MULTI-AGENCY CONTINGENCY PLAN FOR EMERGENCY ENVIRONMENTAL INCIDENTS IN THE LAKE CHAMPLAIN REGION

APPENDIX G: PHYSICAL DESCRIPTION OF THE LAKE

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1.0 INTRODUCTION

This appendix provides an overview of the physical features of Lake Champlain, its diverse watershed and the environmental risks associated with a spill of oil or hazardous materials. The area has a rich history from its geological and cultural origins to its role as a transportation highway and the many naval battles that have been fought upon its waters. Lake Champlain is one of the largest freshwater lakes in the United States and was designated as a resource of national significance in 1990 under the Lake Champlain Special Designation Act.[1] This act provides valuable funding and requires a higher level of protection and coordination from Federal and State governments. The special designation demonstrates the significant value of the lake as a natural, cultural, and recreational resource. Currently the lake faces many environmental challenges including urbanization, agricultural runoff and aquatic invasive species.[2] There are numerous research initiatives and restoration projects underway to better understand and mitigate the effects of these challenges. The following sections will provide an in-depth description of the physical features, hydrology and climate of Lake Champlain as they relate to environmental response operations.

2.0 GEOGRAPHIC AREA

Lake Champlain lies in the middle of the Champlain Valley between the Adirondack Mountains in New York and the Green Mountains of Vermont. It forms a boundary between the two states as well as an international border with the province of Quebec, Canada. The lake stretches 120 miles (193km) from Whitehall, NY at the Champlain Canal north to the outlet at the Richelieu River near Rouses Point, NY. It is 12 miles (19km) across at its widest point with an average depth of 64 feet (20m). The lake has an extensive drainage basin consisting of 11 distinct watersheds covering 8,234 square miles (21,325km^2).[3] This represents a 19:1 ratio of land to water surface area in the entirety of the basin. The massive size of the basin means the land surrounding the lake has a significant effect on the quality of the water in the lake because of natural and human activities. Lake Champlain has a long, narrow shape and can be divided into 5 distinct sections based on different physical, chemical and biological properties. The lake has shallow, eutrophic bays, deep cold-water troughs, and a narrow southern segment that behaves more like a river. There are many different shoreline types including protected sandy beaches, wetlands, manmade structures and exposed rocky cliffs.[2] The lake has over 70 islands, numerous protected bays and over 300 tributaries further adding to the complexity of this unique freshwater system.

2.1 Lake Champlain Statistics:

Table 1: Lake Champlain Physical Characteristics.[4]

Maximum Length:	120 miles / 193 kilometers
Maximum Width:	12 miles / 19 kilometers
Maximum Depth:	400 feet / 122 meters
Average Depth:	64 feet/ 20 meters
Surface Area (Water):	435 square miles / 1,127 square kilometers
Average Lake Level (Above Mean Sea Level):	95.5 feet / 29.1 meters
Maximum Measured Lake Level: (2011)	103.57 feet / 31.57 meters
Length of Shoreline:	587 miles / 945 kilometers
Number of Islands:	Greater than 70
Number of Beaches:	54 Public + 10 Private
Surface Area of Watershed:	8,234 square miles / 21,326 square kilometers
Typical Periods of Stratification:	May to October and during periods of ice cover

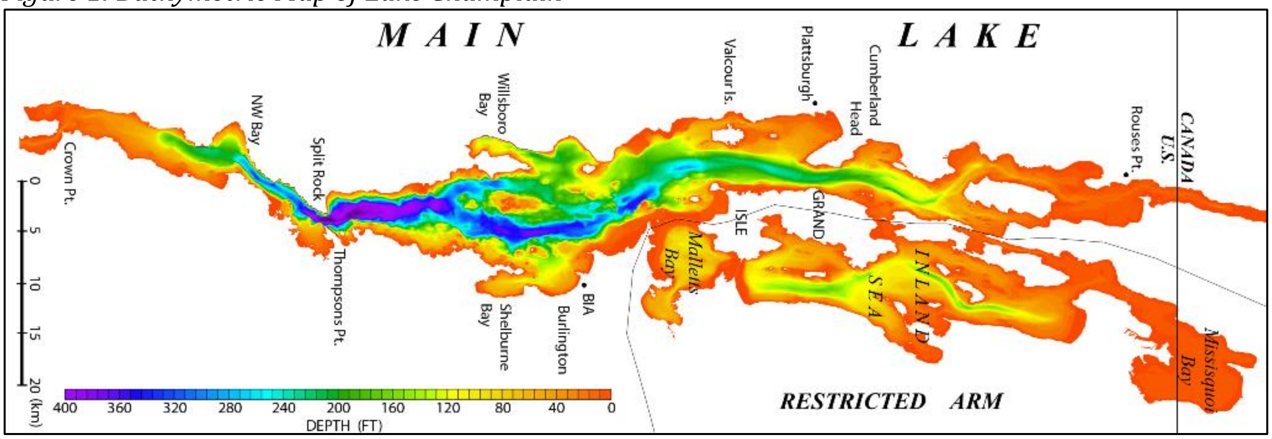
2.2 Geology and Origins:

The Champlain Valley has a rich geologic history. The Green Mountains were formed by a thrust fault around 450 million years ago.[5] The Adirondacks were formed 10 million years ago when ancient rocks were pushed upward in a dome-like formation. Although these two mountain ranges cradle the Champlain Valley for much of its length, it was the stretching of the continental crust that formed the lake's current basin. As two parallel faults stretched apart, a block of land between them dropped to form what is called a graben, which is now where the lake resides.[2] The valley was further sculpted by numerous ice sheets that occupied the area ending with the Laurentide Glaciers which reached their southernmost extent nearly 18,000 years ago. As the final glaciers melted and receded, Lake Vermont was formed which occupied an area much larger than the current lake and flowed south into the Hudson River. Around 12,000 years ago, the glaciers retreated enough to the north to allow the flow of freshwater north to the St Lawrence River. The land underneath the glaciers had been so depressed from the weight of the snow and ice that after the initial outflow of freshwater, the Atlantic Ocean soon flowed into the basin forming the brackish Champlain Sea which persisted for nearly 2,000 years.[2] After a brief period of being an inland sea, the land that was once under the ice sheets rebounded and the northerly flow of the lake was restored. The waters were then diluted back to freshwater from terrestrial runoff and snowmelt. The Lake Champlain Basin is widely studied for its unique and accessible geological features including ancient fossilized coral reefs and thrust fault formations.[5]

2.3 Lake Bathymetry:

Lake Champlain has many unique bathymetric features which influence water and sediment movement, ice formation and weather conditions throughout the basin. Figure 1 is a bathymetric map created by Middlebury College to easily depict the deeper areas of the lake.

Figure 1: Bathymetric Map of Lake Champlain



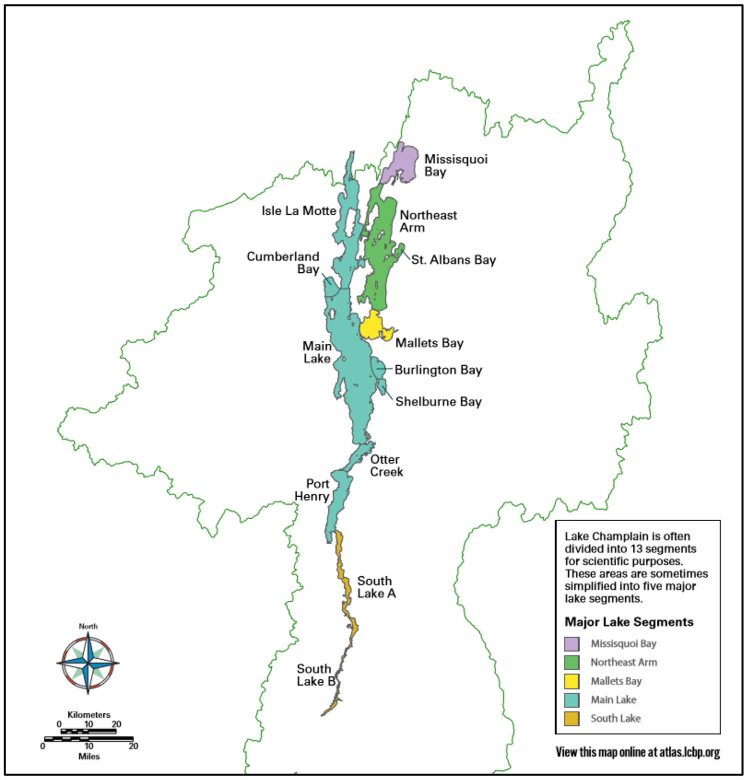
The National Oceanic and Atmospheric Administration (NOAA) developed navigational charts for Lake Champlain and are available at https://www.charts.noaa.gov. These charts along with electronic charts are periodically updated and represent the most current bathymetric data for navigational use on Lake Champlain. Each of the following charts is hyperlinked to its online source:

- Chart # 14781 Riviere Richelieu to South Hero Island
- Chart # 14782 Cumberland Head to Four Brothers Islands
- Chart # 14783 Four Brothers Islands to Barber Point
- Chart # 14784 Barber Point to Whitehall
- Chart # 14785 Burlington Harbor

2.4 Five Distinct Sections of Lake:

Lake Champlain can be divided into five distinct sections based on their unique physical, chemical and biological characteristics. Some of the sections have limited hydrological connection to the rest of the lake and are sometimes treated as separate waterbodies. The characteristics of each section will have an effect on the fate of an oil or hazardous material spill and should be considered when planning for response operations. Figure 2 shows the five distinct sections, and a detailed description of each, moving from north to south.[3] For a more detailed map of the lake and its named features, access the links above in Section 2.4 to view the NOAA Navigational Charts

Figure 2: The Five Distinct Sections of Lake Champlain



- <u>Missisquoi Bay:</u>

This large, shallow bay extends northeast from the Alburgh/Swanton bridge and includes an international border (NOAA Chart # 14781). The majority of Missisquoi Bay lies in Quebec and has an average depth of approximately 14 feet (4m). It has three major tributaries that feed it including the Missisquoi River which has the largest influence on the water quality in this section. The shallow water in the bay is typically warmer than other areas of the lake and is murky due to runoff from the surrounding drainage basin and constant mixing. The bay forms ideal habitat for fish and wildlife due to the warmer water and significant wetland areas including the 6,729-acre Missisquoi National Wildlife Refuge. In the summertime, the bay experiences cyanobacteria blooms due to high nutrient loading from agricultural runoff. The water from this bay circulates counterclockwise and flows south into the Northeast Arm under most conditions.[2,4]

Response Considerations: The majority of Missisquoi bay is in Canada and the international border may present challenges in deploying response personnel and equipment during a trans-border response. The bay is shallow and is home to extensive wetlands and other important habitat that may restrict some response operations. The currents in the bay generally flow in a counterclockwise direction and exit to the south through the Alburgh/Swanton Bridge. This bridge and its channel could be a control point to prevent pollutants from entering or exiting Missisquoi Bay.

- Northeast Arm:

The Northeast Arm is also known as the Inland Sea and stretches from the Sandbar Causeway near South Hero, north to the Alburgh/Swanton bridge including the Alburgh Passage, Carry Bay and The Gut (NOAA Chart #14781). It is bordered by Grand Isle and North Hero Island to the west and mainland Vermont to the east. It has an average depth of 42 feet (13m) and is very isolated from the rest of the lake. There are no major tributaries in this section which often causes it to have higher overall water quality and less turbidity.[2] Water from this section flows in from Missisquoi Bay and Malletts Bay and exits into the Main Lake through narrow openings at The Gut and Carry Bay. St. Albans Bay and Maquam Bay are shallow and experience eutrophic conditions including harmful algae blooms and oxygen deficiency.

Response Considerations: The Northeast Arm is mostly isolated from all other sections of the lake. It is only connected through narrow openings through causeways and bridges. Depending on the lake level, wind direction and other hydrologic conditions the water at each of these narrow openings can flow in either direction so it is important to understand relevant conditions at the time of a spill. There are no major tributaries and very few sources for oil or hazardous material spills.

- Malletts Bay:

Malletts Bay is divided into the Inner and Outer Malletts Bay (NOAA Chart 17482). This is a popular boating and recreation area due to its protection from the winds on the main lake. It is formed by manmade causeways to the north at Sandbar State Park and to the west by the Colchester causeway, an old railroad crossing. The Lamoille River, a major tributary, enters the Outer Bay south of the Sandbar Causeway. This area hosts the Sandbar Wildlife Management Area (WMA) with Class 1 wetlands and over 1200 acres of protected habitat.[8] The Inner bay is separated by two rocky outcroppings that create a pinch point between Malletts Head and Red Rock Point. The inner bay is especially popular for sailing and other watersports. This section has some shallow areas but has a maximum depth of 105 feet (32m) and a higher water volume which increases the dilution of various nutrients and decreases the occurrence harmful algal blooms.[2,7]

Response Considerations: Malletts Bay is another very isolated section of the lake that is only connected to other sections through three narrow openings in causeways. It could be completely isolated with containment boom at the openings. There is a large recreational boating and watersport community in this section that would be heavily affected if there were a spill. The Class 1 wetlands at the Sandbar WMA are a priority for protection from a spill. With no major industry in this section, recreational boats pose largest threat for a spill. Malletts Bay will freeze over before the Main Lake.

- Main Lake:

The Main Lake covers over 300 square miles (777 km^2) and contains the majority of the lake's surface area and water volume.[4] It includes the deepest part of the lake near Thompsons Point (NOAA Chart # 17483) at 400 feet (122 m) deep.[2] The Main Lake begins at the Crown Point Bridge (NOAA Chart # 14784) and includes a continuous stretch of water on the west side of Grand Isle up to the Richelieu River outlet and the Canadian border(NOAA Chart # 17481). It is a popular area for recreation including boating and fishing and provides clean drinking water for numerous public water intakes. There are 14 major tributaries in this section including the Lamoille River and Otter Creek in Vermont, and most of the rivers draining the Adirondack region in New York State which are identified in Table 3 below. The Main Lake has a valuable cold-water fishery for lake trout and landlocked Atlantic salmon. The two most populous cities in the basin, Burlington, VT (42,260 in 2016) and Plattsburgh, NY (19,780 in 2016) are situated along the shores of the Main Lake.

Response Considerations: The Main Lake is by far the largest section of the lake. It also has the majority of the oil and hazardous material threats in the region. This large section is oriented north/south and seasonal winds can build up significant waves and surface currents due to its large fetch. Conditions on the main lake can often be more like the Great Lakes or an ocean and complex hydrological characteristics can challenge response operations. This section often does not freeze completely due to its size and depth. It does experience periods of strong stratification mainly during the summer months which can influence surface current patterns. The railroad tracks running down the western side of the Main Lake are the biggest threat for a large spill into the lake. Most of the Commercial vessels on the lake operate in this section. The lake only has one outlet at the Northern end of the Main Lake in Rouses Point. Here, the Richelieu River marks another international border and also the only way to regulate the lake level during flooding conditions.

- South Lake:

The South Lake is a 30 mile (48km) section that has an average width of 2/3 of a mile (1 km) and behaves more like a river.[8] It begins at the final lock on the Champlain Canal in Whitehall, NY (NOAA Chart # 17484) and flows north until it transitions into the Main Lake at the Crown Point Bridge. This section has three major tributaries, the Poultney, Mettowee and LaChute Rivers, the last of which drains from Lake George. The water in the South Lake averages 8.8 feet (2.7m) and this section is known for its warm water fishing. [2] The South Lake has issues with invasive species like zebra mussels, water chestnut and others that have been transported through the Champlain Canal, which enters the South Lake at Whitehall, NY.[8] The South Lake does not usually experience strong summer stratification.

Response Considerations: The South Lake is more like a river due to its distinct northerly flow, shallow depth and narrow width. Fast water spill techniques may be required depending on conditions. It would be easier to respond to a spill in this section because it is geographically closer to resources in Albany, NY. The consistent currents and narrow width make it easy to predict how the oil or hazardous material is going to move. The railroad runs along most of this section on the western side of the lake in New York. The Champlain Canal at the southern end could be used to bring spill resources into Lake Champlain from Albany and the Hudson River.

2.5 Historic and Current Use of the Area:

Lake Champlain has a long history of human use dating back more than 10,000 years to native populations who relied on the lake for food, water, transport and trade.[2] The valley alongside the lake was settled by Europeans because of its productive farmland and easy access to reliable trade routes up and down the lake. Following European colonization, the lake developed a significant military history and hosted important naval battles during the American Revolution and the War of 1812.[5] At one time it was substantial transportation corridor for goods transiting between Canada and New York City. Although the waterway remains open for business, commercial trade on the lake is largely a thing of the past. Now, Lake Champlain generates over $300 million dollars a year in tourism in Vermont alone.[8] It continues to be an important natural resource to northern Vermont, New York and Quebec, supporting agriculture and generating significant revenue from year-round recreation and tourism. In 2018, Lake Champlain was ranked as one of the eight premier freshwater boating destinations in the United States by BoatUS magazine.[8] It remains popular among recreational boaters, SCUBA divers, kite surfers, kayakers and many other water sport users. The lake supports multi-sport recreational paths along its shores and is a vital part of many paddler trails traversing the northern U.S. and southern Canada.[8] Numerous summer camps and educational programs use the lake as a classroom teaching research methods and environmental conservation principles.[6]

Fishing is an important economic draw that places great importance on healthy habitats and clean water. Fishing on Lake Champlain is responsible for approximately $205 million dollars in economic benefit per year.[8] The lake is home to more than 80 species of fish including many sportfish that draw anglers from all over the country.[8] Several species are actively stocked to help support populations including lake trout, Atlantic salmon and others.[3] There are dozens of fishing tournaments throughout the summer months and a substantial ice fishing community in the winter.

2.6 Industry and Infrastructure on the lake:

Industry on the lake and along its shorelines is limited. The primary infrastructure that may be affected during a spill of oil or hazardous materials on the lake is drinking water intakes and the transportation sector. Other infrastructure on the lake include 98 wastewater treatment plants[3], and the International Paper Mill in Ticonderoga, NY.

2.6.1 Drinking water:

More than 145,000 people rely on the lake for clean drinking water. There are approximately 100 public water suppliers and over 4,000 seasonal residences that draw over 20 million gallons (75 million liters) of water a day from various locations around the lake. In 2015, the Champlain Water District in Vermont won an award for the best tasting water in North America.[8] In Vermont, public drinking water intakes are identified on GIS maps available on the Agency of Natural Resources (ANR) website: http://anrmaps.vermont.gov/websites/anra5/. In New York, the intakes are available from the County Departments of Health. In Quebec, the Minister of Sustainable Development, Environment and Parks is responsible for public drinking water.

2.6.2 Transportation:

Lake Champlain hosts two ferry companies that operate four transport routes across the lake (Table 2). The Lake Champlain Transportation Company operates nine passenger and vehicle ferries at three different crossing points on the lake. The ferries are operated by diesel engines and are a prominent feature on the lake in the summer months. The Charlotte and Burlington ferries run seasonally, dependent on weather and ice conditions while the Grand Isle Ferry operates 24 hours a day all year long (https://ferries.com/). There is a smaller privately-owned ferry in the southern part of the lake. This Ticonderoga Ferry is a barge style vessel that utilizes a cable system to transit the ½ mile (0.8km) crossing from Shoreham, VT to Ticonderoga, NY (http://www.forttiferry.com/). The ferry system is an important transportation option for tourists, bikers and residents, many of whom use it to commute to their jobs. While the ferries may be impacted by a spill, they could also serve an important purpose during a response to an oil or hazardous material incident. For instance, they could transport equipment and personnel around the lake or carry large capacity storage tanks for removal operations.

Table 2: Lake Champlain Ferry System.

Route	Distance/Time	Operation	Propulsion
Grand Isle, VT to Plattsburgh, NY	2 miles/ 15 minutes	Year Round	Diesel
Burlington, VT to Port Kent, NY	10 miles/ 60 minutes	Seasonal	Diesel
Charlotte, VT to Essex, NY	3 miles/ 25 minutes	Seasonal	Diesel
Shoreham, VT to Ticonderoga, NY	0.5 miles/ 7 minutes	May - October	Cable

The Lake Champlain Basin is also home to a significant network of roads and highway systems that are adjacent to the lake or cross one of the hundreds of tributaries leading to the lake. There are eight bridges crossing portions of the lake. Route 22 crosses the southernmost section of the lake near Whitehall, NY. The Crown Point Bridge near the middle of the lake is the largest span connecting Crown Point, NY and Chimney Point, VT. Route 2 winds through the islands in the northern section of the lake. It crosses the lake in Colchester connecting mainland Vermont to Grand Isle and crosses two more times in the Northeast Arm before finally crossing the Main Lake to Rouses Point, NY near the Canadian border. There is a bridge crossing from Alburgh to Swanton, VT which is the boundary between Missisquoi Bay and the Northeast Arm. Lastly, there is a bridge crossing from South Alburgh to Isle La Motte. The bridges are all marked on standard driving maps and the NOAA navigational charts linked in Section 2.4.

Railroads were built along the lake starting in the mid 1800's. One connected Burlington to Boston and the other ran along the shores of the lake in New York, connecting Montreal and Albany. Railroads supported developing industrial and commercial enterprises and largely replaced the need for barge and steamship traffic on the lake.[5] Currently the Canadian Pacific Railway operates the rail line in New York that runs along nearly 100 miles (161 km) of the Lake Champlain shoreline – sometimes within feet of the lake – and then continues to follow the Champlain Canal on its way south. In Vermont, the New England Central Railroad crosses over the lake near the Alburgh/Swanton bridge and then heads inland on its way from Montreal to White River Junction. The Vermont Railway begins in Burlington and runs alongside the lake through Shelburne before heading inland on its way south to Rutland. From Rutland, the line heads to Whitehall, New York crossing the Champlain Canal twice.

3.0 HYDROLOGY

The hydrology of Lake Champlain is very dynamic and is significantly influenced by the massive basin that supplies its water. There are 11 distinct watersheds that drain into the lake. Collectively, these watersheds include hundreds of tributaries that drain to and through the Champlain Valley.[3] A detailed map of the Lake Champlin Watershed is available in the Lake Champlain Basin Program's atlas: https://atlas.lcbp.org/wp-content/uploads/2018/04/Basin_Poster_2016.png. The temperature, quantity and quality of the freshwater draining to the lake dictate currents, lake levels and water quality parameters. It is important to look at the watershed to understand the forces that influence these important characteristics of the lake. The fate and effects of oil and hazardous materials will be influenced by the hydrological forces in the basin.

3.1 Tributaries:

There are over 300 tributaries that empty into Lake Champlain (Tables 3,4 and 5).[7] Tributaries are critical factors in controlling the water quality of any lake. They influence the lake level, convey sand and sediments, provide critical habitat, and transport massive amounts of stormwater and runoff from across the landscape. Tributaries affect chemical, physical and biological processes in Lake Champlain. On Lake Champlain, such processes are closely monitored through the USGS WaterWatch system and the Lake Champlain Long-Term Monitoring Program. The USGS data are available in real time and are important for predicting surface current flows and other water quality parameters. The Long-Term Monitoring Project complements the USGS Stream gauges and reports data on numerous water quality parameters.

- Vermont Streamflow Data: https://waterwatch.usgs.gov/?m=real&r=vt
- New York Streamflow Data: https://waterwatch.usgs.gov/index.php?r=ny&m=real

- Quebec Streamflow Data: http://www.cehq.gouv.qc.ca/suivihydro/ListeStation.asp?regionhydro=03&Tri=Non
- Long-Term Monitoring Program Data – Tributary Monitoring Data https://anrweb.vermont.gov/dec/_dec/LongTermMonitoringTributary.aspx

Below is a list of the major tributaries of Lake Champlain. Drainage area and mean flow rates from the USGS Waterwatch and Quebec Hydrographic Region's websites are listed to show their overall effect on waterflow within the lake:

Table 3: Major New York Tributaries to Lake Champlain.

River Name	Main Stem Length	Drainage Area	Mean Flow	Point of Entry into Lake Champlain
Great Chazy River	43 mi (70km)	299 mi^2/ 774 km^2	244 ft^3/s 6.9 m^3/s	Champlain, NY; King Bay.
Little Chazy River	20 mi (32km)	53 mi^2/ 137 km^2	32 ft^3/s 0.9 m^3/s	Chazy, NY; North of Chazy Landing
Saranac River	56 mi (90km)	614 mi^2/ 1,590 km^2	715 ft^3/s 20.2 m^3/s	Plattsburgh, NY; Cumberland Bay.
Salmon River	13 mi (21km)	68 mi^2/ 176 km^2	43 ft^3/s 1.2 m^3/s	Plattsburgh, NY; South of Airport.
Little Ausable River	27 mi (43 km)	73 mi^2/ 189 km^2	36 ft^3/s 1.0 m^3/s	Peru, NY; North of Ausable Pt.
Ausable River	20 mi (32km)	513 mi^2/ 1,329 km^2	441 ft^3/s 12.4 m^3/s	Ausable, NY; North of Port Kent, NY.
Bouquet River	50 mi (80km)	272 mi^2/704 km^2	220 ft^3/s 6.2 m^3/s	Willsboro, NY; South of Willsboro Bay.
Putnam Creek	9 mi (14km)	62 mi^2/ 161 km^2	82 ft^3/s 2.3 m^3/s	Crown Point, NY; Gilligans Bay.
Mettawee River	41 mi (66km)	424 mi^2/ 1,098 km^2	274 ft^3/s 7.8 m^3/s	Whitehall, NY; Feeds Champlain Canal.

Table 4: Major Vermont Tributaries to Lake Champlain.

River Name	Main Stem Length	Drainage Area	Mean Flow	Point of Entry into Lake Champlain
Missisquoi River	96 mi (154km)	865 mi^2/ 2,240 km^2	1270 ft^3/s 36.0 m^3/s	Highgate, VT; North of Alburgh Passage.
Lamoille River	85 mi (137km)	723 mi^2/ 1,873 km^2	952 ft^3/s 27.0 m^3/s	Milton, VT; South of Sandbar Causeway
Winooski River	88 mi (142km)	1,063 mi^2/ 2,753 km^2	1460 ft^3/s 41.3 m^3/s	Burlington, VT; South of Colchester Point
LaPlatte River	18 mi (29km)	53 mi^2/ 137 km^2	31 ft^3/s 0.9 m^3/s	Shelburne, VT; Shelburne Bay
Lewis Creek	29 mi (46 km)	81 mi^2/ 210 km^2	85 ft^3/s 2.4 m^3/s	Ferrisburgh, VT; Hawkins Bay
Little Otter Creek	19 mi (31 km)	73 mi^2/ 189 km^2	51 ft^3/s 1.4 m^3/s	Ferrisburgh, VT; Hawkins Bay
Otter Creek	102 mi (163km)	944 mi^2/ 2,445 km^2	1010 ft^3/s 28.6 m^3/s	Ferrisburgh, VT; South of Thompsons Point.
Poultney River	29 mi (46km)	263 mi^2/ 681 km^2	325 ft^3/s 9.2 m^3/s	West Haven, VT; North of Whitehall, NY.

Table 5: Major Quebec Tributaries to Lake Champlain.

River Name	Main Stem Length	Drainage Area	Mean Flow	Point of Entry into Lake Champlain
Riviére Aux Brochets/ Pike River	42 mi (67km)	373 mi^2/ 966 km^2	58 ft^3/s 1.6 m^3/s	Saint-Armand, QC; Missisquoi Bay.

3.2 Richelieu River Outflow:

The Richelieu River marks the northern terminus of Lake Champlain near Rouses Point, NY and is the only outlet for the basin. The river flows 78 miles (125 km) north to Sorel-Tracy, Quebec, where it meets the Saint Lawrence River.[9] The lake level in Lake Champlain is directly governed by the flowrate through the Richelieu River. For the first 23 miles (37 km), the river only drops 1 foot in gradient, creating a very slow-moving channel. Near Saint-Jean-Sur-Richelieu, Quebec, the river narrows and drops 82 feet (25 meters) over 7.5 miles (12 kilometers). In order to facilitate vessel traffic through the rapids, the Chambly Canal was constructed in 1843 and consists of 9 locks allowing passage from the Saint Lawrence River to Lake Champlain. Below the Chambly Canal, the water level is controlled by a dam in Saint-Ours, Québec but it is not designed for flood control. There is currently no flood control infrastructure for the Richelieu River or Lake Champlain.[9] A spill of oil or hazardous materials on the lake could allow pollutants to be transported through the Richelieu River impacting important habitat, agricultural, and residential areas.

3.3 Champlain Canal and locks:

At the southern end of the lake, the Champlain Canal connects to the Hudson River. The 63-mile (101 km) canal begins in Fort Edward, NY, just east of Glens Falls and ends in Whitehall, NY, in the South Bay of Lake Champlain. It was constructed in 1823 as a branch of the Erie Canal to facilitate commerce in New York State. It was constructed as a barge canal and was used extensively throughout the 19th and 20th centuries to transport people and goods.[10] Although commercial transport through the canal has been reduced to almost nothing, it is still operable and could be an asset for transporting spill response vessels and equipment. It is maintained to minimum depth of 12 feet and the lowest overhead clearance is 17 feet. More information on canal operations can be found at: http://www.canals.ny.gov/wwwapps/navinfo/navinfo.aspx?waterway=champlain.

3.4 Dams in the Basin:

There are both hydroelectric and flood control dams on various tributaries in the Lake Champlain Basin. Most hydroelectric dams have little or no storage capacity and do not influence river flow rates.[11] Flood control dams were built in specific areas in response to major flooding events and were designed to protect downstream communities. Releases from flood control dams have a minor effect on the overall level of the lake at any given time because the volume of Lake Champlain is so large.[11] Lake George is the largest tributary lake draining into Lake Champlain and its flood control dam on the LaChute river is mainly used to regulate levels for recreational purposes.

3.5 Lake stratification:

In many large freshwater systems temperature gradients form during certain times of year. The difference in temperature between the surface layer (epilimnion) and the bottom layer (hypolimnion) leads to density differences in the water layers which act as barriers to pollutants, plankton and other dissolved substances. The temperature and density gradient is called stratification and it has a significant effect on the overall hydrology of a lake. Lake Champlain is a dimictic lake, meaning that parts of it experience two distinct periods of stratification and mixing per year.[2] Stratification does not occur in the entire lake. Shallower areas may remain isothermal (uniform in temperature) in the summertime and will fully mix. In deeper areas of Lake Champlain, stratification occurs in the summer (typically May through October) as the surface water warms and the dense cold-water sinks and, in the winter, when colder water and ice sit on top of warmer water below.[2]

During periods of stratification, currents may be enhanced in surface waters because of the reduced vertical mixing and separation of the surface currents from bottom friction.[12] It means that pollutants may spread faster over a larger area but only in the upper most layer of water column. Stratification also supports the formation of surface and internal seiche waves that occur because of the thermal and density layers. This phenomenon is discussed in section 3.6.

Periods of mixing mean the entire water column is able to homogenize and it has a relatively uniform temperature from the surface to the bottom. Nutrients, sediments and biota are able to move throughout the entire water column. For pollutant transport, at such times, any dissolution or diffusion of a specific substance can affect the entire water column down to the sediment.[12]

Thermal stratification is not a common water quality parameter reported by buoys or weather stations, but the Lake Champlain Long-Term Monitoring Project collects Multi-Probe Sonde data that tracks water temperature with depth. These data can be used to determine the current conditions in specific parts of the lake. Current and historical thermal profile data are available at: https://anrweb.vt.gov/DEC/_DEC/MultiProbeSonde.aspx.

3.6 Surface and Internal Seiche:

One unique phenomenon to be aware of on Lake Champlain is the wind-driven seiche. The lake has a long and narrow shape and is mostly oriented in a north/south direction. After longer periods of strong north or south winds, the surface water piles up at one end of the lake. The lake level rise is based on the velocity and duration of the wind but can usually be measured in inches. At times it has been observed that the seiche could reach a foot or higher based on wind conditions.[2] Once the prevailing wind reduces in speed, the water that had been pushed up releases and creates a sloshing effect in the basin. The resulting wave period can last for several hours.[13] The most observable effect is a rise in lake level at one end, but the seiche can reverse current flows through the most constricted areas of the lake like the Colchester Causeway and the Gut. This can be seen in Figures 3 and 4 marked with the red arrows. The effects of the surface seiche will only be noticeable in water less than 15 feet in depth like nearshore areas and shallow bays. The seiche occurs during the period of stable stratification typical in the summer and early fall because of the stronger density gradients in the water column.[13] The surface seiche, or wind tide, can influence surface flow and currents, which may move pollutants in the water in a direction opposite of the wind or predicted flow.

As the surface seiche pushes the surface water up on one end of the lake, the epilimnion, or upper layer of warmer, less dense water, subsequently pushes down in the water column. This creates a deeper warm water layer at the end of the lake where the wind is pushing and a shallower warm layer at the opposite end. Like the surface seiche, as the wind eases, an internal seiche is formed that will slosh back and forth in the basin for a period of around 4 days. These oscillations in the thermocline continue during most of the stratified summer period.[2] Although the internal seiche only affects the deeper parts of the lake where the density difference in the water is more pronounced, it can increase currents and transport water particles a significant distance. “A water parcel will be transported up and down the lake basin by the 4-day oscillation and will carry with it any dissolved materials or particulate matter it contains”. [13 p. 18,427]

3.7 Surface Currents:

The mass transport in Lake Champlain reflects a mean surface water current of 10cm/s (0.23mph or 0.36kph) to the North.[14] The mass transport describes the long-term average movement of surface waters. This calculation does not account for the multitude of short-term variations present including prevailing winds, gyre circulation, internal seiche (discussed above), tributary outflow, shoreline features and coastal jets. Though relatively limited, studies of surface currents on the lake indicate that wind direction and intensity are the primary drivers of surface water movement.[14] The surface currents generally follow the prevailing wind direction and can be predicted using a progressive vector diagram (PVD) using 3% of the wind magnitude.[14] There are observed eddies and gyres present in the lake that can alter the surface transport of pollutants. Given the complex structure and morphology of the lake it is safe to assume there will be many localized variations to average flow expectations. It is best to consult with a physical oceanographer or physical limnologist to understand wind driven current mechanisms in more detail.

General Surface flow observations are detailed in Figures 3 and 4.[7] The black arrows indicate generally observed surface currents in the lake. The red bi-directional arrows indicate narrow openings between major basins in the lake. The surface currents in these constricted areas have been observed to flow in both directions dependent on wind direction, seiche movement and lake water levels. It is important to note that these charts were created from limited studies in summer months with a south wind. [7,14] These currents are typical for the lake, but wind direction and velocity are the largest factors affecting surface currents. Shoreline features, tributary inputs, seiche oscillations and stratification also influence surface currents and must be considered when predicting surface currents. The South Lake portion is not depicted on a chart because it generally flows in a northerly direction due to tributary inputs and its shallow and narrow shape. The northern sections are more complicated due to depth, hydrology and relative isolation from the rest of the lake.

Figure 3: Northern Lake Surface Currents

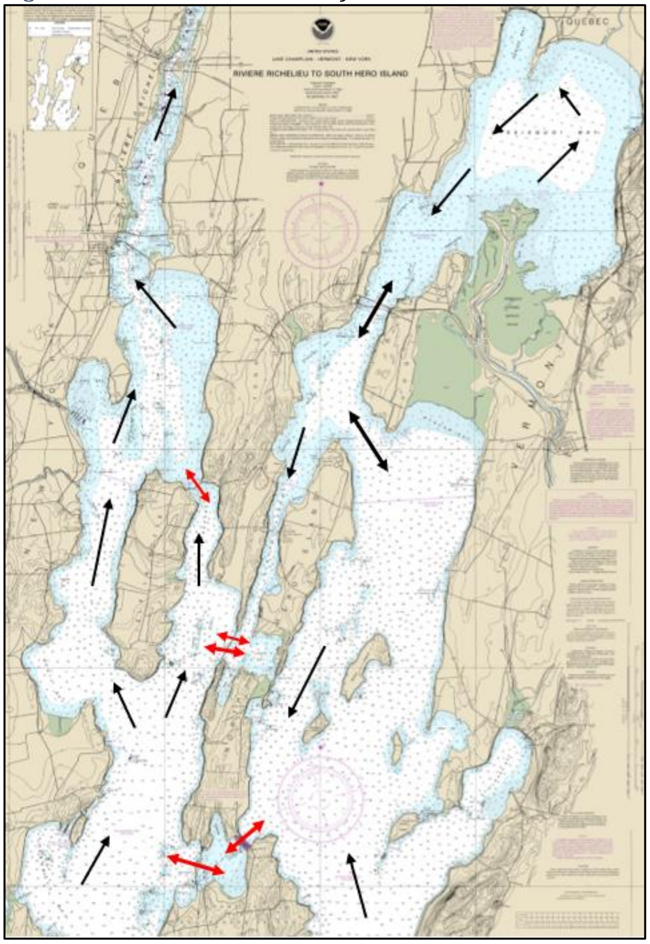


Figure 3 displays surface currents in the northern sections of Lake Champlain. The arrows do not reflect the velocity of the surface currents, only typical flow patterns.

The red, double-ended arrows represent narrow openings where the currents are known to shift direction based on wind and water levels.

The black arrows display average surface current movement in the given area.

Wind is the largest factor affecting surface currents, but shoreline features, tributary inputs and stratification also influence surface currents and must be considered when predicting surface currents.

Figure 4: Mid Lake Surface Currents

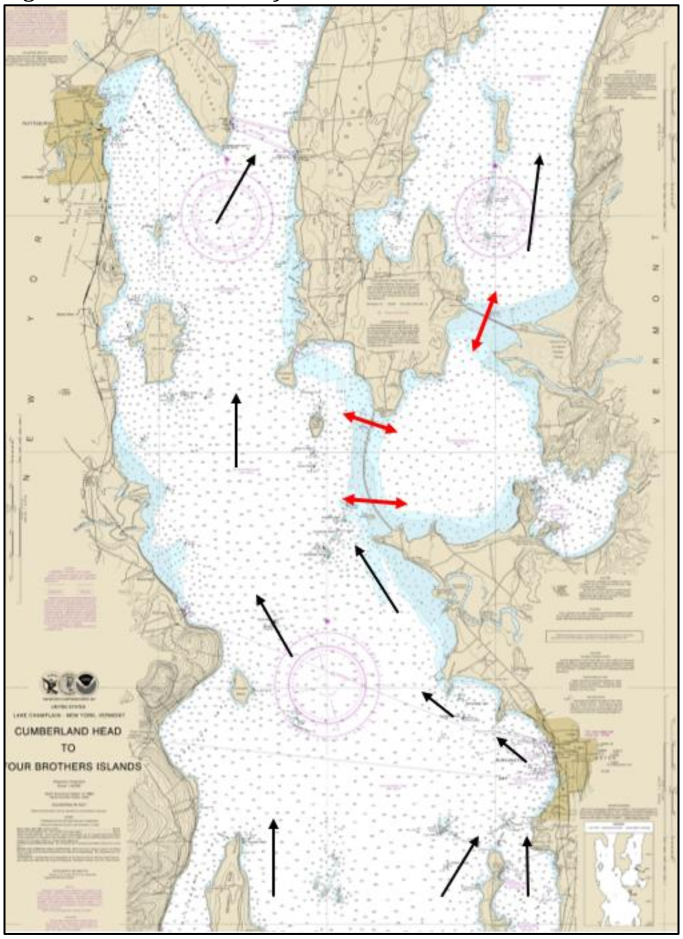


Figure 4 displays surface currents in the middle section of Lake Champlain. The arrows do not reflect the velocity of the surface currents, only normal flow patterns.

The red, double-ended arrows represent narrow openings where the currents are known to shift direction based on wind and water levels.

The black arrows display average surface current movement in the given area.

Wind is the largest factor affecting surface currents, but shoreline features, tributary inputs and stratification also influence surface currents and must be considered when predicting surface currents.

The currents in Lake Champlain have not been extensively studied and there is currently no comprehensive data set or model capable of accurately representing surface currents on the lake.[14] The Vermont EPSCoR Basin Resilience to Extreme Events (BREE) program is currently implementing a 3D coupled physical and biogeochemical model of Lake Champlain that will be capable of modeling localized currents using current weather and buoy data (C. Marti, personal communication, January 28, 2020). Middlebury College is also working on a similar model that may be capable of integrating weather data to create surface current models (T. Manley, personal communication, October 25, 2019). These models may become valuable tools for responders to predict oil and hazardous material transport on the surface and subsurface of the lake.

3.8 <u>Lake level:</u>

The lake level varies naturally throughout the year depending primarily on precipitation and snowmelt. Flooding is expected in the winter and early spring but on rare occasions has also happened in the summer and fall.[9] Many ecosystems along the shores of Lake Champlain and its major tributaries are adapted to natural variations in lake level and are resilient to normal flooding events. In the context of oil or hazardous material spills, the current lake level has a direct effect on which shoreline ecosystems will be affected by a pollutant. The lake has a normal level of 95.5 (29.1 m) feet above mean sea level and it is considered in flood stage at 100 feet (30.5 m).

The United States Geological Service (USGS) Operates multiple gauges on Lake Champlain that monitor Lake level along with other parameters. They can be accessed to see real time lake levels.

- Station # 04294500 Burlington, VT: https://waterdata.usgs.gov/usa/nwis/uv?04294500
- Station # 04294413 Port Henry, NY: https://waterdata.usgs.gov/ny/nwis/uv?site_no=04294413
- Station # 04295000 Rouses Point, NY: https://waterdata.usgs.gov/ny/nwis/uv?site_no=04295000
- Station # 04279085 North of Whitehall, NY: https://waterdata.usgs.gov/nwis/uv?site_no=04279085

The Spring of 2011 produced record level floods on Lake Champlain and its outlet on the Richelieu River. Warm spring temperatures quickly melted a heavy snowpack and record precipitation collectively raised the lake to its highest levels in at least 100 years.[9] The lake rose to a record level of 103.57 feet and remained above flood level for two months. Over 4,000 homes and thousands of acres of farmland were impacted along the lake and Richelieu River basin. [9]

3.9 Wetlands:

One habitat of primary concern within the Lake Champlain watershed is wetlands. There are over 300,000 acres of documented wetlands within the Lake Champlain Basin.[3] They can be viewed on the Lake Champlain Basin Atlas: https://atlas.lcbp.org/nature-environment/wetlands/. Wetlands are extremely important and provide many services to the lake. They help to stabilize shorelines, support numerous natural communities, provide critical habitat, and improve water quality. Many of the wetlands in the basin are directly connected to the shoreline of Lake Champlain and may become inundated with flood water during higher than normal lake levels. If an oil or hazardous material spill were to occur during periods of flooding it could greatly increase environmental damage to the wetlands and decrease the resiliency of the ecosystem altogether.

Figure 5: Spring 2011 North Lake Wetland Flooding[9]

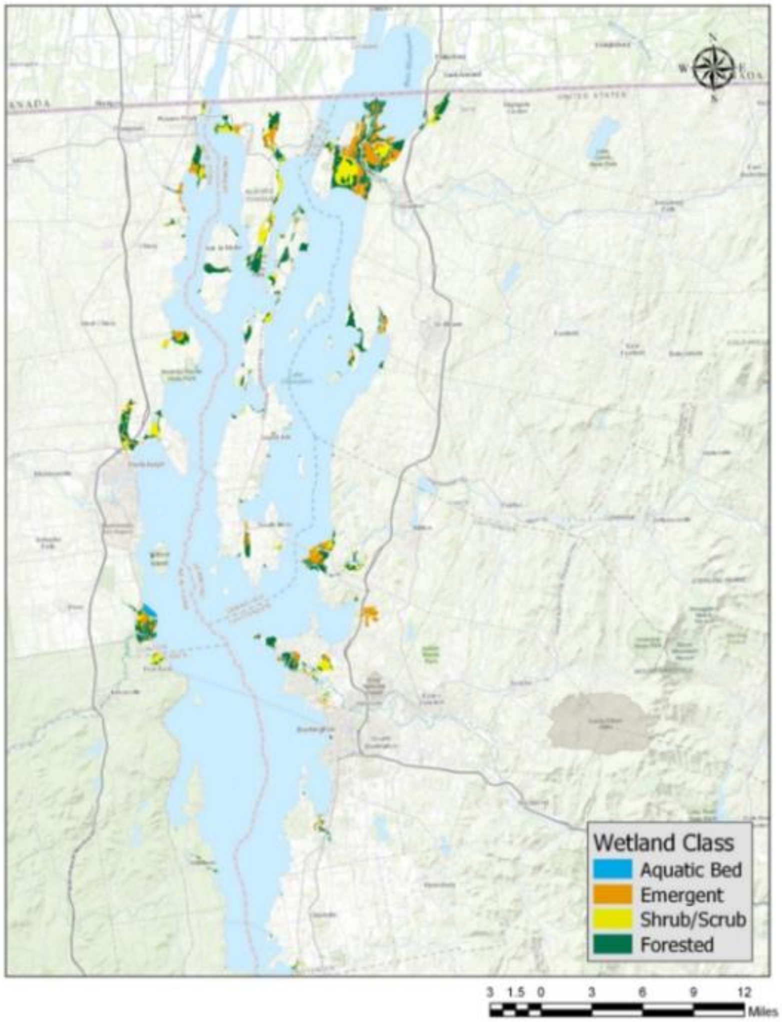


Figure 6**:** Spring 2011 South Lake Wetland Flooding[9]

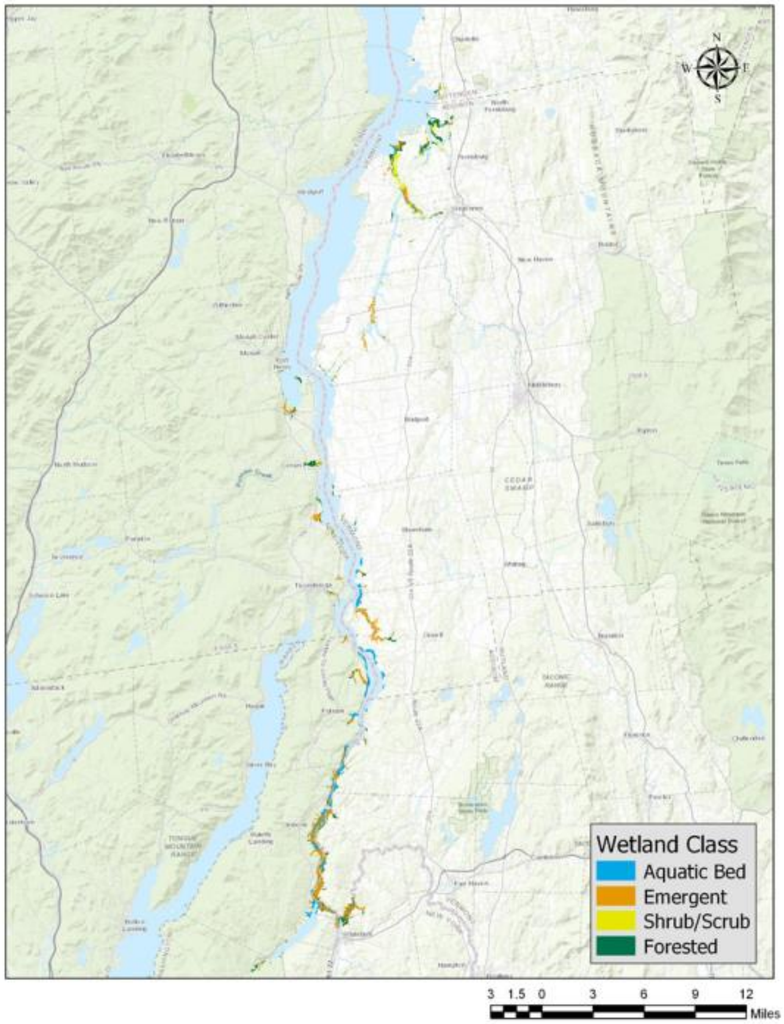


Figure 5 and 6 display wetlands that were impacted by the record spring of 2011 floods on Lake Champlain.[9] Although it is an extreme example, it displays the sensitive environments at risk of being impacted by pollutants associated with flooding events in the basin.

4.0 CLIMATE

The Lake Champlain Basin experiences a sub-humid continental climate, with severe winters. [9] The lake itself is considered a northern temperate lake. In this region, there are four distinct seasons with relatively short summers and long, cold and snowy winters. The higher elevations in the Adirondack and Green Mountains surrounding the lake experience colder temperatures and an average annual precipitation as high as 60 inches (152 cm).[9] The Champlain Valley has warmer average temperatures and an average annual precipitation of as low as 28 inches (71 cm) in part because it resides in the rain shadow of the Adirondack Mountains.[9] The weather in the basin is variable and it is not uncommon to see snowfall from October until May.[15] It is also common to experience at least one major thaw during the winter where temperatures can reach the 60° F (15° C). The Champlain Valley is very susceptible to flooding due to its large basin drainage area and higher levels of mountain snowpack that persist through the rainy spring season.[9]

The Champlain Valley has experienced some extreme weather events including major snowfall, ice storms and tropical storms. In 2011, Tropical Storm Irene tracked up the east coast of the U.S. and dumped 8 inches (20 cm) of rain over portions of Vermont and New York. The precipitation levels exceeded 500-year recurrence levels during this 12-hour storm.[15] The storm caused unprecedented levels of infrastructure damage including structures, roads and bridges. Lake Champlain received a large amount of floodwater including sediment, debris, nutrients and other harmful pollutants. The long-term climate is what has shaped the hydrology of Lake Champlain, but weather shapes the day-to-day conditions. Temperature, wind, and precipitation have profound effects on oil and hazardous material spills. Weather conditions can increase the weatherization, dissolution and emulsification of pollutants and drive their transport throughout the water column.[16] It is paramount to understand the weather patterns as well as current conditions as they can change quickly and influence the fate of pollutants and disrupt mitigation efforts.[16]

4.1 Weather Data:

The following temperature and precipitation data are for South Hero, Vermont, a community on Grand Isle in the middle of Lake Champlain (Table 6). These seasonal averages are a good representation of the climate on the lake. The average weather data are from the 1981-2010 climate normals published by National Climatic Data Center.

Table 6**:** Seasonal Average Temperature and Precipitation.[17]

Period	Precipitation (In)	Avg Low Temp (°F)	Avg High Temp (°F)
Annual	33.64	37.2	55.1
Spring	7.42	34.0	53.5
Summer	11.19	58.8	78.5
Fall	9.75	41.6	57.6
Winter	5.28	14.2	30.3

A full host of historical weather information for the region including temperatures, snowfall, precipitation, and extreme events can be found at the National Weather Service Burlington, VT website: https://w2.weather.gov/climate/local_data.php?wfo=btv.

4.2 Wind data:

Lake Champlain is largely a north-south lake. Many physical processes are directly driven by winds on the lake. Dominant winds drive surface currents, sediment transport, shoreline erosion and subsurface processes like the internal seiche.[7] Seasonally, the lake generally experiences south/southeast winds in the summer months and north/northwest winds in the winter.

There are recreation-based websites that offer detailed wind reports and predictions from sites directly on the lake. The Windfinder website: www.windfinder.com and the Windy App: https://windy.app both provide detailed on-the-water forecasts and current conditions. Table 7 shows data from the Windfinder website that represents average wind speed and direction averaged from up to 7 different weather sites from March of 2007 until January of 2020.

Table 3: Average wind statistics for Lake Champlain taken between 2007 - 2020.[18]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dominant Wind Direction	W	NNW	N	ENE	ESE	ESE	SE	SE	SE	WNW	WSW	NW
Average Wind Speed (MPH)	9	9	10	10	9	9	8	8	9	9	9	8
Average Wind Gusts	23	23	24	24	23	22	22	23	23	23	23	23

4.3 Remote Weather Stations:

There are remote weather stations available to provide real-time data on Lake Champlain. The Forest Ecosystem Monitoring Cooperative (FEMC) operates three primary atmospheric monitoring stations on Lake Champlain. These are excellent options for real-time weather data.

Burton Island- Southwest of St. Albans Bay
https://www.wrh.noaa.gov/mesowest/timeseries.php?sid=UVM01&num=72

Colchester Reef- West of Colchester Point
https://www.wrh.noaa.gov/mesowest/timeseries.php?sid=UVM02&num=72

Diamond Island - West of Kingsland Bay
https://www.wrh.noaa.gov/mesowest/timeseries.php?sid=UVM03&num=72

4.4 Data Buoys:

SUNY Plattsburgh maintains two data buoys in Lake Champlain, one southeast of Valcour Island and one south of Westport, NY in the Main Lake. The data buoys report surface weather and water temperatures in real time. The data can be accessed at: https://leibensperger.github.io/buoy.html. Another data buoy is operated by Vermont EPSCoR and its data can be accessed at the National Data Buoy Center: https://www.ndbc.noaa.gov/station_history.php?station=45166.
**It should be noted that these buoys are removed for the winter to prevent damage from ice cover.

4.5 Ice cover:

During the winter months the Lake Champlain Basin experiences cold Arctic air and significant snowfall. It is common that the shallow and protected bays around the lake ice over during the coldest times of the year. Partial ice coverage can occur as early as November and last until as late as April.[7] Shallow bays and protected areas like Missisquoi Bay, Mallets Bay and Carry Bay will freeze before the Main Lake. Some years the lake freezes over completely, although it occurs less frequently than it had in the past. Historically the lake freezes completely over between January and March. In the last ten years (2009-2019) the lake has completely frozen over three times.[15] The National Weather Service in Burlington, Vermont, utilizes observations and satellite data imagery to provide current ice coverage maps and reports on their website: https://www.weather.gov/btv/recreation. Ice coverage can complicate traditional response tactics and make access to the lake more difficult. Ice can prevent oil from reaching open water or it can trap oil and hazardous materials below the ice where it is difficult to detect and recover.

5.0 RISK ASSESSMENT

Lake Champlain is an important freshwater resource for drinking water, an abundance of natural habitats, and diverse commercial and recreational opportunities. The lake is imperiled by non-point source pollution and aquatic invasive species but point source pollution threats still exist in the basin. The natural resources of the Lake Champlain Basin are at risk from spills of oil and hazardous materials from railroads, vessel traffic, road systems and commercial/industrial infrastructure along the shorelines.

5.1 Railroad:

Railroads in the Champlain Valley pose the largest risk of a major oil or hazardous material spill into the lake. The New England Central Railway (NECR) transports numerous commodities including chemicals and petroleum products.[19] The Vermont Railway (VTR) carries numerous chemical and petroleum products in addition to other freight and aggregate commodities.[20] The Canadian Pacific Railway (CPR) operates the tracks on the western shore of the lake and poses the largest threat to the basin.[21] Along with an array of other chemical and industrial commodities, CPR has transported Bakken crude oil, a light unrefined product from the upper Midwest. The CPR tracks run from Montreal, Quebec, Canada, along almost 100 miles of Lake Champlain shoreline, often within feet of the lake. At its peak in 2014, CPR was transporting as much as 60 million gallons of Bakken crude oil a week along the shores of Lake Champlain. During this same time, crude by rail transport was at a peak across the country and accidents increased 16-fold between 2010 and 2014.[22] Although crude oil transport has declined rapidly since then, the threat still exists as minor changes in the global oil market could quickly increase transports in the Champlain Valley. Trains in the Champlain Valley regularly carry propane, ethanol, gasoline, ammonia, chlorine and various acids (T. Cosgrove, personal communication, November 12, 2019). Extreme weather events, aging infrastructure and human error can all cause accidents and lead to spills of oil or other hazardous materials into the lake or one of its tributaries.

5.2 Vessel Traffic:

Recreational and commercial vessels pose a risk of oil and hazardous material spills on Lake Champlain. Vessel groundings, collisions, allisions and sinking have occurred on the lake do to its many natural hazards and challenging weather. The lake is a popular connection between the Saint

Lawrence River and the Hudson River, attracting a multitude of transient recreational vessel traffic including large yachts throughout the boating season. Residents own more than 7,000 registered motor boats in the counties adjacent to Lake Champlain (K. Stepenuck, personal communication, February 21, 2020). There is a commercial ferry system on the lake with four separate crossings and a total of 10 ferries, 9 of which are powered by large diesel engines, and one which is driven by cables and shore power. There are 21 commercial passenger vessels that use the lake for tours, dinner cruises and other purposes (E. Green, personal communication, February 21, 2019). Other than construction tenders, and the commercial vessels, there are no large capacity vessels on the lake.

5.3 Road Transportation:

The Champlain Valley is home to a significant network of roads and highway systems that are adjacent to the lake or cross one of the hundreds of tributaries. There are eight bridges that cross directly over the lake near Rouses Point, NY, Swanton, VT, Colchester, VT. The largest span bridge is at the Crown Point Bridge, spanning over 2,000 feet (610m).[3] Road traffic poses a threat to the waters of Lake Champlain given the amount of mixed freight and refined fuel cargos that are transported through the region every day. Spills do occur along highways and road systems and threaten to enter the lake if not immediately contained.

5.4 Shoreside Facilities:

Shoreside facilities include any commercial or industrial businesses that support the storage, use or transportation of oil or hazardous materials. Lake Champlain is home to more than 50 marinas most of which offer fueling services.[4] There is a spill risk from each of these facilities which store and distribute diesel fuel and gasoline products. In Burlington, VT, the Global Oil Facility no longer performs over the water transfers of petroleum products but does lie within 250 ft of the water near Oakledge Park. The transload facility is the only bulk refined products terminal in the state of Vermont. It stores large quantities of home heating oil, diesel fuel, kerosene and other refined products that arrive in rail cars and leave on trucks.[23] The International Paper Company operates its Ticonderoga mill next to the lake in Ticonderoga, NY. It is considered a major oil storage facility (MOSF) by the State of New York with a capacity to store over 400,000 gallons of petroleum products as well as chemicals commonly used in manufacturing paper.[24] Both facilities store large amounts of petroleum products and are subject to natural disasters, floods and mechanical failure that could discharge significant amounts of oil or hazardous materials into Lake Champlain.

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