Lake Carmi Tributary Flow Monitoring Feasibility Assessment: Final Report

PROJECT NO.

20-052

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Cover photo: Assessing gauging locations along Prouty Brook

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1. Introduction

Lake Carmi is an approximately 1,364-acre (552 ha) lake in Franklin, Vermont. Ten named tributaries flow into Lake Carmi. The lake drains, via an outlet at its northern end, to Sisco Brook, the Pike River, and on to Missisquoi Bay of Lake Champlain. The lake level is controlled by a dam, although it is not actively regulated.

Due to frequent algae blooms, a Total Maximum Daily Load (TMDL) for phosphorous was established for Lake Carmi in April 2009. While there is ongoing monitoring of lake conditions by the University of Vermont and the Vermont Agency of Natural Resources, and a tributary sampling program is coordinated by the Lake Carmi Campers' Association, flow monitoring has not been conducted on any of the lake's tributaries. Streamflow data from the tributaries would enable the Vermont Agency of Agriculture, Food & Markets (VAAFM) and other stakeholders to gain a better understanding of nutrient loading to Lake Carmi.

Stone Environmental (Stone) performed an evaluation for VAAFM of the feasibility of monitoring streamflow near the outlets of Lake Carmi's 10 named tributaries. These streams are Prouty Brook, Westcott Brook, Sandy Bay Brook, Alder Run, Dicky's Brook, Dewing Brook, Kane's Brook, Hammond North Brook, Hammond South Brook, and Marsh Brook. Stone conducted site visits and evaluated streamflow gauging sites on each tributary. Stone then evaluated methods and instruments appropriate for continuous flow measurement on each tributary and developed cost estimates for a potential stream gauging program. In our considered opinion, flow monitoring is feasible on all the assessed tributaries. However, site specific considerations influence the methods recommended at the proposed gauge locations, and cost considerations may necessitate prioritizing sites for monitoring.

Stone and VAAFM convened a Technical Advisory Committee (TAC) to get feedback on work completed and suggested approaches to monitoring flow. The TAC (Table 1) members include representatives of Vermont state agencies, UVM Extension, watershed organizations, and the public. The first meeting of the TAC was held on October 28, 2020. Stone presented a project overview, a description of potential gauging sites, and our recommendations concerning the most suitable flow gauging site on each stream. A second meeting was held on July 27, 2021, to review recommended stream gauging methods and instruments. In both meetings, the ensuing discussions were informative and much constructive feedback was obtained.

Table 1. Technical Advisory Committee members

Laura Dipietro	VAAFM
Ryan Patch	VAAFM
Oliver Pierson	VTDEC
Karen Bates	VTDEC
Blaine Hastings	VTDEC
Jeff Sanders	UVM Extension
Peter Benevento	FWC/L. Carmi Campers' Assoc.
Bruce McGurk	Local (retired hydrologist)
Matt Vaughan	LCBP

2. Flow Monitoring Overview

Continuous, direct measurement of water flow rate (discharge) is only possible using volumetric methods. However, continuous volumetric flow measurement is infeasible in open channels. Stream gauging entails making more practicable measurements of water level (stage), stream width, and stream velocity and using these measurements in computing flow rate.

The conventional method for quantifying flow rate in open channels is to continuously measure stage, then apply a stage-discharge rating to the continuous stage measurements to derive a continuous record of flow. A stage-discharge rating is a mathematical relation describing the fit among multiple paired measurements of stage and flow.

The instruments most widely used for continuous stage measurement include floats (within a stilling well), pressure transducers, bubbling stage recorders, and ultrasonic level sensors. Discharge measurements are made periodically to develop and verify stage-discharge ratings, using a variety of mechanical (e.g., Type AA and Pygmy) and acoustic (e.g., SonTek FlowTracker) current meters to measure stream velocity across the width of the channel.

All things considered, the conventional method is a well-established method with which the water resource scientist can develop an accurate, continuous record of water flow rate under ideal flow conditions. However, complex flow conditions such as backwater effects, channel ice, mobile channel beds, and changing channel geometry due to scour or sedimentation—all of which commonly occur—can invalidate stable stage-discharge ratings and make the use of conventional methods impractical or impossible. Conventional methods are also labor intensive.

3. Assessing Potential Stream Gauging Sites

Between August and October 2020 Stone evaluated the 10 named tributaries to Lake Carmi to identify the most suitable flow gauging site on each stream. Factors considered in evaluating potential stream sites for installation of flow gauging stations were:

1. Location—preferred sites are as close as possible to the mouth of the tributary, with no significant inflows downstream.
2. Hydraulic conditions—preferred sites have a stable channel cross-section, stable hydraulic control, minimal bank erosion, and no backwater conditions.
3. Operational conditions—preferred sites have reasonable, year-round access, open sun, adequate cellular signal, and low risk of vandalism.

We began evaluating potential gauging locations by examining the culverts at stream crossings along the roads that ring most of Lake Carmi. We then scouted the stream channel from the shore roads to the tributary mouth for suitable open channel flow monitoring locations. At streams where the shore road was located at the tributary mouth, we scouted the stream channel upstream of the stream crossing. In evaluating open channel sites, our intent was to achieve, to the greatest degree possible, ideal hydraulic conditions. Criteria that describe the ideal gauging site include unchanging natural controls that promote a stable stage-discharge relation, a stable channel cross-section with minimal bank erosion, laminar flow with no standing waves, and a satisfactory channel segment with limited floodplain access for measuring discharge throughout the range of stages. In evaluating potential sites, we documented the channel substrate type, location of hydraulic controls, hydraulic and hydrologic impacts associated with tributaries and the lake confluence (focusing particularly on the potential for backwater conditions), and the potential for beaver dams and debris jamming. We contacted property owners to gain access to potential sites. In the process, we assessed their willingness to cooperate in a streamflow monitoring program. We obtained permission to access the majority of sites, and assessed alternate locations where permission was not granted.

Because there are technical and cost advantages and disadvantages with any flow monitoring strategy, we attempted to identify and describe both a culvert site and an open channel site along each of the 10 tributaries. Table 2 summarizes our gauging site recommendations and Table 3 summarizes operational considerations at each of the recommended sites. The watershed area of each tributary, both at its confluence with Lake Carmi and at the recommended gauging site, are presented in Table 4. Note that differences between the tributary watershed areas and the watershed areas at the recommended gauging sites are negligible (<1%) at all sites, with the exception of Dewing Brook (8% difference), Prouty Brook (35% difference), and Alder Run (31% difference). Detailed results of the flow monitoring feasibility assessment are presented for each tributary in Section 3.1 through Section 3.10.

Table 2. Recommended stream gauging sites

Brook	Flags	Recommended Site
Prouty	I (2 gauges)	**North and south culvert crossings at North Sheldon Road (Route 120).** Permission was not received to access the Bessette property, where the northern and southern branches of Prouty Brook join. There is no suitable site downstream of the confluence on the adjoining Mullen Shores property. Therefore, gauging the two main branches at North Sheldon Road appears to be the only viable option. These stream crossings are large, round culverts that have favorable hydraulic characteristics. Neither culvert is backwatered.
Westcott	I	**Culvert on the property of Larry and Jeannie West off Tanner Junction Road.** The culvert outlet is perched above the stream channel. The culvert outlet could be modified to improve the accuracy of low flow measurements. A minor tributary joins downstream of this site in a segment that is potentially backwatered by Lake Carmi.
Sandy Bay		**Stream channel a short distance downstream of Black Woods Road.** This is a well-defined channel with apparently stable hydraulic control, upstream of any lake backwater effects.
Alder Run	I, H	**Culvert crossing at Middle Road.** The dual culverts on Lake Road are partially submerged in Lake Carmi (backwatered at all times). Although the Middle Road culvert may be affected by variable backwater conditions (due to downstream pool and wetland vegetation), it is the recommended site. Access permission was not received for the Lothian property, which lies between Middle Road and Lake Road.
Dicky's		**Stream channel upstream of the Lake Road box culvert.** This is a well-defined channel that has a good straight segment with hydraulic control provided by small boulders.
Dewing	I, S	**Stream channel ~380 ft. upstream of Dewing Road.** This site avoids the segment backwatered by Lake Carmi. A minor tributary joins downstream of this site within the backwatered channel segment.
Kane's		**Culvert crossing at Hammond Shore Road.** The culvert outlet is perched above the stream channel. It should not become backwatered. The slight pool at the upstream end of the culvert should enable submergence of a sensor.
Hammond North		**Culvert crossing at Hammond Shore Road.** The culvert outlet is perched above a scour pool. It should not become backwatered. The slight pool at the upstream end of the culvert should enable submergence of a sensor.
Hammond South	A, H, S	**Stream channel on narrow strip of state park property.** This is a shallow, sinuous stream channel with high flow side channels. The most feasible site is a small riffle located at a slight channel narrowing.
Marsh	Aw	**Stream channel on state park property.** This is a well-defined channel with tight meanders and flood chutes. The recommended site is upstream of the potentially backwatered segment.

A=difficult access, Aw=access only difficult in winter, I = downstream inflow, H= hydraulic challenges, S=poor solar exposure

Table 3. Operational considerations at recommended stream gauging sites

Brook	Access	Cell signal	Solar exposure	Security
Prouty	Year-round access. In N. Sheldon Road (120) ROW. No landowner permission required.	Fair	Good	Good
Westcott	Year-round access. Off Westcott Shore Road (private). Permission obtained.	Fair	Fair	Good
Sandy Bay	Year-round access. On Black Woods Road (private). Expect permission to be granted.	Fair	Fair	Good
Alder Run	Year-round access. On Middle Road. No landowner permission required.	Fair	Good	Fair
Dicky's	Year-round access. A short distance off Lake Road. Will require landowner permission.	Fair	Good	Good
Dewing	On private property off Dewing Road. Permission obtained.	Poor or none	Poor	Good
Kane's	Year-round access. On Hammond Shore Road (private). Permission obtained.	Poor or none	Fair	Poor
Hammond North	Year-round access. On Hammond Shore Road (private). Permission obtained.	Poor or none	Fair	Poor
Hammond South	On state park property. Permission to access the site via private property north and east of the state park was not received; therefore, a long trail walk/bushwhack is required to reach it by land.	Poor or none	Poor	Good
Marsh	On state park property. The access road is plowed as far as the boat launch. State permit required (which should be granted).	Poor	Fair	Fair

Table 4. Tributary watershed areas

Tributary	Watershed area (ha)	Percent of watershed in agriculture (%)	Percent of watershed in forest[1] (%)	Percent of watershed in wetland[2] (%)	Percent of watershed in impervious surfaces (%)	Watershed area at proposed gauge (ha)	Percent of watershed at proposed gauge (%)
Prouty Brook	261.9	43.9	41.0	14.3	2.6	169.1	64.6
Westcott Brook	35.9	14.7	63.8	13.6	2.5	35.7	99.3
Sandy Bay	24.4	24.9	53.6	6.6	4.9	24.2	99.1
Alder Run	318.2	19.3	57.5	17.9	1.5	220.2	69.2
Dicky's Brook	254.9	16.2	74.7	22.5	0.8	253.0	99.3
Dewing Brook	167.2	55.9	35.1	4.8	3.4	153.2	91.7
Kane's Brook	21.6	88.6	9.6	3.8	1.6	21.5	99.6
Hammond North	68.1	64.5	28.2	4.4	1.8	67.7	99.4
Hammond South	124.1	28.8	53.7	15.8	1.3	123.5	99.5
Marsh Brook	662.9	33.6	53.7	21.7	1.4	662.4	99.9

Note: Forested wetlands may be counted both as forest and as wetland

3.1. Prouty Brook

Prouty Brook flows from the southwest into the southern end of Lake Carmi (Map 1), draining an area of approximately 647 acres (262 ha). There are two main branches of Prouty Brook that join east of North Sheldon Road on the Bessette property. Stone was unable to gain access to the Bessette property, and instead assessed the brook downstream on the adjoining Mullen Shores property, where it flows through a large wetland complex extending to Lake Carmi. Through this large wetland Prouty Brook is variously braided, indistinct, flowing through wheel tracks, or flooded by beaver dams; no suitable flow monitoring locations were identified.

Upstream of the confluence, the two main branches of Prouty Brook flow through culverts under North Sheldon Road. These culverts are suitable sites for stream gauging, with favorable hydraulic conditions and year-round access in the road right-of-way. The northern culvert (Figure 1) is a 2.8-ft diameter, circular concrete pipe in poor condition and the southern culvert (Figure 2) is a 5-ft diameter, circular concrete pipe in good condition.

Figure 1. Northern culvert on Prouty Brook

Figure 2. Southern culvert on Prouty Brook

3.2. Westcott Brook

Westcott Brook is a small tributary to Lake Carmi, draining approximately 89 acres (36 ha) along the western shore of the lake (Map 2). Both open channel and culvert sites were assessed on Westcott Brook. The most suitable open channel site consists of a large bolder and cobble riffle 50 ft upstream of the confluence with the lake (Figure 3). This segment of the stream is relatively straight with minimal floodplain access and a stable channel cross-section. However, the riffle was approximately 1 ft above lake level when assessed, indicating that backwater conditions are likely a problem at high lake levels. The riffle section also appears prone to debris accumulation.

Figure 3. Westcott Brook looking downstream at the confluence with Lake Carmi

Stone also evaluated a driveway culvert immediately upstream of the open channel site described above. The 2-ft diameter corrugated plastic culvert (Figure 4) is in good condition and is perched above the channel, minimizing the likelihood of backwater conditions. This site is suitable for flow monitoring. While a small tributary joins Westcott Brook between the culvert outlet and the downstream riffle section, the relative contribution of this tributary to the entire flow through Westcott Brook appears minimal.

Figure 4. Culvert outlet on Westcott Brook, looking upstream

3.3. Sandy Bay Brook

Sandy Bay Brook is located north of Westcott Brook, and it flows east to Lake Carmi (Map 3). The Sandy Bay Brook watershed is approximately 60 acres (24 ha), and consists of forested and agricultural land, as well as some residential properties. Sandy Bay Brook crosses under Black Woods Road through a 2-ft diameter, corrugated metal culvert. There is a sharp bend in the stream channel at the culvert inlet and the culvert outlet is perched (Figure 5).

Figure 5. Sandy Bay Brook at Black Woods Road culvert, looking upstream

Downstream of the culvert the channel becomes progressively steeper and less stable as one moves toward the confluence with Lake Carmi. Approximately 135 ft upstream of the lake, there is a step comprised of small to medium sized boulders that serves as a hydraulic control (Figure 6). This is the recommended site. While the floodplain is inaccessible along the right bank, the left bank floodplain is readily accessible. Downstream of the control, the channel is steep with signs of bank erosion and fewer options for establishing a stable rating.

Figure 6. Open channel site on Sandy Bay Brook, looking upstream

3.4. Alder Run

Alder Run drains an area of approximately 786 acres (318 ha). It flows from north to south to its confluence with Lake Carmi at the northern end of the lake (Map 4). The northern extent of the watershed lies in Canada.

Stone evaluated two culvert locations for flow monitoring. The first location was the Lake Road crossing, where dual culverts outlet to Lake Carmi. These culverts are unsuitable for flow gauging due to their submergence in Lake Carmi. The second location is the culvert crossing Middle Road (Figure 7), approximately 0.6 miles upstream of the mouth of Alder Run. While the Middle Road culvert experiences variable backwater conditions due to a pool at its outlet, it is nevertheless the recommended site. It is possible there is an open channel site between Middle Road and Lake Road that could be preferable; however, Stone was unable to gain landowner permission to access this length of Alder Run.

Figure 7. Alder Run at Middle Road culvert, looking downstream

3.5. Dicky's Brook

Dicky's Brook flows south to the northern end of Lake Carmi (Map 5). The Dicky's Brook watershed is approximately 630 acres (255 ha) and is comprised of forested and agricultural land. The northern extent of the watershed lies in Canada. Approximately 200 ft upstream of its confluence with the lake, Dicky's Brook flows through a large concrete box culvert under Lake Road (Figure 8). Because this box culvert may be backwatered during high lake levels, an open channel site upstream of the culvert was identified (Figure 9).

Figure 8. Box culvert on Dicky's Brook at Lake Road, looking downstream

About 320 ft upstream of Lake Carmi, beyond the influence of backwater effects, Dicky's Brook has a well-defined channel and an accessible floodplain. There is a hydraulic control consisting of small to medium-sized boulders at a change in the channel bed slope (Figure 9). This open channel site is suitable for flow monitoring, and it is accessible from Lake Road.

Figure 9. Open channel site on Dicky's Brook, looking upstream

3.6. Dewing Brook

Dewing Brook flows northwest through farm fields, and then through forest land before discharging to Lake Carmi (Map 6). The Dewing Brook watershed is approximately 413 acres (167 ha).

Upstream of its confluence with the lake, Dewing Brook is a meandering, low gradient stream with a readily accessible floodplain. The segment of Dewing Brook immediately upstream of the concrete box culvert under Dewing Road, through which the brook discharges to Lake Carmi, is backwatered by the lake even at normal lake levels, making it unsuitable for flow monitoring. Approximately 380 ft upstream of the lake, the channel cross-section is better defined and there are several options for open channel flow monitoring (Figure 10). Unfortunately, this location is upstream of a minor tributary. This excluded tributary and the backwatered stream segment represent 8% of the watershed area.

Figure 10. Dewing Brook, looking upstream where the channel becomes more incised

3.7. Kane's Brook

Kane's Brook (Map 7) is a very small stream draining a 53 acre (22 ha) agricultural watershed.

Stone was unable to identify a suitable open channel site along Kane's Brook. Poorly defined channels converge at a culvert crossing Hammond Shore Road, close to Lake Carmi. The channel downstream of this culvert is inundated by the lake at high lake levels. This leaves the culvert under Hammond Shore Road (Figure 11) as the only viable gauging site. This corrugated plastic culvert is in good condition. It is perched more than 1 ft above the normal lake level; hence backwater conditions are unlikely. The slight pool at the upstream end of the culvert should enable submergence of a sensor. Therefore, this site is suitable for gauging.

Figure 11. Culvert outlet on Kane's Brook at Hammond Shore Road, looking upstream

3.8. Hammond North Brook

Hammond North Brook (Map 8) is a small stream draining a primarily agricultural watershed of approximately 168 acres (68 ha). Flow from this watershed converges at a culvert crossing under Hammond Shore Road, close to Lake Carmi. Stone evaluated this culvert as well as the scour pool below the culvert. A cobble and gravel bar at the downstream end of the scour pool (Figure 12) functions as a hydraulic control, and there are no concerns about bypass flow or backwater effects here. Therefore, this site appears suitable for gauging. There are no suitable sites closer to the lake, as the channel becomes braided and meandering and the bed material is highly mobile.

Figure 12. Scour pool on Hammond North Brook below the Hammond Shore Road culvert, looking downstream

Hydraulic conditions at the upstream end of the culvert on Hammond Shore Road (Figure 13) are conducive to flow monitoring. The culvert is a 2.5-ft diameter, corrugated plastic pipe in good condition. The slight pool at the upstream end of the culvert should enable submergence of a sensor.

Figure 13. Culvert inlet on Hammond North Brook at Hammond Shore Road, looking downstream

3.9. Hammond South Brook

Hammond South Brook is located on the eastern side of Lake Carmi (Map 9), with a drainage area of approximately 307 acres (124 ha). Hammond South flows through private property before reaching Lake Carmi State Park and draining into the lake. Stone was unable to access Hammond South upstream of the State Park property.

The segment of Hammond South Brook flowing through the state park is shallow, sinuous, and low gradient. Bankfull depths are less than 1 ft and flood shoots are prevalent. The most suitable site (Figure 14) is located along a small riffle. While there are signs of flood chutes upstream of this riffle, which could allow high flows to bypass the gauge, Stone concluded these could be managed with appropriate placement of sandbags.

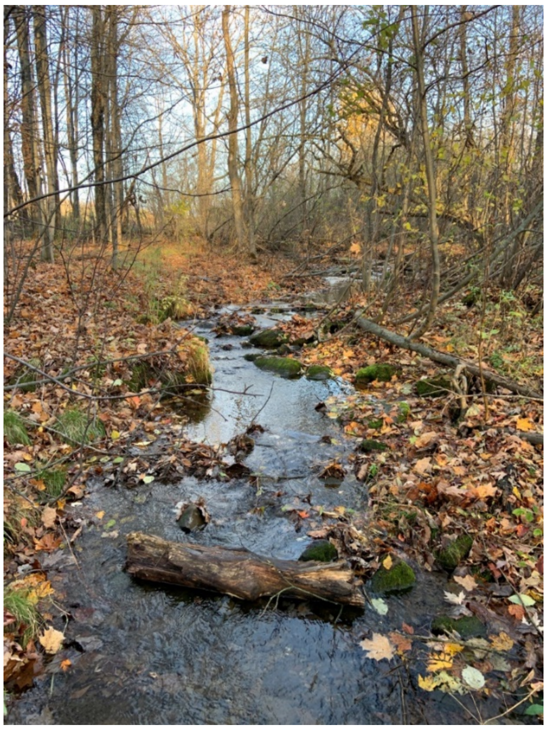


Figure 14. Small riffle on Hammond South Brook in Lake Carmi State Park, looking upstream

3.10. Marsh Brook

Marsh Brook is the largest tributary to Lake Carmi. The brook flows northwest to its confluence with Lake Carmi in Lake Carmi State Park. It drains a 1,638 acre (663 ha), mixed land use watershed. Stone visited two stream crossings along Marsh Brook. The first is a 5.8-ft diameter, corrugated metal pipe under State Park Road (Figure 15), and the second is at a snowmobile trail that crosses Marsh Brook in the State Park. Both structures were determined to be unsuitable for flow monitoring due to their poor condition and distance from the confluence with the lake.

Figure 15. Culvert outlet and scour pool at State Park Road, looking upstream

Moving downstream, Stone investigated several locations along Marsh Brook in the vicinity of the Carmi Nature Trail stream crossing. Downstream of the trail crossing, backwater conditions would occur at high lake levels and there are no stable hydraulic controls. Upstream of the trail crossing, the stream is highly sinuous with a moderately accessible floodplain. There are several options for open channel flow monitoring in the stream segment upstream of the trail, one of which is a cobble and gravel bar approximately 800 feet upstream of the confluence with the lake (Figure 16).

Figure 16. Open channel flow monitoring site on Marsh Brook, looking downstream

3.11. Comparing the Tributaries

This report primarily concerns the feasibility of gauging 10 streams that flow into Lake Carmi. We have also quantified the watershed area—at the stream outlet and at the recommended gauge location—and land use composition of each stream. Other factors that could be considered in evaluating tributaries for inclusion in a stream gauging program include historic water quality data and the geomorphic condition of the streams, neither of which we evaluated. Based on our cursory spatial analyses (Table 4), we have the following observations regarding how the Lake Carmi tributaries compare to one another:

- The northern and southern branches of Prouty Brook are similar in size and land use composition. Consider whether it would be adequate to gauge one branch and apply a gauge transfer equation to approximate flow in the other.
- Westcott Brook and Sandy Bay Brook are similarly sized, small watersheds. Both watersheds are predominantly forested. Consider whether it would be adequate to gauge one of them (perhaps Sandy Bay Brook because of its greater percentage of agricultural land) and apply a gauge transfer equation to approximate flow in the other.
- Alder Run and Dicky's Brook are similarly sized, adjacent watersheds, with similar proportions of agricultural land. Consider whether it would be adequate to gauge one of them, possibly Dicky's Brook (due to the substantial portion of Alder Run downstream of the recommended gauge site) and apply a gauge transfer equation to approximate flow in the other.
- Due to the high proportions of agricultural land in the Dewing Brook and Kane's Brook watersheds, it may be important to gauge both streams.
- Hammond North Brook is a moderate sized watershed with a substantial area in agriculture. The recommended gauge location captures nearly the entire watershed, and it should be a relatively unproblematic site. Therefore, it is probably advisable to gauge Hammond North Brook.
- Hammond South Brook is a moderate sized, mixed land use watershed with extremely limited access to the recommended gauging site. Consider whether flow data might reasonably be derived using a gauge transfer equation from gauges at the slightly larger Dewing Brook and smaller Hammond North Brook.
- Marsh Brook is twice the size of the next largest watershed; therefore, it should be included in any potential gauging program.

4. Evaluating Stream Gauging Methods

4.1. Discussion of Monitoring Tasks

This section describes the tasks that would likely be performed to establish and operate a streamflow monitoring program on Lake Carmi tributaries.

4.1.1. Site Preparation

In preparation for installing instruments, downed trees overhanging the channel and woody debris lodged on the hydraulic control should be cut and hauled away. Loose rocks and boulders in the channel may be repositioned to minimize the likelihood their movement could alter the hydraulic control. Where necessary and permissible, trees may be felled to increase sun exposure on solar panels.

At certain sites, culverts may be modified to improve the accuracy of flow measurement. For example, a steel weir plate may be cut to specifications by a local metal fabricator and affixed to the upstream culvert opening to improve low flow measurement. Weir plates are fastened to culvert faces using brackets, stainless-steel threaded rods, and hydraulic cement. This type of modification could be appropriate at Kane's Brook and Hammond North.

4.1.2. Installation and Use of Water Level Sensors

Primary recording gauges are sensors that are interfaced with a data recorder and automatically provide a continuous record of stage. The most widely used types of primary recording gauges are pressure transducers, bubbling stage recorders, and ultrasonic level sensors.

Stage measuring instruments are typically deployed at the measuring point in the stream through a heavy conduit that is anchored to the stream bed. The conduit protects the sensor and sensor cable from damage and holds the sensor in a fixed position. Laying out and anchoring this conduit in the channel and up the streambank is a major part of gauging station construction.

In considering flow monitoring technologies suitable for gauging streamflow at the proposed Lake Carmi tributary sites, Stone evaluated the advantages and disadvantages of different types of stage and velocity sensing instruments. Several types of instruments were eliminated from consideration relatively early in the evaluation. These include:

> **Ultrasonic level sensors**—Ultrasonic level sensors are available in both downward facing and submerged, upward facing types. Downward facing types require a stable, fixed anchor (such as a bridge) directly above an appropriate measuring point. The only station with an appropriate stream crossing is the box culvert on Dicky's Brook at Lake Road (cover photo); however, we do not believe this is the best measuring point on Dicky's Brook due to the potential for lake backwater effects. Downward facing, ultrasonic sensors are also susceptible to erroneous readings from surface foams, fog, or steam off the water. Upward facing ultrasonic sensors provide no obvious advantages over more commonly available pressure transducers and bubbling stage recorders, in our view.

Flumes—At certain locations, an appropriately sized flume paired with a level sensor can provide a reliable means of measuring flow, without the need to develop and maintain a stage-discharge rating. At the outset of the project, we considered whether a large H flume might be installed to measure flow at the smallest tributaries, Sandy Bay Brook and Westcott Brook. However, judging both by the watershed areas and the channel dimensions, even these smallest streams have flow rates that exceed the maximum rates of Stone's largest flumes (i.e., 2.5-ft H flume). Even larger flumes would cost several thousand dollars each and entail a substantial construction project to install. Flumes are also more prone to freezing than a natural channel or buried culvert.

Insertion-style velocity sensors—For industrial applications, there are many types of sensors that can be inserted through a hole in the wall of a pipe to measure flow velocity. These include insertion magmeters and paddlewheel flowmeters. At the outset of the study, we considered whether these types of devices could be used at certain sites, such as the twin culverts where Alder Run passes under Lake Road. However, the lake backwater effect is too great in this location; the culverts are essentially flooded, and the stream velocities are imperceptible at most times. In some of the smaller streams it could be possible to divert streamflow through a pipe loop containing an insertion style meter to accurately measure low flows; however, since a separate system would be required to measure medium and high flows, the combined cost and complexity of the two systems would be unreasonably high.

Radar and Laser velocity sensors —Several models of radar/laser velocity sensors have been developed to accurately measure surface velocity in rivers and sewer mains. Given the narrow and meandering form of the Lake Carmi tributaries and the need to construct a fixed anchor above the stream measuring point, we do not believe these types of sensors are appropriate for the Lake Carmi tributaries. These units are also quite expensive (for example, ISCO's LaserFlow system costs approximately $14,000).

Based on the foregoing considerations, there are three sensor technologies that we believe warrant further consideration, as follows:

4.1.2.1. Pressure Transducers

Pressure transducers may be unvented, which necessitate post-processing level data to eliminate the effect of changes in barometric pressure, or vented ("gauge"), which eliminates the need to adjust for barometric pressure, but complicates installation. Pressure transducers are reasonably economical. The metal (stainless steel or titanium) diaphragm in most pressure transducers may be damaged by ice forming in the tip. Pressure transducers with ceramic diaphragms are more appropriate for small Vermont streams, though more expensive.

4.1.2.2. Bubbler Flowmeter

Bubbler flowmeters continue to be the most accurate method of measuring stage in small streams. The compressor is mounted in a weather-proof enclosure away from the stream. A vinyl bubbler tube is installed through a conduit to the measuring point in the stream. Bubbler flowmeters have some significant advantages over pressure transducers and ultrasonic sensors: they are generally self-clearing, they are particularly well suited to streams that freeze (the bubbler tube freezes rather than the instrument), and they tend to have very stable calibration. The only significant disadvantages are their higher cost and power consumption.

4.1.2.3. Acoustic Doppler

Continuous measurement of flow velocity in pipes has become standard practice in many industrial applications. These technologies have been adapted for use in monitoring natural waters with complex flow conditions, including tidal flows. The most common instruments used for continuous velocity measurement in streams rely on acoustic doppler sensors. The velocity sensor is typically paired with a pressure sensor (for level measurement). The entry level devices in this category are submerged, continuous-wave sensors that emit a single beam of ultrasonic sound into the flow stream and cannot differentiate among depth intervals. These devices are generally not capable of accurate velocity measurement in clear running streams. The more sophisticated among the instruments are pulsed, profiling sensors, which emit multiple beams (differing in angle) of ultrasonic sound into the flow stream, measure the velocity of different depth intervals independently, and calculate depth-integrated, average velocity. In a shallow stream with suspended particle concentrations adequate to reflect a significant proportion of the emitted signal, these devices can provide highly accurate, averaged velocity measurements. These sensors can look a variable distance to either side; a single sensor would only be adequate to measure streamflow if the channel were unusually narrow and regular in cross-section. In most natural stream channels multiple sensors would need to be deployed across the stream to quantify the average flow velocity. Given that the cost of a high-quality sensor is many thousands of dollars (e.g., SonTek IQ = $8,800), deploying multiple sensors per stream is typically cost-prohibitive. Another disadvantage is that the minimum flow depth for accurate velocity measurement is approximately 3 inches. Low flows at several of the proposed sites (Westcott Brook, Sandy Bay Brook, Kane's Brook, and the northern branch of Prouty Brook) would not be measurable without modifying their culverts. Nevertheless, these instruments could be appropriate for level and velocity measurement in three structures: the Alder Run crossing at Middle Road, Hammond North, and the southern branch (culvert) of Prouty Brook. We expect the Alder Run crossing at Middle Road is the only site where use of this type of sensor is the best option. One sensor at the upstream end of the Middle Road culvert should be sufficient.

4.1.3. Installation and Use of Staff Plates

Accurate stage measurement requires not only accurate instruments, but also proper installation and continual monitoring of all components to ensure the accuracy does not deteriorate with time. Reference gauges enable stream scientists to monitor and maintain the accuracy of the primary recording gauge. Reference gauges are non-recording devices or reference points that can be used to manually obtain a measurement of the water surface elevation. The standard type of reference gauge is a staff gauge installed in the stream. To ensure that instruments accurately record water levels, primary recording and reference water level readings are collected by independent means and compared. The reference gauge is read manually by stream scientists during site visits and compared in real time with the primary recording gauge reading. By doing so, it can be determined if additional maintenance is needed on the primary recording gauge, such as cleaning or uncovering the sensor conduit. This also enables determination of any gauge height corrections that adjust the primary recording gauge to read within the allowable error of the reference gauge reading.

A staff plate with 0.02-ft increments is typically installed at each stream gauging station to allow direct reading of the water level. A metal or fiberglass staff plate is typically installed at the edge of the stream. Where possible, staff plates are anchored to bedrock or boulders using stainless steel threaded rods and epoxy. Steel supports (e.g., welded steel angle and plate) may also be bolted to rock or concrete walls to support the top of the staff plate. Alternately, where hard structures are lacking, staff plates may be mounted on synthetic deck boards and secured to heavy steel rebar or strut driven several feet into the stream channel.

Stone has made substantial use of time lapse cameras in conjunction with stream staff gauges. Time lapse cameras are positioned to record regular photographs of the water level against the staff plate. This provides a secondary (back up) set of water level data in case of failure of the primary recording gauge. Other uses include routine assessment of the accuracy of the primary recording gauge, particularly at hydrograph peaks, and documenting ice, debris, and sediment movement in the channel.

4.1.4. Installation and Use of Data Loggers

Stage data and any meteorological and water quality data collected are continuously logged using an appropriate data logger. The minimum data recording interval is typically 5-minutes. Durable data loggers with low power use are preferred in remote settings such as the Lake Carmi watershed. The data logger should have inputs compatible with common types of sensors. The selected data logger should have multiple digital input/output terminals for SDI-12 sensors and for pulse input instruments, such as tipping bucket rain gauges. SDI-12 is a communications protocol used by many types of environmental instruments, including many level sensors and flowmeters, to transfer measurement data. The data logger should also be easy to integrate with the chosen telemetry system and should have sufficient memory (>1 month) to store data should the telemetry system fail.

4.1.5. Installation and Use of Telemetry Systems

Telemetry systems allow data to be transmitted at regular intervals to a remote computer server. The Lake Carmi watershed is a challenging location with respect to data telemetry. There are three telemetry options to consider: cellular modem, radio frequency transmitters /receivers, and GOES satellite systems. Each of these options is discussed further, as follows:

4.1.5.1. Cellular

There is a Verizon cell tower 7 km west of Lake Carmi and another 7 km southeast, leaving the Lake Carmi watershed in the middle with generally poor signal strength. Stone has raised this issue with Verizon, requesting they improve cellular signal strength, without success. The cellular signal is particularly poor on the eastern shore of the lake at the Dewing Brook, Kane's Brook, Hammond North, and Hammond South sites. While cellular signal strength on the eastern shore is not adequate for voice calls, machine-to-machine data transmission is sometimes possible even where voice calls fail; therefore, it may still be possible to use cellular modems at all sites, especially if antennas can be mounted higher in the air. The signal appears reasonably good at Dicky's Brook, Alder Run, and all three sites along the western shore of Lake Carmi. The cellular signal at these sites is certainly adequate to enable telemetry.

4.1.5.2. Radio

Conditions in the Lake Carmi watershed are generally poor for radio frequency data transmission. Both the lake and the forested shoreline would absorb radio signal. If cellular data transmission is not feasible at sites on Lake Carmi's eastern shore, radio may be the next best option. The type of arrangement with the best chance of success would involve establishing a base station in the maintenance garage at the Lake Carmi State Park, which has year-round power and a wired internet connection. Radio transmitters and receivers would be deployed in a daisy chain along the lake shore from Dewing Brook to Kane's Brook to Hammond North to Hammond South to Marsh Brook and finally to the maintenance garage.

4.1.5.3. Satellite

Satellite transmission should be reliable, but the equipment is quite expensive. The GOES satellite system is an established communications tool for remote sites. GOES transmitters could be installed to provide reliable data transmission at every site; they would not need to be interdependent as with the radio system. The cost of the GOES transmitter package, including all the required peripherals, is considerable; the package sold by Campbell is $3,600. One advantage is that there are no data charges, so for long term operation the system becomes more affordable.

4.1.6. Installation and Use of Rain Gauges

A full discussion of precipitation measuring instruments is beyond the scope of this feasibility evaluation. In our northern climate automated weighing devices, such as the Ott Pluvio2, are perhaps the most accurate option for measuring both wet and dry precipitation. However, these instruments tend to be prohibitively expensive (>$4,000 for the Ott Pluvio2). The workhorse in this industry is the tipping bucket rain gauge, which counts "tips" of rainfall (equivalent to either 0.01 inches or 0.1 mm) captured by a funnel section. The funnel on a standard tipping bucket rain gauge is 8 inches in diameter. Some manufacturers offer heated tipping buckets, which allow quantification of solid and mixed precipitation. Opinions differ regarding the accuracy of heated tipping buckets. Convective air currents may cause a reduction in the amount of precipitation captured. Regardless, for many applications, accurate quantification of rainfall depths and intensity is sufficient, and a standard unheated tipping bucket is therefore appropriate. Among these types of gauges, the more accurate tipping buckets contain siphons, which are intended to improve accuracy under intense rainfall.

Precipitation monitoring sites should be selected with the intent of achieving, to the greatest degree possible, ideal precipitation monitoring conditions. Criteria which describe the ideal site include level ground with an unobstructed view of the sky (minimum distance from a tree or building equal to the height of the tree or building) and no overhanging wires. Locations somewhat sheltered from prevailing winds should also be given preference. To measure rainfall rates in the Lake Carmi watershed, a network of three gauges would be preferable to a single gauge. Possible sites could be the northern gauge on Prouty Brook, the Dicky's Brook gauge, and the Marsh Brook gauge. Operating three gauges would enable calculation of watershed average rainfall as well as rainfall variability across the watershed.

Precipitation gauges should be installed such that the rim of the tipping bucket funnel is approximately one foot above the height of the tallest nearby vegetation. Mounting tipping buckets as low as possible but above the height of surrounding vegetation and potential snow level is recommended to capture the most representative measurement of precipitation possible, while minimizing the problem of debris routinely clogging the gauge.

4.1.7. Establishing and Surveying Elevation Benchmarks

Three elevation benchmarks should be established at each site. Benchmarks are surveyed periodically to assess vertical movement of the staff gauge. Using benchmarks, the staff gauge may be reestablished at a consistent elevation, should it be lost, dislocated, or damaged. New benchmarks include stainless steel rods anchored into bedrock (wherever possible), stainless steel 5/8-inch lag screws set into large trees, and #9 rebar driven below the anticipated frost depth. Benchmarks should be located within 400-feet of the stream gauge. Benchmarks should be painted, and their locations surveyed and described in detail.

4.1.8. Discharge Measurement

Manual discharge measurements used in developing and verifying stage-discharge ratings may be made using a variety of methods and instruments. Discharge measurement locations and methods are determined at each site according to the flow conditions present at the time of the measurement. It is the responsibility of the scientist in the field to recognize and use the method that will result in the highest quality and most efficient measurement, given the conditions at the time of the measurement.

Most flow measurements can be made using the USGS mid-section method by a scientist wading in the stream, equipped with a mechanical current meter mounted on a top-setting wading rod. At all the Lake Carmi tributaries, the appropriate tools for measuring moderate flows will be either a Pygmy current meter mounted on a top-setting wading rod or, at substantially greater cost, an acoustic doppler velocimeter, such as SonTek's FlowTracker. At the larger streams—Marsh Brook and potentially Dicky's Brook, Alder Run, and Prouty Brook, either a Type AA or an acoustic current meter, mounted on a top-setting wading rod, could be used to measure high flows. A device to count meter rotations, such as Rickly's AquaCMD Current Meter Digitizer, is also needed when using the Pygmy or Type AA current meters.

We believe that, with careful cross section selection, wading methods will be adequate to measure discharge under medium and high flow conditions at all the Lake Carmi tributaries (i.e., none are so large as to require cableways or use of a float-mounted acoustic doppler current profiler). During high-flow conditions, additional safety precautions can be taken such as securing the wader to a cable suspended across the stream using a harness.

At extreme low flows, the flow rate may be measured by timing the filling of a container of known volume (the "volumetric" method), using the constant-rate tracer-dilution method, or using a "Baski" portable/collapsible cutthroat flume temporarily installed in the channel. Volumetric measurements are the most accurate, assuming there is a suitable drop below which to fill a container. Volumetric measurements should be particularly good at Hammond North Brook, Kane's Brook, Sandy Bay Brook, Westcott Brook, and the Prouty Brook culverts. The constant-rate tracer-dilution method can work very well in narrow, well-mixed stream segments. This method should work well at or near most of the proposed gauging sites. Prior to using the constant-rate tracer-dilution method, the background conductivity in the stream should be measured to ensure that accurate results can be obtained. It can be difficult to get a good discharge measurement using the portable cutthroat flume; however, in certain streams and flow conditions it is the best option. Marsh Brook, Hammond Brook South, and Dewing Brook may have appropriate conditions for using this method.

4.1.8.1. Measurement Frequency

Direct measurements of discharge are necessary to maintain an accurate and current stage-discharge rating for the gauging site. Discharge measurements must be made at varying stages and on a routine basis to establish a stage-discharge rating and define the timing and magnitude of variations to that rating. A strategy Stone advocates for expediting development of representative stage-discharge ratings is to devote several days of time during a storm event in the first year of the program to repeatedly measure discharge at all the stations over the course of a long event, to acquire perhaps 4-6 datapoints per site over the widest possible range of flows. The preliminary ratings developed through this effort could then be supplemented with an additional 4-6 discharge measurements in the first monitoring year. In subsequent years, several discharge measurements should be made each year to maintain the accuracy of the rating, attempting measurements at or near the maximum and minimum flows of the year, when possible.

4.1.8.2. General Procedures for Making Discharge Measurements

For all measurements of discharge, readings of the reference (staff) gauge are required both before and after the measurement. Readings should be taken as close to the start and end times of the measurement as possible to achieve the most accurate representation of stage for the measurement. The stage associated with a measurement should be based on the reference (staff) gauge. If at the time of the discharge measurement it is determined that the reference gauge is not working (i.e., submerged or damaged), an attempt should be made to establish a temporary reference point from which the elevation can be reconciled by levels as soon as possible.

4.1.9. Operation and Maintenance

Periodic visits to gauging sites are necessary to perform routine inspections and maintenance of the gauging equipment, as well as to inspect the conditions of the stream and make direct measurements of discharge. Gauges should be visited at least once per month, or more frequently, as necessary, based on hydrologic and other conditions. During every site visit, the staff gauge and primary recording gauge (e.g., pressure transducer) should be read, and the condition of the hydraulic control should be documented.

4.1.10. Data Management and Reporting

Processing flow data records is invariably time consuming. In conventional stream gauging, time must be spent reviewing and correcting stage data; interpreting stream conditions affecting stage-discharge relations, such as channel ice, debris jams, and beaver dams; computing flow rates; and summarizing and publishing the data.

4.2. Instrument Specification

There are several components common to any stream gauging station: a stage or stage/velocity sensor, a staff gauge, a data logger, a telemetry system, a power supply, and appurtenances such as an instrument enclosure, cable conduit, and a tripod or other type of stand. These are discussed briefly in this section.

4.2.1. Water Level Sensors

Operation of gauging stations for the purpose of determining discharge necessitates collecting stage data at an accuracy of plus or minus 0.01 ft. Among the numerous models of vented pressure transducer, Stone has relied on two models at our gauging stations, the Seametrics PT12 ($900) and the Ott PLS ($1,400). Each instrument has a reported accuracy of ±0.05% full scale (typical), satisfying the ±0.01 ft accuracy requirement under all but the most extreme streamflow conditions. The measurement range for these instruments is shallow (0-12 ft for the Seametrics PT12 and 0-13.1 ft for the Ott PLS), which should be adequate at all the proposed sites. Of the two models, we find the more expensive Ott instrument to be better built and more reliable. The Ott PLS has a ceramic diaphragm, which should be particularly advantageous in the Lake Carmi tributaries because the sensor can tolerate freezing better than models with metal (stainless steel or titanium) diaphragms, such as the Seametrics PT12.

Despite their substantially greater cost, we should reiterate that bubbler flowmeters have some significant advantages over pressure transducers in gauging small streams in northern climates, as described in Section 4.1.2.2. Several manufactures offer bubbler flowmeters. Campbell recently introduced the LevelVUEB10, which appears to be a good quality, compact unit. With accessories, Campbell's LevelVUEB10 costs approximately $4,070. Other examples include the OTT CBS and the ISCO Signature Flowmeter.

4.2.2. Rain Gauge

Having used tipping bucket rain gauges of widely varying quality and accuracy, Stone recommends higher quality tipping buckets, such as HyQuest Solutions' TB3 Tipping Bucket Rain Gauge. This durable gauge has a siphon and stainless-steel calibration screws.

4.2.3. Staff Gauge and Camera

A standard 4-inch wide, black-on-white, Style A staff plate with 0.02-ft increments is typically installed at each stream gauging station to allow direct reading of the water level. This type of staff plate should be adequate at Lake Carmi tributary gauges. These staff plates cost approximately $50. Vendors offering these staff plates include Fondriest Environmental, Rickly Hydrological Company, and Forestry Suppliers, among others. One 0.00-3.33 ft plate should be adequate at most locations, whereas a second plate (3.34-6.66 ft) will be needed at Marsh Brook and potentially other sites.

Stone strongly recommends installing and maintaining a time lapse camera at every station, aimed at the staff plate. The camera can provide an invaluable secondary source of stage data as well as important information about stream condition. Cuddeback offers suitable cameras for $150. While it would clearly be advantageous to have still photos or video transmitted to the office, Stone has not identified a cost-effective way to transmit high resolution images from remote sites. High resolution images are needed to distinguish staff plate increments at considerable distances. Transmitting numerous high-resolution images via cellular modems is prohibitively expensive.

4.2.4. Data Logger

A basic data logger is required. Stone has had very good experience using Campbell Scientific's affordably priced CR300 data logger ($700), which meets all the requirements given in Section 4.1.4. We recommend this data logger for the Lake Carmi tributary gauging stations.

4.2.5. Telemetry System

The strategy we recommend is to order several cellular modems provisioned with Verizon machine-to-machine data plans and install these at the sites with poor cellular signal strength along the eastern shore. If they function adequately during a trial period, they could be left in place and additional cellular modems could be installed at the remaining (better) sites, where they should perform well. However, if the cellular modems perform poorly at the sites along the eastern shore, they could be moved to the sites along the northern and western shores where we are confident they will work, and radio transmitters and receivers could be installed at the sites on the eastern shore, transmitting data from one station to the next in a daisy chain to a computer at the Lake Carmi State Park.

The cellular modem we recommend is the Sierra Wireless Airlink 4G Industrial LTE Cellular Gateway, which costs approximately $800 per station (including the required mounting and antenna, cables, etc.) and $15-$20 per month in cellular data charges. If radios are needed at the eastern shore sites, Stone recommends using a relatively high power/frequency radio, such as the Campbell Scientific RF850 radio, to increase the reliability of data transmission. Including the required antennae, cables, and surge protection, the radios cost approximately $1,350 per station.

4.2.6. Power Supply

On any site with good solar exposure, a standard 12-volt DC, 20-watt solar panel, in combination with a charge controller and deep cycle battery, should be adequate to power the gauging station. However, two of the proposed Lake Carmi tributary sites have poor solar exposure: Dewing Brook and Hammond South Brook. At these sites larger panels with higher output will be required. Given generally low power demand, a 120-150-watt panel should be adequate even under a tree canopy, with strategic installation. These larger panels typically require two posts and more time to install. The retail costs of suitable 12-volt solar panels are approximately $75 for a 20-watt panel and $250 for a 150-watt panel, not including mounting brackets. Either sized panel would need to be connected to a charge controller (for example, Sunsaver 10L, $65) and a deep cycle battery (for example, Interstate Battery 55 AH SLA deep cycle AGM, $155). These batteries typically last three years.

4.2.7. Infrastructure / Hardware

Considerable infrastructure is required to establish a stream gauging station in the form of tripods or posts, instrument enclosures, and cable conduits. Weather and stream conditions in Vermont can be hard on instruments; durable systems are necessary, or instruments will not survive. The data logger, telemetry system, charge controller, and battery are typically housed in a fiberglass instrument enclosure mounted on a pole or tripod. A solar panel is mounted on the same pole or tripod or on a separate one if better solar exposure can be found. Conduit is run from the instrument enclosure to the appropriate measuring point in the stream channel or culvert. Metal conduit is used within the stream channel for multi-year stations. Longer conduit runs above the streambank may be made using UV-rated plastic. The system is grounded using a copper grounding rod and cable. Purchased new, the infrastructure for a typical station costs $1,500-$2,000.

Custom fabricated weir plates may be installed on the upstream end of road culverts to improve the accuracy of flow determination. The cost of such a custom weir plate is approximately $500.

4.2.8. Equipment for Manual Discharge Measurements

SonTek's FlowTracker is a high-quality instrument for measuring stream velocity; however, at $8,700 its cost may outweigh its benefit on a small stream gauging program. Comparable quality discharge measurements may be made using a combination of a Type AA ($1,140) and Pygmy ($850) mechanical current meters and a top-setting wading rod ($570). Rickly's AquaCMD Current Meter Digitizer ($1,150), or similar, is also needed when using the Pygmy or Type AA current meters.

All three low flow measurement methods are relatively inexpensive. Equipment for volumetric measurements are generally already on hand or of negligible cost. The equipment required for continuous rate salt additions are a portable, battery powered pump, a conductivity meter, and incidentals (salt, carboy, graduated cylinder, tubing). A good quality, portable, peristaltic pump costs about $1,000 and a good conductivity meter costs about $350. A Baski collapsible cutthroat flume with wingwalls costs approximately $1,400.

5. Gauging Program Cost Estimates

The two primary costs of establishing and operating a flow monitoring program are labor and equipment. For the purposes of the cost estimates presented here, we assume that a three-year monitoring program will be conducted involving 5-11 gauging stations. We would need to reconsider the estimates provided here if fewer than five gauges are selected, because essentially all the field work and data processing and reporting tasks would be less efficient with fewer sites. Costs are unitized on a per tributary basis, where possible.

5.1. Equipment Costs

Procurement and installation of monitoring equipment require some significant upfront costs. Table 5 summarizes the equipment costs for the categories of equipment described in Section 4.2. An option is included for each primary sensor type recommended. All other equipment in Table 5 is standard.

Table 5. Instrumentation options

		Cost per stream gauge	
Sensor option	Station components	Retail	Using Stone equipment (if possible)
Pressure transducer	Stream gauge with an OTT PLS pressure transducer, staff gauge, timelapse camera, Campbell CR300 data logger, cellular modem (and data service), solar power supply with 20-W panel, instrument enclosure, tripod, conduit, and misc. hardware.	$6,400	$4,600
Bubbler flowmeter	Stream gauge with a Campbell LevelVUEB10 bubbler flow meter, staff gauge, timelapse camera, Campbell CR300 data logger, cellular modem (and data service), solar power supply with 20-W panel, instrument enclosure, tripod, conduit, and misc. hardware.	$9,070	$7,270
ADCP	Stream gauge with a SonTek-IQ Pipe ADCP unit, staff gauge, timelapse camera, Campbell CR300 data logger, cellular modem (and data service), solar power supply with 20-W panel, instrument enclosure, tripod, conduit, and misc. hardware. *Recommended for Alder Run only.*	$14,300	$12,600

Site-specific considerations demand somewhat different equipment at a given tributary gauge. Therefore, the total estimated equipment cost differs somewhat for each tributary. The non-standard equipment considered in our estimates include: 1) upgrade 20-W solar panel to 140-W panel, 2) substitute radio for cell modem, and 3) add a custom fabricated weir plate. Table 6 presents the total equipment cost estimated for each tributary (including two gauges on Prouty Brook).

Table 7 presents equipment costs if existing Stone equipment were to be used, where available. Stone could provide equivalent data loggers, cellular modems, solar panels, instrument enclosures, and tripods. Any pressure transducers, bubbler flowmeters, or ADCP units should be purchased new.

In the years following installation, an allowance is assumed for the replacement or repair of equipment which fails. While these costs are difficult to predict, Stone calculated a standard equipment repair/replacement allowance based on our experience operating the MS4 flow monitoring program on 11 Chittenden County and Franklin County streams over a 5-year period. Over the assumed three-year monitoring period, this standard allowance is $1,200 per gauge ($800 per gauge if using Stone equipment, where available).

5.2. Labor

Installing gauging stations will entail a similar level of effort regardless of the level or flow instrument or the telemetry options selected. Maintaining a gauging station, performing routine discharge measurements, and working the stage, discharge, and precipitation records typically require 80-100 hours per station per year. Some routine maintenance can be performed by local technicians; however, discharge measurements, instrument troubleshooting, and data preparation, quality control, summary, and publishing should be performed by experienced, professional staff. We recommend comprehensive annual reporting of the data and station operation details. In the year following the completion of monitoring (in this case in Year 4), a final report with data interpretation should be prepared and the stations should be decommissioned. The labor estimates in Table 6 cover all anticipated labor, from acquiring, programming, installing, and calibrating equipment to preparing a final data report. The labor costs vary among stations based on many factors, such as:

- Ease of access: Labor costs are higher for Hammond South Brook given very difficult access
- Data processing effort: Estimated costs are higher for Alder Run due to the need to clean up and interpret ADCP data. Data processing costs are also slightly higher for the smallest stream channel sites, because extreme low flows and dry conditions can be more time-consuming to adjust and interpret.
- Potential for channel adjustment: Labor estimates are higher for Dewing Brook, Hammond South Brook, and Marsh Brook due to the (assumed) greater potential for significant channel adjustments to occur during the monitoring period. Conversely, labor estimates are lower for some of the culvert sites due to their fixed geometries.

The labor estimates presented in Table 7 are slightly lower in Year 1 because time would be saved by repurposing some already assembled Stone equipment.

Table 6. Stream gauging cost by tributary

	Prouty[5,6,7]	Westcott[6]	Sandy[6]	Alder[8]	Dicky's[6]	Dewing[6,9]	Kane's[6,7,9]	Hammond North[6,7,9]	Hammond South[6,9]	Marsh[6,9]	Total
Year 1 labor[1]	$25,500	$14,250	$14,250	$18,000	$13,500	$15,750	$13,500	$13,500	$20,250	$16,500	$165,000
Year 2 labor[2]	$14,450	$8,075	$8,075	$10,200	$7,650	$8,925	$7,650	$7,650	$11,475	$9,350	$93,500
Year 3 labor[3]	$14,790	$8,265	$8,265	$10,440	$7,830	$9,135	$7,830	$7,830	$11,745	$9,570	$95,700
Year 4 labor[4]	$4,930	$2,755	$2,755	$3,480	$2,610	$3,045	$2,610	$2,610	$3,915	$3,190	$31,900
Equipment purchase/rental (retail)	$13,400	$6,400	$6,400	$14,300	$6,200	$6,400	$6,700	$6,700	$6,400	$6,400	$79,300
Equipment repair/replacement allowance	$2,400	$1,200	$1,200	$4,200	$1,200	$1,200	$1,200	$1,200	$1,200	$1,200	$16,200
Mileage	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$5,000
Total per tributary	$75,970	$41,445	$41,445	$61,120	$39,490	$44,955	$39,990	$39,990	$55,485	$46,710	$486,600

Notes

1. Year 1 labor includes acquiring and programming equipment; installing, operating, and maintaining gauges; measuring discharge; processing data and performing quality control checks; and preparing an annual report

2. Year 2 labor includes operating and maintaining gauges; measuring discharge; processing data and performing quality control checks; and preparing an annual report

3. Year 3 labor includes operating and maintaining gauges; measuring discharge; processing data and performing quality control checks; and preparing an annual report

4. Year 4 labor includes decommissioning sites and preparing a final report

5. Estimates assume the branches of Prouty Brook are independently gauged

6. Estimates assume an OTT PLS pressure transducer is used at this site. Upgrading to a Campbell LevelVueB10 bubbler flowmeter would add $2,670 per gauge

7. Estimates include cost of a custom weir plate

8. Estimates assume an acoustic doppler current profiler (SonTek-IQ Pipe) is used at Alder Run

9. Radio frequency telemetry may be required at these sites. Prices for new radio equipment are comparable to cell modems

Table 7. Stream gauging cost by tributary, using Stone's equipment where available

	Prouty[5,6,7]	Westcott[6]	Sandy[6]	Alder[8]	Dicky's[6]	Dewing[6,9]	Kane's[6,7,9]	Hammond North[6,7,9]	Hammond South[6,9]	Marsh[6,9]	Total
Year 1 labor[1]	$22,500	$12,750	$12,750	$16,500	$12,000	$14,250	$12,000	$12,000	$18,750	$15,000	$148,500
Year 2 labor[2]	$14,450	$8,075	$8,075	$10,200	$7,650	$8,925	$7,650	$7,650	$11,475	$9,350	$93,500
Year 3 labor[3]	$14,790	$8,265	$8,265	$10,440	$7,830	$9,135	$7,830	$7,830	$11,745	$9,570	$95,700
Year 4 labor[4]	$4,930	$2,755	$2,755	$3,480	$2,610	$3,045	$2,610	$2,610	$3,915	$3,190	$31,900
Equipment purchase/rental (retail)	$10,200	$4,600	$4,600	$12,600	$4,500	$4,600	$5,100	$5,100	$4,600	$4,600	$60,500
Equipment repair/replacement allowance	$1,600	$800	$800	$3,800	$800	$800	$800	$800	$800	$800	$11,800
Mileage	$500	$500	$500	$500	$500	$500	$500	$500	$500	$500	$5,000
Total per tributary	$68,970	$37,745	$37,745	$57,520	$35,890	$41,255	$36,490	$36,490	$51,785	$43,010	$446,900

Notes

1. Year 1 labor includes acquiring and programming equipment; installing, operating, and maintaining gauges; measuring discharge; processing data and performing quality control checks; and preparing an annual report

2. Year 2 labor includes operating and maintaining gauges; measuring discharge; processing data and performing quality control checks; and preparing an annual report

3. Year 3 labor includes operating and maintaining gauges; measuring discharge; processing data and performing quality control checks; and preparing an annual report

4. Year 4 labor includes decommissioning sites and preparing a final report

5. Estimates assume the branches of Prouty Brook are independently gauged

6. Estimates assume an OTT PLS pressure transducer is used at this site. Upgrading to a Campbell LevelVueB10 bubbler flowmeter would add $2,670 per gauge

7. Estimates include cost of a custom weir plate

8. Estimates assume an acoustic doppler current profiler (SonTek-IQ Pipe) is used at Alder Run

9. Estimates assume use of Stone cell modems; however, radio frequency telemetry may be required at these sites. Purchase of new radio equipment would add $400 per gauge

5.3. Cost Summary

The estimated costs for conducting a 3-year gauging program on Lake Carmi tributaries range from a low of \$39,490 at Dicky's Brook to a high of \$75,970 at Prouty Brook (with two gauges) (Table 6). If all 10 named tributaries were gauged as recommended (including the extra gauge at Prouty Brook, use of the ADCP unit at Alder Run, and use of new monitoring equipment), the total estimated costs of the 3-year gauging program (which would run into a fourth year with data processing and reporting) is \$486,600. This estimate assumes new, high quality pressure transducers would be installed at every gauge except Alder Run, where an ADCP unit is recommended. However, if funding allows, we recommend that bubbler flowmeters be used in place of pressure transducers, which would add \$2,670 to the cost of each gauge.

Use of existing Stone equipment would result in approximately \$40,000 in cost savings, as repurposing already assembled equipment would reduce the costs of new equipment and labor, or time, spent on assembly.

In the event that cellular modems are not adequate for the five gauges on the eastern side of Lake Carmi, radio frequency devices would be used instead. This would not add appreciably to the base cost of the program. However, the costs presented in Table 7 would increase by \$2,000 (\$400 x 5 gauges) to cover the cost of new radio frequency devices.

The estimates provided in Tables 5-7 do not account for precipitation monitoring. We recommend three tipping bucket rain gauges be used, as discussed in Section 4.1.6. Acquisition of these rain gauges would cost ~\$800 each (or \$400 each from Stone's inventory). Installation and ongoing calibration, data processing, and quality assurance would cost approximately \$3,700 per rain gauge (approximately \$11,100 total) over the 3-year program.

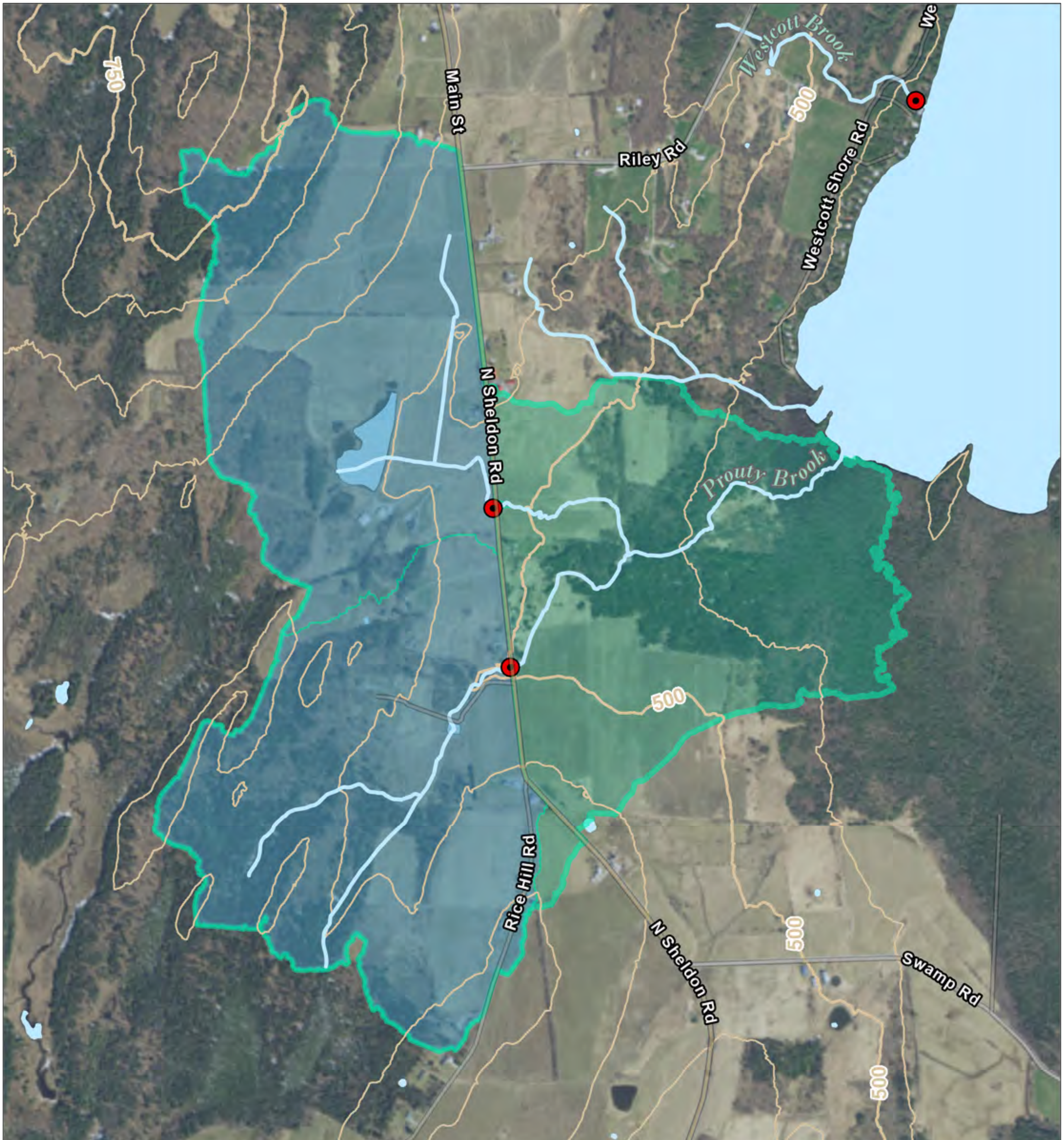
Finally, current meters and other discharge measuring equipment (i.e., wading rod, Type AA-magnetic head current meter, Pygmy current meter, AquaCMD Current Meter Digitizer, 4" collapsible cutthroat flume with wingwalls, 12-V peristaltic sampling pump, and field conductivity meter) would be used across all sites. Purchased new, the necessary equipment would cost approximately \$6,500. If Stone's equipment is used and supplemented, the cost would be \$3,200. These additional costs are included in Table 8.

Table 8. Program costs (all tributaries gauged)

	Retail	Using Stone equipment (if possible)
Gauging program	\$486,600	\$446,900
Rain gauges[1]	\$2,400	\$1,200
Rainfall monitoring[1]	\$11,100	\$11,100
Discharge measuring equipment	\$6,500	\$3,200
Grand total	\$506,600	\$462,400

1. Assumes tipping buckets are installed at three of the recommended stream gauges

Appendix A. Watershed Maps



LEGEND

- Proposed gauge
- Watershed at gauge
- Watershed at lake
- Contour Lines (feet)

N

0 0.1

Miles

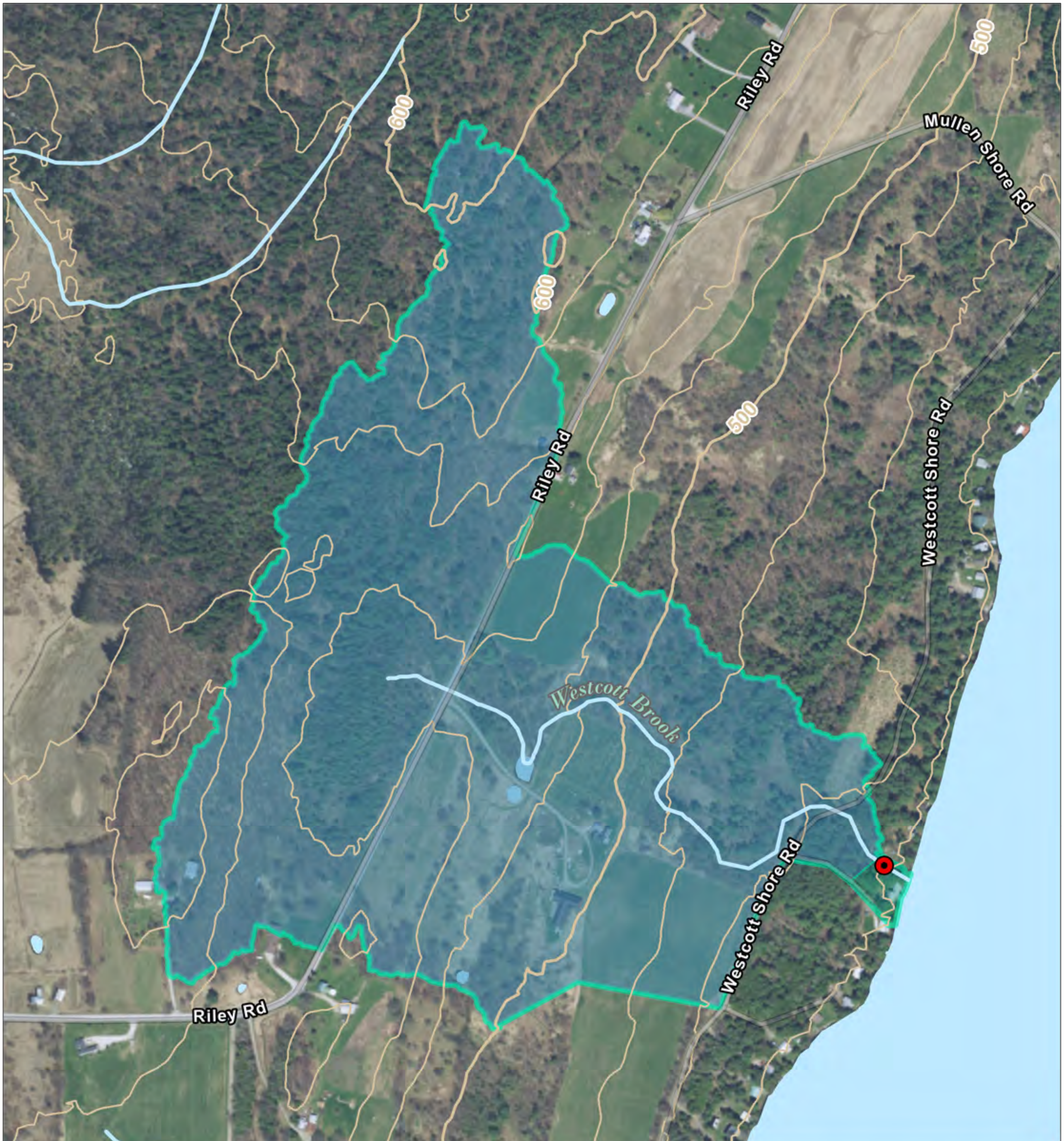
Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

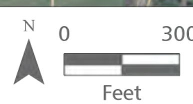
Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx

Map 1. Prouty Brook

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL





LEGEND

- Proposed gauge
- Watershed at gauge
- Watershed at lake
- Contour Lines (feet)

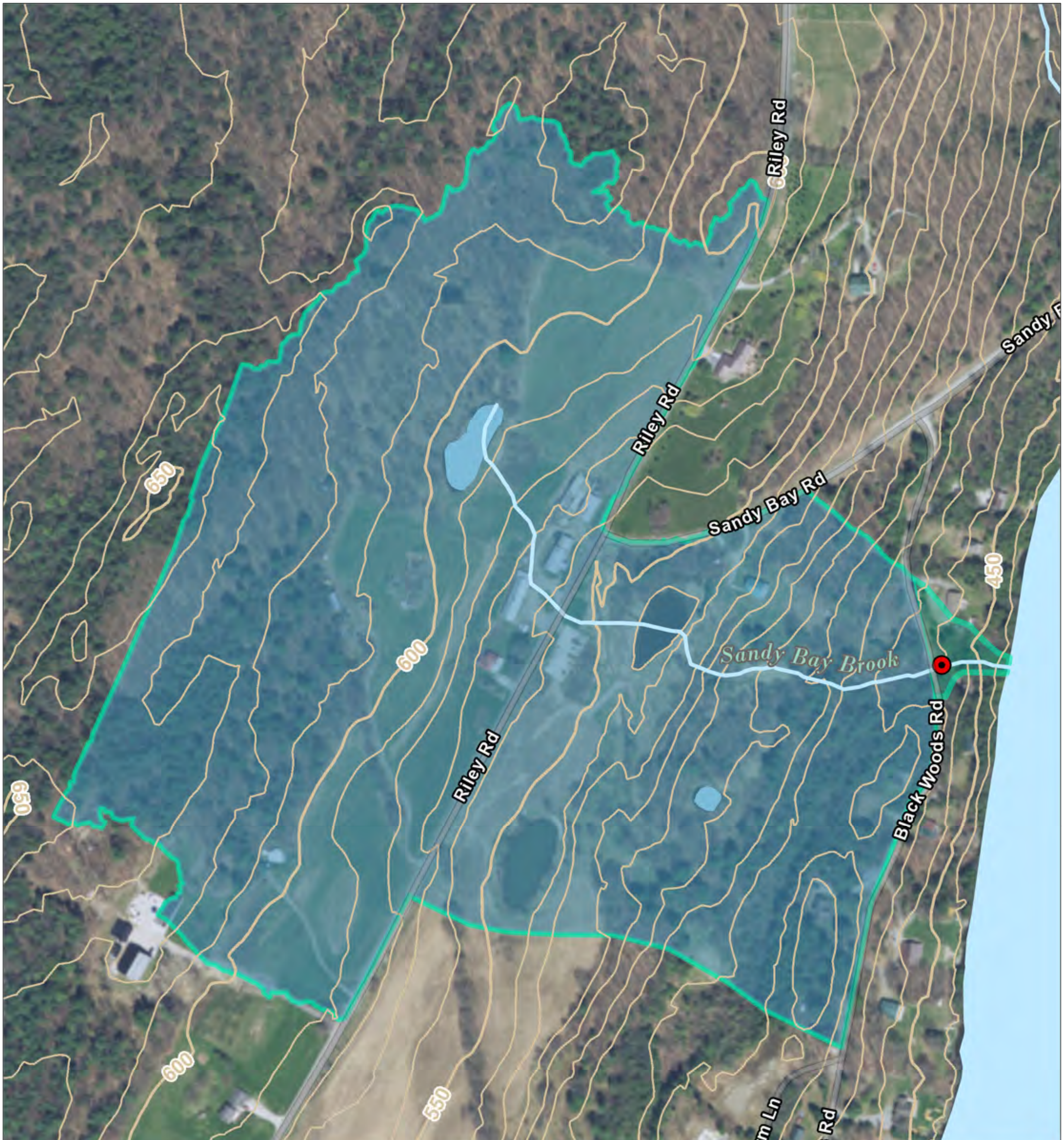
Map 2. Westcott Brook

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL

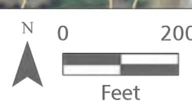
Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx



LEGEND

- Proposed gauge
- Watershed at gauge
- Watershed at lake
- Contour Lines (feet)



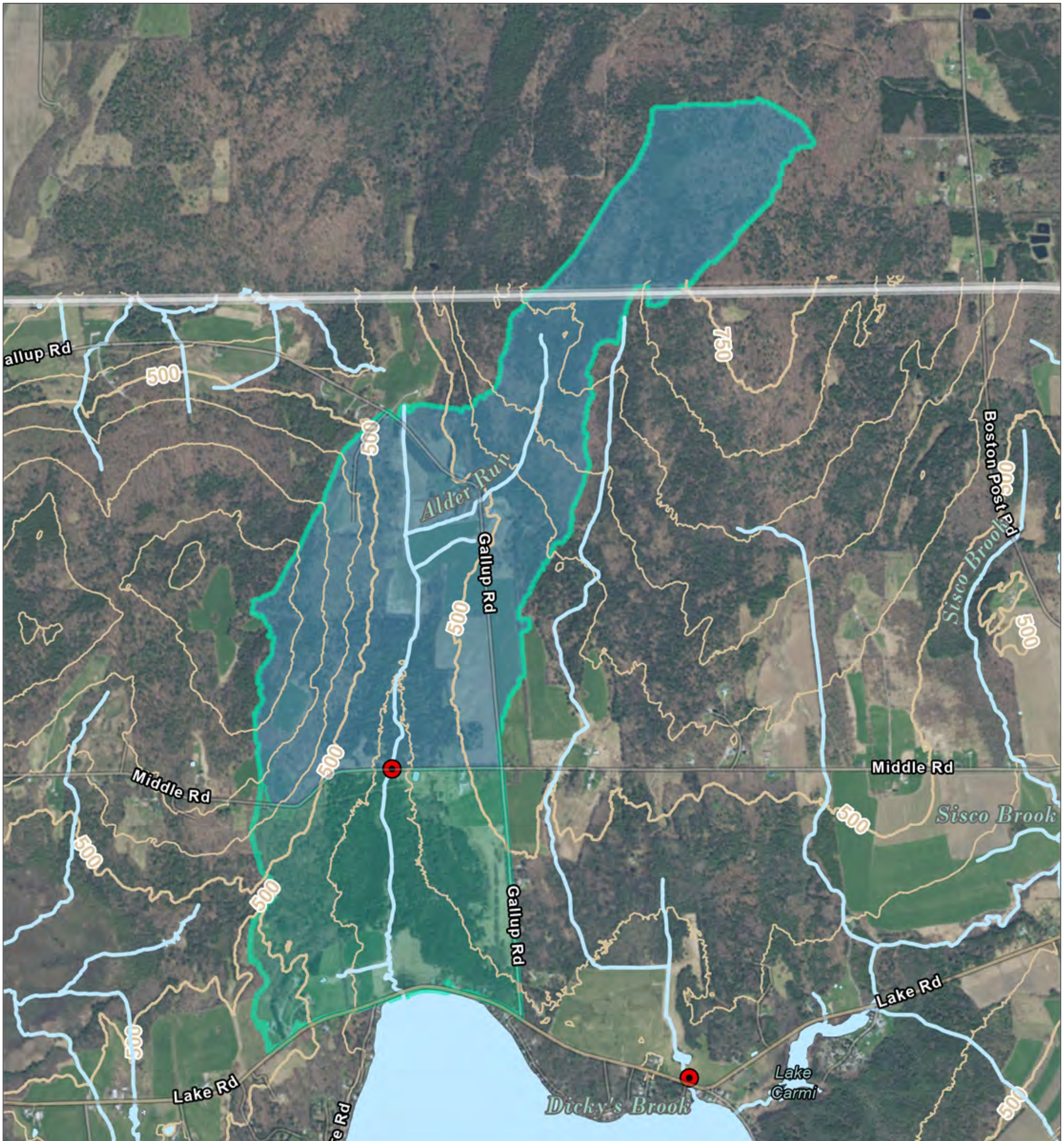
Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx

Map 3. Sandy Bay

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL



LEGEND

- Proposed gauge
- Watershed at gauge
- Watershed at lake
- Contour Lines (feet)

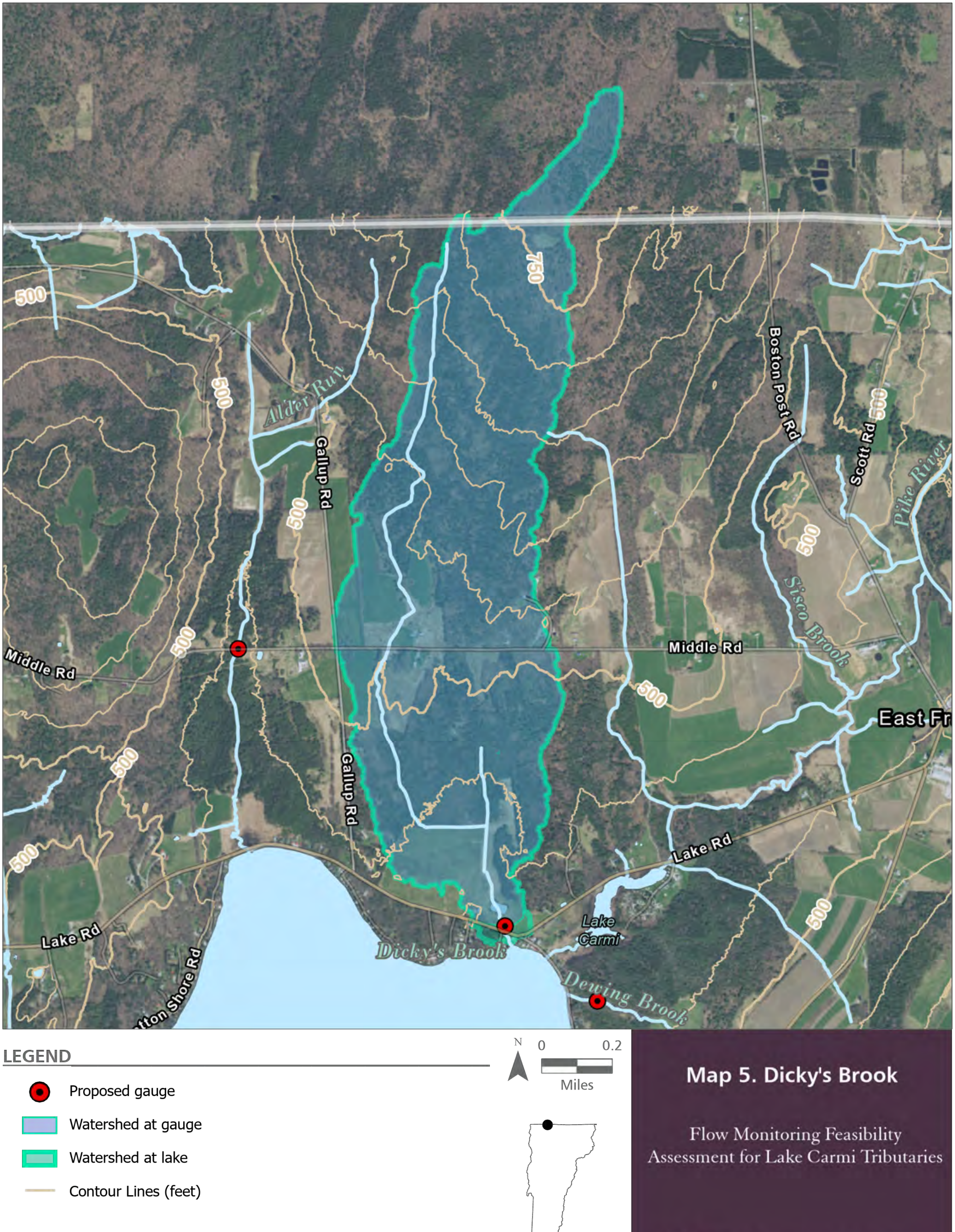
Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx

Map 4. Alder Run

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL



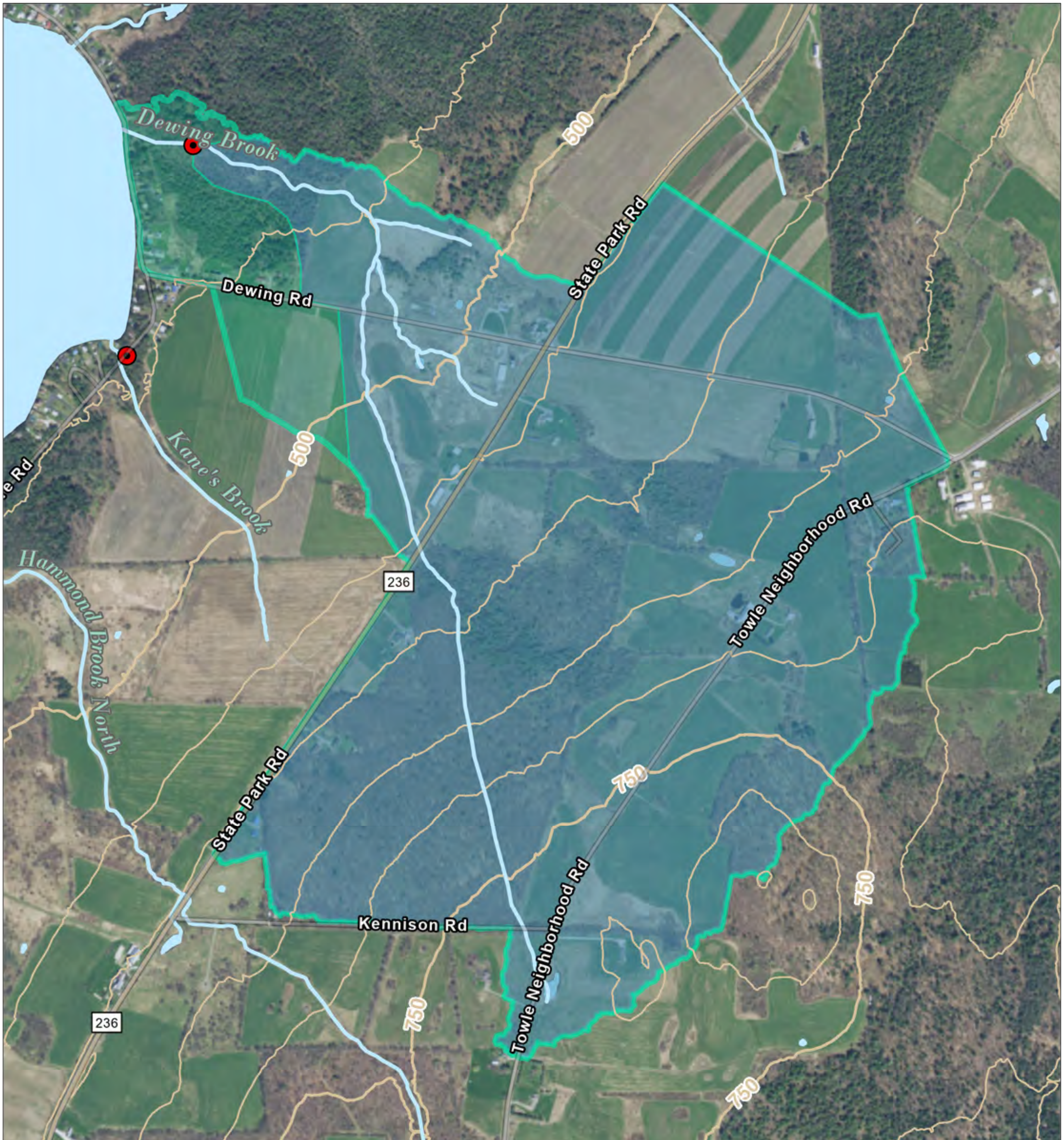
Map 5. Dicky's Brook

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL

Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx



LEGEND

- Proposed gauge
- Watershed at gauge
- Watershed at lake
- Contour Lines (feet)

N 0 0.1 Miles

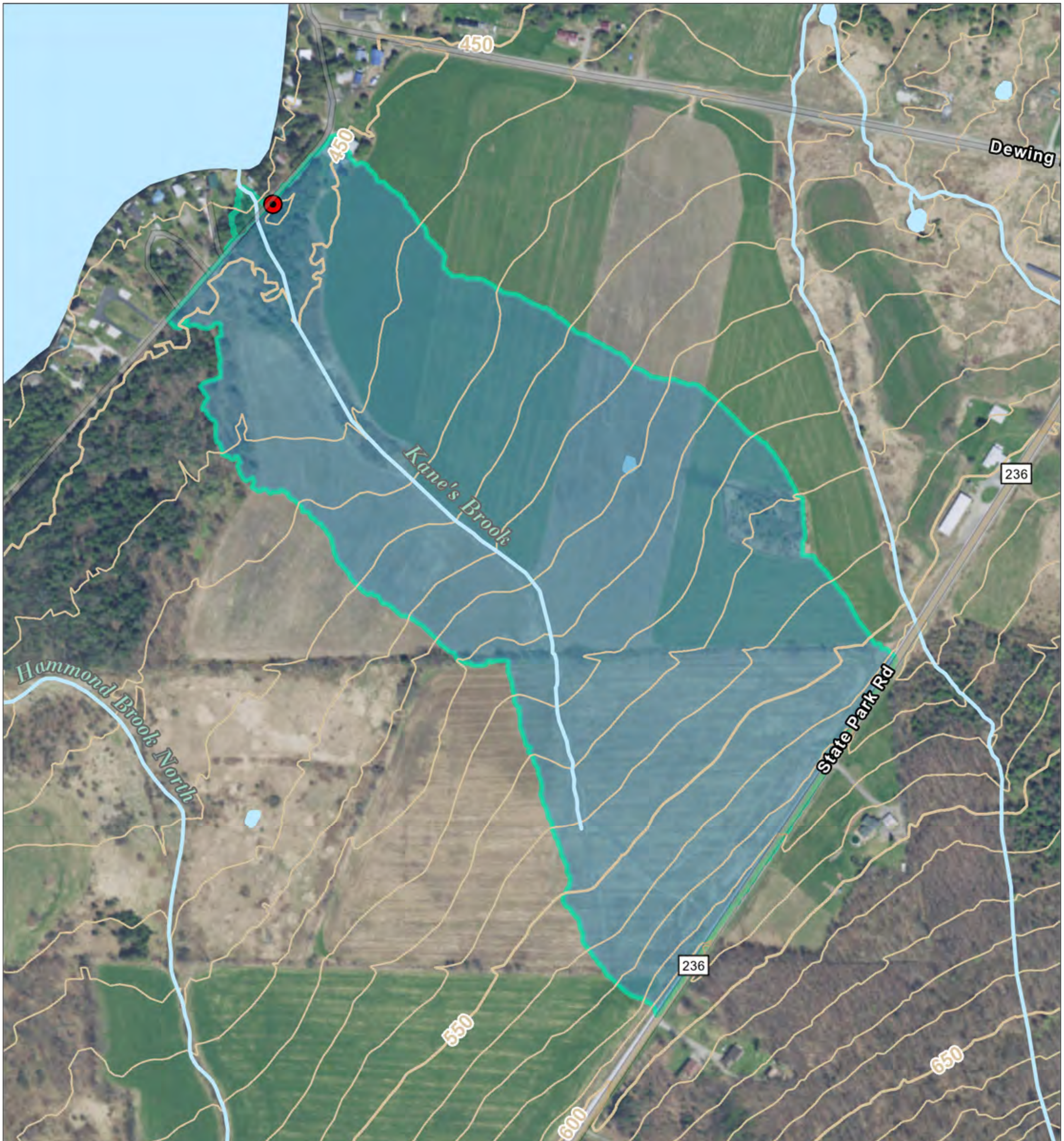
Map 6. Dewing Brook

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL

Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx



LEGEND

Proposed gauge

Watershed at gauge

Watershed at lake

Contour Lines (feet)

N 0 250

Feet

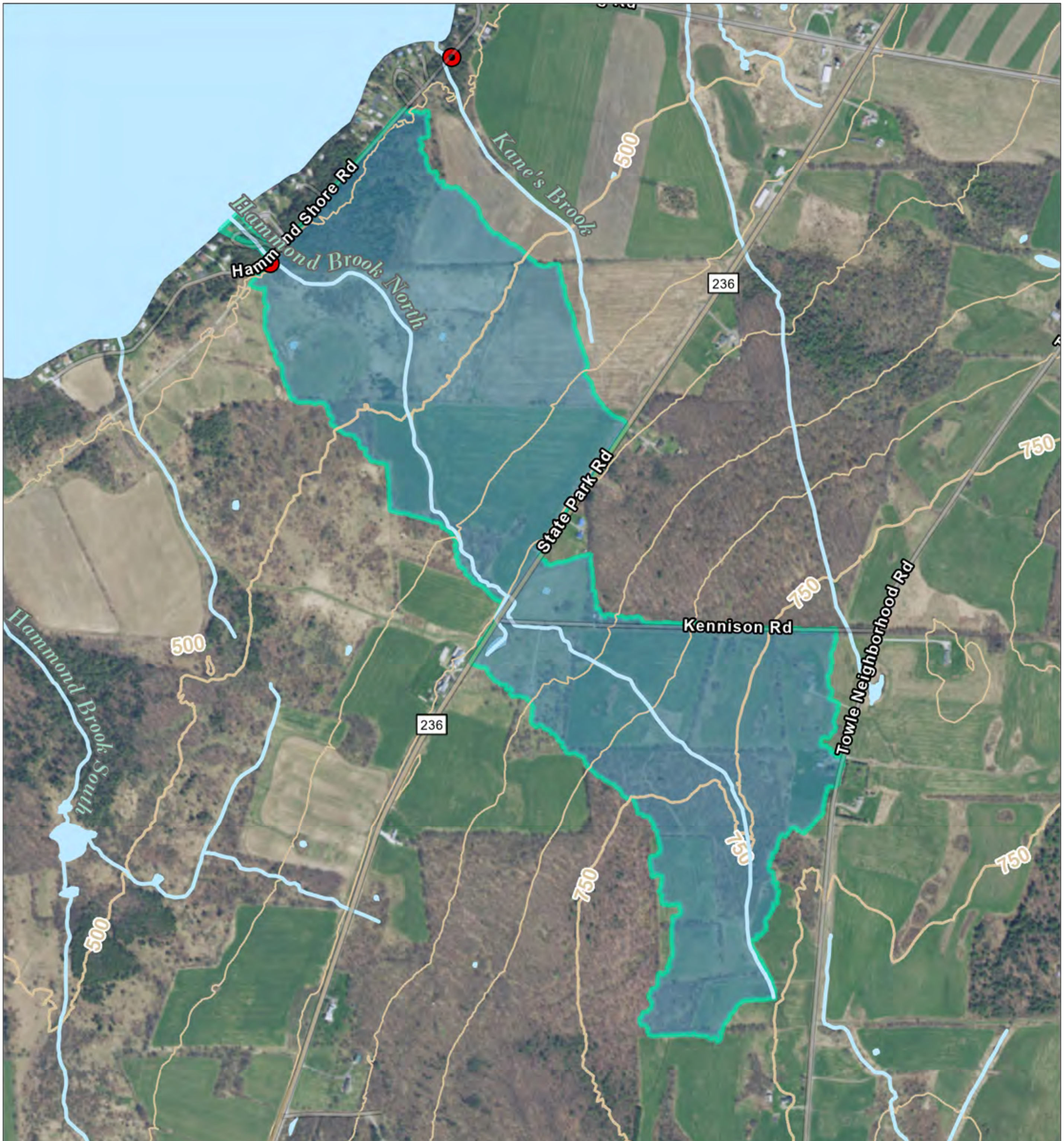
Map 7. Kane's Brook

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL

Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx



LEGEND

- Proposed gauge
- Watershed at gauge
- Watershed at lake
- Contour Lines (feet)

N 0 0.1
Miles

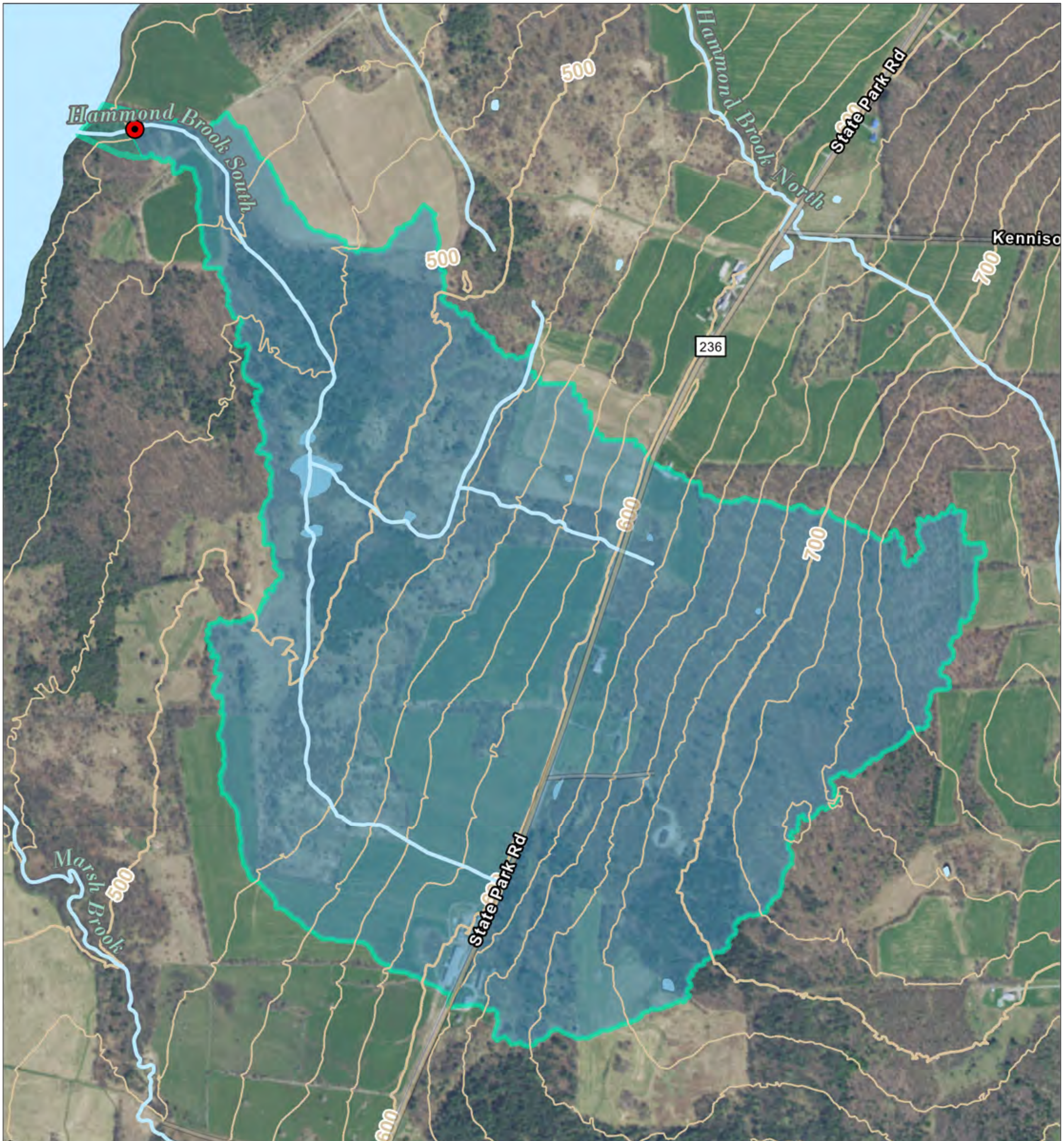
Map 8. Hammond North

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL

Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx



LEGEND

- Proposed gauge
- Watershed at gauge
- Watershed at lake
- Contour Lines (feet)

N 0 0.1 Miles

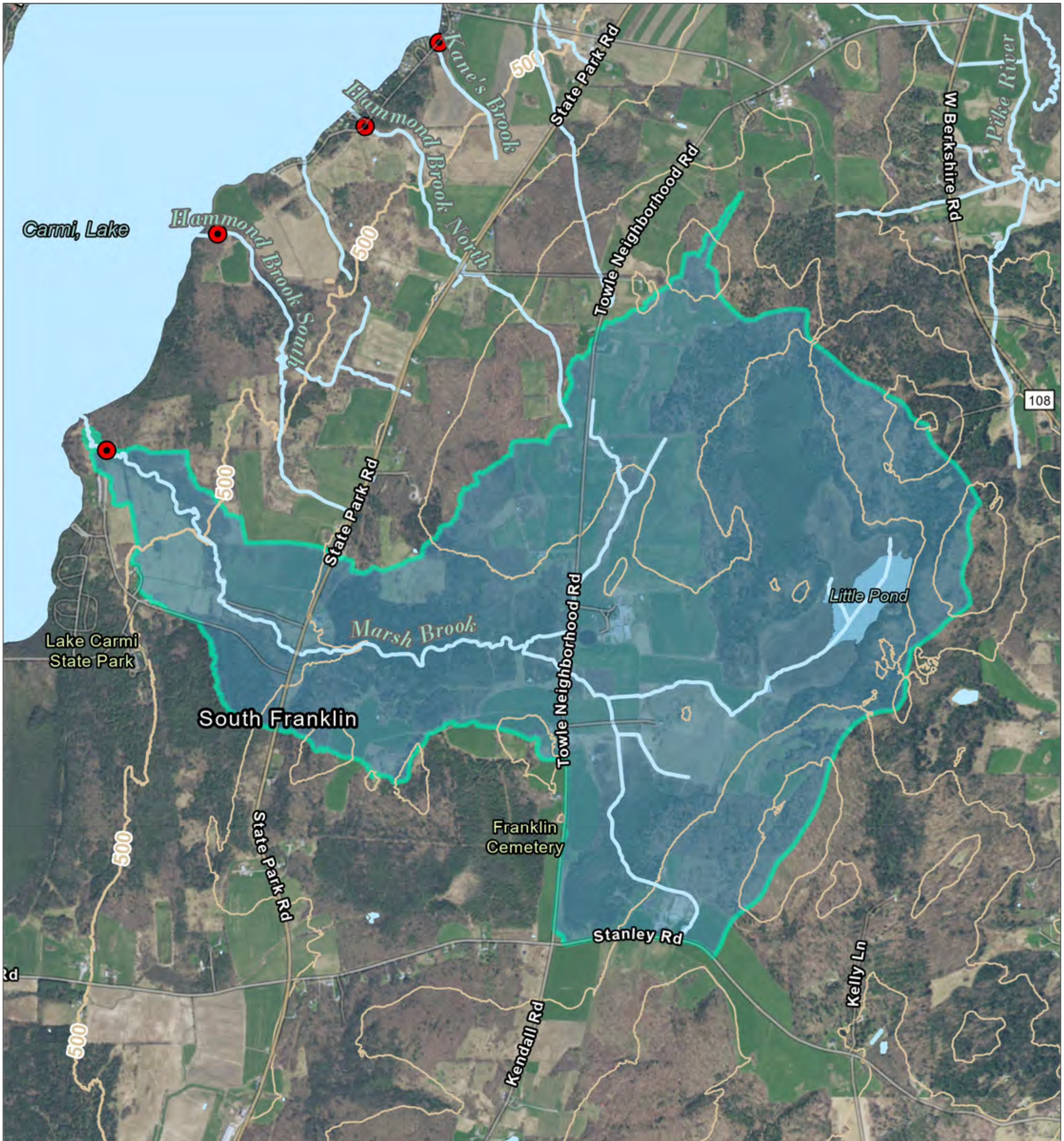
Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx

Map 9. Hammond South

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL



LEGEND

- Proposed gauge
- Watershed at gauge
- Watershed at lake
- Contour Lines (feet)

N 0 0.25 Miles

Map 10. Marsh Brook

Flow Monitoring Feasibility Assessment for Lake Carmi Tributaries

STONE ENVIRONMENTAL

Source: Esri World Imagery, Vermont Center for Geographic Information Hydrography

Path: O:\PROJ-20\WRM\20-052 Lake Carmi tributary gauging assessment\GIS\MapDocuments\PresentationsAndReports\Watershed_hydrography\Watershed_hydrography.aprx