Lake Champlain Basin Program

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Climate Change and Stormwater Management in the Lake Champlain Basin

An Adaptation Plan for Managers

October 2015

Final Report

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For:

The Lake Champlain Basin Program and New England Interstate Water Pollution Control Commission

CLIMATE CHANGE AND STORMWATER MANAGEMENT IN THE LAKE CHAMPLAIN BASIN

An Adaptation Plan for Managers

2015

NEIWPCC
New England Interstate Water Pollution Control Commission

Lake Champlain Basin Program

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ACRONYMS

AOGCM – ATMOSPHERE-OCEAN GENERAL CIRCULATION MODEL

CMIP5 – IPCC COUPLED MODEL INTERCOMPARISON PROJECT PHASE 5

CSO- COMBINED SEWER OVERFLOW

CSS- COMBINED SEWER SYSTEM

ESM – EARTH SYSTEM MODEL

GCM – GENERAL CIRCULATION MODEL

GHCN – GLOBAL HISTORICAL CLIMATOLOGY NETWORK

GSI – GREEN STORMWATER INFRASTRUCTURE

LCBP – LAKE CHAMPLAIN BASIN PROGRAM

LID – LOW-IMPACT DEVELOPMENT

IPCC – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

IPCC AR5 – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE'S ASSESSMENT REPORT 5

MS4- MUNICIPAL SEPARATE STORM SEWER SYSTEMS

NCA – NATIONAL CLIMATE ASSESSMENT

NEIC – NORTHEAST CLIMATE IMPACTS ASSESSMENT

NWS – NATIONAL WEATHER SERVICE

RCM – REGIONAL CLIMATE MODEL

RPC – REPRESENTATIVE PATHWAY CONCENTRATION

TMDL – TOTAL MAXIMUM DAILY LOAD

UCS – UNION OF CONCERNED SCIENTISTS

VCA – VERMONT CLIMATE ASSESSMENT

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EXECUTIVE SUMMARY

The effects of a changing climate have been and continue to be observed in the Lake Champlain Basin. Since the 1970s, there have been notable increases in air and lake temperatures, with the rate of increase progressing more quickly over time. Also since the 1970s, lake water levels have risen due both to land use disturbances and more regional precipitation (Stager and Thill, 2010). In winter, the number of days the lake is covered with ice is decreasing, while the number of days above freezing each year steadily rises. Increasingly, climate models suggest a future with more frequent and intense storm events, more precipitation as rain and less snow in the winter (Frumhoff et al., 2007; Horton et al., 2014). These changes lead to a warmer, wetter future with nearly year-round rainfall. Water resource managers must be prepared for these changes.

When rainfall enters a landscape, water percolates through natural surfaces, is retained on the surface and evaporates, or runs directly into waterways. Much of the time, especially with large events, the majority of precipitation ends up as runoff, or stormwater. Management of this runoff aims to reduce pollution and prevent damage from flooding. However, more frequent and intense storm events in the future could lead to higher runoff volumes and more pollutants entering our waterways. As more land is developed in the Lake Champlain Basin, use of improved stormwater management practices has never been more critical. Currently, both Vermont and New York have some management standards in place that account for predicted changes in climate as well as mitigation strategies for more frequent floods. But the current management standards are limited to addressing the first inch of rainfall in a storm event, and providing flow control determined by historical rainfall records. As storm events become larger and more frequent due to climate change, these state-wide management standards must be updated to accommodate. In addition, implementation of climate-ready stormwater management on the ground is lagging and it is important to understand why. Following the flood events of 2011, many municipalities found they were unprepared. And, though legislative efforts intended to curb poor management were put in place, some communities continue to build within flood-prone areas, failure to maintain stormwater systems, and install undersized infrastructure. Improved stormwater management techniques including the incorporation of green infrastructure and the proper sizing of grey infrastructure, along with education and outreach to municipalities and property managers, is needed throughout the basin. Policy and funding changes that prioritize low-impact development can be the difference between a climate resilient community and one that must rebuild after every flood event.

In light of a changing climate, sound stormwater management adaptation strategies can preserve and strengthen the health of Lake Champlain and its watershed. Working together across the municipal, regional, state and federal levels facilitates the implementation of more effective management strategies. Though the region may feel the effects of a warmer, wetter climate, preparing now for potential flood events can prevent widespread damage to infrastructure and homes and reduce pollution to waterbodies.

INTRODUCTION

Climate change is a globally observed phenomenon, but we are already feeling specific effects from it at the local level. If climate is the typical weather for an area, climate change is the persistent deviation from this typical weather for the region. This can mean changes in average seasonal temperatures and expected precipitation patterns. The observed changes in global climate over the last 50 – 100 years are widely accepted as the result of anthropogenic factors, most significant of which is the addition of greenhouse gases to the Earth's atmosphere (Figures 1 and 2). While this cause-and-effect relationship occurs on a global scale, the consequences of our current human-driven climate change have tangible local effects. These impacts can vary greatly by geographic location, from drought and fire hazard in California, to flooding and sea level rise on the U.S. east coast.

The existence of climate change is well supported by multiple historical datasets, including observations of increasing air and ocean temperatures, increasing extreme precipitation events, shrinking land and sea ice, and an accompanying rise in sea level. What is less well-understood is how the climate will continue to change in the future and what the consequences for local climates will be. Most studies investigating future climate use models to project changes in the near and distant future. These models use quantitative methods to replicate the interaction between different components of the climate system (such as the atmosphere, ocean, land surface, and wind) to varying levels of complexity. Given values for parameters that force climate change, these models can then be used to project how the climate will change in the future.

While the resolution of computer climate models (i.e. at what spatial scale the simulations resolve climate dynamics) is improving with time, raw global climate models are still limited in how well they can project local changes. Another method for predicting climate change- tracking historical climate change trends- can help illuminate how climate may change at a regional scale. Theoretically, if perturbations in the climate system have produced observable changes in a local climate, it is possible that the trend is likely to produce similar changes in the future. This method is limited in its ability to account for non-linear step changes, or changes that are possible but have yet to be observed in the climate. The coupling of a simulated global climate response to locally observed changes may provide the best insight into future local climate change.

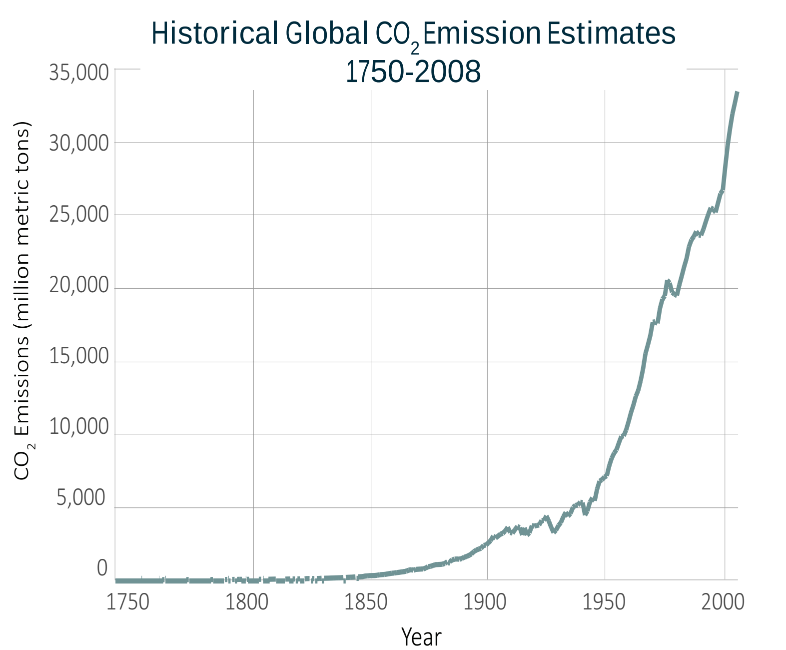


Figure 1. Estimate of historical global carbon dioxide emissions, data from Boden et al. (2010).

Climate models are under constant

revision as new information (such as the interaction between air and ocean surface or the effects of atmospheric aerosols) is added to the simulated climate systems, improving the accuracy of these models in representing the real world. More studies are using historical climate data to validate and localize climate projections. However, some factors, like the human response to climate change and how our rate of greenhouse gas emissions may vary, are difficult to predict. This remains the largest variable in

Global Land and Ocean Temperature Anomalies
June Values, 1880-2015

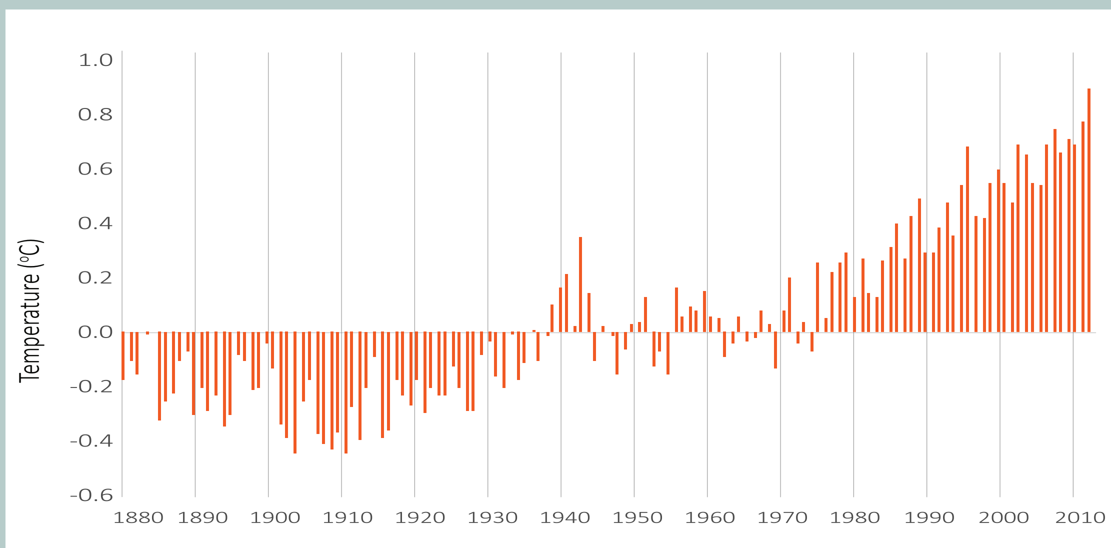


Figure 2. Global land and ocean temperatures for June, described as departure from the 20th century average, in degrees Celsius. Data are from the Global Historical Climatology Network-Monthly data set and International Comprehensive Ocean-Atmosphere Data Set, which compile data from 1880 to the present.

projecting how climate will change in the future. As a result, most studies either specify the conditions under which their projections will be valid, or provide a range of possible values to account for the unknown rates of human emissions.

> We must understand how our climate is likely to change in the future and identify vulnerabilities in our built and natural environments.

Climate change can have very real consequences for local populations. Impacts range from disturbances to the natural ecosystem to changes in social and economic sectors, and there can be complex and exacerbating interations between these factors. For example, climate change could result in more frequent drought and/or heavy precipitation events, which affects the natural environment's ability to cope with stormwater. This in turn leads to more stormwater runoff, resulting in flooding. In the Lake Champlain Basin, we are particularly affected by flooding as many population centers and agricultural operations are located near waterways, so that climate-influenced flooding then produces serious consequences for local economies, infrastructure, and water quality problems.

With these impacts in mind, how can we best combat the impacts of climate change in our local environment? First, we must understand how our climate is likely to change in the future and identify vulnerabilities in our built and natural environments. Then, we must decide how we can adapt to these changes.

POTENTIAL CLIMATE CHANGES IN THE LAKE CHAMPLAIN BASIN

HOW WILL CLIMATE CHANGE AFFECT THE LAKE CHAMPLAIN REGION?

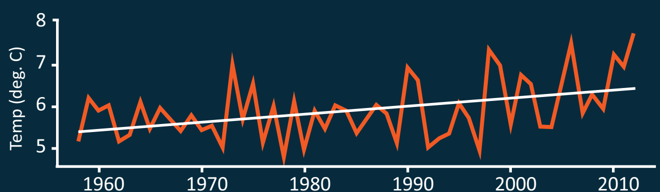
Data from regional studies and models provide evidence of local climate change using historical observed records of long term temperature and precipitation trends. These data are used to inform climate forecasts in the basin in the future, and it appears that Lake Champlain will be a wamer, wetter place with more frequent severe weather and shorter winters.

All of this means that we must be better prepared for floods.

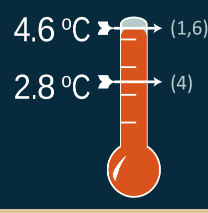
TEMPERATURE

Multiple studies, from local to international, project increasing temperatures in the Lake Champlain basin as a result of climate change. Temperatures have risen approximately 1.8 degrees (C) per decade since 1958, with the most dramatic changes occurring in the last decade.

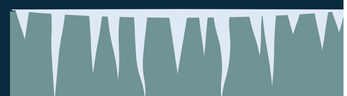
Historical Temperature Trends
after Guilbert et al., 2014



Future Temperature Rise by 2100:



a 310% increase in annual days over 90ºF is predicted by 2050 (1)



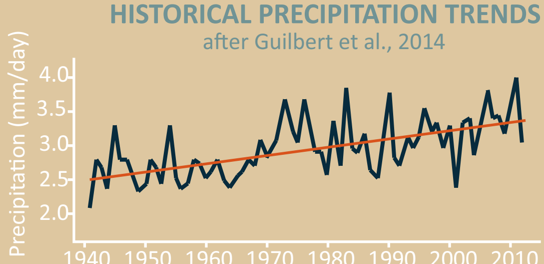
in recent years, there has been less lake ice cover and earlier ice-out on Lake Champlain (2)

Number of heavy precipitation events will also likely increase, as will storm intensity (3,4).

PRECIPITATION

Many climate models suggest the Lake Champlain basin will be **wetter** in the future, with more storm events and more annual rainfall. Precipitation is likely to increase by 4 inches in New England by 2100 (3).

HISTORICAL PRECIPITATION TRENDS
after Guilbert et al., 2014



FUTURE PRECIPITATION RISE

(1)	mid-century	end-century
Daily precipitation may increase	7.1%	9.9%
Mean precipitation may increase	3.9%	7.2%

(6)

SEASONALITY

Since 1940, there has been a -20% decrease in annual freezing days in Vermont (4). By the end of the century, the growing season is projected to increase +20-31% (1).

more winter rain is predicted (3, 7)

possible summer droughts (3)

1. Guilbert et al., 2014; 2. National Weather Service, 2015; 3. Frumhoff et al., 2007; 4. Galford et al., 2014; 5. Stager & Thill, 2010; 6. Climate Wizard; 7. Horton et al., 2014; 8. Stocker et al., 2013

This paper includes a compilation of relevant recent studies on probable temperature and precipitation projections for the near and distant future. With this information, we can look at how our environment will be impacted. Many predicted consequences of climate change are negative, but it is possible to tackle these outcomes through mitigation and adaptation. While mitigating the effects of climate change through the reduction of greenhouse gases is an important strategy on the global scale, human influences on the climate are already large and prolonged enough that some climate change is inevitable and adaptation measures could be valuable locally. Adaptation requires that we adjust to a new climate regime in a way that minimizes detrimental impacts.

The strategy of adaptation is particularly pertinent when we look at how climate change could affect the quantity and quality of stormwater runoff in the Lake Champlain Basin. Problems with stormwater management already affect our communities and are likely to continue in the future if action is not taken. We can use the best available science to predict how our climate may change in the future and concentrate on helping stormwater managers adapt to our future climate.

SECTION I: CLIMATE CHANGE
climate models

The most comprehensive and up-to-date model of global climate change is the Intergovernmental Panel on Climate Change's Assessment Report 5 (IPCC AR5). The final synthesis report of the study was published in 2014, and continues the work of the four previous global climate change assessments. The IPCC AR5 derives climate change observations and projections from literature review, and is compiled by hundreds of volunteer scientists.

The models used in the IPCC AR5 range from standard Atmosphere–Ocean General Circulation Models (AOGCMs), to more complex Earth System Models (ESMs), to geography- and process-limited Regional Climate Models (RCMs)(Stocker et al., 2013). Significant conclusions in this report include more decisive and emphatic statements that the global climate system is warming, that it is extremely likely that anthropogenic drivers are responsible for these changes, and that changes in the climate system are already impacting environments across the globe (Stocker et al., 2013). Like previous assessment reports, the IPCC AR5 describes evidence of current changes in our global system, provides projections of temperature and precipitation changes, and predicts consequences of these changes under a range of emission and mitigation scenarios called Representative Pathway Concentrations (RPCs). The RPCs, which were selected from literature review, describe the degree to which the energy budget of the atmosphere could be out of balance (radiative forcing, in W/m^2) under a variety of conditions and the IPCC

	SCENARIO	2046-2065		2081-2100	
		MEAN	LIKELY RANGE	MEAN	LIKELY RANGE
GLOBAL MEAN SURFACE TEMPERATURE CHANGE (C)	RPC 2.6	1.0	0.4-1.6	1.0	0.3-1.7
	RPC 4.5	1.4	0.9-2.0	1.8	1.1-2.6
	RPC 6.0	1.3	0.8-1.8	2.2	1.4-3.1
	RPC 8.5	2.0	1.4-2.6	3.7	2.6-4.8

Table 1. IPCC AR5 Projected changes in global mean surface temperature, relative to 1986-2005 temperatures (after IPCC AR5 table SPM.2).

does not predict which RPC is most likely (Stocker et al., 2013). However, since these RPCs incorporate possible policy decisions, they are the IPCC's attempt to describe possible climate changes without knowing how emissions and mitigation strategies will develop.

The IPCC report projects that global surface temperatures will rise during the 21st century under all of the RPC scenarios (see Table 1). The frequency and duration of heat waves are very likely to increase, and extreme precipitation events will occur more often and with a greater intensity. Of note for the Lake Champlain basin, mean precipitation amounts are likely to increase by 2100 in many mid-latitude regions (areas between approximately 30 and 60° latitude, which includes the contiguous US). Globally, temperature increases are projected to continue beyond 2100 under all but one of the RPC scenarios (Stocker et al., 2013).

The IPCC AR5 benefits from a comprehensive review of current scientific studies, international experts as contributors, and a very public profile. However, the final publication must be agreed upon by international governments, whose stipulations regarding published material can be political. Additionally, the global scale of the IPCC AR5 makes it difficult to apply the climate projections to the area of the Lake Champlain Basin, except in cases of uniform global outcomes and climate change consequences.

Regional Models

The National Climate Assessment (NCA) is a summary of climate change indicators and impacts in the United States. The U.S. Global Change Research Program has produced three NCAs, with the most recent released in 2014. Like the IPCC assessments, the NCA is compiled from current scientific literature. The 2014 assessment includes contributions from more than 300 experts, guided by a 60-member Federal Advisory Committee, and was extensively reviewed by the public and experts, including federal agencies and a panel of the National Academy of Sciences (Horton et al., 2014). The NCA includes more detailed reports of climate change in regions of the U.S., using historical data and studies that downscale global climate models. The northeast region of the NCA includes New York and Vermont, and describes observed and projected climate change for the area.

In 2007, the Union of Concerned Scientists (UCS) published the Northeast Climate Impacts Assessment (NECIA). Focused on nine states in the northeastern United States, the publication reports on climate modeling and assessments by over 40 research scientists (Frumhoff et al., 2007). The assessments include reviews of historical data and climate projections using both a low (B1) and a high (A1fi) emission scenario. Modeling in this study uses global AOGCMs coupled with statistical and dynamical downscaling. The NECIA is a great example of downscaled climate modeling with accessible results and graphics. Unfortunately, the publication is eight years old, and uses older versions of global climate models and emission scenarios as a basis for the analysis.

In 2014, researchers from the Gund Institute for Ecological Economics within the Rubenstein School for Environment and Natural Resources at the University of Vermont produced the Vermont Climate Assessment (VCA). This report is based on the design of the NCA, but focused specifically on observed and projected climate change in the state of Vermont. Data in the VCA come from published studies, interviews, and National Weather Service (NWS) and citizen scientist observations (Galford et al., 2014). Climate projections are from the IPCC Coupled Model Intercomparison Project Phase 5 (CMIP5), the most recent version of the coordinated global climate model experiments. The VCA provides a detailed look at local climate changes and impacts, but the projections are mostly based on global projections without statistical or dynamical downscaling.

In 2014, a published study by Guilbert et al. (2014) provided downscaled projections for climate change in part of the Lake Champlain basin. This work used statistical methods (referencing historical temperature and precipitation trends) to downscale four general circulation model (GCM) projections to an area of northern Vermont and southern Quebec, and delivers projections for two RPCs- RPC 4.5 and RPC 8.5 (Guilbert et al., 2014). While only four GCMs were used and the geographical area covered does not include the New York state portion of the basin, this peer-reviewed research gives scientifically robust projections for mid- and late century temperature and precipitation for the local area.

Climate Wizard is a web-based tool developed by The Nature Conservancy, in partnership with the University of Washington and the University of Southern Mississippi. Climate Wizard provides historical climate data for the last 50 years (PRISM Climate Group, 2004) and downscaled climate projections for the mid- and late 21st century (Maurer et al., 2007). In an effort to produce data comparable to that of Guilbert et al., 2014, LCBP staff produced a custom analysis for the Lake Champlain basin geographical area using the same GCMs used in their study. While Climate Wizard outputs historical and projected climate data downscaled to the exact region of interest, Climate Wizard modeling is based on older versions of AOGCMs and the projections are based on older emission scenarios (as compared to the IPCC RPCs). Stager and Thill (2010) used the Climate Wizard tool as the basis for their climate projections. In their study, all 16 of the AOGCMs were downscaled to the Lake Champlain basin area to provide projections for a high and a low emission scenario. In addition, this study looks at historical climate data from eight weather stations in the area, lake freeze-up records, and Lake Champlain water level and surface temperature datasets (Stager and Thill, 2010). This publication makes use of older AOGCMs and emission scenarios, but provides the most comprehensive analysis of climate change in the Lake Champlain basin to date.

These studies vary in their preferred reporting units for temperature, from degrees Celsius to degrees Farenheit. For continuity and ease of interpretation, we have converted temperatures to degrees Farenheit (°F) for this report.

historical observations

Data from regional studies and models provide evidence of local climate change, demonstrated by both direct observations, such as historical temperature and precipitation records, and indirect effects (e.g. records of water level and temperature in Lake Champlain, and changes in flora and fauna). These data can then be used to inform forecasts for the future climate throughout the basin. While precipitation projections are more valuable to stormwater management, there is more agreement and precision surrounding observations and projections for temperature than for precipitation. Many studies use temperature data to drive estimates for future precipitation. Current projections for future climate in the Lake Champlain basin are based both on complex global AOGCMS and extrapolated historical observations.

Temperature Changes

Observations of temperature in the Lake Champlain basin and the surrounding region indicate that air temperatures have been rising for more than a century. Stager and Thill (2010) found a 2.1°F increase in air temperature between 1976 and 2005. Meteorological data from the Global Historical Climatology Network (GHCN) indicates that average temperature in the Vermont and Quebec portion of the basin have been increasing by approximately ~0.34°F per decade since 1958 (Guilbert et al., 2014). However, the rate of temperature increase has not been consistent. The VCA used records from 12 NWS meteorological stations in Vermont to determine the rate of temperature rise. Their analysis suggests that temperature is warming faster in recent years: from 1990 to 2012 the average lowland temperature increased by 1.5°F per decade, while the average highland temperature increased by 1.8°F per decade. In the most recent decade (2000 to 2010), the warmest on record, lowland temperatures increased by 3°F per decade, and highland temperatures increased by 2.5°F per decade (Galford et al., 2014).

These changes in temperature are demonstrated in the region's climatic extremes as well. The number of days that Vermont experiences freezing temperatures is down 20% since the 1940s (Galford et al., 2014). This is not surprising, since 9 out of 10 record warmest years in the Vermont and Quebec portions of the basin were between 1990 and 2012, with 2012 recorded as the warmest year on record (Guilbert et al., 2014). The Guilbert et al. (2014) analysis of historical temperature records indicates that both the coldest days (0.05 quantile) and warmest days (0.95 quantile) increased in temperature by ~0.9°F/decade and ~0.09°F/decade, respectively.

The changes in temperature have an effect on the timing of seasons regionally as well. Over the last 100 years, Vermont temperatures are warming twice as fast in the winter (0.9°F per decade) than in the summer (0.4°F per decade), and on average more in the mountains (0.8°F per decade since 1960) than in lowlands (0.4°F per decade since 1960) (Galford et al., 2014). Spring arrives two to three days earlier and the end of fall, or the first freeze, is 2.8 days later in the year. This lengthens the average growing season, which has been observed since at least 1941 (Galford et al., 2014).

Climatic changes in the basin are not as straightforward as a simple warming of temperatures, however. Galford et al. (2014) have also noted changes in meteorological phenomena, such as quasi-stationary blocking patterns. This southward dipping of polar temperatures and stalled weather patterns, possibly caused by recent warming of the arctic, changes the jet stream (Coumou et al., 2014) and brings prolonged periods of abnormally cold temperatures to the area, which are not often seen in the Vermont historical record. In 2012 and 2013, quasi-stationary blocking patterns led to stretches of colder than average temperatures and multi-day record rainfall in Vermont (Galford et al., 2014).

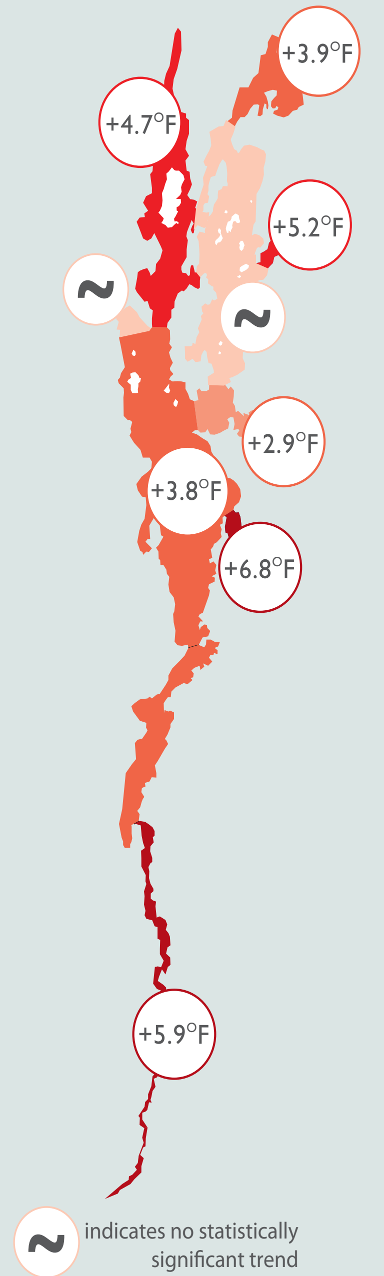
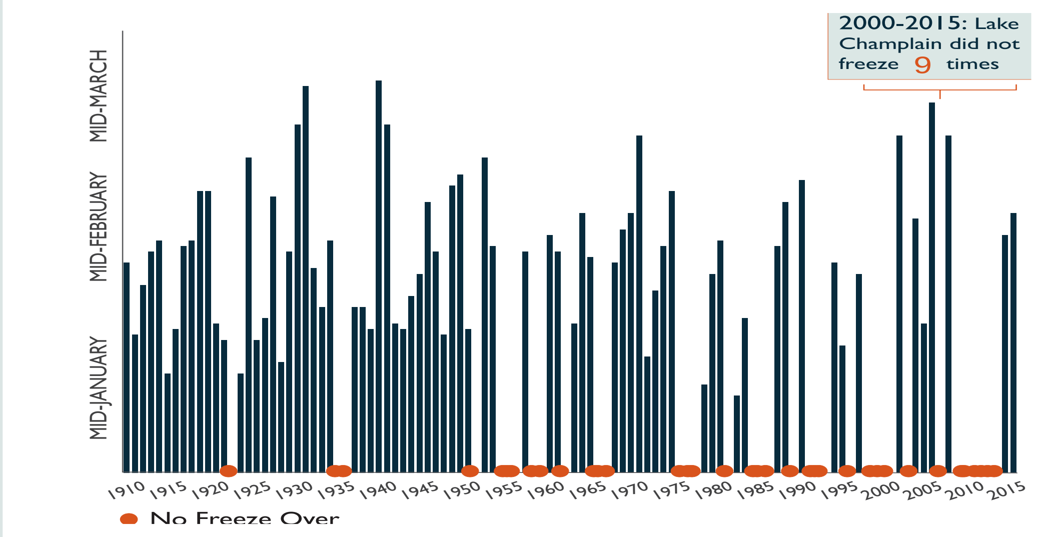


Figure 3. Mean August water surface temperature change (1964-2009) in Lake Champlain. Data are compiled from Smeltzer et al., 2012.

Figure 4. Lake Champlain has been freezing over less frequently in recent decades. Data are compiled from the National Weather Service/ NOAA (2015).



Changes in climate are observable in Lake Champlain and smaller water bodies in the area as well. Observations at locations around Lake Champlain demonstrate an increase in mean August surface water temperatures from 1964 to 2009 (Smeltzer et al., 2012) (Figure 3). Using NWS observations of when Lake Champlain freezes over and thaws in the spring, it is apparent that there are seven fewer days of ice cover per decade (Betts, 2011; National Weather Service, n.d.) (Figure 4). The years when Lake Champlain does not freeze over at all are becoming more common, and when the lake does freeze over, it happens later in the year. Similar trends are observed at Joe's Pond, Vermont and other small lakes (Betts, 2011; Galford et al., 2014).

There is evidence of these climatic changes in the regional flora. There has been a shift of deciduous forests to more northerly locations, and the distribution of all forest make-ups have moved up in elevation (i.e. high elevation forests have reduced their range to the highest elevations as more moderate temperature species move up in elevation). This has reduced the range of evergreen forests and favored species like oak (Tang et al., 2012). The date on which Vermont lilacs first leaf-out also occurs 3 days earlier per decade, supporting the data for an earlier onset of spring in the area (Schwartz and Reiter, 2000).

Precipitation Changes

Historical observations also indicate a change in precipitation patterns and amounts in the Lake Champlain basin. Records from the GHCN describe an increase in precipitation in the Vermont and Quebec portions of the basin between 1941 and 2012. These changes average out to an additional 1 to 2 inches of precipitation per decade (Guilbert et al., 2014). The VCA reports that increases in precipitation in Vermont are even greater in mountainous regions, with an average increase of more than 2 inches per decade (Galford et al., 2014). This trend holds true for the Champlain basin, too- weather stations in the Lake Champlain basin show an increase of 3 inches of precipitation between 1976 and 2005 (Stager & Thill, 2010). The wettest year in the Vermont and Quebec portion of the basin (2011) was much wetter than the annual mean (as calculated from 1948 to 2012)- 2.5 times the standard deviation (Guilbert et al., 2014). More recent years have also shown precipitation extremes, with 2013 having extreme back-to-back monthly precipitation totals (May and June) and June 2015 achieving the 3rd highest precipitation on record (Burlington station, National Weather Service, 2015). Galford et al. (2014) also analyzed changes in snowfall amounts in Vermont. Since 1954, snowfall has increased 10% in Burlington and 22% on Mt. Mansfield. They also note that snowfall has been highly variable in recent years. While the average for Vermont annual snowfall for the last 30 years is 573 inches, snowfall amounts in the 2010-2013 seasons have ranged from 80 to 1073 inches (Galford et al., 2014). In addition to increased average precipitation, there is evidence of an increase in storms and extreme precipitation events.

> Stations in the Lake Champlain basin show an increase of 3 inches of precipitation between 1976 and 2005
>
> (Stager & Thill, 2010)

Statistical analyses of the largest precipitation events (0.95 and 0.99 quantiles) indicate that the amount of rainfall in these events has increased by 0.01- 0.02 inches per day per decade (Guilbert et al., 2014). High intensity events (with precipitation of more than 1 inch in a day) are now more frequent. The type of storm that occurred in Vermont with a frequency of four days a year during the 1960-1980 period increased to a frequency of seven days per year in the last two decades. The trend is for the area's precipitation to arrive in larger bursts over shorter periods of time (Galford et al., 2014). The VCA also measured an increase in recorded lightning strikes as a proxy for storms. An increase in lightning strike occurrence in recent years may indicate storms are becoming more energetic in the region.

The increase in precipitation in the region can be witnessed in changes in the area's rivers as well. Studies show that average annual flows in select New England rivers have increased over the last 50 years (Hodgkins & Dudley, 2006; Huntington et al., 2009). Galford et al. (2014) also report an increase in annual flows in Vermont rivers. In addition, there are seasonal changes recorded in regional waterways which indicate peak flows are occurring earlier in the year. Monthly stream flow data from 1953 to 2002 for New England rivers demonstrate an increase in flow in January, February, and March, and a decrease in May (Hodgkins & Dudley, 2006). Records from 1971 to 2000 show that the center of volume dates (the date in a year at which 50% of a river's flow volume has occurred) have also been coming earlier in the year. As many rivers in the northeast are influenced by snowmelt, this correlates well with warmer March and April temperatures and increased precipitation in January (Hodgkins et al., 2003).

While it is likely that regional changes in precipitation have affected water levels in Lake Champlain, a body of water that is greatly influenced by precipitation variation, the record is somewhat unclear as to the extent of historical changes. USGS records of lake level from the Burlington, VT gauge suggest an increase in average annual lake elevation of approximately 1.5 feet between 1940 and 2013 (USGS, 2015). Stager and Thill (2010) also note a rise in lake level, but reference restrictions to the lake outflow (constructed in the 1970s) as a possible cause for lake level increase. The VCA asserts that there is no evidence of climate-related changes in Lake Champlain water level, and that any increase in water volume is due to restrictions to the outflow (Galford et al., 2014).

future projections

Historical observations can provide information on temperature and precipitation trends in the Lake Champlain basin, but studies that use both past climate data and advanced climate modeling can provide projections for the future that go beyond the current values. As discussed previously, models can vary in local pertinence, comprehensiveness, scientific rigor, and how current the data used is. Different models and studies use different emission scenarios, baseline historical values for describing predicted changes, and time windows for future climate projections. Generally, the science used to describe the atmospheric conditions behind temperature models is better understood than that of precipitation forecasting, so there is more uncertainty surrounding precipitation projections.

Future Temperatures

In the near future (2016-2035) global temperatures are likely to rise by ~0.5-1.3°F (Stocker et al., 2013). The IPCC AR5 reports that a ~0.7-4.7°F rise in global temperature is likely by the middle of this century (2046-2065). The NECIA anticipates mid-century temperatures in the northeastern U.S. will rise by 2.5-4°F in the winter and 1.5-3.5°F in the summer. Vermont temperatures are expected to rise by ~3.1°F by 2050 (Galford et al., 2014). Estimates for mid-century temperature increases in the Lake Champlain basin range from ~3.4°F for a low emissions scenario (Climate Wizard results- Mauer et al., 2007) to ~5.6 °F (Guilbert et al., 2014). The Guilbert et al. study also predicts a 29% decrease in days with freezing temperatures during this same time period.

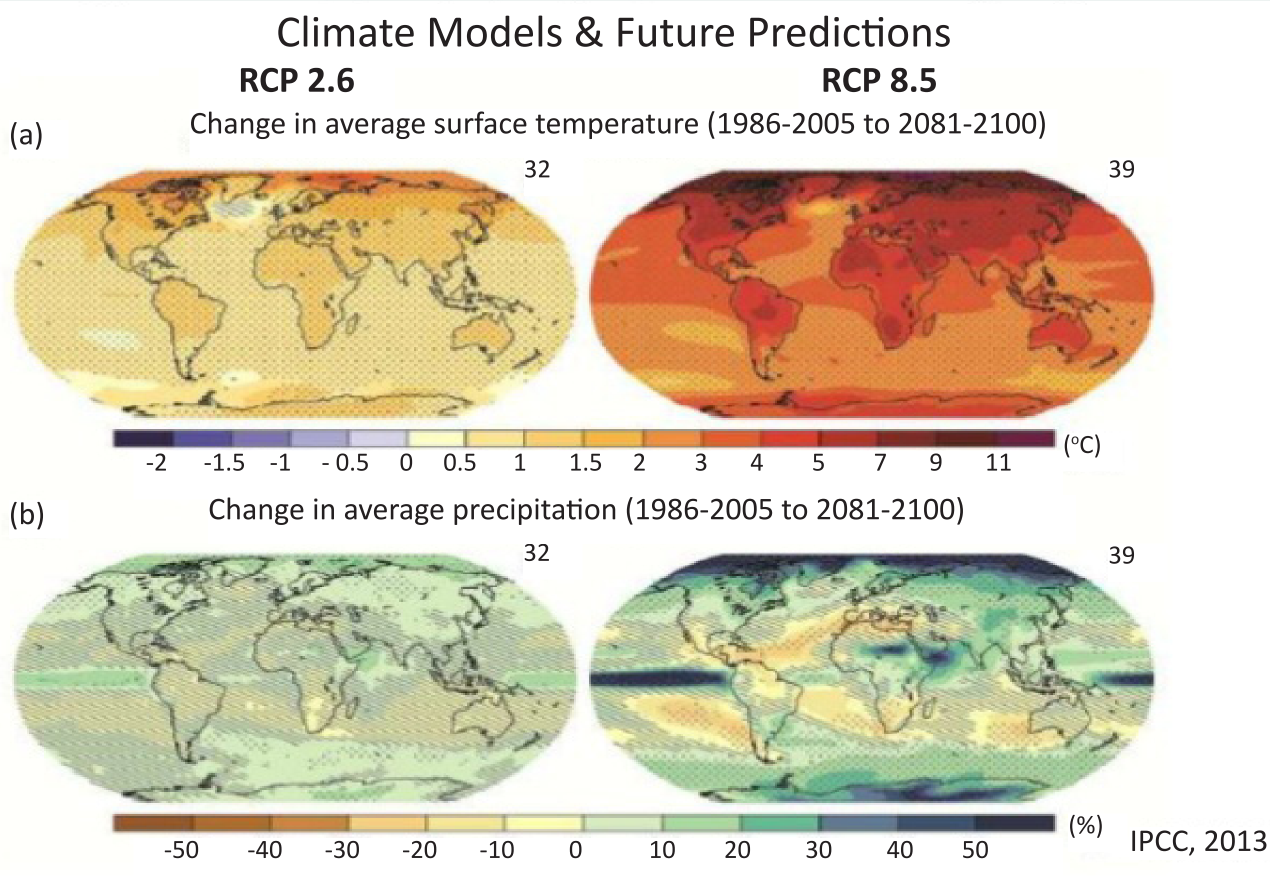


Figure 5. Maps of Maps of CMIP5 multi-model mean results for the scenarios RCP2.6 and RCP8.5 in 2081–2100 of (a) annual mean surface temperature change, and (b) average percent change in annual mean precipitation. Changes in panels (a), and (b) are shown relative to 1986–2005. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. For panels (a) and (b), hatching indicates regions where the multi-model mean is small compared to natural internal variability (i.e., less than one standard deviation of natural internal variability in 20-year means). Stippling indicates regions where the multi-model mean is large compared to natural internal variability (i.e., greater than two standard deviations of natural internal variability in 20-year means) and where at least 90% of models agree on the sign of change (see IPCC AR5 Box 12.1). For further technical details see the IPCC Technical Summary Supplementary Material. {Figures 6.28, 12.11, 12.22, and 12.29; Figures TS.15, TS.16, TS.17, and TS.20}

Over time, as the choices we make regarding greenhouse gas emissions become more consequential, temperatures are expected to increase even more and the impacts of emission scenarios will become more pronounced in climate projections. By the end of the century (2081-2100), global temperatures could rise by ~0.4°F (RPC2.6) to ~8.6°F under the most severe RPC (Stocker et al., 2013) (Figure 5). By 2080, temperatures in the northeastern U.S. will rise by 3-6°F (low emissions scenario) or 4.5-10°F (high emissions scenario)(Horton et al., 2007). Again, temperature increases may not be uniform over the course of the year. The NECIA predicts at least a 3-7°F increase in temperature in the summer and a 4-6°F increase in the winter (low emissions scenario). Under a high emissions scenario, these temperature ranges are doubled. This could represent summers in the northeast with 20 days of temperatures greater than 100°F (Frumhoff et al., 2007). The NECIA specific predictions for Vermont temperatures are similar or slightly higher by the end of the century. Other estimates for Vermont project a ~5.2°F increase in temperatures late this century (Galford et al., 2014). Model estimates for end-of-century temperatures in the basin are also higher: Guilbert et al. project temperatures will rise by ~8.3°F which agrees with the Climate Wizard results. Climate Wizard suggests lower emissions will result in a ~5.6°F rise in temperature (Figure 7). Stager and Thill found a 1-11°F increase in temperature by the end of the century, depending on the emission scenario.

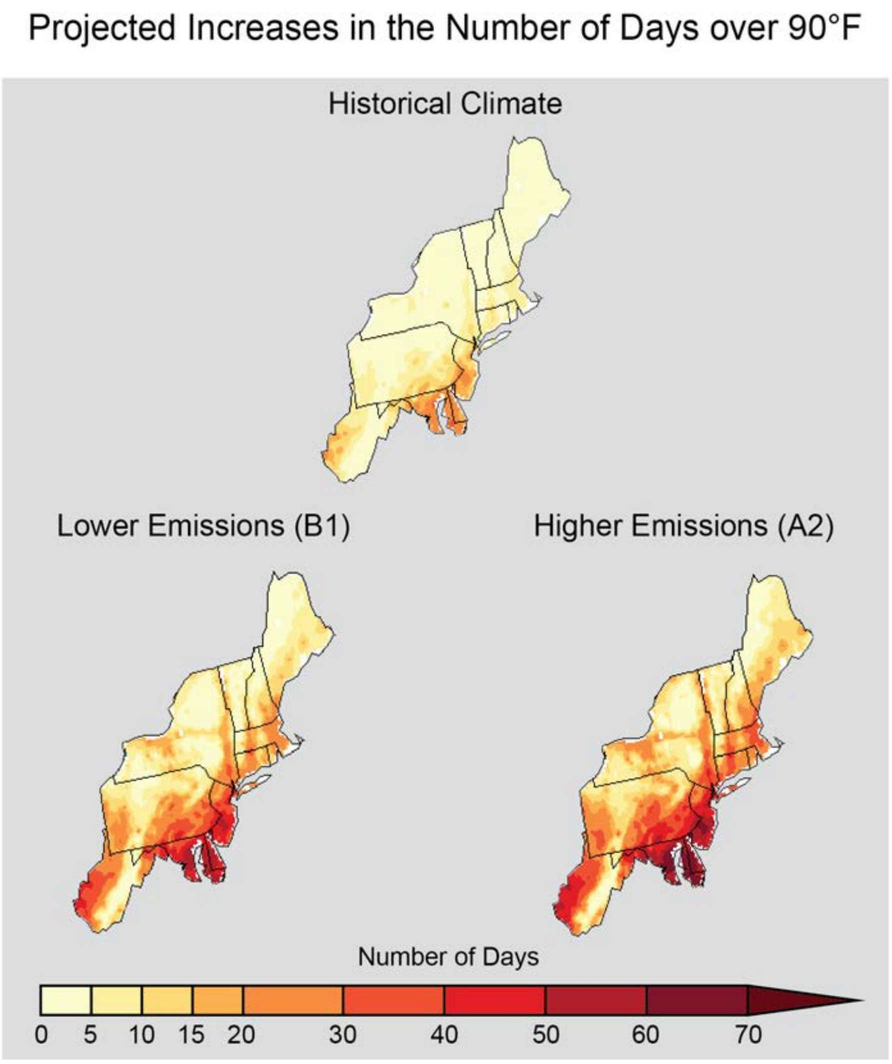


Figure 6. The National Climate Assessment projection for the number of days per year with a maximum temperature greater than 90°F averaged between 2041 and 2070, compared to 1971-2000, assuming continued increases in global emissions (A2) and substantial reductions in future emissions (B1). Data from NOAA; figure from Horton et al., 2014.

Future Precipitation

Projections for precipitation changes are less detailed, but most models agree that the region is likely to experience more precipitation in the future. In the near future (2016-2035) estimates for mid-latitude locations (such as New England) describe a likely increase in mean annual precipitation. Additionally, heavy precipitation events over land are likely to increase (Stocker et al., 2013). The NECIA believes the northeastern U.S. should expect an 8-9% increase in precipitation by the middle of this century. The nature of storm events will also change by mid-century: heavy events (2-day downpours) will increase by 8%, and extreme events (5-day duration) will increase by 10% (Frumhoff et al., 2007). Due to warming temperatures, more of this precipitation will fall as winter rain than snow (Frumhoff et al., 2007), though the VCA projects that in the near future (before temperatures rise too dramatically) Vermont

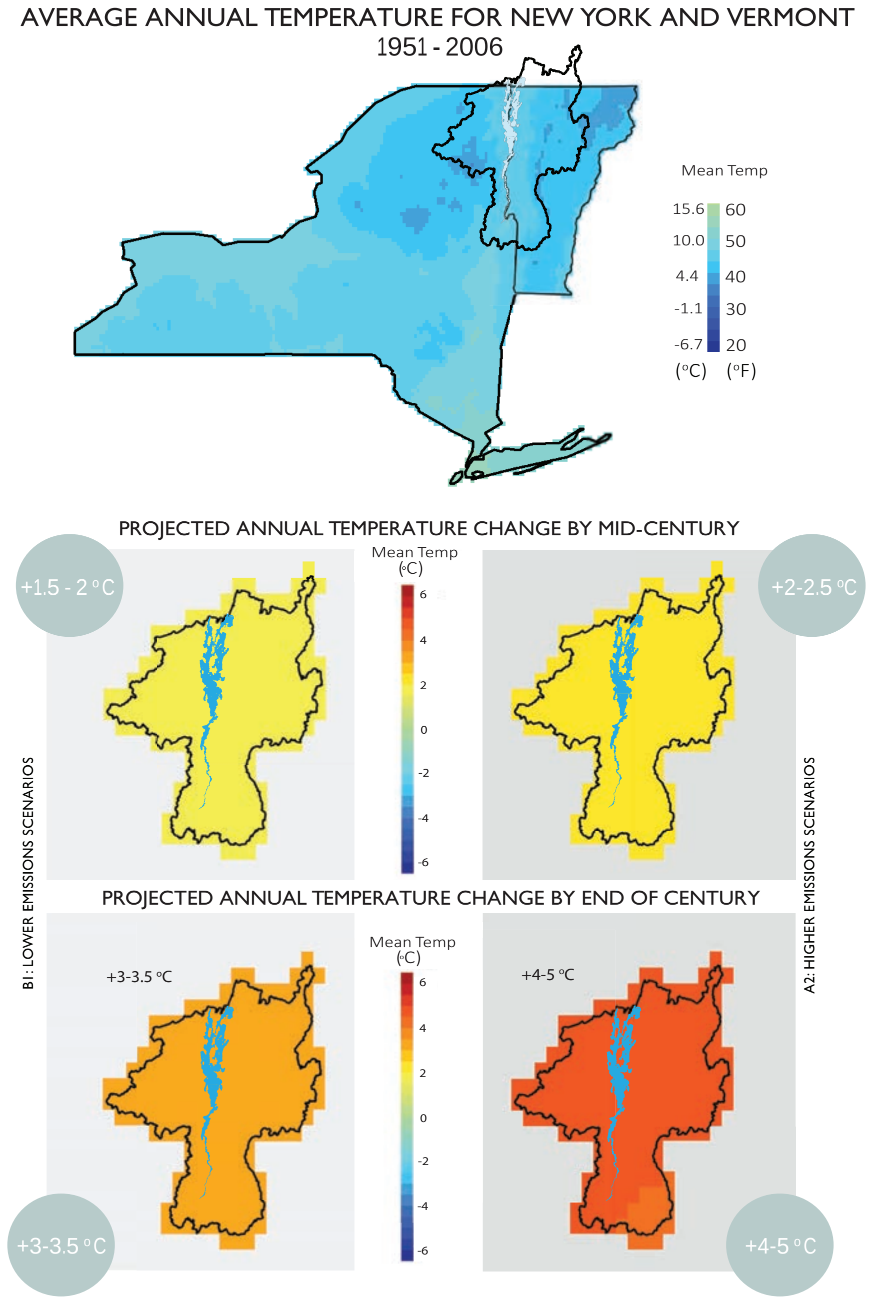


Figure 7. Projected annual temperature change for the Lake Champlain Basin by mid- and end of the century, as modeled by ClimateWizard. Change is relative to the annual mean temperature from 1961-1990. The projections were calculated from an ensemble of four downscaled GCMs: CSIRO-Mk3.0, INM-CM3.0, IPSL-CM4, and MIROC3.2 (medres). The depicted projection is a compiled from the median ensemble projection. Historical data from PRISM Group, 2007; climate modeling by Climate Wizard Online Tool, with base climate projections downscaled by Mauer, et al. (2007).

could see an increase in snowfall. In the Lake Champlain basin, daily precipitation may rise by 7% by mid-century (Guilbert et al., 2014). Our Climate Wizard results indicate average annual mid-century basin precipitation will rise by 4% (low emissions scenario) to 5.5% (high emissions scenario).

By the end of the century, precipitation projections are tremendous. Global estimates tie precipitation increases to higher global surface temperatures. By the end of the century (2081-2100), precipitation will increase 1-4% (depending on the emission scenario) for every degree C of temperature rise (Stocker et al., 2013). Therefore, if the IPCC anticipates global temperature increases of 0.5 to 5°C, precipitation could increase by 2-20% by 2100. Due to the increased energy in a warmer atmosphere, individual storms in the late-century are expected to be more intense (Stocker et al., 2013). The northeastern U.S. projections disagree on the degree of annual precipitation increase: the NCA describes little change in annual precipitation by the end of the century, while the NECIA projects a 10% increase (or an additional 4 inches) of annual precipitation. But both studies predict a difference in seasonal precipitation in the northeastern U.S. The NCA projects a 5-20% increase in winter precipitation (high emissions scenario), but relatively small changes in annual, summer, and fall precipitation totals (Horton et al., 2014). The NECIA projects that end-of-century winter precipitation could be 20-30% greater under a high emissions scenario (Frumhoff et al., 2007). Again, individual storm intensities (the average amount of rain that falls in a day) in the northeast are predicted to increase (10-15%), as well as a 12-13% increase in 2-day events, and a 20% increase in 5-day events (Frumhoff et al., 2007). The NEICA Vermont-specific projections agree with the regional estimates for winter precipitation, and detail the possibility of more frequent short-term summer droughts (Frumhoff et al., 2007; Galford et al., 2014). Estimates for precipitation in the Lake Champlain basin at the end of the century are consistent: an increase in daily values by approximately 10% (Guilbert et al., 2014) and annual increases of around 5.5-7% (Climate Wizard). Stager and Thill (2010) project little or no significant change in precipitation in the basin with a low emissions scenario, but an increase of 4-6 inches if greenhouse gas emissions are high.

One of the most **significant climate-related hazards is increased flooding**

In summary, climate projections for the region vary, but all agree that a warmer climate is likely in the near and end-of-century time frames (Figure 8). An increase in surface temperatures will lead to a more energetic atmospheric system, which will likely result in a wetter regional climate with an increase in storm frequency and intensity. There is less agreement among forecasts for precipitation changes in the future. However, most studies project increases in precipitation, particularly during the winter months, and as temperatures rise by the end of the century more of this precipitation will fall as rain instead of snow.

climate change impacts

While none of these models claim to forecast future climate with perfect certainty, it is possible to predict the impacts of a likely warmer, wetter basin. The influence of a changing climate will be felt in a number of ways, from environmental to economic, and some changes will promote further changes in other areas.

Increasing global temperatures will be felt in the region, leading to longer summers and milder winters. The models suggest that winter temperatures will warm more than summer temperatures (Stager & Thill, 2010). We can expect both fewer days with freezing temperatures in the winter, and an increase in extremely warm days in the summer (Figure 6). Most climate change studies predict the growing season will lengthen, which could be beneficial to agriculture in the region, as crops that require a longer season may become viable in the area. However, a longer, hotter summer coupled with a lack of hard freezing temperatures could also benefit weeds, agricultural pests, and diseases that stress crops (Galford et al., 2014, Guilbert et al., 2014, Stocker et al., 2013). Variability in precipitation (more heavy rain events with intermittent dry periods) can be hard on crops also (Guilbert et al., 2014). The increase in days over 90oF would be stressful on livestock (Galford et al., 2014). Certainly maple sugar operations, a staple in the area, could see shorter sap runs and more pest damage with a transition to a warmer climate with fewer cold nights. Model projections support the prediction that the sugaring season will shorten and shift to mid-winter (Guilbert et al., 2014).

Warmer temperatures are likely to influence human health as well. Earlier onset of spring and warmer summers could increase the occurrence of heat-related air pollution leading to asthma and allergies (Galford et al., 2014). While populations in the basin are prepared for cold winters, we are less adapted to extreme or prolonged heat waves, which are more likely in the future. Heat waves in the last decade in the U.S. and Europe have been responsible for thousands of deaths, as they contribute to heat stroke, and complications with cardiovascular and kidney disease (Altman et al., 2012)(NRDC, 2012). An analysis in Vermont indicates a substantial increase in risk from heat-related illnesses when temperatures exceed 87oF due to a population unaccustomed to hot temperatures and older homes and businesses poorly designed to deal with summer heat (Vermont Department of Health, 2015).

The effects of changes in precipitation in the basin are harder to predict. More precipitation is expected, but the timing of precipitation events is less clear. Most studies suggest that the frequency of storm events will increase, as well as the intensity of these storms. The Lake Champlain basin should expect more bursts of heavy rain. To complicate precipitation issues further, if these events occur in rapid succession the soil can become saturated during the first event and lead to heavy runoff and flooding during subsequent events. Historically, heavy precipitation periods have also been coupled with short periods of drought in the same year (Dupigny-Giroux, 1999; Galford et al., 2014), which leads to complications for water table recharge and increases surface runoff. Due to changing annual temperatures, it is likely that more, if not all, winter precipitation will fall as rain instead of snow at some point in the future. One of the most significant climate-related hazards is increased flooding. The geology of the watershed (steep headwater channels and less permeable soils) leads to rapid runoff during rain events and makes the area prone to flooding (Galford et al., 2014). An increase in precipitation, particularly in large bursts over shorter time periods, may be a recipe for disaster. The combined effects of increased winter precipitation and temperatures that fluctuate near freezing can increase rain-on-snow or-frozen ground events. The inability of the ground to absorb precipitation leads to more surface runoff and increases the risk of flash flooding. The predicted rise in precipitation, coupled with seasonally-reduced ground infiltration suggests that more flooding of Lake Champlain is likely. Stager and Thill (2010) report that the average lake level may rise as much as 1-2 feet on average by 2100 under a high emissions scenario. This could also result in upgradient localized flooding for areas which drain to collection systems which outfall to the lake. It is also possible, with higher temperatures leading to earlier spring snowmelt and higher rates of evaporation and the potential for droughts in the summer, that lake levels could fluctuate dramatically throughout the year, leading to higher maximums and lower minimums (Stager and Thill, 2010).

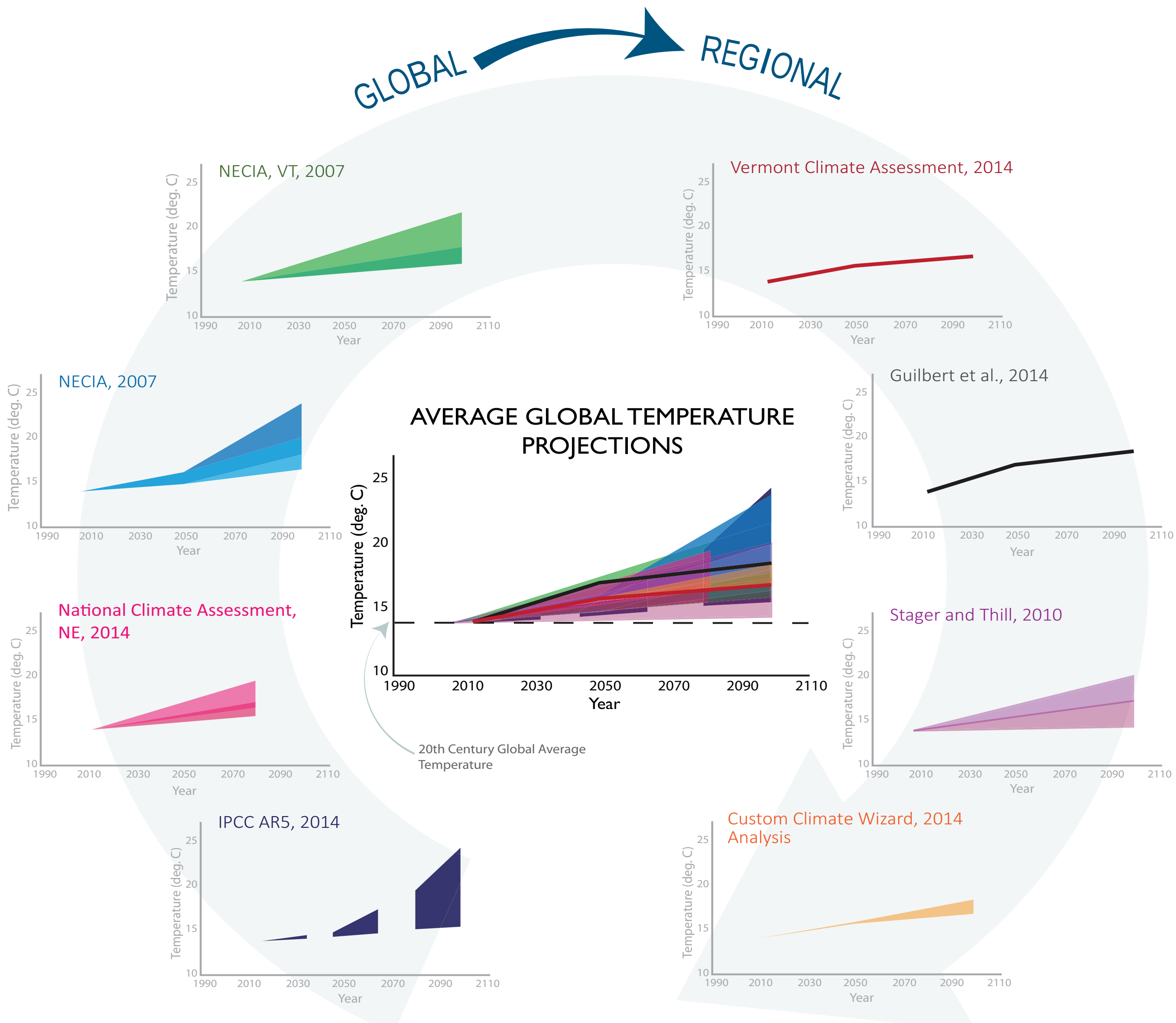


Figure 8. Comparison of climate projection studies used. All forecasts were adjusted to begin at the 20th century average global temperature to facilitate comparison. Each study has benefits and limitations, and the study area ranges from global (bottom left), to the Lake Champlain Basin (bottom right).

In addition to the hazards posed by flood events themselves, increased overland flow of water and higher water volumes in tributaries is likely to increase erosion and sediment transport in the Lake Champlain basin, as seen in in 2011 during Tropical Storm Irene. This can result in channel modifications and nutrient loading, leading to higher pollution potentials. Studies have documented these types of flooding-induced problems in a number of storm-water impaired waterways in the basin (Lake Champlain Lake George Regional Planning Board, 2012; Vermont Department of Environmental Conservation, 2012). Higher lake levels, coupled with wave action, could cause more shoreland erosion and threaten waterfront septic systems (Stager & Thill, 2010; Galford et al., 2014). Along with sediment, it is likely that pathogens, toxins, and other pollutants will increase in the water (Galford et al., 2014).

These climate-related impacts can dramatically affect the Lake Champlain ecosystem. Temperature changes will likely force the continued evolution of the area's forests, increasing the range for some tree species and decreasing the range for others (Iverson, 2008). If the area forests are compromised, the rest of the ecosystem is more vulnerable to erosion, flooding, and changing temperatures in tributaries. Increased temperatures and a change in seasonality can also affect the health of plants: earlier bud development and changes in water availability can make plants more vulnerable to pests and make it harder to compete with encroaching invasive species. Warmer temperatures and greater winter precipitation could change the timing of seasonal flooding, which is a necessary part of spring for some aquatic species (Stager & Thill, 2010). In general, climate change could lead to warmer water temperatures and changes in water and nutrient levels due to increased runoff. These conditions could be taxing on native species, while supporting increased cyanobacteria blooms that thrive on warm, phosphorus-enriched waters.

The projected increase in temperature, precipitation, storms, and flooding is likely to affect infrastructure as well. The northeast has experienced energy, transportation, and communication failures already due to storms, and these events are projected to happen more often in the future. Increased stream flow, a likely future scenario, could destroy culverts and bridges that are undersized and not able to withstand high flows. Homes built in valleys are particularly vulnerable to increased flooding, as are rural and mountain communities that can be isolated during storm-related infrastructure failures (Galford et al., 2014). Even communities that don't suffer from flooding hazard must still cope with stormwater runoff that can overwhelm current stormwater infrastructure management.

The economic impact of a changing climate in the Lake Champlain basin is not yet clear. In some ways, a longer growing season and perhaps a more appealing tourism climate may give the region an economic benefit. The possibility of increased snowfall in the winter in the near future (in the years before continued warming results in winter rain) (Galford et al., 2014) would support more winter sports tourism. However, the cost of climate-driven infrastructure damage is likely to be expensive and could outweigh any potential benefits of increased tourism. Changes in forest communities, due either to climate shift, pest infestation, or damage from extreme events, can adversely affect current forest industries. Flooding also causes long-term community hardship, reduces tourism, increases vulnerability to invasive species, and may completely transform landscapes. It is clear that issues surrounding stormwater and water quality management will be important as the climate changes, and adaptation planning in advance of these changes could mitigate some of the hazards.

SOURCE/PUB YEAR	REGION	OBSERVED CHANGES		PROJECTIONS	
		TEMPERATURE	PRECIPITATION	TEMPERATURE	PRECIPITATION
IPCC AR5 2013	Global	+0.85°C 1880-2012; +0.89°C 1901-2012; +0.72°C 1951-2012	1901-2008, 1.01 - 2.77 mm/yr/decade. 1951-2008, -2.77 - 0.68 mm/yr/decade.	2016-2035, +0.3-0.7°C 2046-2065, +0.4-2.6°C likely 2081-2100, +0.3-4.8°C likely, depending on RCP.	2016-2035: mid-latitude mean likely to increase, heavy precipitation events over land likely to increase. 2081-2100: precipitation increase with rising temperature: 1-3%/°C, except 0.5-4%/°C for RPC2.6. More intense individual storms.
NCA NE 2014	Northeast US	+2˚F (0.16˚F/decade), 1895-2011	1895-2011, +5" or >10% (0.4"/decade). 1958-2010, >70% increase in very heavy events (heaviest 1% of all daily events)	A2 scenario: +4.5-10°F by the 2080s; B1 scenario: +3-6°F by the 2080s.	A2 scenario, +5-20% in winter precipitation by end-cent.; annual, summer, fall only small changes.
NECIA 2007	Northeast US	+0.5°F/decade since 1970; +1.3°F/decade in winter (1970-2000)	Annual average +5 - 10% since 1900. 1980s & 1990s, more high precipitation events in NE (>2" of rain falling in 48 hours).	Next several decades: +2.5 - 4°F in winter, +1.5 - 3.5°F in summer. Late century: +8 - 12°F in winter, +6 - 14°F in summer. Half this under low emissions scenario. 20+ days of 100°F in cities.	+10% (4") annual (end of century). +20 -30% winter precipitation (high emissions scenario). Intensity: +8 -9% mid-century, +10-15% end of century. Heavy events (2-day downpours): +8% mid-century, +12 13% end of century. Extreme (5-day events): +10% mid-century, +20% end of century.
NECIA VT 2007	Vermont	+1.5°F since 1970; +4°F in winter 1970-2000		Late century, +9 - 13°F in winter, +7 - 14°F summer (high emissions). Half that for low emissions. Increase in number of days over 90°F	+20 - 30% winter precipitation (low emissions), increase in extreme rainfall, more rain than snow, more frequent summer short-term droughts
VCA 2014	Vermont	+2.7°F since 1941; +1.6°F since 1960; +0.9°F since 1990; +0.4 °F in last decade (warmest on record)	Annual precipitation +1"/decade since 1941. +2.3"/decade in mountainous regions. High intensity events (>1" in a day): +2 days/yr in last two decades.	+1.7°C by 2050, +2.8°C by late century.	More winter and spring precipitation. More storms predicted.
Guilbert 2014	Vermont/ segment of Quebec	+0.19°C/decade. 9 of 10 record warmest years were between 1990 and 2012. 2012 was the warmest.	Annual precipitation +45.8mm/decade. 0.95 and 0.99 quantiles (heavy precipitation) +0.38 and +0.48 mm/day, respectively.	Annual average +3.1°C by mid-century, and +4.6°C by end of century. Freezing days -29% (mid-century) and -39% (end of century).	Daily precipitation +7.1% (mid-century) and 9.9% (end of century).
Climate Wizard 2014	Lake Champlain Basin (projections) Vermont/ New York (historical)	1951-2006, +0.029°F/yr in VT, and +0.018°F/yr in NY	1951-2006, +0.29%/yr in VT and +0.22%/yr in NY.	Mid-century annual median: +2.1°C (A2 scenario), +1.9°C (B1 scenario). End-century annual median: +4.6°C (A2), +3.1°C (B1)	Mid-century annual median: +5.6% (A2), +3.9% (B1). End-century annual median: +5.6% (A2), +7.2% (B1)
Stager & Thill 2010	Lake Champlain Basin	1976-2005: +2.1° F in air temperature	1976-2005: annual average +3" above 1895-1975. 80's & 90's: more frequent storms	+1-6°F of warming (B1 scenario), +6-11°F (A2 scenario).	Little to no significant change.

SECTION II: STORMWATER ADAPTATION

current management

STORMWATER RUNOFF CARRIES POLLUTANTS INTO OUR WATERWAYS

1. O'Neil-Dunne, 2013; 2. Vermont and New York DEC's, 2015; 3. Wemple et al., 2013

Stormwater is runoff that occurs during and after a rainfall or snowmelt event. It is most often associated with the developed landscape where natural vegetation has decreased and a significant portion of the land is covered with impervious, or hard, surfaces. Impervious areas decrease the natural infiltration and increase both the peak flow and total volume of water entering collection systems and waterbodies. Stormwater management aims to spread out, slow down and infiltrate runoff through built drainage networks, retention ponds or infrastructure that mimics the natural environment, known as Green Stormwater Infrastructure (GSI). The increase in the percentage of the total rainfall that runs off of surfaces versus infiltrating can overwhelm the capacity of both closed pipe and open channel drainage networks. In addition to concerns with the volume of water that is generated, stormwater runoff also carries pollutants such as sediment, chemicals or nutrients from urban environments directly into waterways, potentially causing harm to the biological and physical balance of the aquatic ecosystem downstream.

In the Lake Champlain basin, stormwater runoff has been shown to contribute to pollution in Lake Champlain. According to a recent estimate, stormwater contributes up to 13.8% of the total phosphorus load to Lake Champlain (Vermont Agency of Natural Resources, 2015). Stormwater management is particularly challenging in the basin due to its decentralized nature and the disparity of needs and funding between large cities and rural communities, as well as multiple levels of government (state, provincial, and federal) responsible for implementing policy guidance.

As discussed in the first half of this report, more frequent and more intense storm events have occurred in recent decades and are predicted to continue in the Lake Champlain region (Figure 9). The return interval of large storm events is changing; what used to be a 100-year event has now become a 25-year event as big storms come more frequently. Intense, large-scale floods have occurred more often since the late 1970s and the risk of future damage is rising as these storms are predicted to occur more often and development continues to increase along Lake Champlain and its tributaries (Armstrong et al., 2012, Frumhoff et al., 2007, Galford et al., 2014). Since 1963, there have been 40 federally declared disasters in the state of Vermont; 33 of which have been flood-related (Figure 10a). In New York, there have been 67 declared disasters, 51 of which have been storm or flood-related during the same period (Figure 10b). Since around 1960, there has been a 71% increase in the average number of days with very heavy precipitation (defined as the heaviest 1 percent of all events; Figure 11).

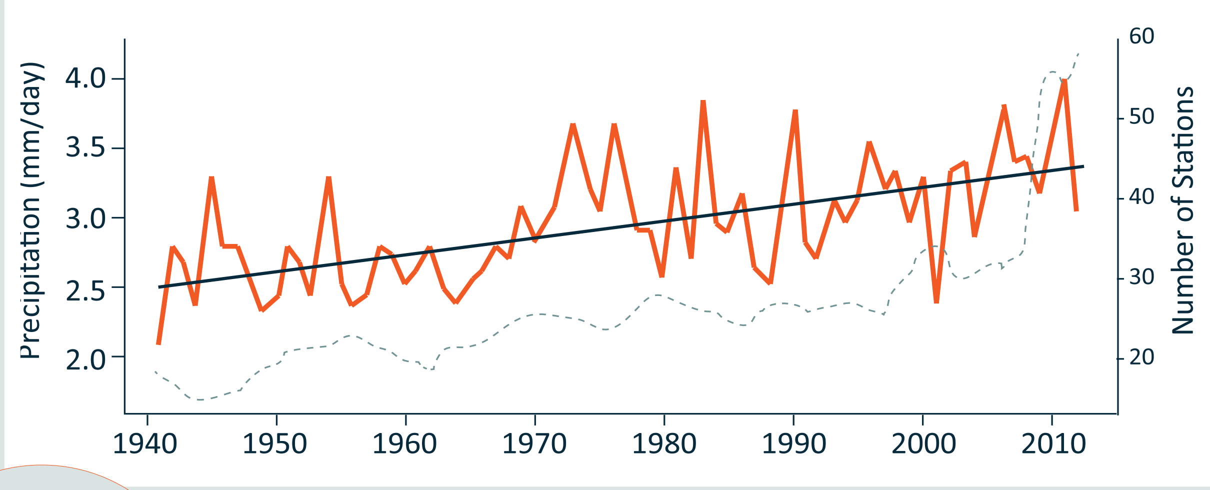


Figure 9. Historic trends in annual precipitation from GHCN weather stations, from Guilbert et al. (2014). The weather stations included in their study covered northwestern Vermont and southern Quebec.

The projected effects of climate change are not good for runoff

Many towns in the watershed have inadequate regulation to build stormwater infrastructure capable of withstanding large floods and development persists in the flood-prone river corridor. Currently, the Federal Emergency Management Agency (FEMA) delineated floodplain maps are the tool of choice to define flood hazard zones where stormwater infrastructure must be built to withstand at least a 25-year storm event. However, these maps are increasingly becoming inadequate as large floods continue to outpace gauge records, leading to predicted annual damages greater than $750 million throughout the US (EPA, 2014), due in part both to more frequent storm events and existing historical development built in flood hazard areas. In response, the Vermont Rivers Program, as an example, is working to delineate the full river corridor of streams throughout Vermont to use as a tool for flood hazard awareness. But regulatory gaps remain, especially in broad-scale infrastructure guidance to build or rebuild climate-ready utilities throughout the basin.

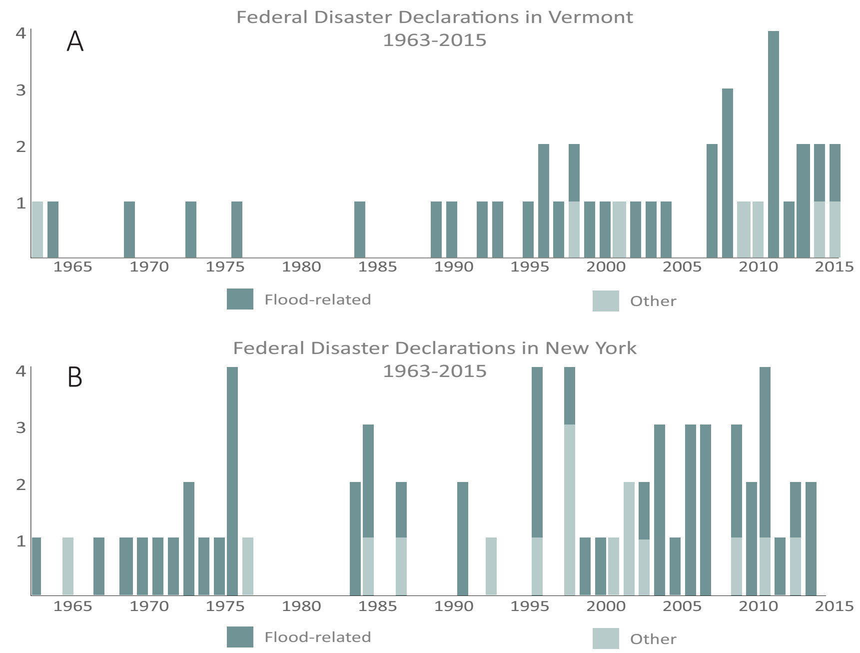


Figure 10. Federal disaster declarations in Vermont (A), and New York (B), from 1963 through August, 2015.

Flooding is a problem that affects many parts of the landscape. Slowing down, spreading out and infiltrating stormwater in the uplands can help alleviate flashy riverine flooding downstream. Conservation of a naturally functioning ecosystem with areas that allow for spreading out and

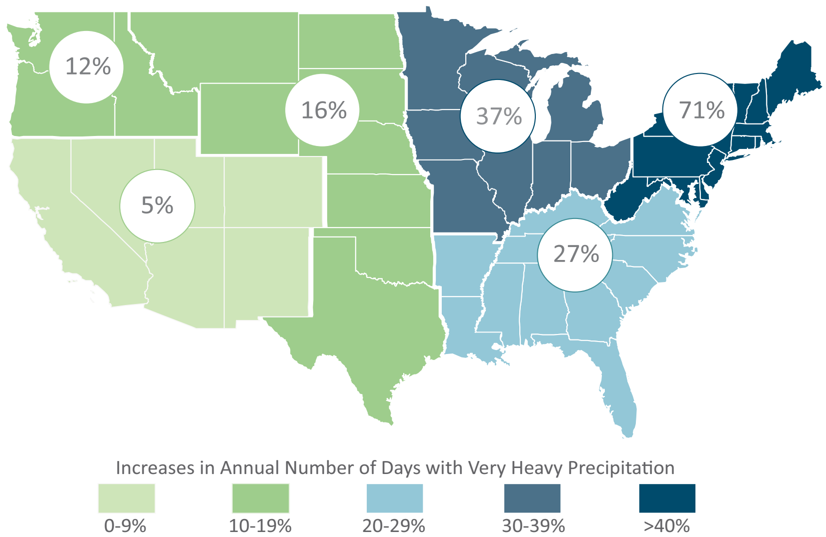


Figure 11. The map shows the percentage increases in the average number of days with very heavy precipitation (defined as the heaviest 1 percent of all events) from 1958 to 2007 for each region. There are clear trends toward more days with very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest. Adapted from the Horton et al., 2014, updated from Karl et al., 2009 and Groisman et al., 2005.

infiltrating rainfall through the use of best practices in new or rebuilt development can reduce future flood damages. Building properly sized stormwater infrastructure throughout the landscape can help spread out runoff. Getting technical and financial assistance to towns and stormwater managers to delineate the most important areas to prioritize protection are another way to reduce the risk of overwhelming stormwater infrastructure. Additionally, reducing stormwater runoff through the implementation of green stormwater infrastructure (GSI) and low-impact development techniques (LID) can alleviate the exacerbation of flooding that results from potential climate change.

Green stormwater infrastructure practices and low-impact development techniques can reduce the overall volume of storm flows, particularly in small to moderate events, by absorbing rainfall, promoting better infiltration and, through LID, developing in a sustainable manner consistent with the natural ecosystem. Whereas traditional stormwater management relies on conveying runoff through constructed road curbs, gutters and pipes or combined sewer systems, green techniques use the natural drainage features for runoff conveyance and treatment. Though GSI and LID have lower capacities, they can be effective when dispersed throughout the landscape. These strategies can help reduce the volume of untreated stormwater that flows into waterways during small to moderate storm events. For larger events, floodplain and wetland protection, consistent permitting guidelines, relocation of existing infrastructure outside the flood hazard zone, and properly-sized, well maintained stormwater drainage networks are ways to reduce runoff and the impacts of increased high flows on the built and natural environments.

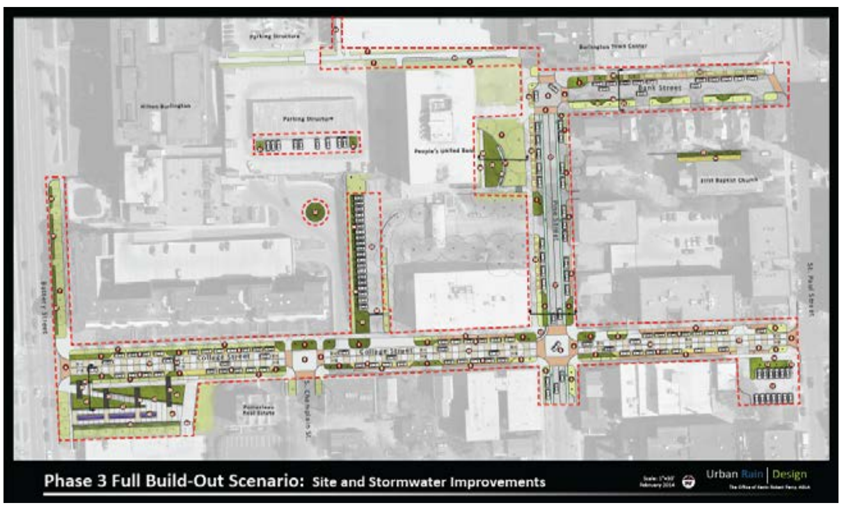
Managing stormwater in the US-portion of the Lake Champlain watershed takes place at the local, state, and federal levels. General policy oversight occurs through the US Environmental Protection Agency at the federal level while permits and enforcement for stormwater discharges happen at the state level. Most often, stormwater maintenance and upgrades are left to municipalities or private property owners and are limited by the technical and financial capabilities of each individual, town or village.

New York

In New York, the state-wide Stormwater Management Design Manual was updated in January 2015 and provides site designers with an overview on how to locate, properly size and design stormwater management practices to comply with state standards (Center for Watershed Protection, 2010). The goals of the updated standards are to comply with the state Construction General Permit, which governs construction activities resulting in soil disturbance of one or more acres, thereby reducing stormwater runoff and its attendant impacts. The manual was prepared by the Department of Environmental Conservation and is distributed by local soil and water conservation districts to ensure statewide availability. The manual details potential pollution impacts from stormwater, including sediment loading from new development, and addresses the need to upgrade existing infrastructure that may be outdated or poorly maintained, but does not retroactively apply to existing permits. Included in the manual is a section devoted to green infrastructure techniques as well as new methodologies that can reduce the amount of nutrient loading coming from stormwater. Towns within the Adirondack Park must adhere to park development standards, which aim to preserve and protect the natural integrity of the Adirondack ecosystem.

Vermont

The State of Vermont's stormwater management manual provides an overview of accepted treatment standards, regulatory requirements and technical guidance for municipalities. The manual was last revised in 2002 and is currently under revision to explicitly incorporate climate change and green infrastructure practices as standard methodology (Vermont Agency of Natural Resources, 2002). The revision of the manual is expected to be completed in late 2015 or early 2016. Twelve Vermont waterbodies are impaired due to stormwater runoff (Vermont Agency of Natural Resources, 2015). The state issues permits in accordance with the federal Clean Water Act to regulate runoff from impervious surfaces, construction sites and industrial facilities. Since permitting began in the 1970s, the program has expanded substantially to include nearly all construction, industry and large impervious surfaces in the state to reduce pollution loading to waterways from developed lands. With the implementation of the new Lake Champlain Phosphorus Total Maximum Daily Load (TMDL), along with the Vermont Clearn Water Act (Act 64), the state developed a plan to reduce pollution loading to Lake Champlain and its tributaries, with specific actions for individual stormwater-impaired waters. Some of these actions include:



- Develop a State Highway Stormwater General Permit
- Develop a Municipal Roads Stormwater General Permit
- Develop an Existing Developed Lands Stormwater General Permit for sites having greater than three impervious acres
- Revise the Municipal Separate Storm Sewer System General Permit to require existing regulated municipalities to control phosphorus discharges consistent with the TMDL wasteload allocation.
- Update the Vermont Stormwater Management Manual

In 2009, Vermont launched a statewide green stormwater infrastructure initiative which called for

state agencies to work together to promote the widespread use of green stormwater infrastructure practices. The team consists of the Agency of Natural Resources, the Agency of Administration, the Agency of Commerce and Community Development and the Agency of Transportation. Together, they work to identify challenges in green stormwater infrastructure implementation, develop training modules for state and municipal officials, and increase the widespread adoption of green stormwater infrastructure practices. As part of this initiative, a statewide Green Infrastructure Roundtable was established with a coordinator appointed to educate and guide the diverse group of stakeholders in furthering the adoption of GSI. The State still serves as the regulatory and enforcement entity while the roundtable exists to identify challenges and provide training and communications to stormwater managers (Green Infrastructure Roundtable, 2014).

Regional Stormwater Management Challenges

Throughout the Lake Champlain basin, established communities struggle to maintain aging and outdated stormwater infrastructure. Very few cities near Lake Champlain fall into the federally regulated municipal separate sewer systems with stringent runoff regulations in place (explained more in the urban vs. rural section below). A number of the oldest urban areas within the basin are served by combined sewer and stormwater systems (CSS) that, when overwhelmed with runoff, allow dilute sewage and stormwater to flow directly into waterways (combined sewer overflows, or CSOs) and may contain high pollutant loads. Sixteen cities in the basin, including Burlington, Rutland, St Albans and Vergennes in Vermont and Plattsburgh in New York, have combined sewer systems. Once in place, they are very expensive to mitigate through implementation of GSI, installation of treatment plants, or separation. Though some upgrades are planned, these systems continue to be a problem on both sides of the lake.

Vermont is a small state where local initiatives are often supported and can move forward quickly. Following the devastating floods in 2011, the State quickly passed legislation delineating flood hazard zones and enforcing stricter infrastructure guidelines within these zones. Opportunities for funding for stormwater projects is now more readily available in Vermont, though the smaller population base provides for more limited funding sources for the State to draw from. Vermont, as a whole, prioritizes green infrastructure implementation and flood preparedness. State agencies often work together to develop stormwater projects, an example of which is the partnership between the Agency of Natural Resources and the Agency of Transportation, in the recent development of post-flood reconstruction guidelines for first responders. The guidelines call, in part, for proper sizing of reconstructed infrastructure and relocation of flood prone infrastructure, if possible, to minimize the impact of future stormwater floods downstream (Vermont Agencies of Natural Resources and Transportation, 2013).

In contrast, New York is a large, diverse state. The majority of the area of New York that is within the Lake Champlain watershed lies in the Adirondack Park, a sparsely populated area with few urban centers. Communication between local municipalities and state agencies often is not closely connected and funding for stormwater projects can be difficult to obtain as towns are competing across a much larger state with more populous cities for funding opportunities. Much of the infrastructure in northern New York is aged and funds are lacking to keep up with necessary training and maintenance. A recently completed project in Plattsburgh mapped the city's stormwater infrastructure and identified areas most in need of improvement. Nearly all of the city's stormwater outfalls drain directly into the Saranac River and Lake Champlain. As a result of the project, city engineers launched a public outreach effort to increase awareness of good stormwater management practices and implemented a widely publicized green infrastructure upgrade in the city center (Farrington, 2014). The project demonstrated the need for more awareness of green stormwater infrastructure projects in northern New York.

Following the floods in 2011, parts of New York had a much longer recovery as compared to Vermont, and no new legislation was passed to ensure a better response for the next flood event. New York adopted post-flood response training as a state-wide initiative following flooding in the southern part of the state in 2006. The training was developed by the New York Department of Environmental Conservation and is now implemented statewide at the local soil and water conservation district level (New York State Department of Environmental Conservation, 2013), and has been used as a starting point for other programs, including those in Vermont. New York's post-flood response training program focuses on sound engineering practices to reconstruct resilient infrastructure following a flood event. A project is currently underway to tie together the post-flood response trainings in Vermont and New York to ensure consistent response guidelines exist throughout the Lake Champlain watershed.

Currently, state-level agencies design infrastructure to withstand a 25-year, 24-hour storm and though stormwater facilities must be built to pass a 100-year event, they are only required to treat the first inch of rainfall for water quality. These facilities are also required to treat average annual (or 1-year) storms for channel erosion. These minimum standards have consistently proven inadequate in recent years as 25-year storms have grown in intensity and frequency and 100-year events now occur four times as often as they have historically. Many small towns in the basin have no stormwater design standards aside from meeting the minimum state regulations. Implementing a stormwater utility is one way for municipalities to gain financial backing to implement higher design standards for flood capacity and water quality. The city of South Burlington was the first in the state to install a stormwater utility, followed by Burlington. The towns surrounding the utilities soon established the Regional Stormwater Education Program in 2003, which pools funding for stormwater outreach and public participation. The feasibility of a state-wide stormwater utility is currently under investigation in Vermont, but towns in the New York portion of the basin have yet to implement a utility.

Urban vs. Rural Issues

A recent study concluded there are 165,000 acres of impervious surfaces in the US-portion of the Lake Champlain Basin (O'Neil-Dunne, 2013). Impervious surfaces include paved roads, dirt roads, parking lots, railroads, driveways and highly compacted soil. These areas often contribute to high volumes of stormwater runoff and can contain pollutants that end up in waterways. Analysis of the impervious surfaces by sub-watershed

showed that both sides of Lake Champlain have high concentrations of developed land, particularly the Burlington to St. Albans corridor in Vermont and the area around Plattsburgh, New York. Implementation of green infrastructure techniques and low-impact development within these impervious surface hot spots may be particularly useful for curbing stormwater runoff in urban areas.

The large base of rural communities in the Lake Champlain Basin correlates to a particularly high concentration of unpaved roads. An estimated 80% of all Vermont public road miles in the basin are maintained by towns (Stone Environmental, Inc., 2012). A 2013 study determined that stormwater-induced erosion of unpaved roads may contribute significant amounts of sediment and phosphorus into Lake Champlain (Wemple, 2013). Focusing specifically on the Winooski River watershed, the researchers estimated that 6% of the total phosphorus load in that watershed was attributable to outwash from gravel or dirt roads. As of 2012, the Lake Champlain-Lake George Regional Planning Board identified 319 roadside erosion sites within the New York portion of the watershed that required action. Programs focusing on maintenance and improvement of stormwater management along unpaved roads exist in both states. Following the completion of the backroads study, funding was secured to continue the important work of these “better backroads” programs. In Vermont, the Better Backroads Program is managed by the Vermont Agency of Transportation with support from the Vermont Department of Environmental Conservation (Northern Vermont & George D. Aiken Resource Conservation and Development Councils, 2009). In the New York portion of the basin, the program is overseen by the Champlain Watershed Improvement Coalition of New York (Champlain Watershed Improvement Coalition of New York, 2013). When funding is available, both programs offer grants for municipalities to improve stormwater discharge from dirt or gravel roadways.

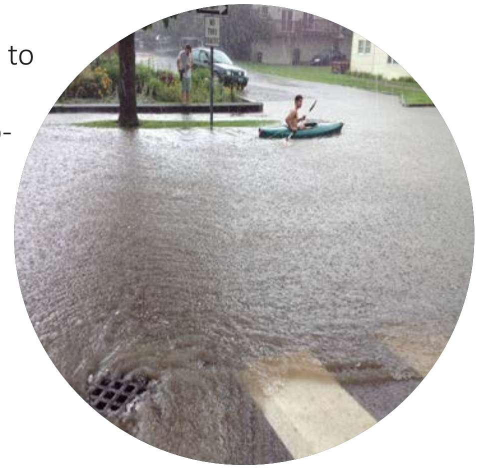
Throughout the region, improving existing stormwater management remains difficult. Permitting oversight occurs at the federal and state levels, while implementation occurs largely at the municipal-scale or with the individual property owner. Stormwater management is a complicated process that intersects with local zoning regulations, land use policies, state-wide floodplain regulations and public works specifications. Currently, there are twelve municipalities and three institutional entities in the Vermont portion of the Lake Champlain watershed, as well as four New York municipalities subject to federal Municipal Separate Storm Sewer System (MS4) permitting regulations (see Appendix II for a full list of MS4s). According to federal law administered by the US Environmental Protection Agency (EPA), urbanized areas classified as MS4 must be in accordance with federal pollution discharge standards. Compliance is monitored by the state and reported back to the EPA. The goal of the MS4 program is to implement good stormwater practices that reduce pollution into Lake Champlain and other waterbodies. Roughly 10% of the total impervious surface cover within the watershed is covered by an MS4 permit (Stone Environmental, Inc., 2012). To be in compliance, MS4 communities must meet minimum control measures, including:

- Public Education and Outreach
- Public Participation/Involvement
- Illicit Discharge Detection and Elimination
- Construction Site Runoff Control
- Post-construction Runoff Control
- Pollution Prevention

MS4 Required Minimum Control Measures

With the new stormwater TMDL plan in Vermont, MS4s must also now develop flow restoration plans if they discharge into a stormwater-impaired waterbody. Within the watershed, disparities persist between urban centers, such as Burlington and other MS4s, and the rest of the largely rural village centers. Burlington is quickly becoming a model of cutting edge stormwater management with highly visible large-scale projects and comprehensive development reviews of all projects disturbing more than 400 ft^2, as well as requiring redevelopment to manage up to 50% of existing impervious surface area to improve stormwater runoff. Also leading the way is the neighboring city of South Burlington, which was the first municipality to implement a stormwater utility in the state (there are now three utilities operating in the Basin, including Burlington and WIlliston). The city also has a full staff dedicated to managing stormwater with many green infrastructure projects on the ground. In New York, the Lake George watershed stands as an example of good stormwater management practices. Recent projects have reduced suburban runoff into Lake George and introduced porous asphalt paving on the heavily traveled Beach Road, one of the only high-traffic roads in the northeast to be paved with pervious material.

In contrast, small municipalities are left to devise stormwater solutions with very little training or funding available for large-scale projects. Many towns lack dedicated staff to manage stormwater, and only require the state minimum standards for construction permitting and infrastructure guidelines. Both small and large towns throughout the basin struggle with routine maintenance of stormwater infrastructure. Frequent storm events can damage the stormwater drainage network and northern winters quickly erode roads, requiring near-constant repair, and most roads in the basin fall under the jurisdiction of local municipalities. In 2014, the Lake Champlain Sea Grant initiated a low-cost stormwater management training series focused on public works staff, conservation districts, and town planners to increase participation in climate-ready green infrastructure practices in small municipalities. The organization plans to continue the series in 2016. On the New York side, there are regional stormwater training centers that provide education and outreach to municipalities. However, there remains a need for municipal-level staff to advance stormwater management initiatives in new or retrofitted development.



climate change impacts

As discussed in the Climate Impacts in the Basin section of this report, the most persistent climate change prediction for the region is heavier, more frequent rainfall events, which is based on historical precipitation observations coupled with modelled projections (Figure 11). Overall, the effects of climate change are not good for runoff in the Lake Champlain Basin. Heavier, more frequent storm events may result in systemic stormwater problems. Existing infrastructure must be continuously maintained in order to properly function with repetitive flooding and new infrastructure must be built to withstand these large flood events. Some climate change models also call for higher temperatures, changing seasonality, and the possibility of flash summer droughts. Earlier spring rains falling on still-frozen ground are one detrimental climate change impact that contributed to the prolonged flooding of Lake Champlain in spring of 2011.

Following the events of 2011, many municipalities found they were unprepared for floods. And, though legislative efforts meant to curb poor development practices, some communities continue to build within flood-prone areas, improperly maintain stormwater systems, and install undersized infrastructure. Historical development in flood-prone river valleys has been flooded more often over the past several decades and will continue to flood as historical infrastructure continues to be rebuilt at the same capacity in the same flood-prone locations. Antiquated drainage networks have been overwhelmed more often in recent years as storms come more frequently, and rebuilding or upgrading these networks, including the several combined sewer systems throughout the basin, has been a slow and costly process.

Following the events of 2011, many found they were unprepared **for floods.**

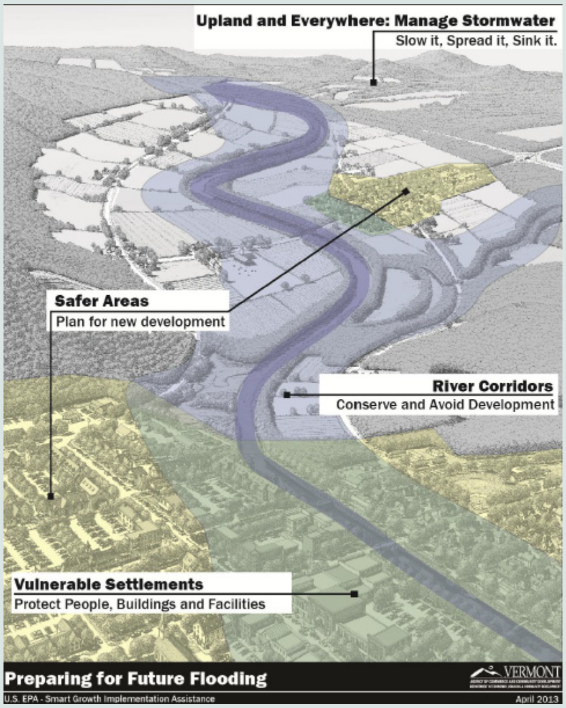
As overall precipitation has increased, coupled with larger, more frequent storm events, the natural ecosystem increasingly has been overwhelmed by stormwater. Grounds, saturated with frequent rain, lose the capacity to infiltrate stormwater. Saturated soils were a problem when Tropical Storm Irene hit the area in 2011, leading to enhanced localized flooding. Some climate models are predicting more of these northerly hurricanes in the future. As the climate warms globally, northerly hurricanes could move later in the season, striking New England anytime between August and mid-November when the ground is already potentially frozen. Late-season hurricanes have impacted the region in the past, leading to the single most devastating flood in November of 1927, after which some communities spent decades rebuilding. Hence, communities, in planning for future change, must be prepared for any variations in the impact of different-sized rain events. As urban centers around Lake Champlain continue to grow, increased development means that more people may be at risk of flooding and already impaired waterways could continue to be impacted by stormwater. Though management efforts aim to curb these impacts, the potential effects of climate change may be exacerbated as larger storms overload a continuously aging infrastructure while impervious surface areas expand with new development.

The population in the Lake Champlain watershed has been steadily growing at about 4% per decade since the mid-twentieth century and some areas have been growing at twice that pace (US Census, 2010). As a result, new development is rapidly happening throughout the basin, especially in existing urban areas and along highly desirable shorelines. Legislative efforts, such as the Vermont Shoreland Protection bill, have worked to reduce development in fragile areas including wetlands, riparian zones and within 100 feet of a lakeshore. In both states, development over one acre is regulated by the state and must adhere to standards that reduce runoff and regulate impervious surface area. But small projects on the local level often have no stormwater requirement unless the municipality has regulations and staff in place to regulate all new development. New and retrofitted small-scale development should adhere to the highest existing local, regional and state standards for stormwater management, including limiting impervious surface area, building new structures outside the River Corridor, and designing gray infrastructure such as culverts and retention ponds that can withstand larger and more frequent flood events.

Currently, grey stormwater infrastructure including closed and open pipe drainage and culverts, are required to withstand a 25-year storm event (4" rainfall over 24 hours). But, as shown after the 2011 flood events, some development that met only the minimum standards suffered damage. Town select boards and planning commissions in municipalities need to carefully consider the impacts of potential climate change as they plan new developments and retrofits to their communities.

Unfortunately, many land use regulations on the local level were developed with goals other than stormwater management in mind, and can unintentionally impede the implementation of low-impact development. Impervious cover of 10% or more has been shown to negatively impact water quality in small watersheds (Center for Watershed Protection, 2006). The width of new roads was often established based on ideals for emergency services, and have a right-of-way width of 50+ feet resulting in wide roads serving a relatively small number of homes. Parking lot sizes are based on parking minimums for business square footage and have continued to increase over time, resulting in large swaths of paved areas and spaces that are rarely used. Hard pavement surfaces are required for paving parking lots, main roads and roads serving developed areas, effectively eliminating the use of pervious surface alternatives. Given the desire to preserve the rural identity in the basin, setback requirements where new construction is planned far from a roadway to preserve the rural view, can result in longer driveways that contribute to backroads stormwater runoff issues.

To best prepare for climate change, these local land use policies must be reviewed with an eye toward striking a balance between limiting the amount of new impervious cover and supporting other local development goals. Some work towards this



stormwater management:

SLOW IT DOWN
SPREAD IT OUT
SINK IT DOWN

to protect vulnerable development downstream, manage stormwater in the uplands and conserve and limit development in the flood-prone river corridors.

effort has already been achieved through the Vermont League of Cities and Towns assisting municipalities in rewriting bylaws to prioritize low-impact development and prepare for the possibility of climate-related impacts, but more training, staff and funding is needed.

Currently, there are 86 rivers, lakes and ponds in Vermont classified as impaired on the EPA's 303d list of waterbodies. In New York, there are 10 impaired rivers or lakes that drain into Lake Champlain (see Appendix III for a list of impaired waterbodies). The majority of impairment is a result of development and stormwater or agricultural runoff. In general, there is wide support for stormwater improvements and conservation of water quality. But, as discussed in the Stormwater Management section of this report, funding for improvements can often be difficult to obtain.

Small communities have a smaller tax base and limited funding and tend to be particularly unprepared when it comes to implementing necessary improvements or basic maintenance of their infrastructure. Along with funding challenges, many municipalities lack well-trained personnel to design and maintain properly-sized stormwater infrastructure. Some communities have limited understanding of the location, size and connections within their stormwater system. Existing problems, such as roadside erosion, localized flooding and failing culverts are not always classified as stormwater issues, so identifying climate-vulnerable areas may be difficult. In some areas of the basin, municipal staff lack basic knowledge on the possible impacts of future flooding and climate change. Similarly, green infrastructure techniques are not widely understood throughout the region and many communities end up installing traditional grey infrastructure that may not be best suited to climate change adaptation.

adaptation and mitigation

HOW CAN WE ADAPT?

Our climate is changing and we know that more flooding will likely occur in the Lake Champlain Basin. How can we adapt?

When undeveloped land is converted into constructed development with broad areas of impervious surfaces and altered topography, the decreased infiltration capacity alters the natural hydrology of the surrounding area. When rainfall can no longer infiltrate into soils or be intercepted or taken up by plants, it ends up as surface runoff delivered to receiving waterways, often without treatment. The best method of reducing runoff is by conserving wetlands, shorelands and functioning ecosystems that naturally take up rainwater and snowmelt. Thus, stormwater systems need both to mimic the natural landscape and have the capacity to withstand magnified surface runoff rather than simply collecting and conveying water and pollutants. To be better prepared for climate change-driven large scale floods, existing storm sewer system pipes, bridges, culverts, retention ponds and paved surfaces must be able to withstand larger, more frequent floods. New or re-structured gray infrastructure should adhere to the strictest state building guidelines and be located outside of the flood hazard area.

As a first step in improving existing stormwater management, municipalities must understand how climate change may impact their community. Then, they will be better able to map their current system and identify problem areas in order to prioritize retrofits, maintenance and upgrades. For new develop-

green infrastructure practices

Rain Gardens

Rain gardens are gardens located at the end of a downspout or edge of a driveway or parking lot to collect stormwater. They allow surface runoff to be directed, held, and infiltrated. They can be planted with flowering native perennial plants and can be easily installed by private homeowners or businesses. Their infiltration capacity is limited by the porosity of the underlying native soils, but due to their aesthetic value, they have grown to be one of the most popular GSI techniques.

Bioswales

Bioswales are conveyance infrastructure designed to remove sediment from surface runoff by slowing the flow with vegetation. They are gently sloped, large scale drainage ditches, with surfaces covered in vegetation. They are often found along the edges of parking lots and along road shoulders and can withstand significant runoff events while promoting infiltration of stormwater.

Green Roofs

A green, or living, roof covers a building with growing plants. Often the vegetation is planted on top of a waterproof membrane and reduces roof runoff by capturing water through evapotranspiration and straight evaporation. Installation can range in price based on the size and location of the roof. Weight is a significant factor for considering a green roof on an existing building, as plants, growth media and water contribute to the building's structural burden. This technique is growing in popularity in urban settings nationwide where roof runoff is a significant contributor of volume to the stormwater system, but is still seeing relatively limited applications in areas with harsher winter conditions such as the Champlain basin.

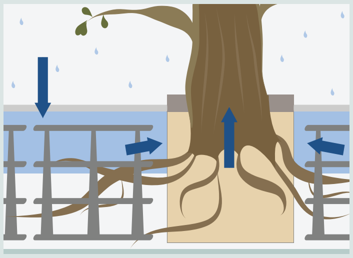
Cisterns

Cisterns have been used to collect rainwater for centuries. They are in-ground or surface tanks that store and collect rainwater for future use. They are easy to install at private homes and can be beneficial in conserving water for use during droughts.

Biofiltration Galleries

Similar to rain gardens, biofiltration galleries are often located next to impervious surface areas, such as parking lots and wide roads. They consist of gently sloping ditches, often vegetated, that aim to collect surface runoff and sediment. The main difference between these galleries and raingardens is that they aim to function during higher flow (2" rainfall over 24 hours) events. In addition to containing plants with high water volume uptake, biofiltration galleries often have multiple layers of substrate designed to catch and slowly filter runoff into the subsurface hydrologic network.

green infrastructure practices



Silva Cells

Below a paved sidewalk or roadway, an infiltration system is built with a porous surface or curb cut to allow runoff to enter and trees are planted nearby to absorb runoff. There are structural elements to the system that allow surfaces to be supported. Silva cells are more expensive to build than street trees, but capture larger stormwater volumes because soil compaction is reduced in these systems and the trees provide long-lasting management..

Constructed Wetlands

A constructed wetland uses a variety of natural processes to remove pollutants and trap sediment from surface runoff through uptake by vegetation, roots and microorganisms, as well as through a gravel sub-base. These wetlands are incorporated into the natural landscape and can take many years to fully mature. However, they have high aesthetic value and the capability to greatly improve water quality.

Street Trees

A popular GSI technique, street trees are most often located along urban or suburban streets but may be planted anywhere. Water-loving trees are planted next to paved areas and the roots absorb most of the runoff. More tree canopy leads to less runoff, and installation is a relatively inexpensive stormwater management alternative.

Permeable Pavement

Permeable pavement consists of asphalt, concrete or pavers that contain holes or permeable material between the rocks that allow surface runoff to pass through the pavement layers and store stormwater in gravel subbase layers allowing for slower infiltration. These materials are sometimes used to replace traditional concrete or asphalt in vulnerable areas, but can be very expensive and potentially fail. The winter resilience of these surfaces requires more study in this region to make the widespread adoption of this technique more feasible.

ment, GSI and LID are a set of practices that strive to manage stormwater through conserving, restoring or maintaining the natural hydrologic regime. GSI techniques have lower flood capacity, but can compete with traditional gray infrastructure capacity when implemented in a decentralized manner across the landscape. These techniques aim to delay and reduce peak runoff from a storm event. Performance of stormwater volume reductions for selected management practices can be compared in Figure 12.

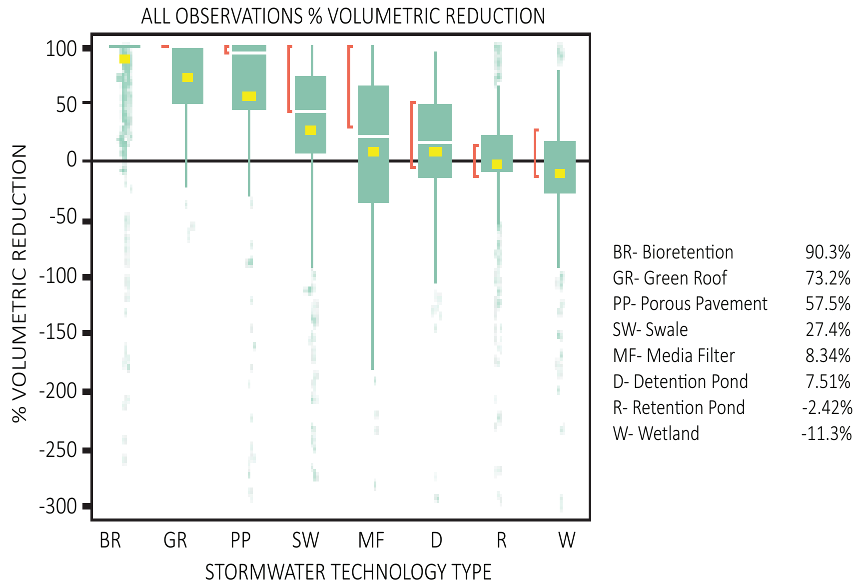


Figure 12. Summary of percent observed volumetric stormwater reduction summarized by technology. The values shown are by individual events. From Driscoll et al., 2015.

As the climate changes, with unpredictable periods of intense rainfall, GSI techniques can help moderate the water table for and allow the natural system to infiltrate stormwater. By incorporating GSI practices into built infrastructure, runoff is reduced and in turn, flood damages downstream can be reduced. Many GSI practices promote infiltration of surface runoff and capturing some stormwater runoff and reducing flows to adjacent waterways during small and moderate rainfall events. Incorporation of GSI techniques throughout the landscape, used in conjunction with traditional stormwater management practices, has shown some of the most promising success for managing surface runoff.

Both Vermont and New York have state-level programs aimed to increase the widespread use of GSI strategies. As discussed earlier in this report, agencies are working together on both sides of Lake Champlain to promote awareness and training of these techniques. However, there remains a gap in public works managers' understanding of the impacts of climate change and best GSI practices to use to prevent flood damage. Though the states have some programs in place, more education about the impacts of climate change is needed. In Vermont, the Green Infrastructure Roundtable is an excellent model that generates awareness of GSI and provides education and training to municipalities. Other organizations, include Lake Champlain Sea Grant, and Vermont League of Cities and Towns, as well as the Lake Champlain-Lake George Regional Planning Commission and the Lake George Association are providing outreach for stormwater management to local communities.

Currently, some state development standards, zoning bylaws and land use regulations impede the implementation of LID and GSI. In some cases, the impediments are not obvious to town boards, like wide street widths which are often required by town fire chiefs but can unnecessarily increase impervious surfaces. Overcoming policy gaps or improving the current structure is necessary to encourage developers and site designers to implement improved practices. GSI experts and state and local stormwater managers can help municipalities identify these problem spots and recommend best management strategies to overcome them, but communication barriers between these groups must first be overcome. The regulatory framework must allow and possibly even incentivize, resilient adaptations.

Current stormwater design standards are based on withstanding flood events that have a probability of recurring every 25 years (typically called a 25 year event). But the magnitude of these events is based on the 1960 National Weather Service precipitation atlas (TP-40), which is currently being revised. As discussed in the beginning of the stormwater adaptation section of this report, the recurrence interval of these design storms is changing. Due to a warmer, wetter climate, 25 year events now happen every five or 10 years and the distribution of precipitation from these events is becoming more unpredictable. Annual events, 10-year events and 100-year event 24-hour precipitation totals have changed substantially in the 55 years since TP-40 became the stormwater design standard. Instead, historical observed and predicted precipitation fluctuations could be used as guidance for new infrastructure. Stormwater managers should proactively design both for more frequent large (25-year) events and also consider major infrastructure upgrades that can withstand very large storms, as climate models predict heavier and more frequent precipitation in the future.

Finally, all stormwater management implementation costs money. Depending on the project, green infrastructure techniques can cost less than traditional management systems, especially for new development, but often have lower capacities and still require annual maintenance. Costs are dependent on design, infiltration capacity and maintenance and must be carefully weighed against traditional methods when determining budgets for new projects or retrofits. Though large pools of funds at the state and federal levels exist, more must be available for proactively building infrastructure large enough to withstand larger, more frequent flood events. Ongoing maintenance and routine upgrades of stormwater systems can be a financial burden to many communities, though the cost of rebuilding after a catastrophic flood outweighs the lifetime maintenance fees of a well-functioning system.

Current state funding for stormwater management in Vermont and New York promote the use of GSI and other best practices but also require communities to have already identified a problem area and developed a remediation plan before funds are distributed. Funding should also be available for these communities to first be able to identify vulnerabilities and determine the best management strategy to overcome the issue, as many towns do not have the staff available to do this work. Training opportunities, either through local organizations or the state, could assist municipalities in identifying these vulnerabilities.

Last, state and federal funds are best spent in on-the-ground education of stormwater managers, town planners and developers about the long-term impacts of climate change and in implementing the best possible strategies to keep communities safe and waterways clean. Prioritizing investments for climate-ready guidance and make incentives for communities to participate is critical in being ahead of the next big flood. Landowners, planners, conservation districts, public works directors and others on the municipal level should be aware of climate change alternatives and potential hazards. State and higher-level officials should ensure that local level workers are engaged in the stormwater management process from beginning to end, with ample opportunities for cross-collaboration and training.

In summary, adaptations for improving stormwater management in light of a changing climate include the following recommendations:

adaptation recommendations

- Conserve naturally functioning ecosystems to reduce stormwater runoff
- Encourage the widespread adoption of Green Stormwater Infrastructure and Low Impact Development
- Properly size stormwater infrastructure, and in flood-prone areas adhere to the highest design standards possible
- Educate local-level managers about climate science to assess infrastructure vulnerabilities and identify needs
- Train and provide technical assistance at the local level to implement best stormwater practices
- Proactively adapt the regulatory framework to incorporate climate change impacts
- Make funding available for the implementation of best practices, education to landowners and municipalities, and maintenance of existing infrastructure
- Collaborate among local, regional, state and federal leaders to adopt and advance resilient infrastructure goals
- Bylaws, design standards, water quality goals and state-issued permitting regulations must all be written to accommodate long-term climate changes

CONCLUSIONS

Climate change is already impacting the Lake Champlain basin. The length of seasons, fluctuations in temperatures and modifications of precipitation regimes are evident. Predictions indicate that the Lake Champlain watershed will see more frequent and severe flood events that will magnify surface runoff, overwhelm existing infrastructure and potentially degrade waterways.

Luckily, Vermont and New York both have some stormwater management strategies in place that incorporate the potential effects of climate change. But adaptation must happen at the local level. Grey infrastructure, such as sewer system pipes, culverts, and paved surfaces must be built, maintained or retrofitted to withstand larger, more frequent floods. If possible, this necessary infrastructure should be located outside of established flood hazard zones. As new development occurs, the conservation of functioning ecosystems, widespread adoption of GSI and LID practices, and awareness of the impacts of flooding are fundamental climate-ready tools. Training and funding for implementation of better management practices is necessary to prepare for future changes.

Lastly, identification of vulnerabilities and a better understanding of how climate change may impact the Basin is a fundamental building block to resilient stormwater management. Education and outreach about climate science and existing state and federal policies should happen at all levels so that those working on the ground have the best available tools at their disposal. Though the region may feel the effects of a changing climate, preparing now for future flood events can prevent widespread damage to infrastructure and homes and reduce pollution to waterbodies.

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Lake Champlain Basin Program: All photos on front cover, Page 2, 5, 6, 8, 22, 23, 29, 31, 35 (bottom), 36 (second from top), 41

Lake Champlain Sea Grant: Page 3, 35 (top), 36 (bottom)

Lake George Association: 4, 7, 35 (second from top), 37

City of Burlington: Page 27

Tim Mihuc: Page 30

Julie Moore: Page 44

Champlain Watershed Improvement Coalition of New York: Page 35 (second from bottom)

University of Vermont: Page 35 (middle)

Greg Maino: Page 36 (second from bottom), 45

Lake Champlain-Lake George Regional Planning Commission: Pages 28, 32, 40, 43 (top and bottom), 46

DESIGN

Report designed by S. Castle, LCBP

Graphics: Stephanie Castle, Pages 9, 13, 14, 24 and 59
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APPENDIX I
additional resources

Lake Champlain-Lake George Regional Planning Board
Roadside Erosion Assessment and Inventory: www.lclgrpb.org/erosion.php

Lake Champlain Sea Grant
Sustainable Landscape Stewards Course: www.uvm.edu/seagrant/

Institute for Sustainable Communities
Resilient Vermont Project: http://resilientvt.org/

Environmental Protection Agency
Vermont TMDL: www.epa.gov/region1/eco/tmdl/lakechamplain.html

The Nature Conservancy
Climate Wizard Tool: www.climatewizard.org/

APPENDIX II
list of combined and separate sewer systems

Combined Sewer Systems:
Vermont
Brandon
Burlington Main and North
Hardwick
Montpelier
Middlebury
Poultney
Rutland
St Albans
Swanton
Vergennes
Winooski

New York
Plattsburgh
Glens Falls
Ticonderoga

Municipal Separate Storm Sewer Systems (MS4)
Vermont:
City of Burlington
Burlington International Airport
Town of Colchester
Town of Essex
Town of Essex Junction
Town of Milton
Town of Rutland
City and Town of St Albans
Town of Shelburne
City of South Burlington
University of Vermont
Town of Williston
City of Winooski
Vermont Agency of Transportation (all stormwater impaired watersheds)

New York:
Glens Falls
Town and Village of Lake George
Queensbury Town

APPENDIX III
303d impaired waterbodies

New York State Final 2014 Section 303(d) List

Waterbody Name	County	Type	Pollutant	Source	Year
Great Chazy River, Lower, Main Stem	Clinton	River	Silt/Sediment	Agriculture, Erosion	2002
Lake George and tribs	Warren	Lake	Silt/Sediment	Urban/Stormwater, Erosion	2002
Tribs to Lake George, East Shore	Warren	River	Silt/Sediment	Urban/Stormwater, Erosion	2002
Tribs to Lake George, Lake George Village	Warren	River	Silt/Sediment	Urban/Stormwater, Erosion	2002
Huddle/Finkle Brooks and tribs	Warren	River	Silt/Sediment	Urban/Stormwater, Erosion	2002
Indian Brook and Tribs	Warren	River	Silt/Sediment	Urban/Stormwater, Erosion	2002
Hague Brook and Tribs	Warren	River	Silt/Sediment	Urban/Stormwater, Erosion	2002
Wood Creek. Champlain Canal and Tribs	Washington	River	Oxygen Demand, Phosphorus, Pathogens	Municipal, SSOs	2010

STATE OF VERMONT

2012

303(d) LIST OF WATERS

PART A - IMPAIRED SURFACE WATERS IN NEED OF TMDL

JUNE 2012

(Approved by USEPA Region 1 – June 13, 2012)

Prepared by:

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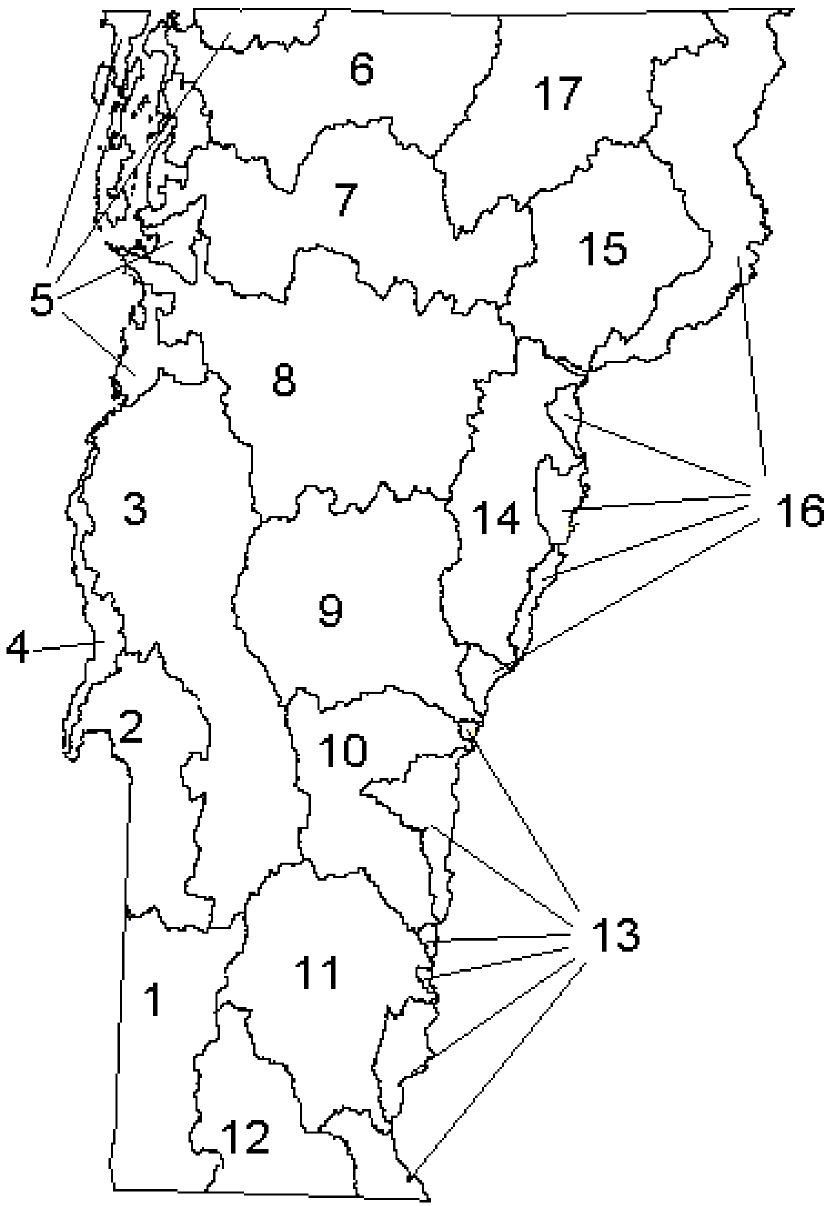
Major Vermont River Basins



1. Battenkill
2. Poultney-Mettawee
3. Otter Creek
4. Lower Lake Champlain
5. Upper Lake Champlain
6. Missisquoi
7. Lamoille
8. Winooski
9. White
10. Ottauquechee
11. West
12. Deerfield
13. Lower Connecticut
14. Wells, Waits, Ompompanoosic
15. Passumpsic
16. Upper Connecticut
17. Lake Memphremagog

List of Acronyms and Terms

As	arsenic
BMP	best management practice
Cfu	colony forming unit
CRJC	CT River Joint Commissions
CSO	combined sewer overflow
Cu	copper
DAF&M	VT Department of Agriculture, Food & Markets
DEC-AP	VT DEC, Air Pollution Division
DEC-ENF	VT DEC, Enforcement Division
DEC-FE	VT DEC, Facilities Engineering Division
DEC-HM	VT DEC, Hazardous Materials Section (of DEC-WM)
DEC-SW	VT DEC, Solid Waste Section (of DEC-WM)
DEC-WM	VT DEC, Waste Management Division
DEC-WQ	VT DEC, Water Quality Division
DEC-WS	VT DEC, Water Supply Division
DEC-WWM	VT DEC, Wastewater Management Division
DF&W	VT Department of Fish & Wildlife
DFP&R	VT Department of Forests, Parks & Recreation
D.O.	dissolved oxygen
DOH	VT Department of Health
E.COLI	Escherichia coli (an indicator bacterium)
EPT	Ephemeroptera/Plecoptera/Tricoptera
FERC	Federal Energy Regulatory Commission
Fe	iron
F/S	feasibility study
Hg	mercury
-HUA	Hydrologic Unit Area (a USDA cost share program)
LCBP	Lake Champlain Basin Program
MG/L	milligrams per liter (same as parts per million)
MOU	memorandum of understanding
MT/YR	metric tons per year
Ni	nickel
NOx	nitrogen oxide
NPL	National Priority Listing
NPS	nonpoint source
P	phosphorus
Pb	lead
PCB	poly-chlorinated biphenol
pH	hydrogen ion concentration (measurement of)
RCWP	Rural Clean Water Program
RI/FS	Remedial Investigation/Feasibility Study
RM	river mile
SCS	Soil Conservation Service (same as USDA-NRCS)
SECT 319	Section 319 [of federal Clean Water Act]
SHG	Small High Gradient
SO2	sulfur dioxide
SRF	State Revolving Fund
UG/L	micrograms per liter (same as parts per billion)
USACOE	US Army Corps of Engineers
USBOM	US Bureau of Mines
USDA	US Department of Agriculture
USDA-ACP	- Agriculture Conservation Program
USDA-HUA	- Hydrologic Unit Area
USDA-SpP	- Special Project
USDA-WQIP	- Water Quality Incentive Program
USDA-NRCS	- Natural Resource Conservation Service
USEPA	US Environmental Protection Agency
USF&WS	US Fish & Wildlife Service
UVM	University of Vermont
UVM-SNR	- School of Natural Resources
VSA	VT Statutes Annotated
VTDEC	Vermont Department of Environmental Conservation
WQ	water quality
WQS	Water Quality Standards
WWTF	wastewater treatment facility
Zn	zinc
1272	Section 1272 of 10 VSA Chapter 47
1272 Order	An order issued by the ANR Secretary to properly manage or eliminate an existing discharge to waters that may cause a violation of the Water Quality Standards.
1277	Section 1277 of 10 VSA Chapter 47
1277 Order	An order issued by the ANR Secretary to a municipality that is discharging untreated or improperly treated sewage that causes a reduction in water quality to construct a sewage collection and treatment system to correct or abate the discharge.
566	PL83-566 (a USDA cost share program)

PART A - IMPAIRED SURFACE WATERS IN NEED OF TMDL

Part A of the 2012 List of Waters identifies impaired surface waters that are scheduled for total maximum daily load (TMDL) development. Part A of the List has been prepared in accordance with the Vermont Surface Water Assessment and Listing Methodology, current EPA Guidance and the Environmental Protection Regulations 40 CFR 130.7 ("Total maximum daily loads (TMDL) and individual water quality-based effluent limitations"). A TMDL is deemed necessary for these waters (unless remediation will be completed prior to the scheduled TMDL) in order to establish the maximum amount of a pollutant that may be introduced into the water after the application of required pollution controls and to ensure the Water Quality Standards are attained and maintained.

Explanation of Column Headings for Part A

Waterbody ID - An alphanumeric code used to spatially locate designated surface waterbodies. For example, VT01-02 and VT01-03L05 represent a river and a lake waterbody, respectively, located in Vermont river basin #01. River basin #01 includes the Batten Kill, Hoosic and Walloomsac rivers; there are 17 river basins for planning purposes identified in Vermont. A statewide map illustrating designated lake and river waterbodies can be obtained upon request from the Water Quality Division, Department of Environmental Conservation in Waterbury, Vermont.

Segment Name/Description - The name of the river/stream segment or lake/pond. Entries denoted by "**" indicate newly discovered impairments since the 2010 list.

Pollutant(s) - The pollutant or pollutants that cause a violation of the Vermont Water Quality Standards (VWQS).

Use(s) Impaired - An indication of which designated or existing uses (as defined in the VWQS) are impaired. The following conventions are used to represent a specific use:

- AES – aesthetics
- ALS - aquatic life support
- AWS - agricultural water supply
- 2CR - secondary contact recreation (fishing, boating)
- FC - fish consumption
- DWS - drinking water supply
- CR - contact recreation (i.e. swimming)

Surface Water Quality Problem - A brief description of the problem found in the particular segment.

TMDL Completion Priority - An indication of priority as to when TMDLs will be completed (H=high 1-3 years, M=medium 4-8 years, L=low 8+ years).

	Lakes and Ponds	Streams and Rivers	Total
Total number of impairment entries listed in Part A:	15	71 (1)	86

Number in parentheses ( ) represents new Part A listings since the 2010 listing cycle. The total number of Part A listings has decreased from 107 in 2010 to 86 in 2012.

Part A. Waters appearing below have documentation and data indicating impairment and do not meet VT Water Quality Standards according to the methodology described in the Vermont Surface Water Assessment and Listing Methodology. Required or needed pollution controls have yet to be fully implemented and further pollutant loading determinations (i.e. TMDLs) are necessary - unless remediation will be completed prior to the scheduled TMDL.

Waterbody ID	ADB Code(s)	Segment Name/ Description	Pollutant(s)	Use(s) Impaired	Surface Water Quality Problem(s)	TMDL Priority
VT01-02	01	HOOSIC RIVER, ENTIRE 7 MILE LENGTH IN VERMONT	PCBs	FC	ELEVATED LEVELS OF TOXIC CONTAMINANT IN BROWN TROUT	L
	02	LADD BROOK, MOUTH TO RM 0.4	SEDIMENT	ALS	INDICATION OF SEDIMENT STRESS; POTENTIAL IMPACTS FROM ERODING DIRT ROADS	M
VT01-03	01	BARNEY BROOK, MOUTH TO RM 1.5	SEDIMENT, IRON	ALS	DOWNSTREAM OF LANDFILL, HAZ SITE, AND CONSTRUCTED WETLANDS; SILT AND IRON PRECIPITATE CAUSING FISH/INVERT IMPACTS	M
VT01-05	01	LYE BROOK, RM 2.5 TO HEADWATERS (4.5 MILES)	ACID	ALS	ATMOSPHERIC DEPOSITION: CRITICALLY ACIDIFIED; CHRONIC ACIDIFICATION	M
VT01-06	01	BRANCH POND BROOK (POND TO ROARING BRANCH)	ACID	ALS	ATMOSPHERIC DEPOSITION: CRITICALLY ACIDIFIED; CHRONIC ACIDIFICATION	M
	02	FAYVILLE BRANCH, RM 3.7 TO HEADWATERS	ACID	ALS	ACIDIFICATION, ACID DEPOSITION	M
VT02-02	01	UNNAMED TRIB TO HUBBARDTON RIVER, BELOW WWTF DISCHARGE	E. COLI, NUTRIENTS, TEMPERATURE	ALS, CR, 2CR	BENSON WWTF, AG RUNOFF POSSIBLE SOURCES; MONITORING & ASSESSMENT REQUIRED	M
VT02-03	01	CASTLETON RIVER, FAIR HAVEN	E. COLI	CR	WWTF PUMP STATION OVERFLOWS	L
VT02-05	02	UNNAMED TRIB TO METTAWEE RIVER	METALS (IRON, ZINC)	ALS	PAWLET LANDFILL LEACHATE	M
VT03-01	02	LOWER OTTER CREEK, BELOW VERGENNES WWTF (APPROX 7 MILES)	E. COLI	CR	PERIODIC & RECURRING OVERFLOWS AT PUMP STATIONS WITHIN THE COLLECTION SYSTEM	L
VT03-05	01	OTTER CREEK, VICINITY OF RUTLAND CITY WWTF	E. COLI	CR	RUTLAND CITY WWTF COLLECTION SYSTEM PASSES CSOs	L
VT03-07	02	LITTLE OTTER CREEK, RM 15.4 TO RM 16.4	NUTRIENTS, SEDIMENT	ALS	AGRICULTURAL RUNOFF	H
VT03-12	02	**HALNON BROOK, TRIBUTARY #1	NUTRIENTS	ALS	ELEVATED NUTRIENTS AFFECT AQUATIC BIOTA	M

Certain local, state and federal regulatory programs refer to impaired segments (or waters draining to those segments) listed on the 303d List of Impaired Waters as part of program operations. Contact the respective regulatory program for details regarding regulated activities in these waters and their watersheds.

Part A. Waters appearing below have documentation and data indicating impairment and do not meet VT Water Quality Standards according to the methodology described in the Vermont Surface Water Assessment and Listing Methodology. Required or needed pollution controls have yet to be fully implemented and further pollutant loading determinations (i.e. TMDLs) are necessary - unless remediation will be completed prior to the scheduled TMDL.

Waterbody ID	ADB Code(s)	Segment Name/ Description	Pollutant(s)	Use(s) Impaired	Surface Water Quality Problem(s)	TMDL Priority
VT03-14	01	EAST CREEK, MOUTH TO 0.2 MI (BELOW CSO DISCHARGE PTS #2 AND #9)	E. COLI	CR	RUTLAND CITY COLLECTION SYSTEM CSO	L
VT04-01L01	01, 02, 03, 04	OTTER CREEK SECTION - LAKE CHAMPLAIN (Ferrisburg)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT04-01L02	01, 02, 03	PORT HENRY SECTION - LAKE CHAMPLAIN (Ferrisburg)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT04-02L01	01, 02	SOUTHERN SECTION - LAKE CHAMPLAIN (Bridport)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT05-01	01	ROCK RIVER - MOUTH TO VT/QUE BORDER (3.6 MILES)	NUTRIENTS, SEDIMENT	AES	ALGAL GROWTH; AGRICULTURAL RUNOFF; FISH KILLS	H
	02	ROCK RIVER, UPSTREAM FROM QUE/VT BORDER (APPROX 13 MILES)	NUTRIENTS, SEDIMENT	ALS	AGRICULTURAL RUNOFF; NUTRIENT ENRICHMENT	H
	03	SAXE BROOK (TRIB TO ROCK RIVER) FROM MOUTH UPSTREAM 1 MILE	NUTRIENTS	ALS	AGRICULTURAL RUNOFF	H
VT05-04L01	01, 02, 03	NORTHEAST ARM - LAKE CHAMPLAIN (Swanton)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT05-04L02	01, 02	ISLE LAMOTTE - LAKE CHAMPLAIN (Alburg)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT05-07	01	RUGG BROOK, FROM MOUTH TO APPROX 3.1 MILES UPSTREAM	NUTRIENTS, SEDIMENT, E. COLI	ALS, CR	AGRICULTURAL RUNOFF	H
	03	JEWETT BROOK (3.5 MILES)	NUTRIENTS, SEDIMENT, E. COLI	ALS, CR	AGRICULTURAL RUNOFF	H
	04	MILL RIVER, FROM ST. ALBANS BAY TO 1.8 MILES UPSTREAM	NUTRIENTS, SEDIMENT	ALS	AGRICULTURAL RUNOFF, STREAMBANK EROSION	H

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Waterbody ID	ADB Code(s)	Segment Name/ Description	Pollutant(s)	Use(s) Impaired	Surface Water Quality Problem(s)	TMDL Priority
VT05-07	05	STEVENS BROOK, MOUTH UPSTREAM 6.8 MILES	NUTRIENTS, SEDIMENT, E. COLI	ALS, CR	AGRICULTURAL RUNOFF; MORPHOLOGICAL INSTABILITY	H
	06	STEVENS BROOK, APPROX. 1 MILE BELOW CTRL VT RAIL YARD UPSTREAM TO YARD	SEDIMENT, OIL, GREASE, HYDROCARBONS	AES, ALS, CR	SEDIMENT, SOIL & WATER CONTAMINATION FROM FUEL SPILLS & MANAGEMENT	L
VT05-07L01	01, 02	ST. ALBANS BAY - LAKE CHAMPLAIN (St. Albans)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT05-09L01	01, 02, 03	MALLETTS BAY - LAKE CHAMPLAIN (Colchester)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT05-10L01	01, 02, 03	BURLINGTON BAY - LAKE CHAMPLAIN (Burlington)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT05-10L02	01, 02	MAIN SECTION - LAKE CHAMPLAIN (South Hero)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT05-11L01	01, 02, 03	SHELBURNE BAY - LAKE CHAMPLAIN (Shelburne)	PCBs	FC	ELEVATED LEVELS OF PCBs IN LAKE TROUT	L
VT06-04	01	BERRY BK, MOUTH UP TO AND INCLUDING NO. TRIB (APPROX. 1 MI)	SEDIMENT, NUTRIENTS	ALS	AGRICULTURAL RUNOFF, AQUATIC HABITAT IMPACTS	H
	02	GODIN BROOK	NUTRIENTS, SEDIMENT	ALS	AGRICULTURAL RUNOFF, AQUATIC HABITAT IMPACTS	H
	03	SAMSONVILLE BROOK	NUTRIENTS, SEDIMENT	ALS	AGRICULTURAL RUNOFF, AQUATIC HABITAT IMPACTS	H
	04	TROUT BROOK, UPSTREAM FROM MOUTH FOR 2.3 MILES	NUTRIENTS	ALS	AGRICULTURAL RUNOFF	H
VT06-05	01	CHESTER BROOK	NUTRIENTS, SEDIMENT	ALS	AGRICULTURAL RUNOFF	H

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Waterbody ID	ADB Code(s)	Segment Name/ Description	Pollutant(s)	Use(s) Impaired	Surface Water Quality Problem(s)	TMDL Priority
VT06-05	02	WANZER BROOK (MOUTH TO RM 4.0)	NUTRIENTS, SEDIMENT	ALS	AGRICULTURAL RUNOFF	H
VT06-08	03	MUD CREEK, FROM VT/QUE BORDER UP TO RM 6.5	NUTRIENTS, SEDIMENT	ALS	AGRICULTURAL RUNOFF; NUTRIENT ENRICHMENT	H
	04	COBURN BROOK (MOUTH TO RM 0.2)	NUTRIENTS	ALS	AGRICULTURAL ACTIVITY AND RUNOFF	H
	05	BURGESS BROOK, RM 4.9 TO 5.4	SEDIMENT	ALS	ASBESTOS MINE TAILINGS EROSION; ASBESTOS FIBERS	L
	06	BURGESS BROOK TRIBUTARY# 11, MOUTH TO RM 0.5	SEDIMENT	ALS	ASBESTOS MINE TAILINGS EROSION; ASBESTOS FIBERS	L
VT07-03	01	DEER BROOK, MOUTH TO 2.5 MILES UPSTREAM	SEDIMENT	ALS	EROSION FROM STORMWATER DISCHARGES; CORRODING ROAD CULVERTS; BMPs IMPLEMENTED	M
VT07-08	01	RODMAN BROOK, MOUTH TO RM 0.6	IRON	ALS	IMPACTS FROM LANDFILL LEACHATE	M
VT07-13	01	TRIB TO BREWSTER RIVER (1 MILE)	METALS (IRON)	AES, ALS	IRON SEEPS ON STREAMBANK; BMPs IN PLACE	L
VT07-15	01	HUTCHINS BROOK, RM 2.0 TO 3.0	SEDIMENT	ALS	ASBESTOS MINE TAILINGS EROSION; ASBESTOS FIBERS	L
	02	HUTCHINS BROOK TRIBUTARY #4, MOUTH TO RM 0.3	SEDIMENT	ALS	ASBESTOS MINE TAILINGS EROSION; ASBESTOS FIBERS	L
VT08-02	02	MUDDY BROOK, MOUTH TO 7 MILES UPSTREAM	NUTRIENTS, TEMPERATURE	ALS	LACK OF BUFFER, LAND DEVELOPMENT; EROSION	M
	03	TRIBUTARY TO TRIB #4, MUDDY BROOK, 0.5MI	TOXICS (TCE, VINYL CHLORIDE)	ALS	SURFACE WATER IMPACT FROM PAST DISPOSAL ACTIVITIES	L
VT08-02L01		SHELBURNE POND (Shelburne)	PHOSPHORUS	ALS	EXCESSIVE ALGAE AND NATIVE PLANT GROWTH CAUSES PERIODIC LOW D.O./FISH KILLS	L

Certain local, state and federal regulatory programs refer to impaired segments (or waters draining to those segments) listed on the 303d List of Impaired Waters as part of program operations. Contact the respective regulatory program for details regarding regulated activities in these waters and their watersheds.

Part A. Waters appearing below have documentation and data indicating impairment and do not meet VT Water Quality Standards according to the methodology described in the Vermont Surface Water Assessment and Listing Methodology. Required or needed pollution controls have yet to be fully implemented and further pollutant loading determinations (i.e. TMDLs) are necessary - unless remediation will be completed prior to the scheduled TMDL.

Waterbody ID	ADB Code(s)	Segment Name/ Description	Pollutant(s)	Use(s) Impaired	Surface Water Quality Problem(s)	TMDL Priority
VT08-05	01	WINOOSKI RIVER ABOVE MONTPELIER WWTF DISCHARGE	E. COLI	CR	MONTPELIER WWTF COLLECTION SYSTEM PASSES COMBINED SEWER OVERFLOWS	L
VT08-11L02	02	WATERBURY RESERVOIR (Waterbury)	SEDIMENT	ALS, AES	SEDIMENTATION, TURBIDITY	L
VT08-12	01	INN BROOK, RM 0.3 TO 0.6	IRON	ALS	IRON SEEPS ORIGINATING FROM DISTURBED SOILS	L
VT08-13	01	LOWER NORTH BRANCH, WINOOSKI RIVER (APPROX 1 MILE)	E. COLI	CR	MONTPELIER WWTF COLLECTION SYSTEM PASSES COMBINED SEWER OVERFLOWS	L
VT08-16	01	GUNNER BROOK, BELOW FARWELL ST. DUMP (APPROX 0.5 MILE)	METALS (Cu, Fe), NUTRIENTS, SEDIMENT	AES, ALS	FARWELL ST. LANDFILL LEACHATE, SURFACE RUNOFF FROM DEVELOPED AREA	M
VT08-20	01	CLAY BROOK, RM 1.8 TO RM 2.3	STORMWATER, IRON	ALS	STORMWATER RUNOFF, EROSION FROM CONSTRUCTION ACTIVITIES & GRAVEL PARKING LOT; INCREASED PEAK STORMWATER FLOWS	L
VT09-06	01	SMITH BROOK (MOUTH TO RM 0.3)	IRON	ALS, AES	APPARENT LEACHATE FROM ADJACENT OLD DUMP	M
VT10-04	01	WETLAND DRAINING TO SMALL STREAM TO OTTAUQUECHEE RIVER (BRIDGEWATER)	METALS (Fe)	ALS	BRIDGEWATER LANDFILL; LEACHATE ENTERING SURFACE WATER VIA WETLAND	M
VT10-06	01	ROARING BROOK, RM 3.5 TO RM 4.2	STORMWATER	AES, ALS	STORMWATER RUNOFF, LAND DEVELOPMENT; EROSION	L
	02	E. BRANCH ROARING BROOK, RM 0.1 TO RM 0.6	STORMWATER, IRON	AES, ALS	STORMWATER RUNOFF, LAND DEVELOPMENT, EROSION	L
VT10-11	01	BLACK RIVER; FROM MOUTH TO 2.5 MI UPSTRM (SPRINGFIELD)	E. COLI	CR	COMBINED SEWER OVERFLOWS	L
VT11-10	01	WEST RIVER, BELOW BALL MOUNTAIN DAM TO TOWNSHEND DAM (9 MILES)	TEMPERATURE	2CR	ELEVATED TEMPERATURES AFFECT FISHERY	L

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in the Vermont Surface Water Assessment and Listing Methodology. Required or needed pollution controls have yet to be fully implemented and further pollutant loading determinations (i.e. TMDLs) are necessary - unless remediation will be completed prior to the scheduled TMDL.

Waterbody ID	ADB Code(s)	Segment Name/ Description	Pollutant(s)	Use(s) Impaired	Surface Water Quality Problem(s)	TMDL Priority
VT11-15	03	BALL MOUNTAIN BROOK, ABOVE NORTH BRANCH CONFLUENCE	ACID	ALS	ATMOSPHERIC DEPOSITION: CRITICALLY ACIDIFIED; CHRONIC ACIDIFICATION	M
	04	BEAR CREEK BROOK, RM 0.7 TO HEADWATERS	ACID	ALS	ATMOSPHERIC DEPOSITION: CRITICALLY ACIDIFIED; CHRONIC ACIDIFICATION	M
	05	KIDDER BROOK, CONFLUENCE OF SUN BOWL BROOK TO HEADWATERS	ACID	ALS	ATMOSPHERIC DEPOSITION: CRITICALLY ACIDIFIED; CHRONIC ACIDIFICATION	M
VT11-16	01	MILL BROOK TRIBUTARY #6, RM 1.9 TO 2.6	STORMWATER	ALS	SEDIMENT IMPACTS ON HABITAT/INVERTS; STREAM HYDROLOGIC IMPACTS FROM IMPERVIOUS SURFACES	L
VT11-18L03		LILY POND (Londonderry)	ACID	ALS	ATMOSPHERIC DEPOSITION; EXTREMELY SENSITIVE TO ACIDIFICATION; EPISODIC ACIDIFICATION	H
VT12-03	01	EAST BRANCH DEERFIELD RIVER, BELOW SOMERSET DAM	ACID	ALS	ATMOSPHERIC DEPOSITION: CRITICALLY ACIDIFIED; CHRONIC ACIDIFICATION	M
VT12-04	01	UPPER DEERFIELD RIVER, BELOW SEARSBURG DAM	ACID	ALS	ATMOSPHERIC DEPOSITION; CRITICALLY ACIDIFIED; CHRONIC ACIDIFICATION	M
VT12-05	01	NO. BRANCH DEERFIELD RIVER, TANNERY BRK RD TO 0.2 MI ABOVE SNOW LAKE	STORMWATER	AES, ALS	STORMWATER RUNOFF, LAND DEVELOPMENT & CONSTRUCTION RELATED EROSION	L
	03	IRON STREAM, TRIB TO TANNERY BROOK (0.3 MILE)	IRON	ALS	LAND DEVELOPMENT, SOURCE(S) NEED FURTHER ASSESSMENT	M
VT13-10	01	COMMISSARY BROOK TRIB, MOUTH TO RM 0.2	SEDIMENT	AES, ALS	BANK FAILURE AND EROSION DUE TO PAST CLAY MINING	L
VT13-13	01	CROSBY BROOK, MOUTH TO RM 0.7	SEDIMENT	ALS	HABITAT ALTERATIONS DUE TO SEDIMENTATION, CHANNELIZATION AND BUFFER LOSS	M
VT13-16	01	NEWTON BROOK, MOUTH TO RM 2.0	SEDIMENT	ALS	AGRICULTURAL ACTIVITY	H

Certain local, state and federal regulatory programs refer to impaired segments (or waters draining to those segments) listed on the 303d List of Impaired Waters as part of program operations. Contact the respective regulatory program for details regarding regulated activities in these waters and their watersheds.

Part A. Waters appearing below have documentation and data indicating impairment and do not meet VT Water Quality Standards according to the methodology described in the Vermont Surface Water Assessment and Listing Methodology. Required or needed pollution controls have yet to be fully implemented and further pollutant loading determinations (i.e. TMDLs) are necessary - unless remediation will be completed prior to the scheduled TMDL.

Waterbody ID	ADB Code(s)	Segment Name/ Description	Pollutant(s)	Use(s) Impaired	Surface Water Quality Problem(s)	TMDL Priority
VT13-16L01		LILY POND (Vernon)	ACID	ALS	ATMOSPHERIC DEPOSITION; EXTREMELY SENSITIVE TO ACIDIFICATION; EPISODIC ACIDIFICATION	H
VT14-02	01	WEST BRANCH OF OMPOMPANOOSUC RIVER (3.8 MILES)	METALS, ACID	AES, ALS	HIGH METALS IN DRAINAGE FROM ABANDONED ELIZABETH MINE & FROM TAILINGS	M
	02	COPPERAS BROOK (1 MILE)	METALS, ACID	AES, ALS	HIGH METALS IN DRAINAGE FROM ABANDONED ELIZABETH MINE & FROM TAILINGS PILES	M
	03	LORDS BROOK (RM 0.5 TO RM 3.3)	METALS, ACID	ALS	ABANDONED MINE DRAINAGE, BELOW "SOUTH CUT"	M
VT14-03	03	SCHOOLHOUSE BROOK AND TRIBUTARY	METALS, ACID	AES, ALS	HIGH METALS IN DRAINAGE FROM ABANDONED ELY MINE	M
VT14-05	01	PIKE HILL BROOK, FROM MOUTH TO 4 MILES UPSTREAM	METALS	AES, ALS	HIGH METALS IN DRAINAGE FROM ABANDONED PIKE HILL MINE & TAILINGS	M
	02	TABOR BRANCH TRIBUTARY #6, MOUTH TO RM 0.1	UNDEFINED	ALS	AGRICULTURAL RUNOFF	H
VT14-06	01	COOKVILLE TRIB #4, RM 1.0 TO 1.7	METALS	ALS	ACID MINE DRAINAGE ASSOCIATED WITH PIKE HILL MINE	L
VT15-01	01	PASSUMPSIC RIVER FROM PIERCE MILLS DAM TO 5 MILES BELOW PASSUMPSIC DAM	E. COLI	CR	ST. JOHNSBURY WWTF COLLECTION SYSTEM PASSES COMBINED SEWER OVERFLOWS	L
VT15-04	01	LOWER SLEEPERS RIVER IN ST. JOHNSBURY	E. COLI	CR	ST. JOHNSBURY WWTF COLLECTION SYSTEM PASSES COMBINED SEWER OVERFLOWS	L
VT17-01L01	01, 02	LAKE MEMPHREMAGOG (Newport)	PHOSPHORUS	AES, CR	EXCESSIVE ALGAE GROWTH, NUTRIENT ENRICHMENT	H
VT17-02	01	STEARNS BROOK TRIBUTARY (HOLLAND)	NUTRIENTS	ALS	AGRICULTURAL RUNOFF	H

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CLIMATE CHANGE AND STORMWATER MANAGEMENT ADAPTATION