1.3***
Ensemble High	***209.5***	***56.3***	***59.1***	***56.0***	***55.6***		***Ensemble High***	***163.9***	***42.5***	***52.4***	***50.7***	***56.1***
St Dev	***51.1***	***16.7***	***21.7***	***25.7***	***25.2***		***St Dev***	***135.0***	***22.8***	***41.6***	***78.5***	***52.8***

Table2 H-7. Projected changes in annual and seasonal precipitation (mm) in Vermont for high (a2) and low (b1) emissions scenarios for late (2070-2099) century compared to a historic (1961-1990) time period. See Table 2G-1 for information on the 15 General Circulation Models (GCM). These data were obtained from the Climate Wizard website (University of Washington and The Nature Conservancy 2009).

Departure Analysis - Late-Century (2070-2099) vs. Historic (1961-1990)												
	a2 (high) emissions scenario							**b1 (low) emissions scenario**				
Model	**Annual**	**DJF**	**MAM**	**JJA**	**SON**		**Model**	**Annual**	**DJF**	**MAM**	**JJA**	**SON**
bccr_bcm2_0.1	132.4	60.1	43.6	-19.4	46.2		bccr_bcm2_0.1	86.8	41.0	42.6	3.9	-1.9
cccma_cgcm3_1.1	119.9	94.9	71.3	-52.3	11.0		cccma_cgcm3_1.1	64.8	49.4	50.8	-28.0	-4.1
cnrm_cm3.1	223.9	63.0	47.8	41.7	65.6		cnrm_cm3.1	148.7	40.0	24.3	35.2	41.6
csiro_mk3_0.1	149.4	50.7	31.6	31.4	36.8		csiro_mk3_0.1	-596.3	-36.1	-124.7	-241.5	-196.2
gfdl_cm2_0.1	62.9	48.8	26.1	-15.7	3.0		gfdl_cm2_0.1	61.8	42.9	18.7	15.7	21.7
gfdl_cm2_1.1	143.0	80.5	58.2	-6.9	47.2		gfdl_cm2_1.1	119.8	47.1	73.3	-3.6	4.7
giss_model_e_r.1	255.1	57.9	103.6	59.6	33.3		giss_model_e_r.1	142.2	16.8	43.5	36.7	42.5
inmcm3_0.1	104.0	23.1	2.4	94.9	-9.8		inmcm3_0.1	45.3	3.9	0.1	39.3	1.5
ipsl_cm4.1	86.6	63.6	5.2	-15.3	30.7		ipsl_cm4.1	92.6	41.6	17.5	4.8	28.6
miroc3_2_medres.1	16.2	43.7	29.9	-31.6	-28.2		miroc3_2_medres.1	144.4	52.4	49.7	29.9	8.0
miub_echo_g.1	58.9	54.0	57.8	-20.9	-33.5		miub_echo_g.1	23.9	18.8	45.5	-20.0	-18.4
mpi_echam5.1	107.3	47.6	22.8	20.3	14.8		mpi_echam5.1	118.7	55.7	24.9	14.6	23.0
ncar_ccsm3_0.1	113.1	25.8	19.6	52.7	10.7		ncar_ccsm3_0.1	51.3	-66.2	-122.6	-256.2	-181.9
ncar_pcm1.1	40.2	13.6	32.8	-0.1	-6.5		ncar_pcm1.1	-506.3	16.2	21.3	34.9	19.9
ukmo_hadcm3.1	71.2	34.9	48.5	14.1	10.1		ukmo_hadcm3.1	148.7	57.4	32.7	59.1	0.4
Ensemble Low	***16.2***	***13.6***	***2.4***	***-52.3***	***-33.5***		***Ensemble Low***	***-596.3***	***-66.2***	***-124.7***	***-256.2***	***-196.2***
Ensemble Average	***112.3***	***50.8***	***40.1***	***10.2***	***15.4***		***Ensemble Average***	***9.8***	***25.4***	***13.2***	***-18.4***	***-14.0***
Ensemble High	***255.1***	***94.9***	***103.6***	***94.9***	***65.6***		***Ensemble High***	***148.7***	***57.4***	***73.3***	***59.1***	***42.5***
St Dev	***64.2***	***21.4***	***26.2***	***39.8***	***28.2***		***St Dev***	***232.0***	***35.4***	***58.3***	***96.5***	***73.1***

Appendix 2I

Climate projection mapping data

Climatic projection data

Future projection data are available from a number of different sources. Some examples are shown in Table 2H-1. The Climate Wizard (Girvetz 2009, University of Washington et al. 2009) and Union of Concerned Scientists (UCS) Northeast Climate data (UCS 2011) are user friendly interfaces on which various parameters can be easily mapped or plotted over different temporal scales and emissions scenarios. If one has access to GIS software, the Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model (University of Washington 2011) data that were used to create the future projection maps in Hayhoe et al. 2007 are available upon request (contact: Justin Sheffield, Princeton University).

The University of Vermont's (UVM) Research on Adaptation to Climate Change (RACC) program is currently conducting some future projection analyses for the Lake Champlain Basin that Vermont ANR may be able to use. In addition, there will be future projection data for climatic variables, stream flow and nutrient loading from the update currently underway to the Lake Champlain Total Maximum Daily Loads (TMDL), which should be completed by 2013. A stream flow/nutrient modeling exercise is also being conducted in the LaPlatte watershed.

Table 2I-1. Future projection data that are accessible, high quality and user friendly (this is not an exhaustive list, nor are we endorsing these over others). Data accessed in September 2012, subject to change.

Source	Time period	Temporal scale	Models	Parameters	Format	Source
Climate Wizard	home page: 1951-2006, 2050s, 2080s; custom data download page: 1895-2099	annual, seasonal, monthly	15 different models	*historic & future*: air temperature (min/max/mean), precipitation (absolute, percent change); *future only*: moisture deficit and surplus, potential evapotranspiration (PET), AET/PET ratio, SPI, rainfall anomaly index (RAI)	Multiple options (tabular, plots, maps, GIS grid files)	http://www.climatewizard.org/
Union of Concerned Scientists (UCS) Northeast Climate data	1961-1990, 1971-2000, 2010-2039, 2040-2069, 2070-2099	annual, seasonal, monthly	HadCM3, PCM, CM2.1	air temperature (min/max/mean), precipitation, snow depth, relative humidity, coldest day of year, hardiness zone, days over 90F, days over 100F, growing season length, JJA heat index	Time series plot, map, GIS grid files	http://www.northeastclimatedata.org