Featured Lake
Lake Champlain

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Research and Management in the Presence of History

Lake Champlain (Figure 1) is one of the most beautiful places on the planet and also one of the most historic. The 193-km-long lake and its 21,326-km^2 drainage basin are shared by the states of Vermont and New York and the Province of Quebec (Figure 2). Lake Champlain is one of the largest lakes in North America, with a surface area of 1,127 km^2, a mean depth of 20 m, and a maximum depth over 120 m. Those of us who study and manage the lake's cultural and natural resources do so with a deep appreciation for the lake's prominent place in North American history and its remarkable physical and ecological features.

Figure 1. View of the broad, open waters of Lake Champlain.

History and Underwater Cultural Heritage

The record of human events in the Lake Champlain Basin and the recent discovery of a vast collection of intact underwater cultural sites offer a cultural legacy that has the potential to enrich generations of residents and visitors. With modern remote sensing equipment, computer systems, and positioning technology, finding shipwrecks has become the easiest part of our work. Determining how to best manage these publicly owned treasures is the next great challenge of our generation.

Human occupation along the shores of Lake Champlain began roughly 12,000 years ago as Paleo-Indian cultures hunted game in the shadow of the receding glaciers. For millennia, native cultures flourished; however, with the 1609 arrival of French explorer Samuel de Champlain (Figure 3), the whole complexion of

Figure 2. Location of the Lake Champlain Basin. Source: Lake Champlain Basin Program.

Figure 3. Nineteenth-century image depicting Samuel de Champlain, along with two Frenchmen and 60 Native American warriors, entering the lake in 24 birch bark canoes. Source: Lake Champlain Maritime Museum collection.

human history in the region changed. For the next 150 years military conflict between France and Britain dominated the Champlain Valley. It was the lake's geographic position in those nations' contested colonial hinterlands that led to its intensive military use, with forts erected along its shorelines and warships sailing its waters. The end of hostilities came with the British victory in 1763, but peace was short-lived with the American Revolution soon engulfing the region.

The early years of the struggle for independence saw considerable activity on Lake Champlain, with the centerpiece of the saga occurring in October 1776 at the Battle of Valcour Island. In this pivotal naval engagement, Commodore Benedict Arnold fought the British in perhaps the most important naval engagement of the war. The naval contest helped to bring about the American victory at Saratoga one year later. With the 1783 Peace of Paris, settlement of the Champlain Valley began in earnest as wooden sloops, schooners, and cross-ferries appeared. Lake Champlain's final military episode occurred during the War of 1812, with a fleet action between the Royal Navy and the U.S. Navy at the Battle of Plattsburgh Bay in September 1814. The decisive American victory helped bring an honorable end to the war. During the remainder of the 19th century, the development of steamboats and the construction of canals transformed Lake Champlain into a key section of a dynamic commercial superhighway.

Lake-port communities grew and prospered as breakwaters, lighthouses, wharves, and warehouses were built to accommodate the ever-increasing lake traffic. Burlington, Vermont and Plattsburgh and Whitehall in New York emerged as the lake's major commercial centers. Today, preserved lake architecture and the historic sites at Mount Independence, Fort Ticonderoga, Crown Point, and Chimney Point are tangible and viewable reflections of the lake's military and commercial past. However, it is from recent underwater surveys that we now know that a vast collection of intact wooden shipwrecks, also reflecting on the years of military conflict and commerce, had found their way to the bottom of the lake.

The collection of intact wooden ships resting on the lake's bottom is, by any measure, extraordinary. In the almost three decades of survey, documentation and development of management practices focused on this previously unknown collection, the shipwrecks have added significantly to our understanding of the past. The collection contains Native American watercraft, French and British warships from the Colonial period, and American and British warships from the Revolutionary War and the War of 1812. One of the most remarkable submerged cultural resources is not a ship at all, but a "Great Bridge" built by American forces during the winter of 1777 to span between Fort Ticonderoga and Mount Independence. Commercial boats, particularly the once-numerous canal boats, make up the largest number of submerged ships. The *Phoenix*, the oldest known surviving steamboat and the unique Burlington Horse Ferry are very special survivors of their day. The discovery of the *General Butler* in 1980 led to a rediscovery of the lake's innovative sailing-canal boats. The Vermont Division for Historic Preservation provides reasonable diver access to appropriate underwater sites through the "Underwater Historic Preserve Program," one of the first in the country (Figure 4).

The Lake Champlain Maritime Museum is a leader in the study, interpretation, and preservation of the region's shipwrecks. The museum has relationships with many federal and state agencies and educational institutions to assist with the best management of the region's submerged collection. To further this mission, the Maritime Museum has built two large and archaeologically correct replicas to help engage the public in the history and archaeology of the region. The Revolutionary War gunboat, *Philadelphia* II, is modeled after one of Benedict Arnold's warships that sunk at the Battle of Valcour Island on October 11th, 1776. The *Philadelphia* II was launched in 1991 and helps tell the story of this important chapter of American history. The canal schooner *Lois McClure* is a full-sized working replica patterned after two shipwrecks built in 1862 and which now are sunk in Burlington Harbor (Figure 5). Since its launching in 2004, the *McClure* has traveled the region's waterways as an ambassador of the lake's history and underwater resources.

In 1996, Lake Champlain Maritime Museum, in partnership with Middlebury College and with public-private funding, initiated a landmark "Whole Lake Survey," a ten-year project to systematically inventory the entire bottom of Lake Champlain. Launched as a response to the invasion of zebra mussels, the survey, utilizing state-of-the art survey equipment, located 80 new shipwrecks and produced a new bottom bathymetry map of Lake Champlain. Arguably, the most important shipwreck discovered is the *Spitfire,* a survivor from Benedict Arnold's Valcour Island fleet. The 1776 warship sits upright, in deep water, with its mast still standing and its bow cannon still searching for the enemy (Figure 6). Determining how best to manage and preserve *Spitfire* for future generations is a complicated task. Our mission is to help define the best management options to preserve and share this important cultural legacy for this and future generations.

In 2009, the region will commemorate the 400th anniversary of Samuel de Champlain's brief, but profound, visit to the lake that now bears his name. It will provide an opportunity to re-examine the incredible record of history that helps define our world today. This cultural legacy has left us with special places both around and under the lake that provide a window into the Old World and the New. These places offer fascinating stories and important lessons that give Lake Champlain the potential to provide a very special cultural perspective.

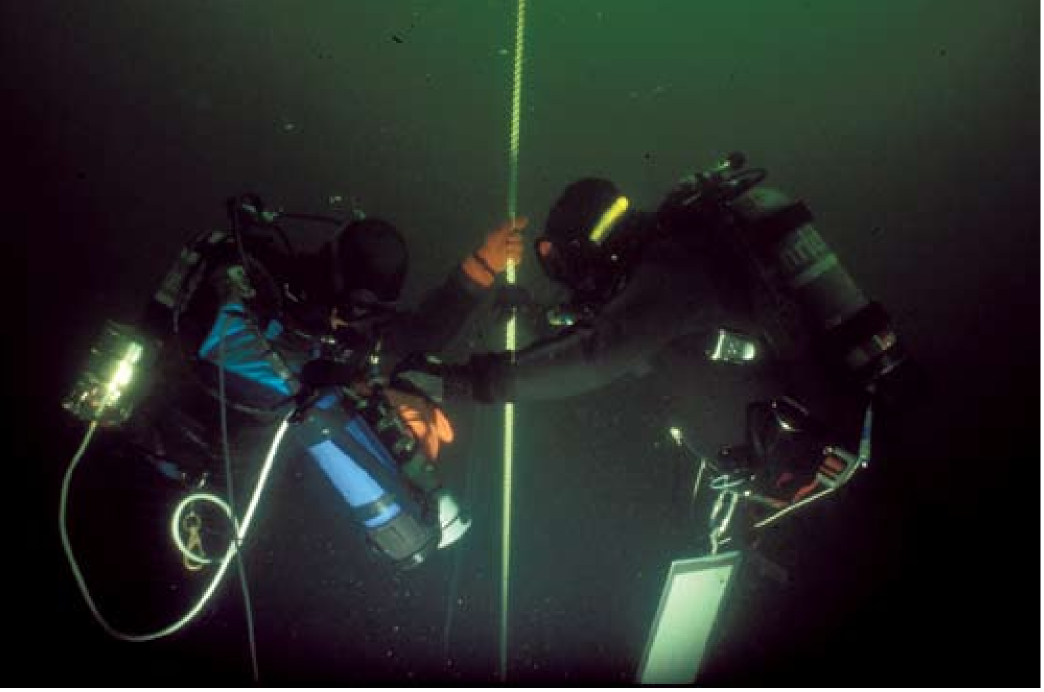

Figure 4. Divers exploring a site in the Lake Champlain Underwater Historic Preserve. Source: Lake Champlain Maritime Museum collection.

Figure 5. The canal schooner Lois McClure*, a full-size working replica shown here with her trusty companion, the tugboat* C. L. Churchill. Source: Lake Champlain Maritime Museum collection.

Lake Hydrodynamics

The movement of water within Lake Champlain is amazingly complex and still not completely understood. Looking at the narrow, elongated lake nestled between the Adirondack Mountains to the west and the Green Mountains to the east, one might expect that the circulation of water would be virtually unidirectional. Lake Champlain drains directly into the Richelieu River and eventually into the St. Lawrence Seaway to the north, thus it is quite understandable that most people within the basin view this body of water like a large river. However, beneath the surface the flow is far more complicated.

So what makes Lake Champlain so unique among the other lakes in the world? The answer appears to be that it lies between two mountain ranges that preferentially channel the wind northward over Lake Champlain's long North-South axis and second, its unique bathymetric structure and size. The wind sets up an extremely long-standing wave or *seiche* (~200 km) that is hidden from everyone's view. If you have rocked your coffee cup from side to side and looked at the resulting motion of the fluid as it sloshes back-and-forth, you have actually set up what is known in physics as the "fundamental standing wave". Though it's difficult to interpret its direction of motion because the coffee simply rises and falls on either end of the cup, it does oscillate with a very stable period. Every closed container has its own fundamental seiche that can be mathematically determined based on the length of the container and the depth of the fluid within it. Lake Champlain's fundamental surface seiche is about four hours, a period that has been confirmed using a series of water level gauges around the perimeter of the lake. This surface seiche has elevation changes of only a few inches and does not significantly contribute to the circulation dynamics of the lake.

The unique hydrodynamic aspect of Lake Champlain is its hidden, internal seiche. The internal seiche is the driving force behind a majority of the circulation of Lake Champlain during periods of thermal stratification (April to November). In contrast to the surface seiche, the internal seiche is found along the boundary separating the warm upper and cold deep layers of the lake (i.e., the metalimnion). Since the density difference between the upper and lower layers is significantly smaller than at the air-water boundary, the internal seiche moves nearly 30 times slower than the surface seiche (~4.5 days) and has a larger wave height.

The working mechanics of an internal seiche are not obvious. Two masses of water are moving in response to this large wave existing at the lake's metalimnion. Within the lake, these bodies of water are placed into motion by wind forcing (Figure 7). Under a northward blowing wind, the warm upper layer of water

Figure 6. Artist's presentation by Ernie Haas of the gunboat Spitfire *from Benedict Arnold's Valcour Island fleet as she rests in the deep water of Lake Champlain.* Source: Lake Champlain Maritime Museum collection.

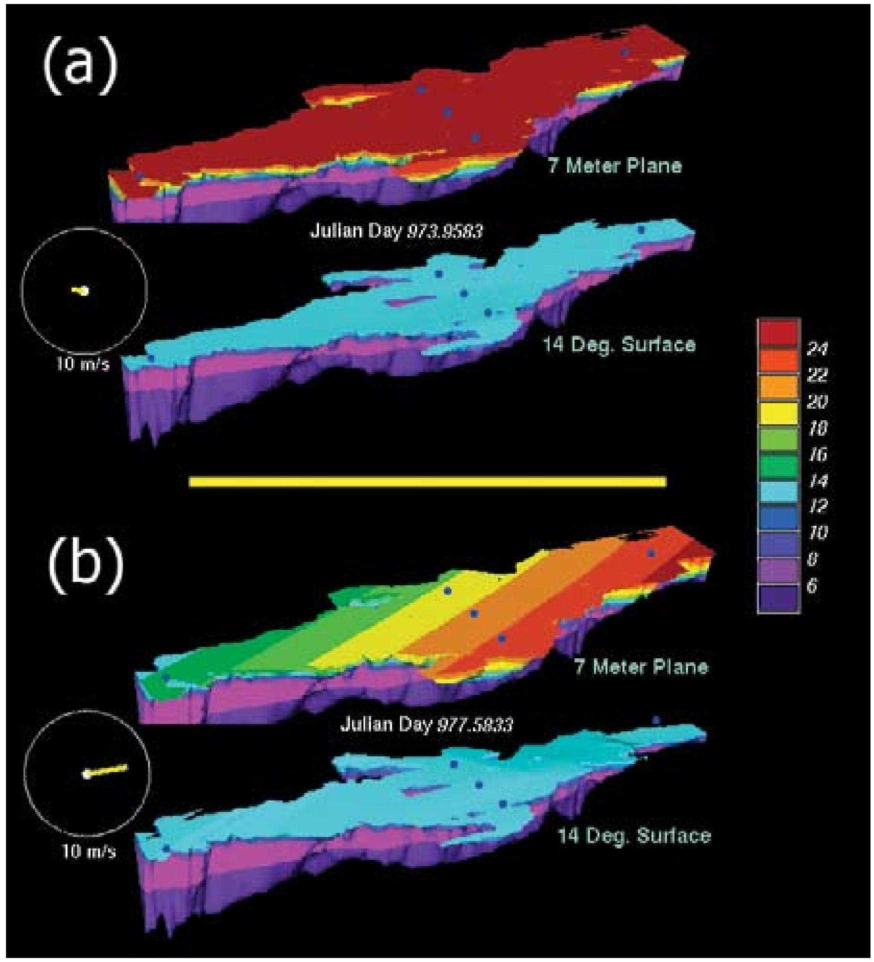

Figure 7. Two-time steps from an observational model of Lake Champlain using four months of hourly temperature data (from five subsurface moorings shown as blue dots) showing the various characteristics of its internal seiche from Valcour Island in the north to Thompson's Point in the South. The first time step (a) shows both temperature at a horizontal plane of 7 m (upper) as well as the 14°C isosurface (defining the center of the metalimnion) during low wind conditions. The wind vector is shown within the circle that defines 10 in/s wind velocity. In this low wind situation, the upper-level temperature field across the entire lake is quite uniform. The 14°C isosurface is also relatively flat. Within six hours of the onset of 8 m/s winds to the north, one can see a rapid transport of most of the warm, upper-level water to the north end of the lake, which concurrently depresses the metalimnion. In the southern sector of the lake, deep cold water is brought up near the surface as the metalimnion rises.

moves toward the north end of the lake and piles up along this boundary. This increased elevation of the lake surface (about 10 cm) is compensated by the subsequent depression of the metalimnion directly under it, which forces the deep body of water to move south and rise vertically at the southern boundary. Once the wind weakens, the metalimnion tries to go back to its neutral position but overshoots due to momentum, thus beginning the oscillation process of the internal seiche (somewhat like that of a teeter-totter).

In order to conserve mass throughout the system, water that moves in one direction in the upper layer must move in the opposite direction within the lower layer. This pattern reverses every half period, or roughly 2.25 days. Acoustic Doppler Current Profilers (ADCPs) and temperature sensors on long-term subsurface moorings have been used to capture the interrelationships of water circulation and metalimnion movement at the northern (Valcour Island) and southern (Thompsons Point) sectors of the lake (Figure 8). The isotherms show the metalimnion rising and falling at both ends of the lake while being 180° out of phase from each other. Also quite apparent is that above and below the metalimnion, water is moving in opposite directions. As the metalimnion changes its position vertically (i.e., from shallow to deep or deep to shallow), water motion also changes. Two and a half years of observations at Thompsons Point (Figure 9) have shown that the internal seiche never stops so long as the water is stratified.

The more we study the internal seiche, the more complex it seems. For instance, the Earth's rotation affects this very long period wave and changes it from a simple teeter-totter-like oscillation to that of a rotating Kelvin wave that moves counterclockwise around the perimeter of the lake. Higher frequency variants of the wave, and reflection off the basin's walls, can change these individual waves into very complex waveforms. Yearly stratification variations within the lake (e.g., warmer versus colder summers) can change the period of oscillation between 3.8 - 5.3 days and wind variations can induce internal oscillations of 7.1 and 10.7 days. Combining all of the above with a complex basin of bays, submarine ridges, islands, shoals, steep cliffs, and natural constrictions, one begins to acknowledge that water flow within this lake is exceedingly complex.

The internal seiche has three dynamic regimes: linear, nonlinear, and extremely nonlinear. The more typical linear mode, where the metalimnion represents a rigid plane, is produced by very light winds with accompanying low volume water transport. Under higher wind, the metalimnion can have a slight nonlinear or warped appearance. Under these conditions, the metalimnion can be pushed down at such a significant rate that it creates a backward traveling "surge" (Figure 10). Under even stronger wind forcing conditions, the metalimnion can actually be driven down far enough to intersect with the lake bottom at depths of over 200 feet. The release of this highly anomalous condition back to a neutral state forces the cold deep water to move rapidly across the bottom of the lake as a "gravity current" with speeds of up to a knot. This high-velocity current can easily resuspend sediments and redistribute them throughout the lake. High-speed currents such as these can also create very unique sediment bed forms called furrows (Figure 11) through the formation of helical cells in the water that actually coalesce heavier sediment particles and gouge out troughs in the softer sediment beneath. Seismic evidence shows that these furrows have been maintained over thousands of years.

One final unique feature of the hydrology of the lake is the presence of several fields of "pockmarks", which are created by groundwater moving upward through the sediments from fractures in the deep basement rock of the lake. The largest pockmark in Lake Champlain, known as "The General" is located in Burlington Bay (Figure 12). It is approximately 40 m in diameter and is ~10 m deep. This pockmark has been resident within Lake Champlain for over 10,000 years, and has laterally migrated through time. However, water budgets do not show pockmarks to produce significant amounts of water to the overall volume of the lake.

While it is impossible to go through all of the new and exciting research that is going on in Lake Champlain, one last comment should be mentioned regarding its climatic history. Over the past 14,000 years, Lake Champlain has gone through three major phases of

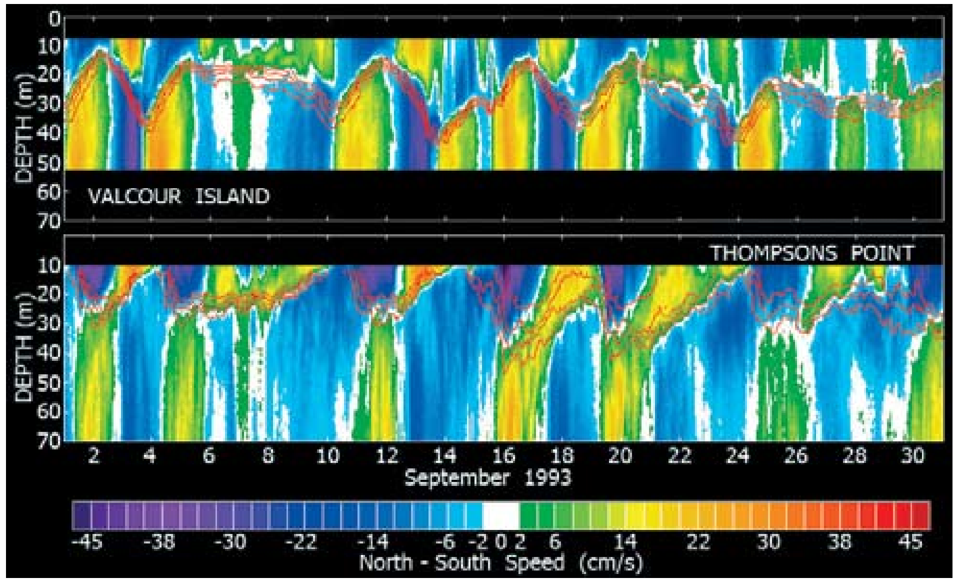

Figure 8. Composite views of metalimnion structure superimposed upon north-south water velocity obtained from ADCPs at Valcour Island and Thompsons Point during September 1993. Red lines define the 13, 14, 15 and 16°C isotherms which represent the core of the metalimnion. Northward and southward velocities are positive (green to red) and negative (blue to purple), respectively. Very consistent out-of-phase relationships between isotherms and velocities are evident in these two regions since Valcour Island and Thompsons Point are roughly the same distance away from the nodal point located at the latitude of Burlington, VT. This supports the general premise that the uninodal internal seiche dominates the dynamics of the main, central lake. East-West velocities were removed since they compose only a very small component of the total velocity field.

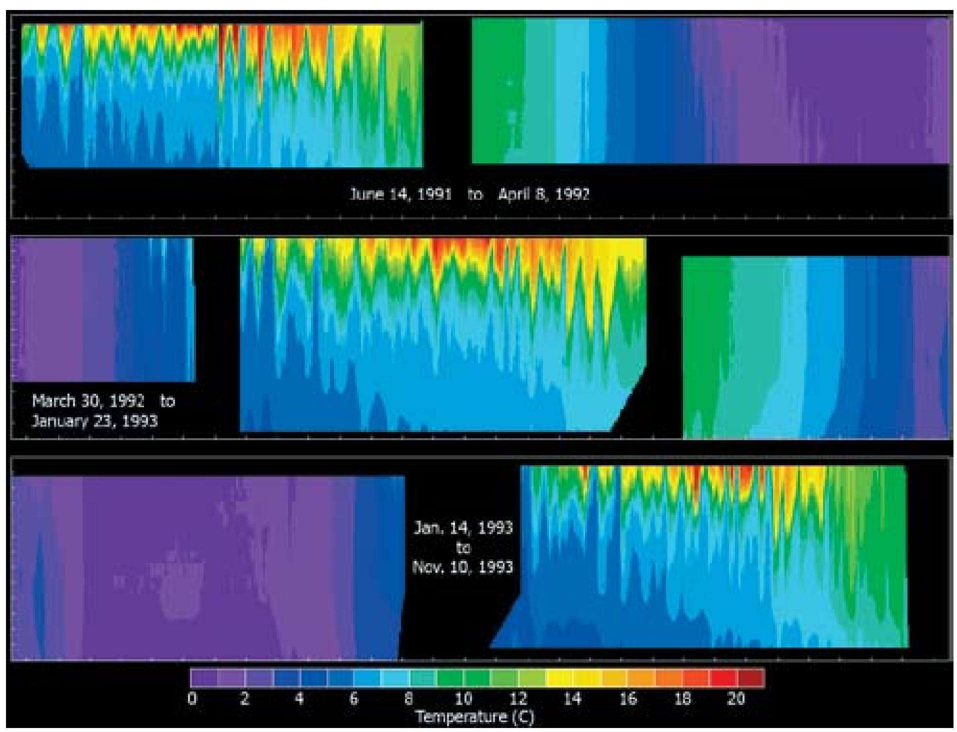

Figure 9. A 2.5 year composite of temperature observations at the deepest part of Lake Champlain located between Thompsons Point (VT) and Split Rock (NY). The vertical axis is depth which goes from 10 to 75 m. Regions of black define times when the instruments were pulled out of the lake, refurbished and then reinstalled. When stratification is present, the internal seiche is always present.

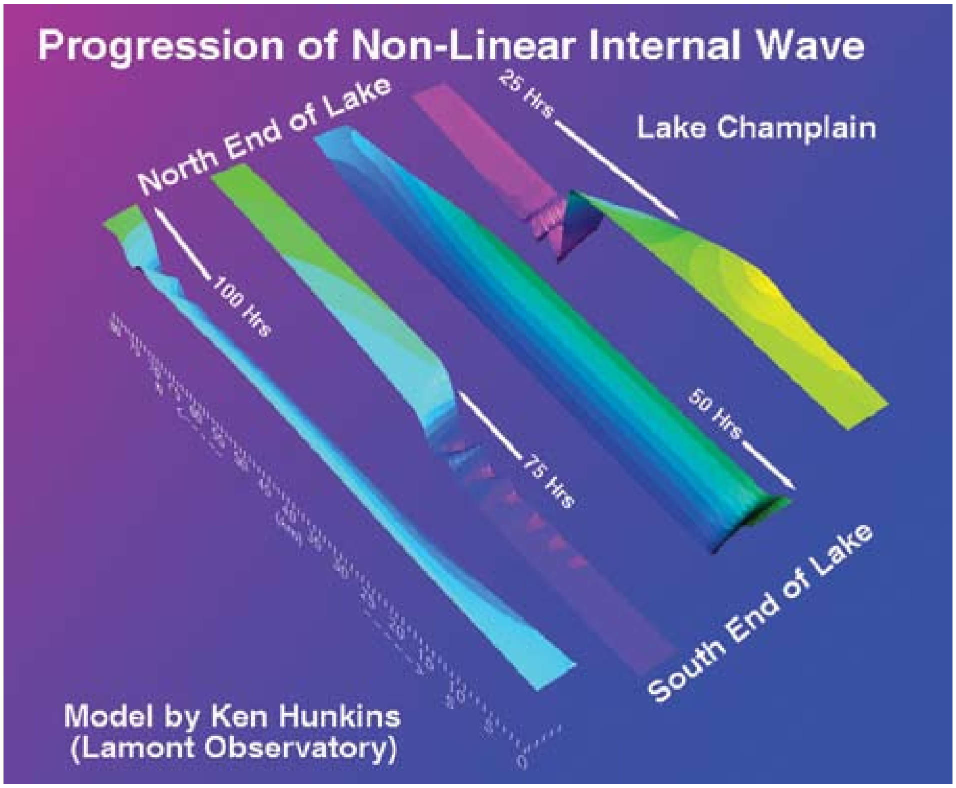

Figure 10. One of the unique, nonlinear characterizations of the internal seiche of Lake Champlain known as the surge. The four discrete panels, from top to bottom, characterize the movement and structure of the surge every quarter period from a one-dimensional rectangular model created by Dr. Ken Hunkins of Lamont-Doherty Earth Observatory. This high amplitude (10-30 m) "solitary-like" wave propagates upwind initially (25 hrs), is reflected at the southern boundary of the lake (50 hrs) and then propagates through to the northern end of the Lake (75 hrs), there to be reflected again toward the south end of the Lake (100 hours). Courtesy of Dr. Ken Hunkins.

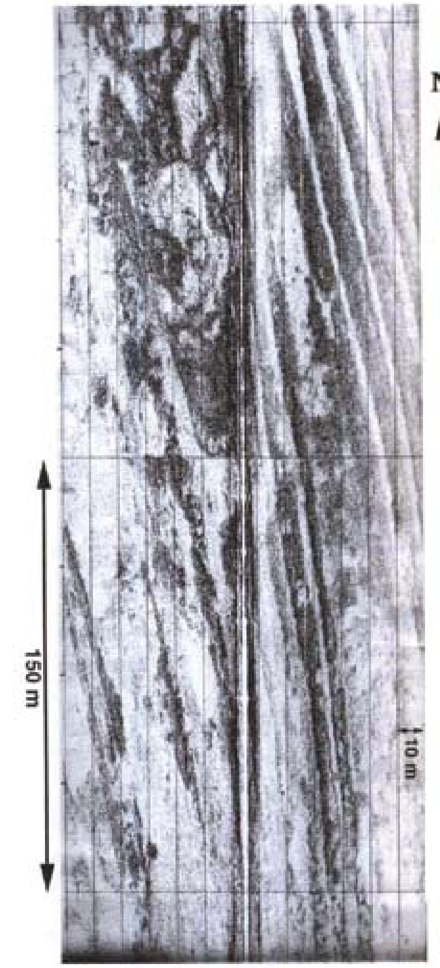

Figure 11. Side scan record of furrows observed at ~200 feet in the deep central channel east of Valcour Island. The furrows are best defined in the upper right-hand quadrant of the image as nearly parallel white lines which represent deep channels of approximately 1 to 3 m.

development. First, when the glaciers were receding northward into Canada, large proglacial lakes (known collectively as Lake Vermont) were present. Second, the influx of Atlantic Ocean water into the region created a brackish body of water known as the Champlain Sea that lasted from approximately 13,100-9,000 years ago. Finally, as the continental landmass finally rebounded and cut off the flow from the North Atlantic, present-day Lake Champlain was created. All of these phases created very unique deposits in the bottom of Lake Champlain (Figure 12) and within them are unique tracers as to the climate and its variability. It is expected that within the next several years, long sediment cores (over 60 m) will be taken in these deposits and analyzed for climate variations over the past 14,000 years.

Phosphorus Management

Lake Champlain's complex morphometry and hydrodynamics create a variety of water quality environments within the lake (Figure 13). Some of the shallow and partially enclosed areas such as Missisquoi Bay and St. Albans Bay, experience severe algal blooms resulting from the high phosphorus levels there (30-50 µg/L), and the South Lake is choked with aquatic plants. Deep, open-water regions such as the Main Lake have lower phosphorus levels (near 10 µg/L), and algal blooms are much less frequent in those areas.

Controlling eutrophication by reducing phosphorus is probably the greatest challenge for water quality management in Lake Champlain. With the lake's 21,000-km^2 watershed (Figure 2), coordination among Vermont, New York, and Quebec is essential. Fortunately for the lake, the U.S. federal Lake Champlain Special Designation Act of 1990 established the Lake Champlain Basin Program for the purpose of creating and implementing a comprehensive environmental management plan for the lake, with involvement of all of the different governments and stakeholders.

The state and provincial governments have worked with the Lake Champlain Basin Program to put in place the key elements of a comprehensive phosphorus management plan for the lake. New York, Quebec, and Vermont signed a water quality agreement in 1993 that established a consistent set of total phosphorus concentration criteria for each segment of Lake Champlain. These annual mean lake phosphorus targets generally range from 10-25 µg/L (Figure 13). Vermont and New York developed a phosphorus budget and mass balance model that provided a way to quantitatively link phosphorus loads from all sources to in-lake water quality conditions. In 1996, Vermont and New York negotiated a

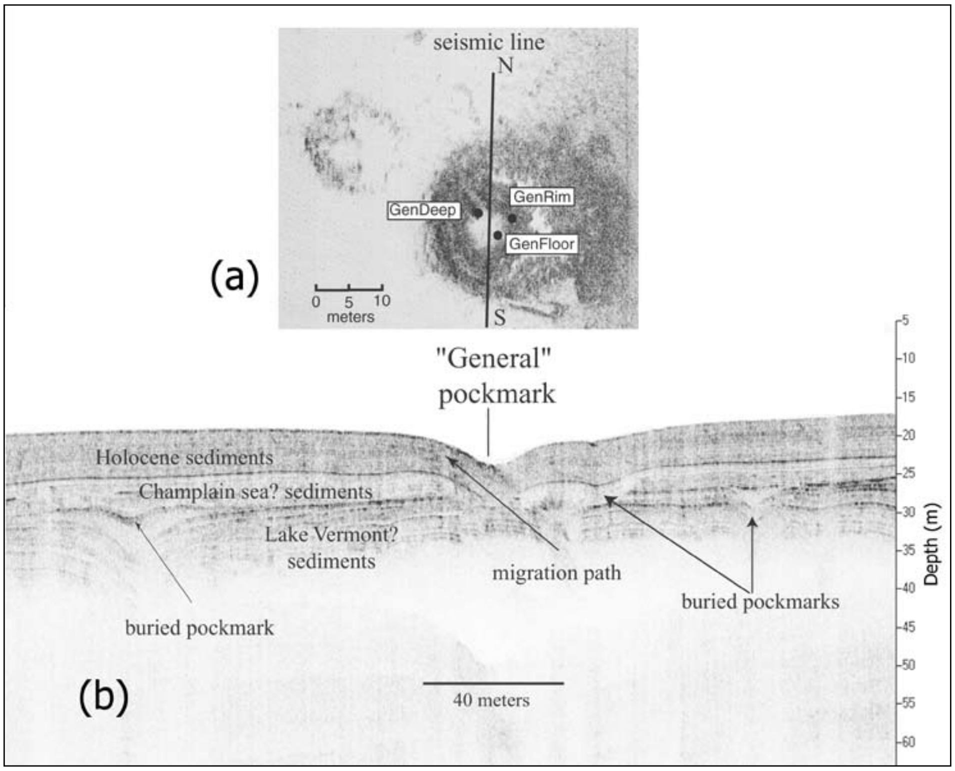

Figure 12. Side scan sonar image (a) of the largest pockmark in Burlington Bay known as "The General". Dots define piston cores taken at the deepest spot, the flat central region and along the rim. The north-south seismic line through the pockmark is shown below. (b) An extended north-south seismic line showing the three major sediment depositional regimes (Holocene or Lake Champlain, Champlain Sea and Lake Vermont). Lateral migration of "The General" can also be seen over several thousand years of depositional history as well as evidence of older, extinct pockmarks that appear to have been terminated near the Lake Vermont – Champlain Sea interface.

division of responsibility for phosphorus reduction, and used the lake phosphorus model to establish preliminary target loads in the management plan adopted by the Lake Champlain Basin Program. A corresponding phosphorus reduction agreement was signed by Vermont and Quebec in 2002 for the shared watershed of Missisquoi Bay. Finally, Vermont and New York completed a Lake Champlain Phosphorus TMDL (Total Maximum Daily Load) in 2002 that defined total loading capacities and allocations for each sub-watershed in the basin, and also included detailed implementation plans.

Past efforts to reduce phosphorus loading to Lake Champlain have focused on point source discharges as a first priority. There are nearly 100 municipal and industrial wastewater treatment facilities in the Lake Champlain Basin. Thirty years ago, about half of the phosphorus loading to Lake Champlain came from these point sources. Since then, Vermont, New York, and Quebec have been funding upgrades to these facilities to install advanced wastewater treatment for phosphorus removal, and as a result point source loads to the lake have declined significantly (Figure 14). Today, less than ten percent of the phosphorus loading to Lake Champlain comes from wastewater discharges. The vast majority of lake clean-up efforts are now appropriately focused on nonpoint sources.

Vermont is pursuing the phosphorus reductions called for in the TMDL through one of the largest water quality initiative in the state's history, known as the Vermont "Clean and Clear Action Plan." Over the last four years, more than $65 million in state and federal funds have been committed to support a wide variety of programs with phosphorus reduction benefits, including the following. Many of these same activities are underway in New York and Quebec, as well:

- Continued wastewater treatment plant upgrades
- Stricter water quality regulations for farms
- Agricultural practices such as manure storage, barnyard runoff control, nutrient management planning, and riparian buffer protection
- River corridor protection and restoration (Figure 15)
- Enhanced stormwater permitting requirements
- Erosion control on back roads and construction sites
- Riparian wetland restoration
- Local municipal zoning for water quality protection
- Public education about nonpoint source pollution reduction
- Continued water quality monitoring by agency staff and citizen volunteers

With excessive phosphorus levels and algae blooms existing in parts of Lake Champlain (Figure 13) and the large amount of public funds being spent on the problem, lake managers are coming under intense public pressure to show results. However, documenting actual reductions in nonpoint source phosphorus loading to Lake Champlain is proving to be a difficult challenge. Monitoring of phosphorus loads at 18 major tributary rivers over the period of 1990-2004 has shown mixed results (Figure 16). Almost all of these rivers are delivering phosphorus loads in excess of their TMDL targets. However, there may be some hopeful signs in the data. Several rivers are showing downward phosphorus trends when natural hydrologic variability is controlled in the statistical analysis.

There are reasons why water quality improvements have been slow in spite of the recent acceleration of clean-up efforts. Controlling nonpoint sources is not as simple as building treatment plants. Gaining the cooperation of landowners to change traditional practices takes time. It can take years or decades to achieve full results from the nonpoint source control practices listed above because of the time it takes for soils, vegetation, river corridors, and the lake to respond to better management. We expect that the monitoring data will eventually show more widespread phosphorus reductions, but it will take a sustained implementation

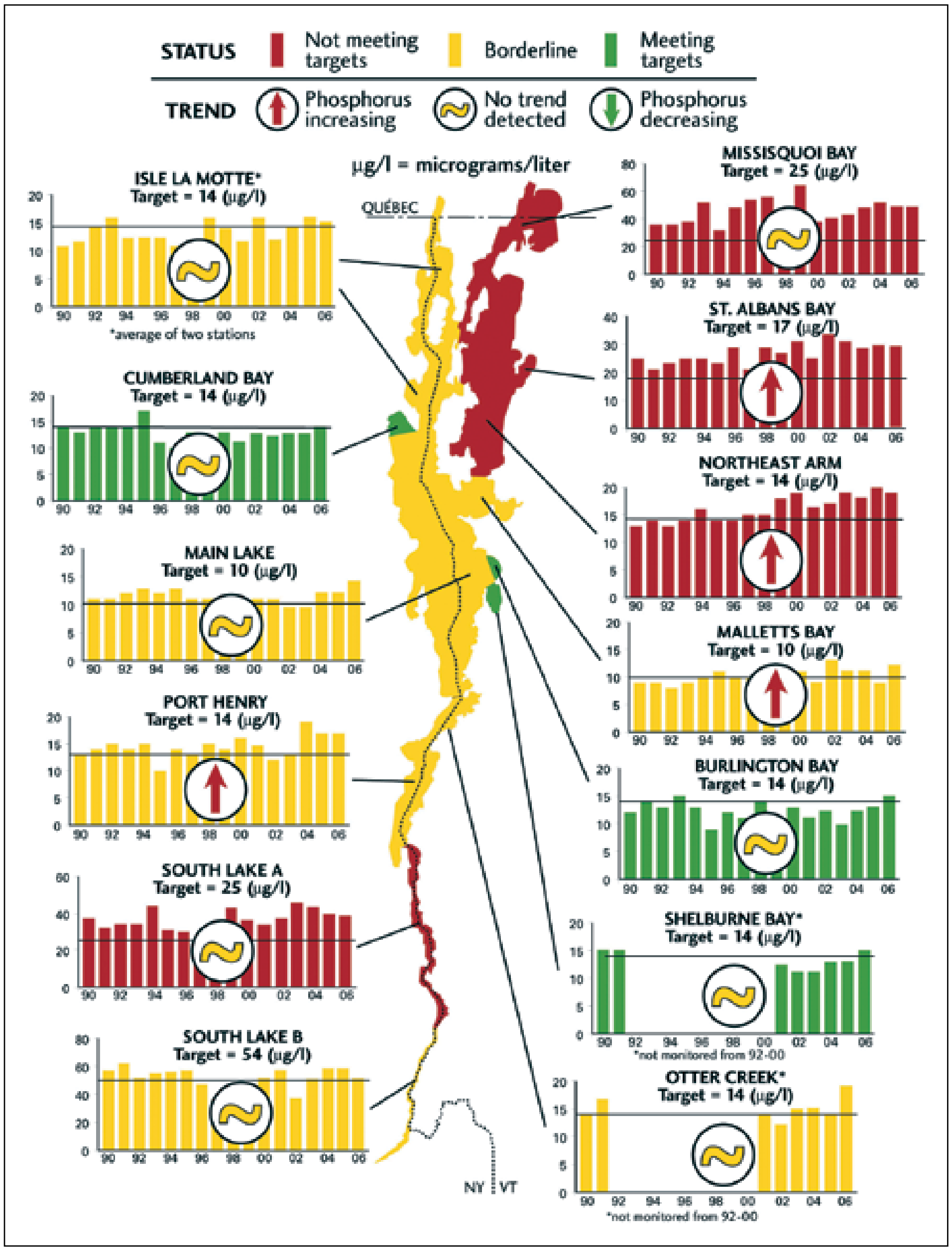

Figure 13. Status and trends in total phosphorus concentrations in Lake Champlain, 1990-2006. Status assessments are relative to the in-lake phosphorus targets adopted by Vermont, New York, and Quebec. Trend indicators are based on linear regression of annual mean phosphorus concentrations over the period of 1990-2006. Source: Lake Champlain Basin Program *2005 State of the Lake Report* (updated with data through 2006).

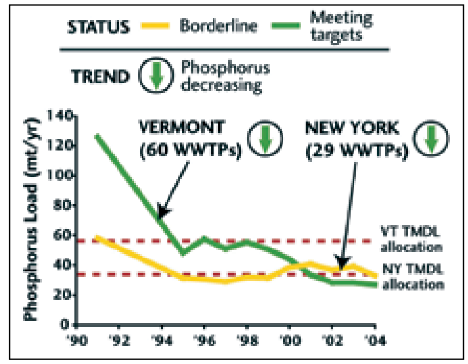

Figure14. Trends in wastewater phosphorus loading (metric tons per year) to Lake Champlain from Vermont and New York, 1991-2004, and status in relation to the wasteload targets established in the Lake Champlain Phosphorus TMDL. Source: Lake Champlain Basin Program *2005 State of the Lake Report.*

effort over the long term to achieve success.

Lake Ecology

Aquatic ecologists and watershed scientists at the University of Vermont and its sister institutions throughout the region have spent decades investigating the mysteries of the Lake Champlain Basin. Because the different sections of Lake Champlain vary so much physically, it is like studying half a dozen lakes, not one. Its watershed is huge, covering almost 19 times as much area as the lake itself.

The biodiversity of the lake is high, with both shallow and deep, and thus warm- and cold-water communities of plants and animals. These communities reflect the lake's glacial origins (just like the Great Lakes), its large and geologically diverse watershed, and its many connections to adjacent water bodies. The natural communities of Lake Champlain are a highly valued part of the region's natural heritage and form the basis of a multi-million dollar economy that includes swimming, boating, diving, fishing, birding, and many other forms of wildlife watching.

There is little doubt that poor water quality is a significant threat to the living resources of Lake Champlain. Northwestern New England, however, is much less industrialized and has a lower population density than the areas surrounding the Great Lakes and many other nationally significant lakes. Therefore, Lake Champlain has not experienced the same level of toxic pollution as many other lakes. While mercury pollution, largely from atmospheric sources, is a challenge, and has resulted in fish consumption advisories for some large predatory fish such as walleye, bass, and lake trout, the greatest water quality concern is eutrophication.

Like many other freshwater lakes all over the world, Lake Champlain now experiences fairly regular toxic cyanobacteria, or blue-green algae, blooms in the most eutrophic sections of the lake (Figure 17). Blue-green algae have always been a component of the Lake Champlain phytoplankton community, but until the new millennium, they did not dominate the plankton. Not only do these blooms pose health risks to people and pets, but they provide a different support to the plankton-based food web.

It remains a mystery why these blooms have become more pervasive

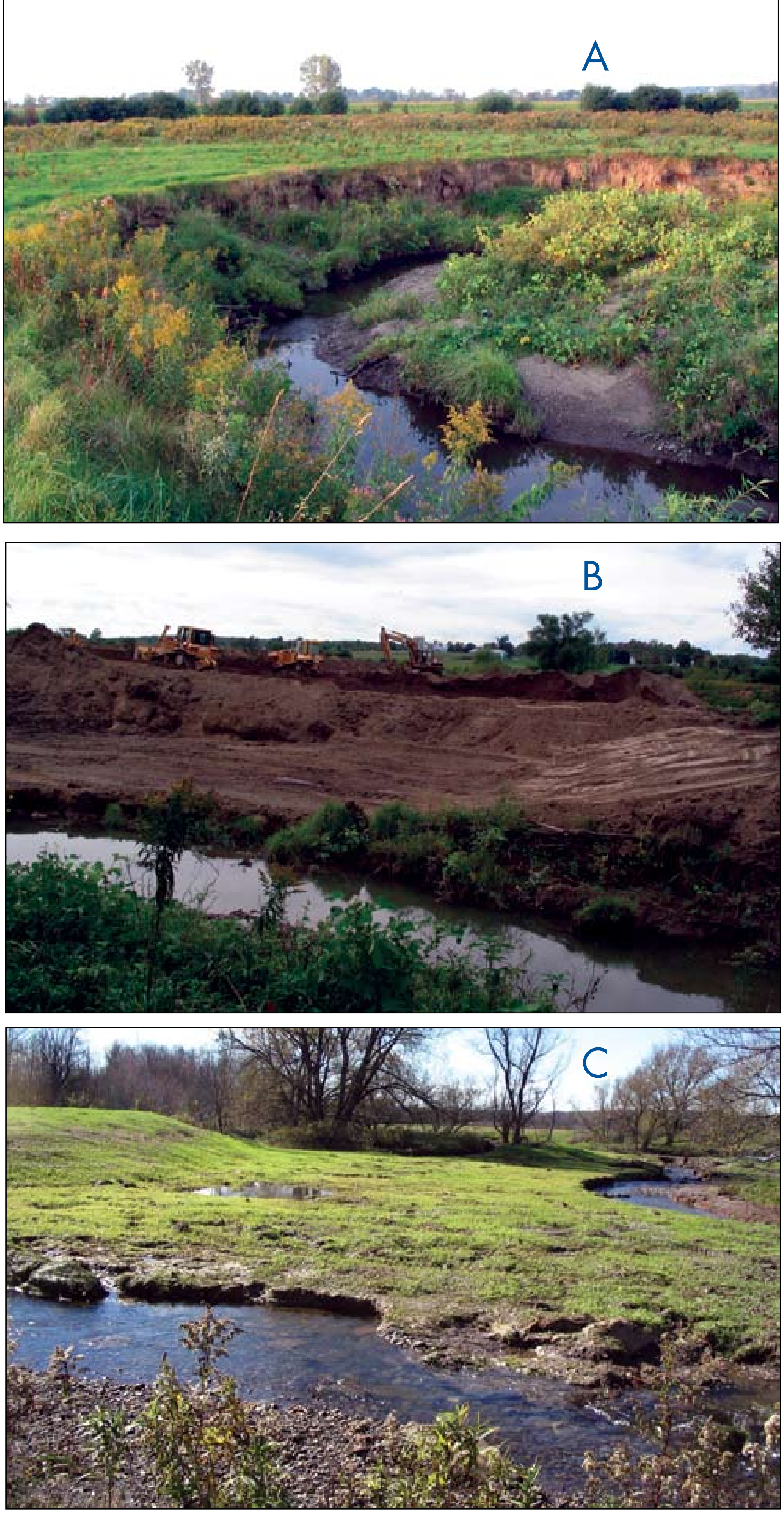

Figure 15. Flood plain restoration project on Rugg Brook in the St. Albans Bay watershed. (A) Rugg Brook before restoration showing incised and eroding stream channel. (B) Construction in progress. (C) Rugg Brook with restored access to its flood plain after completion of the project. Source: Vermont Department of Environmental Conservation River Management Program.

because phosphorus loading has not significantly increased in most areas (Figure 16). It may reflect a combination of other factors, like warming water temperatures associated with global climate change, changes in the ratio of nitrogen to phosphorus in the lake, and sediment loading, which often accompanies nutrient loading from non-point sources. Scum-forming blue-green algae can out-compete other algae when suspended sediment loads are high. It is also possible that the invasion of non-native, or exotic species into Lake Champlain is playing a role.

There are literally dozens of plants and animals that are not native to Lake Champlain, but are now firmly part of its ecosystem. And these species can have myriad effects on native species and human uses of the lake. White perch, a non-native fish in Lake Champlain, has thrived in shallow eutrophic sections of the lake, and alewives, the lake's most recent fish invader, are also becoming common in these habitats. Both these fish eat zooplankton, small animals that float continuously in the water (Figure 18). And here is where the feedback to algae might occur. If the density of zooplankton is declining because of fish grazing, consumption of phytoplankton in the lake will also change. Lower grazing rates by zooplankton might allow large colonies of blue-green algae to form and to dominate. Those zooplankton that remain may also offer a very different menu to other species that feed on the plankton as well.

Exotic species may pose other interesting dilemmas, too. For example, in large areas of the lake that are now infested with Eurasian watermilfoil, a densely growing non-native aquatic plant, other cascades of changes have been observed. The density of these plants can make boating and swimming difficult, but some native fish thrive in their midst. Young yellow perch, a favorite catch of anglers on Lake Champlain, thrive in these weedy beds because they are less visible to their predators when hiding among the weeds. So the abundance of yellow perch has increased. However, the average size of these fish has declined because visually feeding yellow perch seem to get less food in these beds, and thus grow more slowly. Fish predators, like bass and pike, lurk around the perimeter of these beds, as any good

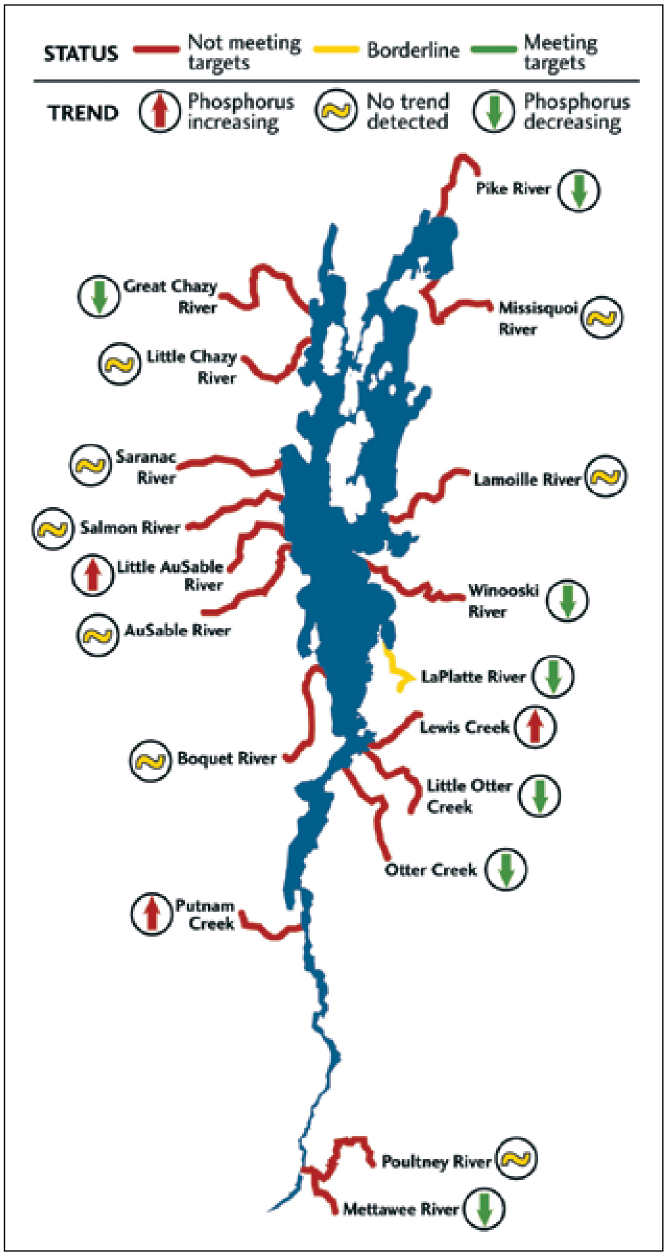

Figure 16. Status and trends in tributary phosphorus loading to Lake Champlain, 1990-2004. Status assessments are relative to watershed loading targets established in the Lake Champlain Phosphorus TMDL. Trend analyses were conducted on flow-adjusted total phosphorus concentrations. Source: Lake Champlain Basin Program 2005 State of the Lake Report.

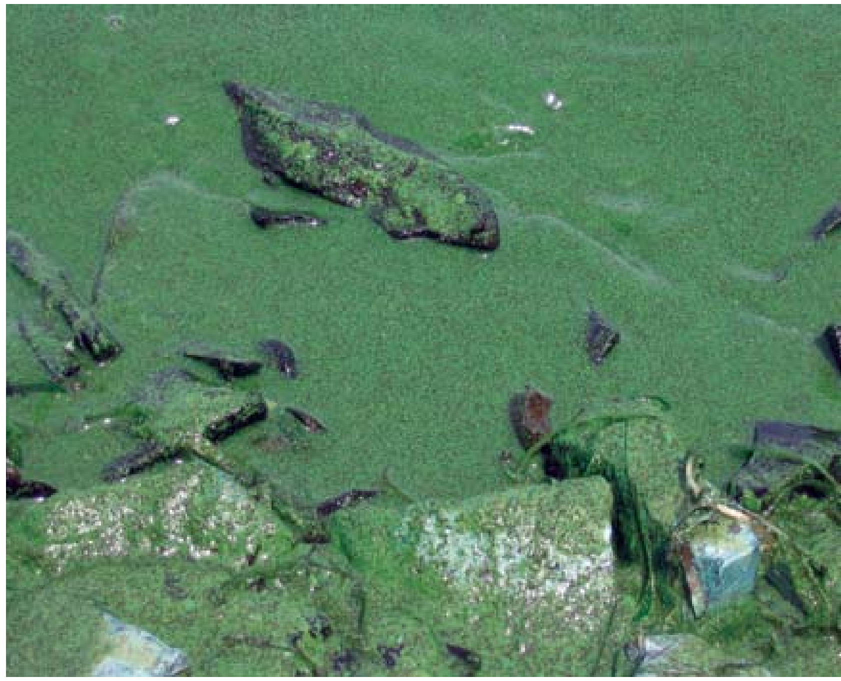

Figure 17. A blue-green algae bloom in Missisquoi Bay.

fisherperson has learned, and take advantage of wandering prey.

Another invasive exotic species, the zebra mussel, has also changed the community dynamic in the lake. Zebra mussels are filter feeders, consuming small plankton from the overlying water column. As their numbers have expanded, especially in the South Lake where they have reached very high densities, water clarity has increased. As light now penetrates deeper into the water column, aquatic plants like Eurasian watermilfoil can expand their range and grow more densely.

There are other winners and losers with zebra mussels as well. Lake Champlain used to have an incredible density and high diversity of native mussels. As zebra mussels grow on these native mussels (to them, a native mussels is just a nice place to attach), the native mussels lose out. Native mussels are filter feeders, too, but now they are feeding on water that zebra mussels have filtered first – and they must contend with a constant rain of zebra mussel waste. The natives also cannot move as easily, or sometimes, even close their shells. Thus, Lake Champlain is losing its native mussels at a rapid rate.

Small, shrimplike amphipods and other invertebrates, however, love to live in the nooks and crannies of a zebra mussel bed, so the density of these animals has increased dramatically. Bottom-feeding fishes are increasingly taking advantage of this food. Some fish, like freshwater drum and pumpkinseed sunfish, have even learned to eat zebra mussels, and this exotic species can now comprise 40 percent of their summer diet.

Now the circle can come all the way back to those cultural treasures that tell us so much about the history of people in the Lake Champlain basin, the historic shipwrecks on the bottom of the lake. Those shipwrecks that lie in shallow water are being covered with zebra mussels, too (Figure 19), and over the long term, zebra mussels will hasten their deterioration by increasing the rate of corrosion of their iron fastenings and ornaments.

Conclusion

Lake Champlain is a treasure – its unique culture, history, circulation dynamics, and biodiversity offer much to anyone who visits its shores or explores its depths. It gives identity to Vermont, and even to the broader region. Even more, Lake Champlain offers the opportunity to learn about the workings of nature and the intimate connections between people and their living world in a system that has a manageable size. It is the connections and feedbacks in natural systems that offer the greatest challenges for environmental managers of the future. But a healthy lake is a

Figure 18. Lake Champlain filter-feeding zooplankton of the genus Daphnia.

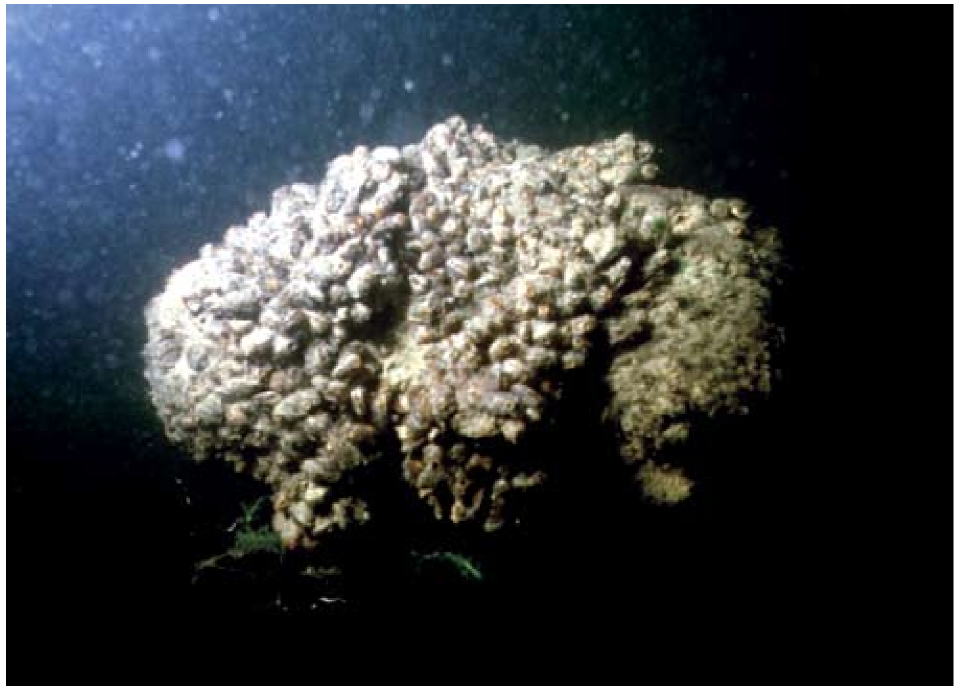

Figure 19. Zebra mussels covering the sternpost of an historic Lake Champlain shipwreck.

realistic goal for Lake Champlain. We have learned much about the mysteries of Lake Champlain, and are committed to learning, appreciating, and protecting the full breadth of her secrets.

Links

Lake Champlain Maritime Museum
http://www.lcmm.org/

New Bathymetry of Lake Champlain
https://cat.middlebury.edu/newstore/catalog/index.php?cPath=57&osCsid=b1b6a47749cd697703f7dd3020f62969

Lake Champlain Basin Program
http://www.lcbp.org/

Lake Champlain Management Plan
http://www.lcbp.org/impofa.htm

Lake Champlain Basin Program 2005 State of the Lake Report
http://www.lcbp.org/lcstate.htm

Lake Champlain Phosphorus TMDL
http://www.vtwaterquality.org/lakes/htm/lp_phosphorus.htm

Vermont Clean and Clear Action Plan
http://www.anr.state.vt.us/cleanandclear/index.htm

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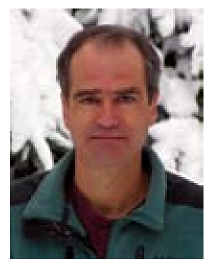

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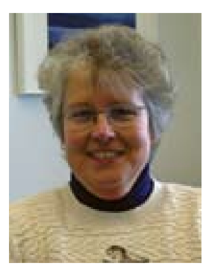

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