A NATURAL AND HUMAN HISTORY OF LAKE CHAMPLAIN

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INTRODUCTION

Lake Champlain is a glacially carved water body in the St. Lawrence River drainage.[1] The lake sits in the low point of a valley between the Adirondack Mountains of New York and the Green Mountains of Vermont.[2] The border between New York and Vermont follows the deepest part of the lake.[3] A small portion of the lake resides in Quebec.[4] Land use in the basin is 64.3% forest, 16% agriculture, and 5.6% developed land with the remainder being wetlands and open water.[5] Relatively flat, fertile lands extend to the east between the lake and the Green Mountains.[6] This area has

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1. RICHARD W. LANGDON ET AL., FISHES OF VERMONT 6 (2006).
2. *Physiographic Regions*, LAKE CHAMPLAIN BASIN ATLAS, atlas.lcbp.org/PDFmaps/nat_geologyA.pdf [https://perma.cc/CZV3-9TLD] (last visited Apr. 24, 2016).
3. 10 VT. STAT. ANN. § 114(a) (defining the border between Vermont and New York).
4. *Political Boundaries*, LAKE CHAMPLAIN BASIN ATLAS, http://atlas.lcbp.org/PDFmaps/nat_political.pdf [https://perma.cc/SP7X-CC28] (last visited Apr. 24, 2016).
5. *People and Economy: Basin Landscape*, LAKE CHAMPLAIN BASIN ATLAS, http://atlas.lcbp.org/HTML/so_landuse.htm [https://perma.cc/DC7H-NGV2] (last visited Apr. 12, 2016).
6. *Geological History of the Champlain Valley*, U. OF VT., http://www.uvm.edu/~shelburn/nature/geology.html [https://perma.cc/2M6A-3CH9] (last visited Apr. 3, 2016).

the highest concentration of agricultural lands.[7] To the west, the Adirondacks are much closer to the lakes shore.[8] As a result, the Vermont portion of the basin has a higher population density and more farmland than does the New York portion.[9]

Lake Champlain is within the Laurentian Mixed Forest Ecoregion.[10] As such, it shares a similar climate, topography, forest type, and soil type with the Great Lakes, St. Lawrence Valley, central and western New York, and northern Pennsylvania.[11] Precipitation ranges from 760 to 1020 mm; snowfall averages 1,020 to 1,520 mm in the Champlain Valley.[12] Mean annual temperature ranges from 39 to 45 °F (4 to 7 °C).[13] The growing season generally lasts about 160 days.[14] The Lake Champlain drainage basin to lake volume ratio (19:1) is quite high for a glacially carved lake.[15] It is reasonable to expect areas of Lake Champlain with higher watershed to lake area ratios to have greater issues with cyanobacteria and other plant growth. Larger watersheds generate more nutrient pollution.[16] The ratio of a lake's drainage area to its surface area is positively correlated to external inputs of nutrients, thus to increasing primary productivity.[17] Missisquoi Bay and the South Lake have the highest watershed to lake area ratios.[18]

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7. *Phosphorus Loading by Land Use*, LAKE CHAMPLAIN BASIN PROGRAM, atlas.lcbp.org/PDFmaps/is_pnps.pdf [https://perma.cc/V369-ZXHL] (last visited Apr. 24, 2016).

8. *Physiographic Regions*, *supra* note 2.

9. *What the 2012 U.S. Census Estimates Tell Us About the Adirondack Park's Population and the State of Rural America*, PROTECT THE ADIRONDACKS, www.protectadks.org/2013/03/What- the-2012-U.S-Census-Estimates-Tell-Us-about-the-Adirondack-Park's-Population-and-the-State-of-Rural-America [https://perma.cc/MMG8-VPX6] (last visited Apr. 3, 2016); *People & Economy*, LAKE CHAMPLAIN BASIN PROGRAM, atlas.lcbp.org/HTML/so_pop.htm [https://perma.cc/89ND-FBP2] (last visited Apr. 3, 2016).

10. *Ecological Subregions of the United States*, U.S. FOREST SERV., http://www.fs.fed.us/land/pubs/ecoregions/ch14.html#212E [https://perma.cc/284R-RC5N] (last visited Apr. 9, 2016).

11. *Id.*

12. *Id.*

13. *Id.*

14. *Id.*

15. *Watershed Wise*, U. OF VT. WATERSHED ALL., http://www.uvm.edu/watershed/watersheds [https://perma.cc/8PXX-WZ8Z] (last visited Apr. 19, 2016).

16. Simone R. Alin & Thomas C. Johnson, *Carbon Cycling in Large Lakes of the World: a Synthesis of Production, Burial, and Lake-Atmosphere Exchange Estimates*, 21 GLOBAL BIOGEOCHEMICAL CYCLES 1, 7 (2007).

17. *Id.*

18. U. OF VT. WATERSHED ALL., *supra* note 15.

I. PEOPLE IN THE BASIN

Approximately 600,000 people live in the Champlain Basin.[19] Population is centered in Chittenden County, Vermont and Clinton County, New York. In Chittenden County, the largest communities by population according to the 2010 U.S. Census are Burlington (42,417), Essex (19,587), South Burlington (17,904), and Colchester (17,067).[20] Plattsburgh, at 19,740 people, is the largest community in Clinton County.[21] In the southern part of the basin, Rutland, Vermont has 16,495, and Queensbury, New York, which is only partially in the basin, has 27,901.[22]

Lake Champlain provides drinking water for approximately 145,000 people.[23] In total, there are 73 public water supply systems drawing from the Vermont side of the lake and 26 on the New York side.[24] By far, the largest water suppliers are the city of Burlington, Vermont, serving 42,000 people, and the Champlain Water District, which serves 70,000 in a number of cities and towns in Chittenden County, Vermont.[25] Public drinking water suppliers comply with the Federal Safe Drinking Water Act, which requires monitoring for 84 potential contaminants.[26]

The lake serves as a major recreational and tourist draw for the region. Vermont's four main lakeside counties generate approximately $300 million in tourist revenue annually.[27] Fishing related expenditures for the basin were estimated at $104 million in 1997.[28]

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19. WILLIAM G. HOWLAND ET AL., LAKE CHAMPLAIN EXPERIENCE AND LESSONS LEARNED BRIEF ¶ 2, http://www.worldlakes.org/uploads/07_Lake_Champlain_27February2006.pdf [https://perma.cc/Y874-V2QM] (last visited Apr. 3, 2016).

20. U.S. DEP'T OF COMMERCE, VERMONT: 2010 CENSUS OF POPULATION AND HOUSING 16, 11, 28, 29 (2010), https://www.census.gov/prod/cen2010/cph-2-47.pdf [https://perma.cc/ZTV6-RAAV].

21. U.S. DEP'T OF COMMERCE, NEW YORK: 2010 CENSUS OF POPULATION AND HOUSING 15 (2010), https://www.census.gov/prod/cen2010/cph-2-34.pdf [https://perma.cc/E4XM-BHNM].

22. VERMONT CENSUS 2010, *supra* note 20, at 13.

23. LAKE CHAMPLAIN BASIN PROGRAM, 2015 STATE OF THE LAKE AND ECOSYSTEMS INDICATORS REPORT 16, http://sol.lcbp.org/images/State-of-the-Lake_2015.pdf [https://perma.cc/EY8K-WGD6] (last visited Apr. 4, 2016).

24. *Id.*

25. *Welcome to Champlain Water District*, CHAMPLAIN WATER DIST., http://www.champlainwater.org/ [https://perma.cc/58VB-9W9Q] (last visited Apr. 3, 2016).

26. Safe Drinking Water Act, 42 U.S.C. § 300f (1974).

27. BRIAN VOIGT ET AL., AN ASSESSMENT OF THE ECONOMIC VALUE OF CLEAN WATER IN LAKE CHAMPLAIN 3 (2015), http://www.lcbp.org/wp-content/uploads/2013/03/81_VoigtEconomicsFinalReport1.pdf [https://perma.cc/JP6N-B8VQ].

28. GILBERT, ALPHONSE HENRY, LAKE CHAMPLAIN ANGLER SURVEY 1997: A REPORT SUBMITTED TO THE FISHERIES TECHNICAL COMMITTEE, LAKE CHAMPLAIN FISH AND WILDLIFE COOPERATIVE (2000).

II. LAKE LEVELS

The minimum level of Lake Champlain is established by a bedrock sill overlain by silty moraine material downstream of the lake in the Richelieu River at St. Jean Sur Richelieu, Quebec.[29] This geologic feature prevents the lake from falling below 27.7 meters above sea level.[30] Alterations to the channel at the outlet of the lake have led to a 0.15 meter increase in lake level since the 1960s.[31] There are no structures that can be manipulated to control the lake's level.

Lake levels fluctuate by approximately 1.5 meters each year and there is over a 3 meter difference between the highest lake level recorded and the lowest.[32] Lake level typically peaks during the spring snowmelt, which represents a basin-wide contribution of a large volume of water.[33] In addition to accumulated winter snow pack melt, there is limited evapotranspiration during this period, so all precipitation that falls runs off quickly.[34] Lake levels recede through the summer months as evapotranspiration increases.[35] Summer storms tend to be localized with little watershed-wide impact.[36] Groundwater inputs to the lake are of minimum importance relative to runoff from the watershed.[37]

The lake is at flood stage when its level reaches or exceeds 30.48 meters.[38] The highest lake level ever recorded was approximately 31.5 meters on May 6, 2011.[39] The lowest lake level occurred in November of 1908 when the lake reached 28.16 meters.[40]

The International Joint Commission ("IJC") has been asked to study the impacts of flooding on Lake Champlain on three separate occasions. The IJC is "an international organization created by the Boundary Waters Treaty, signed by Canada and the United States in 1909" to prevent and

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29. James B. Shanley & Jon C. Denner, *The Hydrology of the Lake Champlain Basin*, *in* LAKE CHAMPLAIN IN TRANSITION FROM RESEARCH TO RESTORATION 41, 51 (Thomas O. Manley & Patricia L. Manley eds., 1999).
30. *Id.*
31. *Id.* at 58.
32. *See id.* at 56 (indicating the historic minimum level of Lake Champlain); *see also Advanced Hydrologic Prediction Service*, NAT'L WEATHER SERV., http://water.weather.gov/ahps2/hydrograph.php?gage=burv1&wfo=btv [https://perma.cc/E7X4-GZP3] (last visited Apr. 4, 2016) (indicating the historic maximum level of Lake Champlain).
33. Shanley & Denner, *supra* note 29, at 58.
34. *Id.* at 46.
35. *Id.* at 51.
36. *Id.*
37. *Id.* at 49.
38. NAT'L WEATHER SERV., *supra* note 32.
39. *Id.*
40. Shanley & Denner, *supra* note 29, at 56.

resolve disputes between the United States of America and Canada.[41] In the 1930s, IJC performed studies and presented a plan for and approved construction and operation of flood control works in the Richelieu River.[42] This led to the construction of the Fryers Dam in 1939, but the dam was never placed into operation.[43] In 1973, IJC studied the desirability of regulating Lake Champlain outflows using either Fryers Dam or new control structures.[44] They concluded that regulation was technically feasible but left assessments of whether such projects were desirable to the federal governments.[45] Neither government built a regulating structure.[46] Most recently, in 2013, IJC developed a plan of study to identify means of mitigating floods.[47] This effort led to production of static flood inundation maps and development of an approach for future flood forecasting and floodplain mapping.[48]

III. THE FIVE PRINCIPAL LAKE SEGMENTS

Lake Champlain is divided into five distinct basins with significant differences in morphology and land use from basin to basin.[49] The Main Lake holds the bulk of the water and sits in a deep narrow trough, stretching along a north south axis.[50] To the north, a series of large islands separates the Main Lake from the moderately deep Northeast Arm.[51] North of the Northeast Arm and draining into it, the broad shallow Missisquoi Bay straddles the Vermont-Quebec border.[52] South of the Northeast Arm and separated by a series of road and railroad causeways lays Mallets Bay.[53] At

41. *About the IJC*, INT'L JOINT COMM'N, http://ijc.org/en_/About_the_IJC [https://perma.cc/CS82-GTVA] (last visited Apr. 25, 2016).

42. INT'L JOINT COMM'N, A REAL-TIME FLOOD FORECASTING AND FLOOD INUNDATION MAPPING SYSTEM FOR THE LAKE CHAMPLAIN AND RICHELIEU RIVER 1 (2015), http://ijc.org/files/publications/Lake-Champlain-IJC-Report-to-Govts-Dec-2015-NEW.pdf [https://perma.cc/3ZGC-FLQN].

43. *Id.*

44. *Id.* at 1–2.

45. *Id.*

46. *Id.*

47. *Id.* at 2.

48. *Id.* at 2–3.

49. *Lake and Basin Facts*, LAKE CHAMPLAIN BASIN PROGRAM, http://www.lcbp.org/about-the-basin/facts/ [https://perma.cc/ZQM2-AAQN] (last visited Apr. 21, 2016).

50. VT. GEOLOGICAL SOC'Y, THE GEOLOGY OF THE LAKE CHAMPLAIN BASIN AND VICINITY 4 (1980), http://www.anr.state.vt.us/dec/geo/GMGVTSoc/VTGS_1980_1.pdf [https://perma.cc/BFW2-DMZ3].

51. *Id.*

52. *Id.*

53. *Id.*

the extreme south of the Main Lake is the long, shallow, almost riverine South Lake.[54]

The Main Lake covers over 680 square kilometers and contains over eighty percent of the lake's water volume.[55] This section stretches from the Crown Point Bridge to the lake's outlet in Rouses Point. At its deepest point, the Main Lake is 122 meters in depth and it averages over 30 meters in depth.[56] The population centers are on the shores of the Main Lake and it contains a multitude of bays and shallow areas around the periphery.[57]

The Northeast Arm covers over 265 square kilometers and reaches 49 meters at its deepest point.[58] Much of the Northeast Arm is clear and cold, though shallow bays like St. Albans are more weed filled. There are no major tributaries that drain to this lake segment, a factor which likely helps protect its water quality. The Northeast Arm is segmented by road and railroad causeways built in the 19th century.[59] These factors reduced sediment inputs into this basin for several decades.[60]

Missisquoi Bay fills a shallow basin at the northeastern-most portion of the lake—only 2.8 meters deep at its maximum, but covering over 7 kilometers in breadth.[61] Three significant tributaries discharge to Missisquoi Bay: the Pike River, the Rock River, and the Missisquoi River.[62] The Pike and most of the Rock watersheds sit within Quebec. High nutrient levels and extensive sedimentation from these rivers make Missisquoi Bay one of the murkier lake segments.[63] Missisquoi Bay, with less than 1% of the lake's water receives 24.2% of the total phosphorus load for Lake Champlain; only the Main Lake receives more.[64]

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54. *Id.*
55. *Id.*
56. *Id.*
57. *Id.* at 3.
58. *Id.*
59. Suzanne N. Levine et al., *The Eutrophication of Lake Champlain's Northeastern Arm: Insights from Paleolimnological Analyses*, 38 J. GREAT LAKES RES. 35, 36–47 (2012).
60. *Id.*
61. *Bathymetry (Lake Depths)*, LAKE CHAMPLAIN BASIN ATLAS, http://atlas.lcbp.org/PDFmaps/nat_depth.pdf [https://perma.cc/3QYF-F7SQ] (last visited Apr. 25, 2016).
62. VT. AGENCY OF NAT. RES., MISSISQUOI BAY BASIN WATER QUALITY MANAGEMENT PLAN 19 (2013), http://dec.vermont.gov/sites/dec/files/wsm/mapp/docs/mp_Basin06Plan.pdf [https://perma.cc/PY25-KYKV].
63. INT'L JOINT COMM'N, A PRELIMINARY ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED CHAMPLAIN-RICHELIEU FLOOD CONTROL PROJECT 18 (1973).
64. U.S. ENVTL. PROT. AGENCY, PHOSPHORUS TMDLS FOR VERMONT SEGMENTS OF LAKE CHAMPLAIN 14 (2015), https://www.epa.gov/sites/production/files/2015-09/documents/phosphorus-tmdls-vermont-segments-lake-champlain.pdf https://perma.cc/M39S-M5XA].

Analysis of sediment cores from Missisquoi Bay indicate dramatic changes in inputs to the bay since 1900.[65] Deforestation and agricultural practices throughout the landscape have driven an increase in sedimentation rate and carbon inputs.[66] Sedimentation rates have increased to 0.7 cm/year as compared to approximately 0.02 cm/year before 1700.[67] As a result, Missisquoi Bay has become more eutrophic.

The accumulation of phosphorus and sediment over many years means that Missisquoi Bay has a massive reserve of nutrients.[68] Phosphorus mobilizes from the sediment under conditions of low pH and low oxygen.[69] When cyanobacteria bloom, the decomposition of cells reduces oxygen levels at the soil water interface, releasing more phosphorus and creating a positive feedback loop.[70] As a result, forty-three percent of the summer phosphorus in the water column of the Missisquoi Bay comes from the sediments.[71] The high concentration of sediment phosphorus means water column phosphorus concentrations in the bay are extremely resistant to changes in watershed phosphorus loading. A fifty percent reduction in watershed loads would cause only a minimal change in in-lake phosphorus concentrations over a thirty-year period.[72]

Mallets Bay is isolated from other parts of the lake by an abandoned railroad causeway to the west and a road causeway to the north.[73] Mallets Head and Red Rock Point pinch the bay into two distinct segments: an inner bay and an outer bay.[74] The Lamoille River, the bay's largest tributary, enters the outer bay.[75] The Winooski River delta forms much of the southern boundary, though the Winooski itself drains in to the Main

65. Andrew T. Koff, A Multi-Proxy Paleolimnological Study of Holocene Sediments in Missisquoi Bay, USA-Canada 99 (Sept. 8, 2011) (unpublished thesis, University of Vermont) https://www.uvm.edu/geology/documents/Koffthesis.pdf [https://perma.cc/7LYP-2F4Y].

66. *Id.*

67. *Id.*

68. U.S. ENVTL. PROT. AGENCY, *supra* note 64, at 39.

69. Christophoros Christophoridis & Konstantinos Fytianos, *Conditions Affecting the Release of Phosphorus from Surface Lake Sediments*, 35 J. ENVTL. QUALITY 1,181, 1,185 (2006).

70. Lydia Smith et al., *Relating Sediment Phosphorus Mobility to Seasonal and Diel Redox Fluctuations at the Sediment-Water Interface in a Eutrophic Freshwater*, 56 LIMNOLOGY & OCEANOGRAPHY 2,251, 2,264 (2011).

71. LIMNOTECH, DEVELOPMENT OF A PHOSPHORUS MASS BALANCE MODEL FOR MISSISQUOI BAY (2012), http://www.lcbp.org/wp-content/uploads/2013/03/65_PhosphorusMassBalanceModel_MissisquoiBay_2012.pdf [https://perma.cc/8WJY-FZY6].

72. *Id.* at 42–43.

73. LAKE CHAMPLAIN BASIN PROGRAM, MALLETTS BAY RECREATION RESOURCE MANAGEMENT PLAN 17 (1995).

74. *Id.* at iii.

75. *Lamoille Basin*, LAKE CHAMPLAIN BASIN ATLAS, http://atlas.lcbp.org/PDFmaps/nat_lamoille.pdf [https://perma.cc/4RGB-YMUQ] (last visited Apr. 24, 2016).

Lake. Mallets Bay is smaller in surface area than Missisquoi Bay, but contains greater than three times more water because of its depth.[76] Half the outer bay is over fifteen meters deep, but at the same time nearly forty percent of the bay is less than six meters deep.[77] In other words, the bay contains steep drop-offs to deep water. Nutrient levels, and thus cyanobacteria blooms, in Malletts Bay are comparable to the Main Lake and lower than other lake segments.[78] Because it is well sheltered from the weather, Mallets Bay hosts numerous marinas, making it a popular spot for boaters.[79] As a result, recreational conflicts between different types of lake users can be as much of an issue as environmental problems.[80]

The thin, narrow, nearly 50 kilometer stretch between Whitehall, New York and Crown Point, New York constitutes the South Lake.[81] In physical appearance, this area is more like a river than a lake, though there is limited elevation difference between the southern and northern end and thus there are minimal fluvial processes.[82] The South Lake receives most of its water from two tributaries: the Poultney and Mettowee Rivers.[83] In all, over 15% of the lake's watershed empties into this segment, which contains only 0.6% of the lake's water.[84]

IV. GLACIAL HISTORY

Lake Champlain is a product of the last ice age. Approximately 18,000 years ago, a sheet of ice over a mile-and-a-half thick sat on what is today the Champlain Valley and stretched as far south as Long Island.[85] Under the great weight of the ice, the land subsided into the underlying upper mantle of the earth, decreasing the entire region's elevation.[86] Additionally, the

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76. VT. GEOLOGICAL SOC'Y, *supra* note 50, at 4.

77. Welcome to the Watershed Management, AGENCY OF NAT. RESOURCES, http://www.vtwaterquality.org/mapp/docs/mp_Basin06Plan.pdf [https://perma.cc/TV9C-2XR4] (last visited June 17, 2016).

78. Eric Smeltzer et al., *Environmental Change in Lake Champlain Revealed by Long-Term Monitoring*, 38 J. GREAT LAKES RES. 6, 6–18 (2012).

79. *See* Alicia Freese, *Who Decides? New Buoys in Lake Champlain Roil Colchester Board*, SEVEN DAYS (July 22, 2015), http://www.sevendaysvt.com/vermont/who-decides-new-buoys-in-lake-champlain-roil-colchester-board/Content?oid=2758287 [https://perma.cc/SFD3-FRA9] (calling Mallets Bay a "boating mecca").

80. *Id.*

81. *Political Boundaries*, *supra* note 4.

82. *See Physiographic Regions*, *supra* note 2 (displaying the shape of the south lake and the elevation of the surrounding area).

83. VT. AGENCY OF NAT. RES., SOUTH LAKE CHAMPLAIN TACTICAL BASIN PLAN 18 (2014).

84. VT. GEOLOGICAL SOC'Y, *supra* note 50, at 4.

85. MIKE WINSLOW, GLACIERS AND THE CHAMPLAIN WATERSHED 2 (2009).

86. *Id.*

movement of the glaciers along lines of weakness in the bedrock caused tremendous erosion, carving out deep trenches.[87] The erosive force of the ice and associated rubble, along with the freshwater flowing into the low-point in the landscape created by land depression, created Lake Champlain.[88]

As the glacier retreated beginning about 13,500 years ago, meltwater pooled to the south.[89] Meanwhile, the northern outlet, via the St. Lawrence River, was blocked by the still extant ice sheet.[90] The pooled water formed a precursor to Lake Champlain—Lake Vermont—which discharged to the south via the Hudson River.[91] Shorelines of Lake Vermont have been identified over 180 meters higher than today's lake, meaning much of Lake Champlain's current basin was once underwater, and the shores of the lake would have sat as far to the east as the base of the Green Mountains.[92]

The Champlain Sea, a saltwater body, followed Lake Vermont about 11,500 to 12,000 years ago.[93] The Champlain Sea formed when the ice blocking what is now the St. Lawrence River melted.[94] The northern portion of the watershed was still lower in elevation because the sheer weight of the glaciers had depressed the land 150 to 190 meters into the earth's mantle.[95] Meanwhile, sea levels were also rising as the water locked in the glaciers was released.[96] Instead of freshwater Lake Vermont draining away, salt water rushed in. The Champlain Sea was approximately 100 meters lower in elevation than Lake Vermont, but still substantially higher than present day Lake Champlain.[97] The Champlain Sea persisted for about 1,500 and 2,000 years until the land rebounded from the weight of the glaciers and the bedrock sill in St. Jean rose above sea level.[98]

The rebounding of land from the weight of the glaciers was not uniform. Southern portions of the basin rebounded earlier than northern portions because the ice melted there sooner.[99] Over the last 10,000 years, the elevation of the lake has increased by about eight meters.[100] As the land rose, the lake got deeper; the bedrock sill increased in height above sea

87. LANGDON ET AL., *supra* note 1, at 6.
88. *Id.*
89. *Id.*
90. *Id.* at 9.
91. *Id.*
92. CHARLES W. JOHNSON, THE NATURE OF VERMONT 22 (1998).
93. LANGDON ET AL., *supra* note 1, at 9.
94. *Id.*
95. JOHNSON, *supra* note 92, 22.
96. *Id.*
97. *Id.*
98. LANGDON ET AL., *supra* note 1, at 9.
99. JOHNSON, *supra* note 92, 22.
100. Koff, *supra* note 65, at 6.

level and thus held back more water. For example, about 10,000 years ago, before most of the rebound had occurred and when the bedrock sill was still nearly at sea level, Missisquoi Bay was dry or at least much more shallow than it is even today.[101]

The soils of the fertile Champlain Valley were deposited during the time of Lake Vermont and the Champlain Sea.[102] In the uplands, the glaciers scraped away topsoil and left behind a rocky mix of till.[103] In the lowlands, clays carried down from the mountains settled out over a period of centuries in the still waters of Lake Vermont and the Champlain Sea to be revealed when water levels fell.[104] The fertile soil combined with a relatively flat topography has led to the concentration of agriculture in the valley.

V. CHANGES IN FORESTRY AND AGRICULTURAL PRACTICES

The population of the Champlain Valley increased dramatically in the years following the Revolutionary War.[105] Immigrants settled in the valleys to take advantage of rivers and lakes for transportation.[106] During this period of increasing development much of the Champlain Basin's forest land was cleared for timber, agriculture, and settlements.[107] Hillside farms lost their fertility in just a generation or two as cleared land eroded.[108]

In the valleys, various grasses grew well, leading many settlers to clear trees and raise livestock.[109] In the early 1800s, the predominant agricultural venture was raising sheep.[110] Merino sheep imported from Spain grew heavier fleeces in the cold northern climates than in their native land. In 1824, Congress put a tariff on imported woolen cloth, expanding the market for domestic production.[111] By 1840, there were six sheep for every person in Vermont.[112] The market for Vermont wool cratered after the 1840s.[113]

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101. Richard Henry Fillon, The Sedimentation and Recent Geologic History of the Missisquoi Delta (Feb. 1970) (unpublished master's thesis, University of Vermont) (on file with Vt. J. Envtl. L.).

102. DAVID P. STEWART & PAUL MACCLINTOCK, THE SURFICIAL GEOLOGY AND PLEISTOCENE HISTORY OF VERMONT 36–37, 60–61 (1969).

103. *Id.* at 25.

104. *Id.* at 37, 60–61.

105. JAN ALBERS, HANDS ON THE LAND: A HISTORY OF THE VERMONT LANDSCAPE 84 (2000).

106. *Id.*

107. *Id.* at 99.

108. *Id.* at 145.

109. *Id.*

110. *Id.*

111. *Id.*

112. *Id.* at 146.

Wool tariffs were relaxed in 1841 and 1846 and railroads began to bring wool to the East from the West where it could be produced at a lower cost.[114]

Clearing trees for lumber and potash also transformed the landscape. Potash, a potassium based compound used in agriculture and industry, is produced by "burning huge quantities of wood, leaching the ashes, and boiling away the liquid to leave a gritty residue."[115] In 1791 alone, over two million pounds were shipped to Great Britain from Vermont.[116] In 1823, the Champlain Canal was constructed and offered an easy route for shipping lumber to markets.[117] Burlington was the third largest lumber port in the nation in the mid-1800s.[118] By 1840, the Champlain Valley was devoid of marketable trees.[119] By the late nineteenth century, Vermont was seventy-percent cleared and thirty-percent forested, the reverse of what it is today.[120]

The severity of erosion of topsoil and flooding brought on by forest clearing earned widespread attention. In 1864, Vermonter George Perkins Marsh wrote his seminal book *Man and Nature*, documenting changes in climate, soil erosion, flooding, and drought that resulted when forests were cleared.[121] In 1885, the New York state legislature established a Forest Preserve with the intent of keeping the lands forever wild.[122] This preserve became the Adirondack Park in 1892 and two years later the park received "forever wild" protection in the New York state constitution.[123] In 1925, the Vermont legislature approved funding purchase to land to help establish the Green Mountain National Forest.[124] These actions helped restore forest cover in large parts of the basin.

When sheep were no longer profitable, farmers turned to dairy cows. Between 1845 and 1860, dairy cows appear to have increased proportionally to the decline in sheep.[125] Refrigerated rail cars allowed the

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113. *Id.* at 148.
114. *Id.*
115. JOHNSON, *supra* note 92, at 60.
116. *Id.*
117. *Id.*
118. *History*, CITY OF BURLINGTON, VT., https://www.burlingtonvt.gov/CEDO/History [https://perma.cc/K887-HPXV] (last visited Apr. 1, 2016).
119. ALBERS, *supra* note 105, at 156.
120. *Id.*
121. *See generally* GEORGE PERKINS MARSH, MAN AND NATURE (David Lowenthal ed., Harvard Univ. Press 1961) (1864).
122. *History of the Adirondack Park*, ADIRONDACK PARK AGENCY, http://apa.ny.gov/about_park/history.htm [https://perma.cc/HDY3-CAMQ] (last visited Apr. 4, 2016).
123. *Id.*
124. *History of Forestry in Vermont*, DEP'T OF FORESTS, PARKS & RECREATION, http://fpr.vermont.gov/forest/vermonts_forests/history [https://perma.cc/73AP-LYGH] (last visited Apr. 1, 2016).
125. U.S. TARIFF COMM'N, THE WOOL-GROWING INDUSTRY 92 (1921).

transport of milk and milk products to burgeoning urban markets in New York and Boston.[126] Cows were much more difficult to raise than sheep, requiring winter forage and twice-daily milking.[127] However, high milk prices coupled with falling wool prices drove the transition.[128]

As dairy farming became more mechanized following World War II, the number of farms decreased even though milk production increased, a trend that continues today.[129] Marginally profitable hill farms were the most likely to go out of business.[130] The remaining farms have come to rely more and more on inputs of nutrients from outside the basin in the form of feed and fertilizer to sustain their herds.[131] Larger herds can also make animal waste management a greater challenge.[132] Specifically, "[e]nvironmentally sound recycling of manure from ever-larger herds requires greater energy and planning for transport and spreading."[133]

Agriculture changes the hydrology and pollutant loads in a watershed.[134] Herds of animals, such as sheep or dairy cows, generate waste that must be managed. Cultivation of land usually involves tilling. This changes flow paths for water and transpiration rates compared to a forested landscape.[135] Tile drainage of land transfers water movement and nutrient loads from surface to sub-surface.[136] Farmers add nutrients in the form of fertilizers and manure, which can promote unsightly algal blooms if the nutrients reach waterways.[137] Annual cropland has a greater impact than

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126. James A. Kindraka, *The Story of Milk Transportation by Rail*, 13 DISPATCH 17, 18 (1990).

127. F. H. BRANCH, THE PLACE OF SHEEP ON NEW ENGLAND FARMS 11 (1981) (explaining that dairy cattle are more costly to raise than sheep).

128. ALBERS, *supra* note 105, at 206–11.

129. Bob Parsons, *Moving from Sheep to Dairy Lands: Vermont as New England's Top Milk Supplier*, LANCASTER FARMING (Mar. 21, 2016), http://www.lancasterfarming.com/market_news/market_reports/market_movements_monthly/moving-from-sheep-to-dairy-lands-vermont-as-new-england/article_d2155ff9-fca4-5439-893e-ac22c7598380.html [https://perma.cc/H2QG-V9ZS].

130. *See id.* (stating that from 1965 to 2015, Vermont has lost more than 5,000 dairy farms).

131. Smeltzer et al., *supra* note 78, at 1, 7.

132. William L. Bland, *Impact of Land Use Fragmentation and Larger Herd Sizes on Manure Recycling Energy and Cost*, 62 J. SOIL & WATER CONSERVATION 119A, 119A (2007).

133. *Id.*

134. ANDREW N. SHARPLEY, AGRICULTURE, HYDROLOGY AND WATER QUALITY 4 (P.M. Haygarth & S.C. Jarvis eds., 2001).

134. R. HORTON ET AL., MECHANICS AND RELATED PROCESSES IN STRUCTURED AGRICULTURAL SOILS 187, 192 (W.E. Larson et al. eds., 1989).

136. Kevin W. King et al., *Contributions of Systemic Tile Drainage to Watershed-Scale Phosphorus Transport*, 44 J. ENVTL. QUALITY 486, 492–93 (2015).

137. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 9–10.

land in perennial vegetation, such as pasture, particularly if soil is left bare between plantings.[138]

In modern times, the basin has become more developed. Developed lands, including buildings, roads, and parking areas, contribute three to four times more phosphorus per acre than agricultural lands.[139] Once between ten and twenty percent of a landscape is impervious, meaning it sheds rather than absorbs water, surfaces become connected and water can channel directly to streams, lakes, and rivers sooner and with greater energy.[140] Thus, pollutants are transferred a greater distance and the water has greater erosive force once it reaches a receiving water.

VI. MANAGEMENT CHALLENGES

Perhaps the first report on ecological conditions in Lake Champlain was produced by the United States Geological Survey in 1905.[141] The principal concerns expressed in this report centered on disposal of sewage and sludge from paper making.[142] The author did comment on algal build up in the lake, noting that the "super abundance of algae of the offensive species" had been cited as evidence that "the lake is being damaged by municipal and industrial wastes," but the author did not find algae in excess of what "the natural conditions would warrant."[143]

Today, cyanobacterial blooms plague Lake Champlain's northeastern bays.[144] Cyanobacteria are naturally occurring photosynthetic organisms.[145] In the presence of warmer water and high nutrient levels, particularly nitrogen and phosphorus, cyanobacteria outcompete other algae and vascular plants.[146] Certain species form aesthetically unpleasing scums on

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138. Keith E. Schilling et al., *Impact of Land Use and Land Cover Change on the Water Balance of a Large Agricultural Watershed: Historical Effects and Future Directions*, 44 WATER RESOURCES RES. ¶ 28 (2008).

139. AUSTIN TROY ET AL., UPDATING THE LAKE CHAMPLAIN BASIN LAND USE DATA TO IMPROVE PREDICTION OF PHOSPHORUS LOADING 2 (2007), http://www.lcbp.org/wp-content/uploads/2013/04/54_LULC-Phosphorus_2007.pdf [https://perma.cc/2K4X-4U7B] (last visited Apr. 9, 2016).

140. Thomas R. Schueler, *The Importance of Imperviousness: The Practice of Watershed Protection*, 1 WATERSHED PROTECTION TECHS. 100 (2000).

141. MARSHAL O. LEIGHTON, PRELIMINARY REPORT ON THE POLLUTION OF LAKE CHAMPLAIN (1905), http://pubs.usgs.gov/wsp/0121/report.pdf [https://perma.cc/9D3T-9NEW].

142 *Id.* at 9.

143 *Id.* at 108, 110.

144. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 13.

145. WALTER K. DODDS, FRESHWATER ECOLOGY: CONCEPTS AND ENVIRONMENTAL APPLICATIONS 131 (James H. Thorp ed., 2002).

146. Nathalie Fortin et al., *Toxic Cyanobacterial Bloom Triggers in Missisquoi Bay, Lake Champlain, as Determined by Next-Generation Sequencing Quantitative PCR*, 5 LIFE 1,346, 1,368 (2015).

the surface of the water, referred to as blooms.[147] Some species under some conditions can produce toxins, which have led to dog deaths and human illnesses.[148] The mechanisms behind toxin formation are not clearly understood and it is not possible to tell if a given bloom is toxic without analytical testing.[149]

Blooms occur intermittently in various places throughout Lake Champlain, but routinely strike Missisquoi Bay and St. Albans Bay in the Northeast Arm in late summer.[150] Both of these bays are somewhat shallow and have high nutrient levels—conditions that promote cyanobacterial blooms.[151] Blooms can become trapped in the bays by prevailing summer winds from the south.[152] Sediment cores from these bays show increasing growth of algae species typical of nutrient rich waters beginning in the early 20th century for St. Albans Bay and in the 1960s and 1970s for Missisquoi Bay.[153] For St. Albans Bay, the timing coincides with sewer installations and expansions in the watershed.[154] For Missisquoi Bay, with little direct discharge, the driver was more likely increasing intensification of agriculture.[155]

Attempts to control cyanobacterial blooms have focused on reducing inputs of phosphorus.[156] Agricultural operations have imported phosphorus in the form of fertilizer and animal feeds.[157] Such imports were necessary because the soil lost much of its fertility due to erosion caused by excessive grazing and the clearing of forests.[158] For many decades, imports (phosphorus) have exceeded exports (milk and other agricultural products) and the excess phosphorus accumulates in the soil. In Franklin County, Vermont, there has been an increase in the net import of phosphorus from

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147. DODDS, *supra* note 145, 131–32.
148. *Id.* at 133.
149. *Testing and Beach Closures*, LAKE CHAMPLAIN BASIN PROGRAM, http://www.lcbp.org/water-environment/human-health/swimming-concerns/beach-closures/ [https://perma.cc/8KMD-BEHE] (last visited Apr. 22, 2016).
150. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 13.
151. MIKE WINSLOW, LAKE CHAMPLAIN: A NATURAL HISTORY: IMAGES FROM THE PAST (2009).
152. *Id.*
153. Levine, *supra* note 59, at 47.
154. *Id.*
155. *Id.*
156. DEP'T OF ENVTL. CONSERVATION, VERMONT LAKE CHAMPLAIN PHOSPHORUS TMDL PHASE 1 IMPLEMENTATION PLAN 1 (2014).
157. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 9–10.
158. *See* J. C. Anyanwu et al., *The Impact of Deforestation on Soil Conditions in Anambra State of Nigeria*, 4 AGRIC. FORESTRY & FISHERIES 64, 68 ("[D]eforestation leads to poor soil physical, chemical and biological conditions.").

14 tons/year in 1924 to 821 tons/year in 2007.[159] The total net import of phosphorus to Franklin County from 1924 to 2007 was 48,000 tons.[160] When the soil erodes, the phosphorus does too.

Additional inputs of phosphorus occurred when the element was added to laundry and dishwasher detergents.[161] Phosphates improve the cleaning effectiveness of detergents without increasing toxicity.[162] By 1959, essentially all laundry detergents in the U.S. contained seven to twelve percent phosphorus by gross dry weight.[163] Phosphorus was banned from laundry detergents in 1976 in New York and 1978 in Vermont.[164] It was banned from dishwasher detergents in 2010 in both states.[165]

In-lake water quality standards for phosphorus were established for thirteen different lake segments in the mid-1990s.[166] Since that time, extensive state and federal resources have been invested in reducing phosphorus exports from agricultural lands and reducing stormwater runoff from developed lands.[167] However, there have not been reductions in in-lake phosphorus levels.[168]

The impact of dramatic land use changes on water quality, such as those that have occurred in the Champlain Basin since European settlement, are difficult to reverse. The best predictor of present day biodiversity in streams is past, not present, land-use.[169] Application of best management practices to farms is not sufficient to reverse changes as any benefits can be overwhelmed by seasonality of a given lake's hydrology, time-lag effects,

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159. Russell F. Ford, Agricultural Phosphorus in Vermont's Missisquoi Bay Watershed: History, Status, and Solutions (2012) (unpublished M.S. thesis, University of Vermont), https://library.uvm.edu/dissertations/?search_type=item&bid=2471519 [https://perma.cc/H8EV-DMLB].

160. *Id.*

161. *See* LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 9 ("Regulations banning phosphorus in detergents have greatly reduced the amount of phosphorus entering treatment facilities.").

162. *See* Michael McCoy, *Goodbye, Phosphates*, C&EN (Jan. 24, 2011), https://pubs.acs.org/cen/coverstory/89/8904cover.html [https://perma.cc/VZ67-38Y6] (noting the cleaning properties of phosphates and their widespread use in detergent manufacturing).

163. Chris Knud-Hansen, *Historical Perspective of the Phosphate Detergent Conflict* (Univ. of Colo., Working Paper 94-54), http://www.colorado.edu/conflict/full_text_search/AllCRCDocs/94-54.htm [https://perma.cc/DZ5V-JMSU].

164. DAVID W. LITKE, REVIEW OF PHOSPHORUS CONTROL MEASURES IN THE UNITED STATES AND THEIR EFFECTS ON WATER QUALITY 6 (1999).

165. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 9.

166. VT. DEP'T ENVTL. CONSERVATION, VERMONT WATER QUALITY STANDARDS 43–44, 65–66 (2014).

167. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 14.

168. *Id.* at 6–7.

169. J. S. Harding et al., *Stream Biodiversity: The Ghost of Land Use Past*, 95 PROC. NAT. ACAD. SCI. 14,843, 14,844 (1998).

and a long history of agricultural use of the landscape.[170] Slow release of phosphorus from over fertilized soils can maintain eutrophication of lakes for centuries.[171]

Eutrophication is not the only challenge to Lake Champlain's ecology; invasive exotic species have also had a profound impact. The lake currently hosts fifty non-native species.[172] They have arrived in the lake via bait releases, aquarium releases, and transfer on boats.[173] However, the single most significant vector for invasive species are the canals that have connected Lake Champlain to the Great Lakes and St. Lawrence Rivers since 1823.[174] Species that have arrived via the Champlain Canal include zebra mussels (Dreissena polymorpha in 1993) and plants such as Eurasian watermilfoil (Myriophyllum spicatum in 1962) and water chestnut (Trapa natans in 1940) that clog boating channels and impair recreation.[175] The arrival of filter-feeding zebra mussels has led to an increase in water clarity,[176] which likely promotes expansion of plant growth by allowing photosynthesis at greater depths. Each of these species first arrived in the southern part of Lake Champlain where the Champlain Canal empties into the lake.[177]

The means of introduction for some more recently arrived species is unknown. These include the spiny waterflea (Bythotrephes longimanus in 2014)—the first invasive zooplankton to reach the lake—and the alewive (Alosa pseudoharengus in 2003), which competes with rainbow smelt as the dominant forage fish in the lake.[178]

Climate change is expected to play a role in promoting future species invasions. A warmer lake will support species from southern climates that could not compete at this time.[179] Flooding events can help species spread from one water body to another and a warming climate is anticipated to

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170. Nolan J.T. Pearce & Adam G. Yates, *Agricultural Best Management Practice Abundance and Location Does Not Influence Stream Ecosystem Function or Water Quality in the Summer Season*, 7 WATER 6,861, 6,861 (2015).

171. Stephen R. Carpenter, *Eutrophication of Aquatic Ecosystems: Bistability and Soil Phosphorus*, 102 NAT'L ACAD. SCI. 10,002, 10,005 (2005).

172. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 2.

173. MARK MALCHOFF ET AL., FEASIBILITY OF CHAMPLAIN CANAL AQUATIC NUISANCE SPECIES BARRIER OPTIONS 3 (2005).

174. *Id.* at 16.

175. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 25.

176. J. Ellen Marsden et al., *Influence of Environmental Factors on Zebra Mussel Population Expansion in Lake Champlain, 1994-2010*, *in* QUAGGA AND ZEBRA MUSSELS: BIOLOGY, IMPACTS, AND CONTROL 33, 34, 49, 50 (Thomas F. Nalepa & Don W. Schloesser eds., 2d ed. 2012).

177. MALCHOFF ET AL., *supra* note 173, at 8.

178. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 24.

179. Frank J. Rahel & Julian D. Olden, *Assessing the Effects of Climate Change on Aquatic Invasive Species*, 22 CONSERVATION BIOLOGY 521, 529 (2008).

have more intense storms.[180] Climate change can disrupt ecological connections between predators and prey in aquatic systems and this can present an opportunity for invasive species.[181]

Climate change already impacts the physical character of Lake Champlain. Though the lake routinely froze during the winters, now full lake freezes are sporadic at best.[182] When it does freeze, the freeze-over date is roughly two weeks later than it was in the early 1800s.[183] During the summer, the average August surface water temperature has increased by as much as 6.8 °F since 1964.[184] Increased water temperatures can shift the timing of breeding for aquatic organisms.[185] A warmer climate is expected to generate more intense storms throughout the basin which would lead to increases in nutrient loading, combined sewer overflows, and streambank erosion.[186] More nutrients and a warmer climate increase the competitiveness of potentially toxic cyanobacteria.[187]

Cyanobacteria are not the only source of toxins for Lake Champlain. Like other waterbodies around the country, Lake Champlain faces challenges from the addition of potentially toxic substances from industry and consumers. Both Vermont and New York have consumption advisories for some fish species as a result of high PCB and mercury levels.[188] PCB production has been banned in the United States since 1979, but the chemicals persist.[189] Mercury sources include wastewater discharges and atmospheric deposition from regional, national, and international sources.[190] Both mercury and PCBs bioaccumulate so larger older fish have higher concentrations.[191] Mercury concentrations tend to be lower in fish from

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180. *Id.* at 522, 529.

181. Monika Winder & Daniel E. Schindler, *Climate Change Uncouples Trophic Interactions in an Aquatic Ecosystem*, 85 ECOLOGY 2,100, 2,105 (2004).

182. J. CURT STAGER & MARY THILL, CLIMATE CHANGE IN THE CHAMPLAIN BASIN 17 (2010), http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/vermont/what-we-do/champlain-climate-report-5-2010-2.pdf.

183. *Id.* at 2.

184. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 31.

185. Ned W. Pankhurst & Philip L. Munday, *Effects of Climate Change on Fish Reproduction and Early Life History Stages*, 62 MARINE & FRESHWATER RES. 1,015, 1,020 (2011).

186. STAGER & THILL, *supra* note 182, at 15.

187. *Id.* at 19.

188. LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 23, at 14.

189. Press Release, Envtl. Prot. Agency, Envtl. Prot. Agency Bans PCB Manufacture; Phases Out Uses (Apr. 19, 1979), https://www.epa.gov/aboutepa/epa-bans-pcb-manufacture-phases-out-uses [https://perma.cc/7E94-Z2B7].

190. CONN. DEP'T ENVTL. PROT. ET AL., NORTHEAST REGIONAL MERCURY TOTAL MAXIMUM DAILY LOAD vi–vii (2007).

191. *Toxics Release Inventory (TRI) Program: Persistent Bioaccumulative Toxic (PBT) Chemicals Covered by the TRI Program*, ENVTL. PROT. AGENCY (2015), https://www.epa.gov/toxics-release-inventory-tri-program/persistent-bioaccumulative-toxic-pbt-chemicals-covered-tri [https://perma.cc/T5FS-68QR].

eutrophic waters where the high concentration of phytoplankton dilutes the amount of mercury ingested by any one fish.[192] As a result, fish from the Main Lake would be expected to have higher concentrations than those from Missisquoi Bay.

There are many human-made substances with unknown toxicity have been detected in the lake. These include pharmaceuticals, fragrances, pesticides, and a wide variety of other byproducts of modern life.[193] Little is known about the individual effects of all these potential contaminants and even less is known about potential synergistic effects. Many of these substances can mimic natural hormones, causing unexpected changes in aquatic biota. For example, in one survey of smallmouth bass from the Missisquoi River, sixty to seventy percent of the males had eggs in their testes, which may be related to exposure to endocrine disrupting chemicals.[194] This rate was lower than other waterbodies near National Wildlife Refuges in the Northeast, but higher than reported from other surveys.[195]

CONCLUSION

Lake Champlain has undergone tremendous changes since the glaciers left the landscape. It has transitioned from a much larger freshwater lake to a saltwater sea and back to a smaller freshwater lake. The forests were cleared for timber and agriculture following the arrival of Europeans. Agriculture transitioned from homesteads to sheep grown for outside markets to dairy cows. Clearing land led to erosion and eutrophication of the waterbody. Eutrophication, coupled with climate change, has promoted growth of cyanobacteria in shallower portions of the lake, specifically Missisquoi and St. Albans Bays. Attempts to reverse eutrophication have thus far not been successful and there is little evidence, particularly in Missisquoi Bay, that reversal is possible. Other management challenges for the lake also loom. Intense focus on reversing decades of excess nutrient loading risks blinding us to management options that more effectively

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192. Piet Vieburg et al., *Mercury Biomagnification in Three Geothermally-Influenced Lakes Differing in Chemistry and Algal Biomass*, SCI. TOTAL ENV'T. 342, 351 (2014).

193. P. Phillips & A. Chalmers, *Wastewater Effluent, Combined Sewer Overflows, and Other Sources of Organic Compounds to Lake Champlain*, 45 J. AM. WATER RESOURCES ASS'N 45, 51 (2009).

194. *Sex Switching Bass Found in Lake Champlain's Waters*, LAKE CHAMPLAIN COMM. (Dec. 30, 2015), https://www.lakechamplaincommittee.org/learn/news/item/sex-switching-bass-found-in-lake-champlain-waters/ [https://perma.cc/WCK2-D434].

195. L.R. Iwanowicz et al., *Evidence of Estrogenic Endocrine Disruption in Smallmouth and Largemouth Bass Inhabiting Northeast U.S. National Wildlife Refuge Waters: A Reconnaissance Study*, 124 ECOTOXICOLOGY & ENVTL. SAFETY 50, 55 (2016).

prevent future problems. Priority conservation efforts to address future issues should include protecting the forested landscape, restoring and protecting river corridors, shutting off vectors for invasive species like the Champlain Canal, and minimizing impacts of new developments.