Surficial Geology of the Lake Carmi Watershed and Adjacent Map Area "A", Northwestern Vermont

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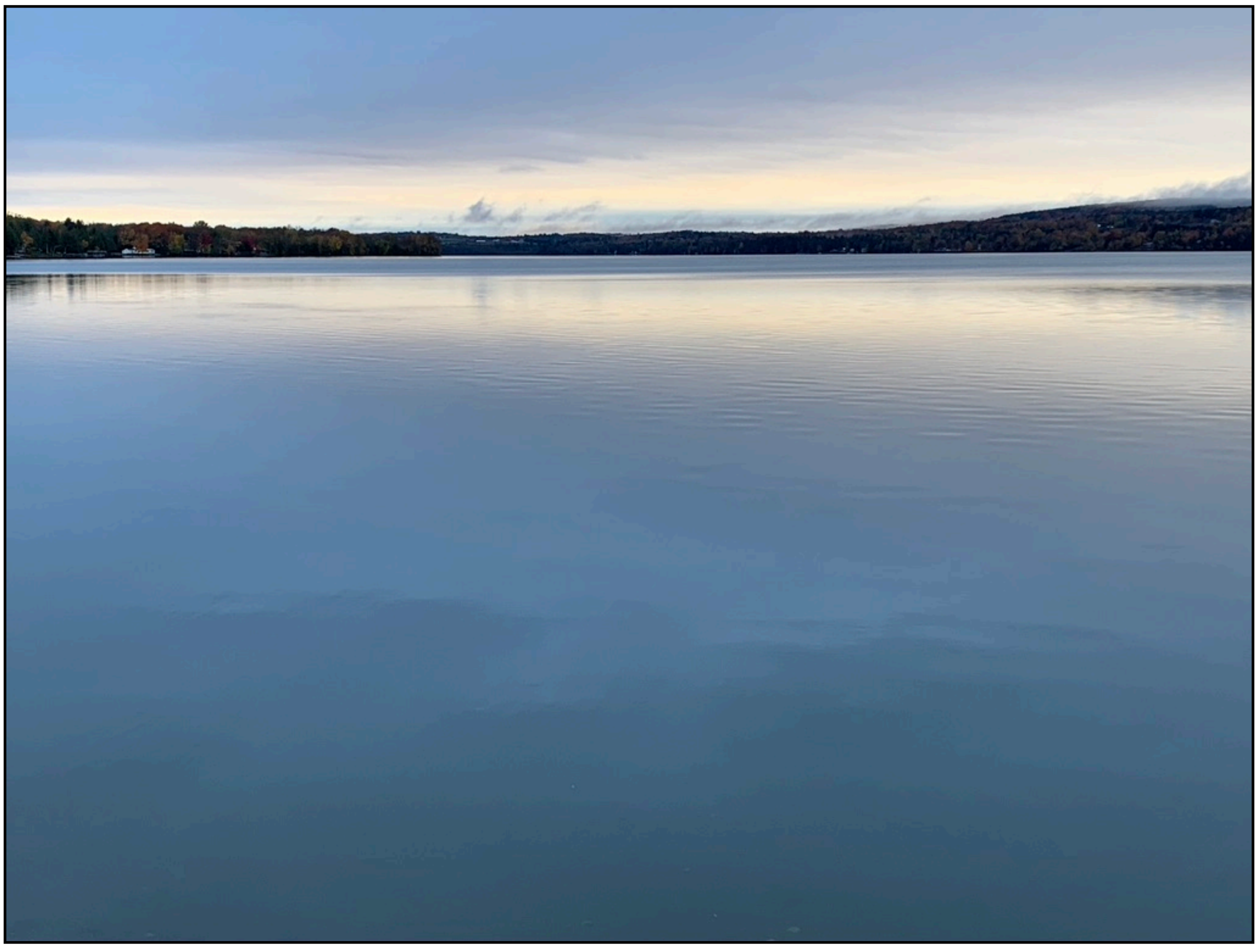
December 2020



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Abstract

The following report summarizes the results of surficial geologic mapping in the Lake Carmi Watershed and an adjacent area northeast of the watershed. This report compliments (1) a Surficial Geologic Map, (2) an Isopach Map contouring the thickness of surficial materials, (3) a Recharge Potential Map, and (4) three geologic cross-sections all prepared as part of this project for the Vermont Geological Survey[1]. The aerial distribution and thickness of surficial materials affects the infiltration of surface water into the subsurface and its subsequent movement as groundwater. This study can be utilized to better understand the movement of nutrients into Lake Carmi via groundwater.

The dominant surficial materials occurring in the mapped area are glacial till and stratified diamict, a material derived from till mobilized by debris flows and deposited in the two bodies of water that once flooded this area, Glacial Lake Vermont and the Champlain Sea. Fine-grained glaciolacustrine and glaciomarine sediment was deposited concurrently with the stratified diamict and makes up a larger percentage of the surficial materials in the valley centers, farther from the shorelines of these former water bodies. Lake Carmi is likely underlain by stratified diamict close to shore and fine-grained glacial lake/sea sediment (silt/clay) farther from shore. An unusual low amplitude ridge, largely composed of diamict, occurs around most of Lake Carmi's perimeter. This shoreline ridge may have formed by repeated episodes of lake ice pushing near-shore sediments into a ridge. This process is likely particularly active during both isolated cold winters and extended periods of cold winters, e.g. The Little Ice Age.

Minor deposits of stream sediments occur along the course or modern streams, on terraces that were once occupied by streams, in alluvial fans, and in one modern delta where Marsh Brook enters Lake Carmi. While the fluvial sediments are permeable and serve as good recharge zones, in many areas these same sediments lie in or adjacent to groundwater discharge areas. The one exception are some of the alluvial terraces near East Franklin. Otherwise, most of the Lake Carmi drainage basin is underlain by low-permeability surficial materials. Surface water infiltration into these materials is relatively slow and groundwater movement through them is also slow. Furthermore, the fine sediment that limits the permeability of these materials also provides significant surface area to adsorb dissolved ions in the groundwater. Unless nutrients responsible for the algal blooms are uncharged and can avoid being adsorbed onto the surfaces of sediment, it seem unlikely that a significant concentration of these ions travels via groundwater into the lake. On the other hand, in all these otherwise low-permeability surficial materials there is a near-surface zone where permeability is enhanced by frost heave, animal and insect burrowing, and roots. This near-surface zone may be the common pathway nutrients make their way from the surrounding uplands into the lake.

[1] 2020 Surficial Geologic Mapping—Lake Carmi Watershed Project: Contract 40564

Introduction

Lake Carmi is a broad shallow lake in northwestern Vermont. Its water quality is impaired by summer algal blooms fueled by relatively high phosphorous concentrations in the lake water. This report details the findings of a geological survey of the Lake Carmi drainage basin and an adjacent area bordering the outlet stream draining of the lake, “Map Area A” (Fig. 1). The objective of this work is to understand the composition, distribution, and hydraulic properties of surficial materials overlying the bedrock in this area. The infiltration of surface water into these materials and subsequent movement as groundwater through these materials is a fundamental part of the hydrologic cycle, one that cannot be understood without a good geologic map. This report describes the surficial materials presented on the Surficial Geologic Map of the Lake Carmi Area which accompanies this report, interprets their thickness via an isopach map and 3 geologic cross-sections, and maps areas where surface water infiltration rates are likely relatively high and relatively low.

Location

Lake Carmi, its surrounding drainage basin, and the adjacent Map Area A, are located in the town of Franklin, northwestern Vermont, along the Québec border (Fig. 1). The lake (elevation 132.5 m, 435 ft) is surrounded by low mountains and the maximum vertical relief across the map area is ~140 m (~540 ft). The lake is fed by several small brooks, only two of which are named, Alder Run entering from the north and Marsh Brook entering from the east (Fig. 1). The lake outlet is along its northeast corner via an unnamed brook which joins the Pike River north of East Franklin. The Pike River flows north into Québec along the eastern boundary of the map area. The lake elevation is maintained by a small dam located along the outlet brook where Vermont Route 120 crosses that brook. The southern end of the lake is bordered by a large wetland. The drainage divide between surface water flowing north-into and out of Lake Carmi and water flowing south into the Missisquoi River lies in that wetland, less than a meter or two above the elevation of the lake. At least some of the lake’s outflow likely moves through this wetlands and into the Missisquoi drainage basin.

Bedrock Geology

Bedrock underlying the map area consists almost entirely of one map unit, the Fairfield Pond Formation, which is largely composed of phyllite and metagreywacke, metamorphosed late Proterozoic to Cambrian fine-grained clastic sedimentary rocks (Fig. 2), (Ratcliffe et al., 2011). Layering within these rocks, both original bedding and the metamorphic fabric, as well as geologic contacts between the Fairfield Pond and adjacent units are aligned NNE-SSW, parallel to the long axis of Lake Carmi (Ratcliffe et al., 2011). These NNE-SSW bedrock structures are prominently visible on the LiDAR shaded relief imagery.
Major bedrock lineaments cross-cutting the dominant layering are uncommon, but several N-S lineaments extend north from the NW shore of Lake Carmi, cross the drainage basin boundary and Vermont Route 120 (Fig. 2). Alder Run, entering the lake from the north, has a similar orientation and the valley it occupies may is likely underlain by a bedrock lineament. These lineaments owe their existence to fractured rock, joint sets or faults, and are a major source of secondary porosity in metamorphic rocks and are major conduits for groundwater flow in the bedrock.

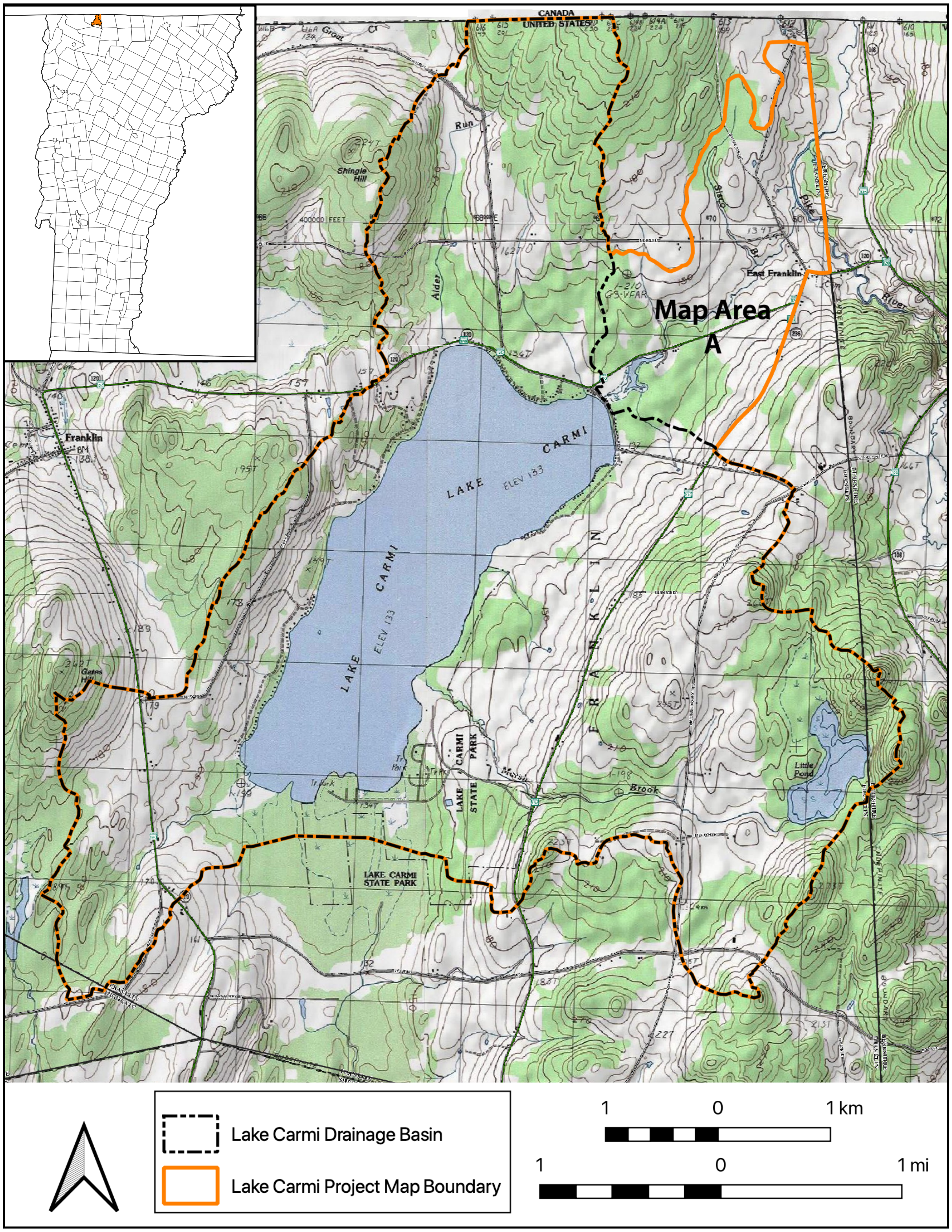

Figure 1: Topographic map showing the location of Lake Carmi, its surrounding drainage basin, and Map Area A. Elevations and contours are in meters.

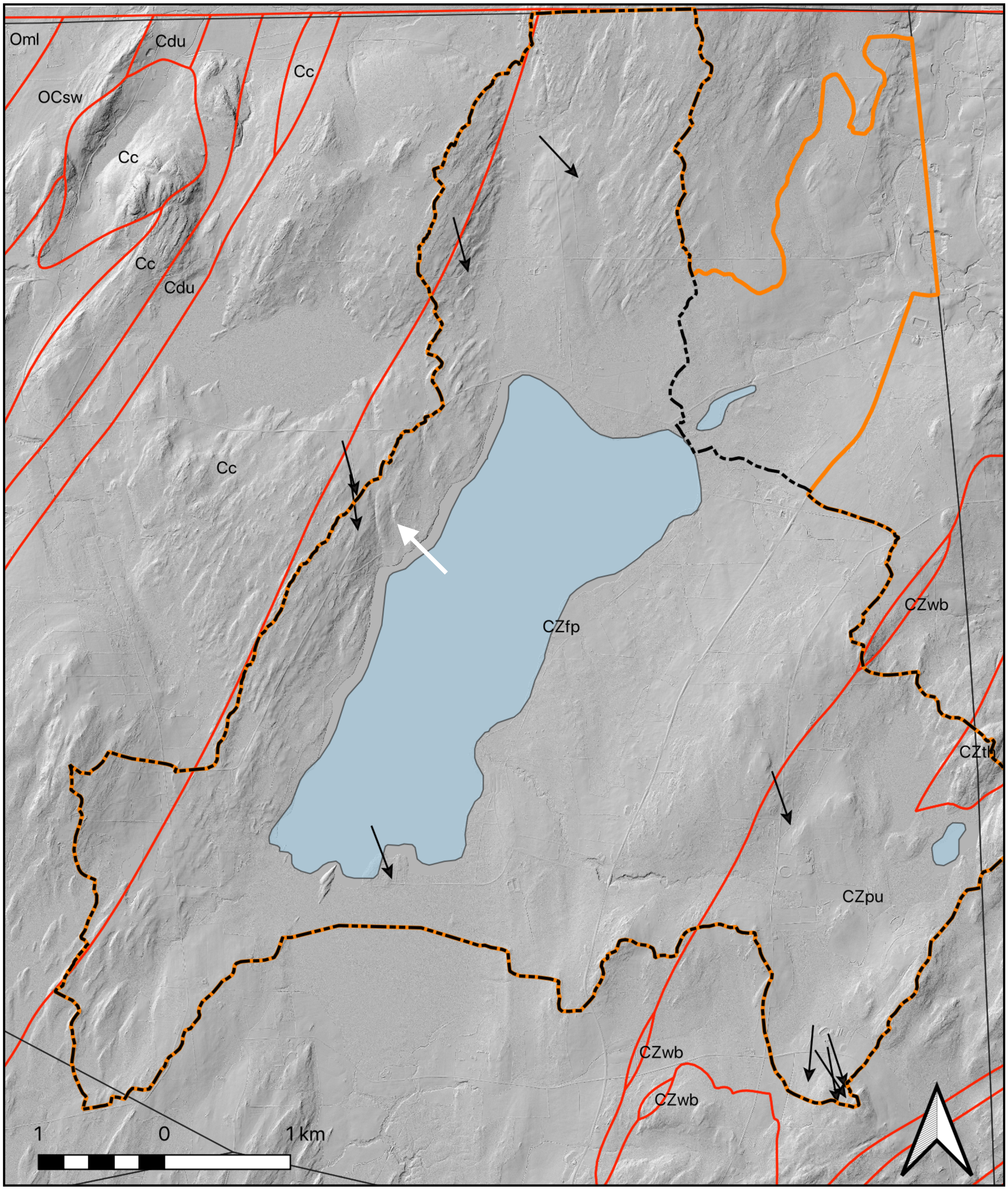

Figure 2: LiDAR shaded relief map of Lake Carmi and surrounding areas showing the map area, bedrock contacts (red lines), and glacial striations. NNE-SSW bedrock layering is parallel to geologic contacts. White arrow points to bedrock lineaments. Large-scale grooves in glacial till and crag and tail structures are aligned parallel to glacial striations. Rock units in the map area: Cc = Cheshire Formation, CZfp = Fairfield Pond Formation, CZpu = Pinnacle Formation, CZwb = White Brook Formation, CZth = Tibbit Hill Formation.

Background Surficial Geology

At the peak of the last (Wisconsinan) glacial period, ~25,000 years ago, the Laurentide Ice Sheet (LIS) completely covered the mountains in Vermont and extended to Cape Cod and well out into the Gulf of Maine. The ice margin retreated to the southern border of Vermont by 15,600 years ago and was retreating across Vermont's northern border into Québec between 13,200 and 13,400 years ago (Ridge, 2016). At the peak of glaciation glacial ice flowed obliquely across Vermont, generally from NW to SE (Wright, 2015). Most glacial striations recorded in the Lake Carmi area record this regional ice flow (Fig. 2). Large-scale grooves in glacial till (visible in the LiDAR shaded-relief imagery) and crag and tail landforms similarly record this direction of ice flow (Fig. 2).

As the ice sheet retreated northwards, down the Champlain Valley, it prevented meltwater from draining to the north. Instead, this meltwater pooled in front of the retreating ice sheet forming Glacial Lake Vermont which drained to the south. By the time the ice sheet retreated to the Québec border its elevation was controlled by the drainage divide near Fort Ann, New York, what's referred to as the Fort Ann Stage of Glacial Lake Vermont. In the Lake Carmi area, the shoreline of that lake was at an elevation between ~196–198 m (643–650 ft), high enough to inundate all but the highest parts of the map area. Once the ice sheet retreated above the St Lawrence River Valley, Glacial Lake Vermont drained into the north Atlantic Ocean and the Champlain Valley and adjacent areas that were isostatically depressed below sea level were flooded by the Champlain Sea. In the Lake Carmi area this water body reached an elevation of 155 m (~510 ft), sufficient to maintain most parts of the map area underwater. Isostatic rise of the land surface eventually elevated the Lake Carmi area above sea level allowing the basin under Lake Carmi to convert to a lake and streams to begin flowing across sediments that had accumulated in the valley bottoms while under standing water.

In short, the surficial materials occurring in the Lake Carmi area were deposited sequentially in three distinctly different environments: (1) beneath the Laurentide Ice Sheet, (2) within the standing, generally deep, water of both Glacial Lake Vermont and the Champlain Sea, and (3) in fluvial environments existing after the Champlain Sea drained.

The map area that is the focus of this report lies within the Enosberg Falls 15' Quadrangle which was mapped by Cannon (1964) and compiled into the Surficial Geologic Map of Vermont (Stewart and MacClintock, 1970). Cannon mapped glacial till in all areas surrounding Lake Carmi with the exception of the large wetland area at the lake's south end and several smaller, but still extensive wetlands (Fig. 3). Additionally, Cannon's map of the the Pike River drainage (Map Area A) shows an extensive area of marine sand ("ms" Fig. 3).

Figure 3: Surficial geologic map of the Lake Carmi area (Cannon, 1964). Uncolored area are glacial till, P = peat (wetlands), LS = Littoral Sand, MS = Marine Sand.

Methods

Surficial geologic mapping of the Lake Carmi area was completed during the late summer of 2020. Field observations were recorded using a Fulcrum data collection App modified for surficial field mapping. During this time over 350 separate field observations were recorded using the (1) shaded-relief LiDAR imagery, (2) topographic map, and (3) aerial photography as base maps. The locations of these observations are shown on the geologic map. A geodatabase file detailing the location and geological observations recorded at each site was generated by the Fulcrum mapping app. These field data, the LiDAR imagery, and 2 m topographic contour lines generated from the LiDAR DEM's provide the basis for generating the surficial geologic map that accompanies this report. Most of the mapping area was defined by the drainage basin of Lake Carmi. The drainage basin boundary outlined in both the map project proposal and the VT Subwatershed Boundaries HUC12 GIS file (obtained through VCGI) is inaccurate and was consequently redrawn using the 2 m contour map (see above).

Stratigraphic Framework/Mapping Units

The stratigraphic units mapped during this project and described below largely follow those utilized in recent mapping projects, e.g. Wright (2020). The surficial geologic map that accompanies this report shows the aerial distribution of different types of surficial materials, landforms constructed of these materials, glacial striations, and water wells. During the spring of 2018 the Vermont Geological Survey developed a uniform set of mapping units which are utilized on the Lake Carmi Surficial Geologic Map (Springston et al., 2018). The boundaries between these different materials are geologic contacts and are shown as solid lines on the geologic map. It's important to realize, however, that these contacts are non-planar 2-D surfaces that extend out-of-sight below Earth's surface and their extension above Earth's surface has eroded away. In some areas geologic contacts could be closely located in the field and these locations were recorded and used when constructing the map. However, in most areas the location of these contacts is interpreted from field observations, distinctive landforms, and aerial imagery. Every effort was made to make these contacts as accurate as possible, but there is an element of interpretation in the placement of these contacts.

The different surficial materials mapped within quadrangle are described below, in stratigraphic order, from oldest to youngest. Also included is a brief note about bedrock outcrops. The hydrologic properties of these materials are discussed as well.

Bedrock Outcrops

Bedrock outcrops were mapped where encountered in the field, but no attempt was made to visit all areas of outcrop. The orientation of any glacial striations present were measured. Otherwise, the location of outcrops was used to help outline areas where surficial materials are thin or absent. Extensive areas of outcrop occur across many of the high ridges in the area. These areas were not mapped, but are clearly visible in the LiDAR shaded-relief imagery.

Pt: Glacial Till

Glacial till directly overlies the bedrock in most areas. Till is the ubiquitous surficial material in most areas above the valley bottoms. Till in the area consists of angular to subrounded pebbles, cobbles, and boulders, many with striated surfaces) suspended in a fine clay/silt/sand matrix. Most of the till occurring in this area is lodgement consisting of materials eroded, deformed, and deposited beneath the ice sheet. Having sustained the full weight of the ice sheet, this material is very compacted and dense, earning it the colloquial name "hardpan," which appears in many well logs. Close to the ground surface frost heaving, plant roots, and animal borrows have loosened the till and surface run off has eroded some of the smaller-sediment (the "fines") in the till. A variable thickness of ablation till was undoubtedly deposited on top of the lodgment till, but its texture is so similar to lodgment till loosened by frost heaving etc. that no attempt was made to distinguish the two. Till in the uplands is thin and patchy, but well logs in isolated upland areas record >50 feet of till. Till thickness generally increases near the base of slopes.

The silt/clay sediment in the till matrix limits its permeability. As such, the till acts as an aquitard, only slowly allowing groundwater to move through it. As noted earlier, the action of frost, roots, animals, and insect loosens the dense till texture near the ground surface enhancing the ability of surface till to absorb rainfall and snowmelt. This relatively permeable soil zone, in most areas well above the water table, likely focuses the downslope movement of near-surface groundwater following rain or snowmelt events. Despite being relatively impermeable, till is quite porous and can hold a lot of groundwater. Saturated till in the upland areas serves to recharge the fractured bedrock beneath the till. While groundwater movement through the till is slow, the volume of the bedrock fracture systems (secondary porosity) is quite low, meaning that a relatively low, but constant discharge of groundwater through the till into the bedrock is sufficient to keep these bedrock aquifers saturated.

Pmf: Fine-grained Lacustrine/Marine sediments

This mapping unit consists of well-sorted medium to fine sand, silt, or clay deposited in the deeper/quieter parts of Glacial Lake Vermont and the Champlain Sea. These sediments only constitute a mappable unit in the Alder Run valley extending north from the north end of Lake Carmi. Field observations could not discern if these sediments originated in a lacustrine vs marine environment. However, given that the older lacustrine sediments are likely covered in most areas by younger marine sediments, surface exposures are assumed to be marine and any fine-grained lacustrine sediments lie beneath.

These sediments are generally quite porous, but have low permeabilities, especially so when the unit grain size diminishes to fine silt and clay. As such, they can be classified as aquitards when consisting of fine sand/coarse silt, but as aquicludes when consisting of fine silt/clay.

Pldi: Lacustrine/Marine Stratified Diamict

In a recently deglaciated, unvegetated, landscape, till deposited on hillsides frequently fails when the ground is saturated and slides downhill as a slurry of remobilized till—a debris flow. If a lake or sea has flooded a mountainous area, these debris flows can begin on the steep slopes above or below the water surface, but once underwater will transition to a dense turbidity current capable of transporting remobilized till (diamict) both downslope and out across the floor of the lake/sea. Following deposition of the coarse fraction of the debris flow, finer-grained sediment in suspension is deposited followed by sediment that normally reaches this environment. What results is a stratigraphic unit consisting of layers of diamict interbedded with fine sand, silt, and clay (Fig. 4). On the weathered landscape, i.e. areas without fresh vertical exposures, this material will look like glacial till.

In the Lake Carmi area, broad areas of "till" were mapped in low-lying areas well away from the valley sides. In some of those areas silt was also mapped. Similarly, many water well logs record both a mixture of “boulders and clay” and layers of till/hardpan and clay. Consequently this mapping unit is *inferred to exist* as a way of explaining these field observations, despite the fact that no exposures were found that prove its existence in the area. The contact between this unit and glacial till is impossible to map with certainty. However, given the depositional model outlined above, contacts have generally been drawn near the base of hill slopes. Cross-section A-A’ (Fig. 5), drawn across the wetlands at the north end of Lake Carmi depicts these stratigraphic relationships. A cross section across Lake Carmi’s outlet (B-B’, Fig. 6) similarly shows a section dominated by stratified diamict transported from the adjacent valley sides by debris flows. *Importantly, this same stratigraphy likely extends across Lake Carmi, i.e. some combination of till and stratified diamict extends beneath the lake close to shore, but most of the lake bottom, well away from the valley sides, is underlain by fine-grained sediments (very fine sand, silt, clay) deposited first in Glacial Lake Vermont and subsequently in the Champlain Sea.*

The hydrologic properties of this material lie between glacial till and the fine-grained lacustrine/marine sediments, i.e. they are porous, but have a low permeability. Consequently, if the mapped extent of stratified diamict on the geologic map proves incorrect, this should not significantly alter interpretations of groundwater flow in the area.

Figure 4: Stratified lacustrine diamict exposed in the Cotton Brook landslide, east of the Waterbury Reservoir. Large rocks deposited in a debris flow into Glacial Lake Winooski are interlayered with finely laminated grey silt.

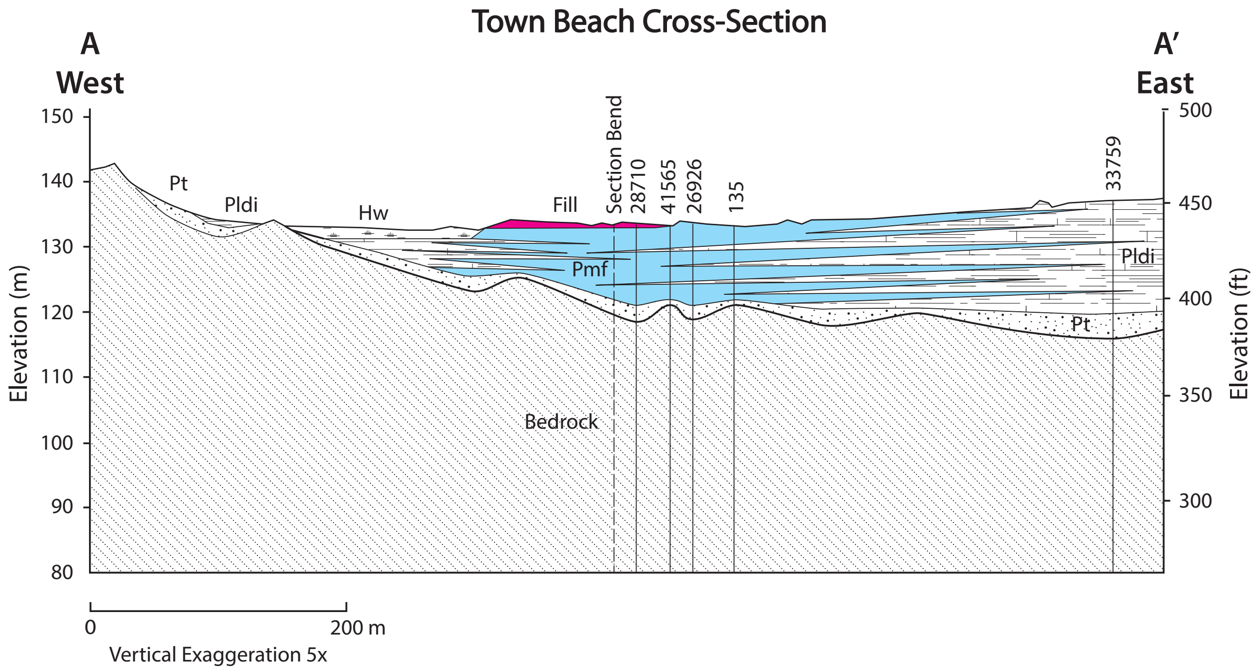

Figure 5: Cross-section A-A' extends across the north end of Lake Carmi. Most of the section consists of sediments deposited first in Glacial Lake Vermont and later in the Champlain Sea. Fine-grained glaciomarine sediment dominates the valley center whereas stratified diamict, deposited as debris flows, is more common along the valley margins. Pt = Glacial Till, Pldi = Stratified Diamict, Pmf = Fin-grained marine sediments, Hw = Wetlands. Well Report Numbers are shown above water wells.

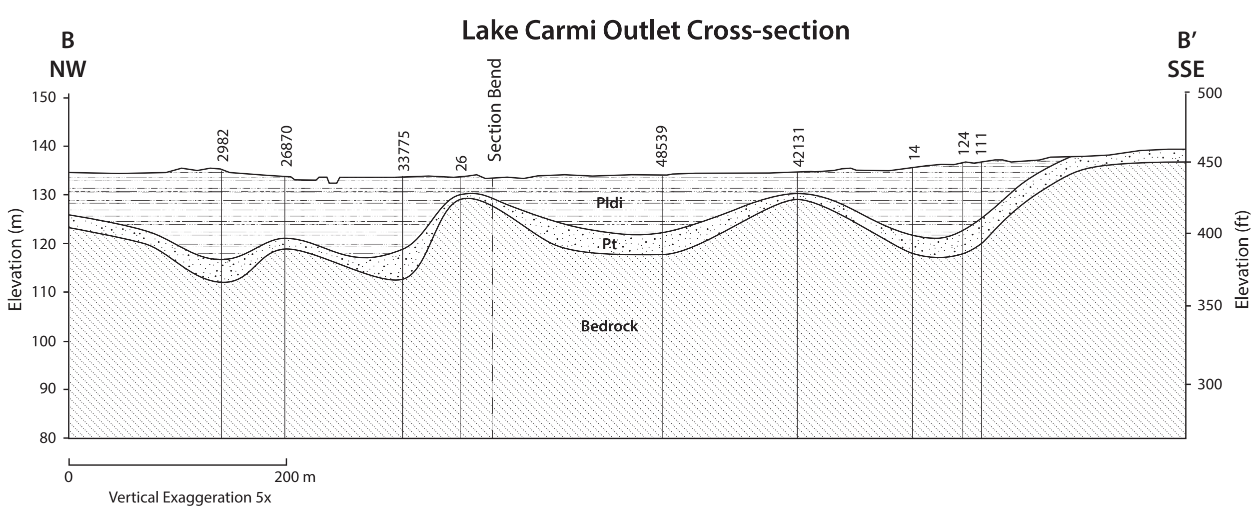

Figure 6: Cross-section B-B'crosses the outlet of Lake Carmi and is controlled by numerous water wells drilled for lake shore residences. Bedrock topography is similar to that observed in the uplands where bedrock is exposed. The extensive deposit of stratified diamict is inferred from the mixed sediment reported in the water well logs. Lenses of fine-grained lacustrine and marine sediment are likely interbedded with the diamict. Pt = Glacial Till, Pldi = Stratified Diamict. Well Report Numbers are shown above water wells.

Ice-Contact Deposits

No ice-contact deposits, e.g. esker, subaqueous fan deposits, were observed in the map area or noted in the water well logs. However, it's possible these deposits might lie hidden beneath thick sections of stratified diamict and fine-grained lacustrine and marine sediment. A subglacial drainage system might have extended across the drainage divide to the south of Lake Carmi, continued up the length of the lake, and then up the Alder Run valley, but there's no evidence of this. Another likely conduit for subglacial drainage would be along the Pike River valley.

Hw Wetlands Deposits

Wetland areas generally occupy closed basins and display varying amounts of open water depending on the season and the water table elevation. The dominant surficial material in wetland areas consists of both living and partially decayed organic materials but also includes inorganic fine-grained clastic sediment washed into these areas by streams and overland flow. Wetland areas are underlain by either till, stratified diamict, or fine-grained lacustrine/marine sediments. Wetlands in the uplands, particularly the extensive wetlands surrounding Little Pond along the eastern margin of the map, act as significant recharge areas for the underlying fractured bedrock aquifers.

Holocene Fluvial Deposits: Ha Alluvium, Hat Alluvial Terrace, Haf Alluvial Fan, Hld Delta

A variety of fluvial deposits were mapped. These are all deposits of streams depositing sediments in different environments following the draining of the Champlain Sea from the area. All of these materials are porous, permeable, and are good recharge areas except in stream bottoms where groundwater discharges to the surface.

Alluvium (Ha) refers to sediments deposited by modern rivers and streams. These sediments include sand and gravel deposited in river channels and point bars as well as sand and silt deposited on floodplains. Organic materials are a frequent component of modern alluvium. These sediments were first deposited when streams began flowing across recently deglaciated valley sides and later when valleys occupied by glacial lakes and the Champlain Sea drained. The thickness of alluvium is proportional to the size of the stream that deposited it, but generally corresponds to the depth of the modern stream channel.

Alluvial terrace deposits (Hat) are stream sediments (alluvium) occurring on terraces above modern streams. As streams eroded channels more and more deeply through earlier-deposited sediments, older channels and adjacent flood plains were abandoned. In many areas there are several different terrace above the modern streams (Fig. 7). Alluvial terraces are underlain by a veneer of sand and gravel corresponding in thickness to the depth of the stream channel that deposited the sediment. Alluvial terraces were mapped near the confluence of Lake Carmi's outlet stream and the Pike River and are deposited above either stratified diamict or fine-grained marine sediments. Some of these deposits may have been deposited as deltaic sediments by these streams as the elevation of the Champlain Sea slowly fell relative to the isostatically rising land surface.

Alluvial fans (Haf) are fan-shaped deposits formed where streams deposit sediment where they flow out onto a gently-sloping valley floor, e.g. a fluvial terrace or modern floodplain. Sediments deposited in alluvial fans generally grade from coarse to fine between the apex of the fan to its toe. The absolute size range of sediment in fans depends on the source of sediment. In many upland areas fans are sourced from till remobilized as debris flows and the fans consist largely of unsorted diamict. In areas where streams are eroding channels through fine-grained lacustrine or marine sediment, that will be the size of sediment deposited in the fan. Several, generally small alluvial fans are shown on the geologic map. Studies in northern Vermont indicate that alluvial fans have been active episodically throughout the

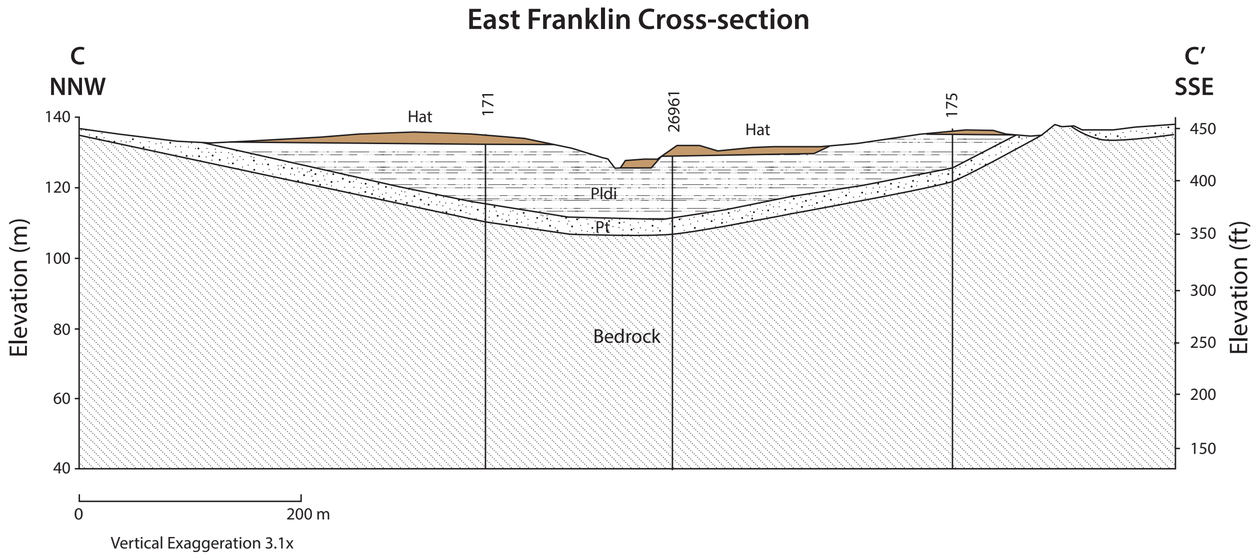

Figure 7: Cross-section C-C' extending NNW from the village of East Franklin. The outlet stream from Lake Carmi crosses the middle of the section a short distance from its confluence with the Pike River. Abandoned terraces underlain by alluvium overlie stratified diamict or, farther down the valley, fine-grained marine sediments.

Holocene and have many received their most recent pulse of sediment following European land clearing in the late 18th and early 19th centuries (Bierman et al., 1997; Jennings et al., 2003). Related work by Noren et al. (2002) recording pulses of clastic sediment deposited in ponds and small lakes, indicates that pre-European settlement erosion has not been uniformly distributed throughout the Holocene and seems instead to be concentrated during periods of increased high-intensity storms. If climate shifts produce a greater frequency of high-intensity storms, further sedimentation on the area's alluvial fans seems likely.

Deltas (Hld) One modern *delta* was mapped where Marsh Brook enters the east side of Lake Carmi near the north end of the State Park. This delta is largely composed of sand, gravel, and organics deposited where the brook slows and enters the lake. Older, buried parts of this delta likely formed during the later stages of the Champlain Sea. Similar to alluvial fans (see above) major sediment pulses occur during high-discharge events associated with storms and snowmelt.

<u>*Artificial Fill*</u>

Artificial fill constitutes material transported into the area for construction purposes. Limited areas of fill were mapped underlying portions of roadways and the Lake Carmi outlet dam. Most of these areas are of limited extent and will not significantly alter the hydrology of the area. The exception is the dam which has raised the level of the lake by several meters flooding the reach of the outlet stream upstream from the dam allowing wetland vegetation to flourish.

<u>*Shoreline Ridge*</u>

One notable landform occurring in the area is a ridge occurring around the periphery of Lake Carmi. In most areas it's composed of unsorted coarse-grained sediment, i.e. till/diamict without the fines, and rises 2 to 3 m above lake level. Notably, this ridge also extends across part of the delta at the mouth of

Marsh Brook on the eastern side of the lake where it is composed of sand and gravel. Given that the delta is a landform that's actively forming in the modern environment, it follows that this ridge must have formed/be forming from processes that are currently active, i.e. this is a modern (Holocene) as opposed to Pleistocene landform. Lake Carmi is very broad shallow (<10 m deep) lake and in many years lake ice must extend to the bottom. Lateral expansion of this lake ice as it freezes from edge to center might provide the mechanism that created this ridge. This process would be particularly effective during cold winters when the ice was thick. It's possible that the ridge formed or was most recently active during the Little Ice Age when several hundred years of cold winters occurred.

Isopach Map

The "Isopach Map of Surficial Materials" contours the thickness of surficial materials (overburden) within the map area. The data used to generate this map are (1) bedrock outcrops recorded from field work (areas where surficial materials don't occur), (2) bedrock outcrops visible on the LiDAR shaded-relief imagery, (3) records of overburden thickness from domestic water wells, and (4) landforms visible on the shaded-relief maps generated from LiDAR data. The well utilized are limited to those located using GPS or matched to an E911 address. In some instances wells are shown in unlikely areas, well away from private residences, barns, etc. and were ignored. In other cases incorrectly recorded overburden thickness data appears in the well database. Two common examples are (1) when the overburden thickness does not closely match the casing length and (2) when a drilled well does not extend to bedrock. The data table was corrected, where these issues could be resolved, and well data ignored, where not. These data are contoured using a 20-foot contour interval between 0 and 60 feet. Contour maps of overburden thickness generated using contouring algorithms produced geologically unrealistic contours, so these data were contoured by hand. While the above data provide good constraint on these contours in some areas, in many parts of the map area these contours are poorly constrained. An extension of this poor constraint is that there are likely many areas where surficial materials are sufficiently thick and extensive to contour, i.e. they exceed 20 feet, but are not. Isolated wells reporting thick surficial materials were generally ignored, i.e. bullseyes were not drawn around these isolated wells.

Generally, areas of thick surficial materials occur in the major stream valleys, e.g. Alder Run, the Lake Carmi outlet stream, and the Trout River. Another area of potentially thick surficial material is the valley extending south of Lake Carmi. Much of this area is underlain by wetlands and no wells are known to exist. There's little surficial material covering bedrock in most areas east side of Lake Carmi. The west side of the lake is more gently sloped and is overlain by a thicker accumulation of surficial materials.

Groundwater Infiltration Potential Map

Groundwater recharge depends on (1) how easily rainfall and snow melt can infiltrate the ground surface, (2) the rate at which water can move through the surficial material or rock it infiltrates into—its permeability, (3) the amount of time that water is available to enter different groundwater systems. Infiltration is enhanced when the ground surface is permeable and rainfall and snow melt can linger on the ground surface. Coarse-grained surficial materials on level ground provide the best infiltration whereas steep bedrock surfaces provide the worst. Vegetation, burrowing animals, and frost heaving usually enhances infiltration by increasing the permeability of surficial materials and providing a myriad of small depressions where surface water can linger and infiltrate. Fine-grained surficial materials usually have a low permeability. Even if vegetation allows water to infiltrate, the rate it can percolate (seep) into the material may be far slower than the rate at which new water from rainfall or snow melt is available. In fine-grained materials with low permeability, e.g. many tills and fine-grained lacustrine/marine sediments, a significant amount of water can move though these materials if enough time is available.

The recharge potential map included with this report groups surficial materials into 1) those with high porosity and high to moderately high permeabilities and 2) those with low permeabilities.

<u>High Recharge Potential to Surficial and Bedrock Aquifers</u>
Alluvium, Alluvial Fan sediments, Fluvial Terrace sediments, Deltaic sediments, and Wetlands are all materials that readily absorb surface water. They all consist of coarse-grained surficial materials and lie in valleys where slopes are gentle. Where these materials overlie moderate- to low-permeability materials, they have the capacity of soak up surface water allowing it to slowly seep into these underlying surficial materials. With the exception of the wetlands areas, these materials make excellent surficial aquifers where they extend below the water table. Wetlands uniquely serve as good recharge sites because they occur in closed depressions where surface water collects. Even if the surficial materials underlying a wetland have a low permeability, they will have a near constant flow of well-filtered surface water through them into the underlying groundwater system.

<u>Low to Moderate Recharge Potential to Surficial and Bedrock Aquifers</u>
Lacustrine and marine very fine sand, fine sand, silt, stratified diamict, most till and artificial fill (commonly covered with pavement) all have low permeabilities. Till mantles most upland areas and usually directly overlies bedrock. As noted earlier, animals, vegetation, and frost heave enhance near surface infiltration and thick areas of till that remain saturated much of the year are common. Therefore, despite till's low permeability, a significant amount of recharge can enter the underlying fractured bedrock aquifers. The stratified diamict likely has hydrologic properties lying between those of till and fine-grained lacustrine/marine sediment. Unlike till, this material is layered. While some of these layers may be almost impermeable (fine silt/clay), some layers may consist of coarser material without the fines (carried by suspension into deeper water) and consequently be relatively permeable layers, generally parallel to the overlying hill slope. That said, these same layers will generally fine down-slope and these more permeable layers, if they exist at all, may well pinch out. The lacustrine/marine fine sand, silt, and clay occurs in the valley bottoms and likely underlies Lake Carmi and many of the wetlands, especially the large wetlands at the south end of the lake. The lake is a groundwater discharge area and these low-permeability sediments likely limit the rate at which groundwater can recharge from the underlying bedrock or surficial materials into the lake.

Conclusions

The dominant surficial materials occurring in the mapped area are glacial till and stratified diamict, a material derived from till mobilized by debris flows and deposited in the two bodies of water that once flooded this area, Glacial Lake Vermont and the Champlain Sea. Fine-grained glaciolacustrine and glaciomarine sediment was deposited concurrently with the stratified diamict and makes up a larger percentage of the surficial materials in the valley centers, farther from the shorelines of these former water bodies. Lake Carmi is likely underlain by stratified diamict close to shore and fine-grained glacial lake/sea sediment (silt/clay) farther from shore. Minor deposits of stream sediments occur along the course or modern streams, on terraces that were once occupied by streams, in alluvial fans, and in one modern delta where Marsh Brook enters Lake Carmi. While the fluvial sediments are permeable and serve as good recharge zones, in most areas these same sediments lie in or adjacent to groundwater discharge areas. The one exception are some of the alluvial terraces near East Franklin. Otherwise, most of the Lake Carmi drainage basin is underlain by low-permeability surficial materials. Surface water infiltration into these materials is relatively slow and groundwater movement through them is also slow. Furthermore, the fine sediment that limits the permeability of these materials also provides significant surface area to adsorb dissolved ions in the groundwater. Unless nutrients responsible for the algal blooms are uncharged and can avoid being adsorbed onto the surfaces of sediment, it seem unlikely that a significant concentration of these ions travels via groundwater into the lake. On the other hand, in all these otherwise low-permeability surficial materials there is a near-surface zone where permeability is enhanced by frost heave, animal and insect burrowing, and roots. This near-surface zone may be the common pathway nutrients make their way from the surrounding uplands into the lake.

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