WATER QUALITY PLANNING ON THORP AND KIMBALL BROOKS
CHARLOTTE AND FERRISBURG, VERMONT

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Prepared for:

Lewis Creek Association
Charlotte, Vermont

Prepared by:

Milone & MacBroom, Inc.
1233 Shelburne Road, Suite 180
South Burlington, Vermont 05403
802.864.1600
www.miloneandmacbroom.com

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EXECUTIVE SUMMARY

Nutrient and sediment loading are well-documented water quality issues for Lake Champlain. Past and current studies have highlighted hotspots in need of better management of point and nonpoint sources of pollution. Although progress has been made, water quality improvement in Lake Champlain and its tributaries remains a state and local goal.

The Champlain Valley has low topographic relief that is approximately flat approaching the edge of the lake. The dominant land use in the region is agriculture and soils largely consist of clay. The near-lake area once dominated by lake-edge floodplain forests and riparian wetlands now consists of agricultural fields, rural residential areas, and remnant forest and wetland patches. This land use conversion has increased runoff rates by smoothing the landscape, ditching fields, and increasing impervious surfaces.

The level of impacts associated with altered hydrology near the edge of Lake Champlain needs further evaluation. Some water quality sampling and other forms of monitoring are taking place in select locations where local concerns or obvious problems exist. Although common sense suggests that polluted runoff closer to the lake is a problem, a detailed understanding of loading from the small watersheds draining directly to the edge of Lake Champlain (i.e., direct drainages) is needed. Resource managers need to know if there are ways to maintain agricultural productivity while better managing runoff and improving water quality in streams, bays, and Lake Champlain.

Three general tools are available for investigating direct drainages – data collection, field reconnaissance, and critical source area identification. Data collection can allow for a detailed understanding of water quality and loading, yet sampling and analyses at high frequency and adequate spatial resolution are often cost prohibitive. Field reconnaissance is a quick way to know your watershed and observe obvious impacts, yet subtle impacts or large-scale changes may not be visible from the ground. Critical source areas are mapped locations that contain both a source and a transport mechanism of a pollutant of concern, and mapping often is performed using hydrology and sediment transport models, GIS, and field verification. Mapping critical source areas provides a nice overview of possible areas of concern, yet can miss important locations at smaller scales. The ideal investigation method draws on the positive aspects of data collection, field reconnaissance, and critical source area identification to maximize understanding.

A case study was performed on Thorp and Kimball Brooks in Charlotte and Ferrisburg, Vermont to review past data collection, conduct additional field reconnaissance, develop a plan for continued investigation of local conditions, make management recommendations for current water quality improvement, and initiate creation of a template for investigating direct drainages of Lake Champlain.

Field observations were made during varying combinations of lake water level and stream flow to identify the transition zone between flowing water and water body. On Kimball Brook the zone was typically located at Town Line Road, yet during high lake

levels and flows the transition to ponded water appears to extend up to the Railroad Culvert. On Thorp Brook, the lake-stream transition is typically located near the Railroad Culvert, yet the lake may influence approximately halfway between the railroad and Greenbush Road during high flows.

Staff gauges were installed and rating curves were developed for both streams so volunteers can quickly estimate flow during future water quality monitoring. Flow measurements are important to convert concentrations to loads and watershed yields to gain an understanding the importance of the water quality threat from direct drainages relative to other tributaries of the lake.

Analysis of past water quality data for Thorp and Kimball Brooks generally indicates that total phosphorus concentrations are high in Kimball and Thorp Brooks for freshwater streams, but values are typical relative to other rivers and streams in the region. Water quality monitoring revealed several possible pollution hotspots on Kimball Brook near Vermont Route 7 (K4 and K5) and the tributary to the north of Thorp Brook (T3.5). Other areas of concern were identified during a stream walk on Kimball Brook:

- The co-located cattle/stream crossing under the railroad;
- The north to south farm field flow path that enters Kimball Brook before the channel turns north towards Town Line Road;
- The flow path draining the barnyard area adjacent to Town Line Road; and
- The field flow paths that enter the tributary of Kimball Brook that flows into the lake-edge floodplain.

Priority areas to investigate on lower Thorp Brook include:

- The east to west field ditch that flows into Thorp Brook to the east of Greenbush Road; and
- Thorp tributary and the documented flow paths from farm fields entering the channel north of Thompson's Point Road.

Local landowners should be contacted and field investigation should be performed to try and identify the possible sources of nutrient inputs.

The on-going volunteer monitoring should continue and be adjusted to focus on characterizing the load and yield of sediment and phosphorus on Kimball and Thorp Brooks. Kimball Brook sampling should continue at Greenbush Road (K2) and Thorp Brook sampling should continue at Greenbush Road (T1) and the northern tributary with high nitrogen (T3). Samples should be collected monthly or when flows permit in the summer. Staff gauges should be read each time a sample is collected. In addition, daily readings for several months each season will allow for determination of an annual load or yield.

Turbid flows from field runoff, field ditches, and road ditches have been observed during flooding. NRCS mapping illustrates the widespread ditching in the Thorp and Kimball Brook watersheds. Altered hydrology is the primary impact in direct drainages since runoff now moves to the lake much faster with less opportunity for sediment deposition and nutrient uptake on floodplains. Plugging ditches and conversion of select pieces of land back to natural vegetation is desired to naturalize hydrology and improve water quality. Restoring natural channel pattern and providing space for channels to naturally move in the floodplain will also improve water quality.

1.0 INTRODUCTION

Thorp and Kimball Brooks drain approximately 6.5 square miles that discharge directly to Lake Champlain via Town Farm Bay in Charlotte (Figure 1). Roughly 2 square miles of land drain directly to the bay via overland runoff or flow in small ditches. The topography is generally flat as channels approach the lake-edge floodplain forests of Lake Champlain. The watershed mostly consists of clay soils from lake and marine deposits that are cohesive yet transported long distances at moderate flows once initially mobilized. Farm fields, roads, and remaining naturally-vegetated floodplain are typically inundated each year. Land use (2001 National Land Cover Data processed by University of Vermont Spatial Analysis Laboratory) in the watershed consists of agriculture (53 %), forest (26 %), urban (e.g., rural residential and roads) (17 %).

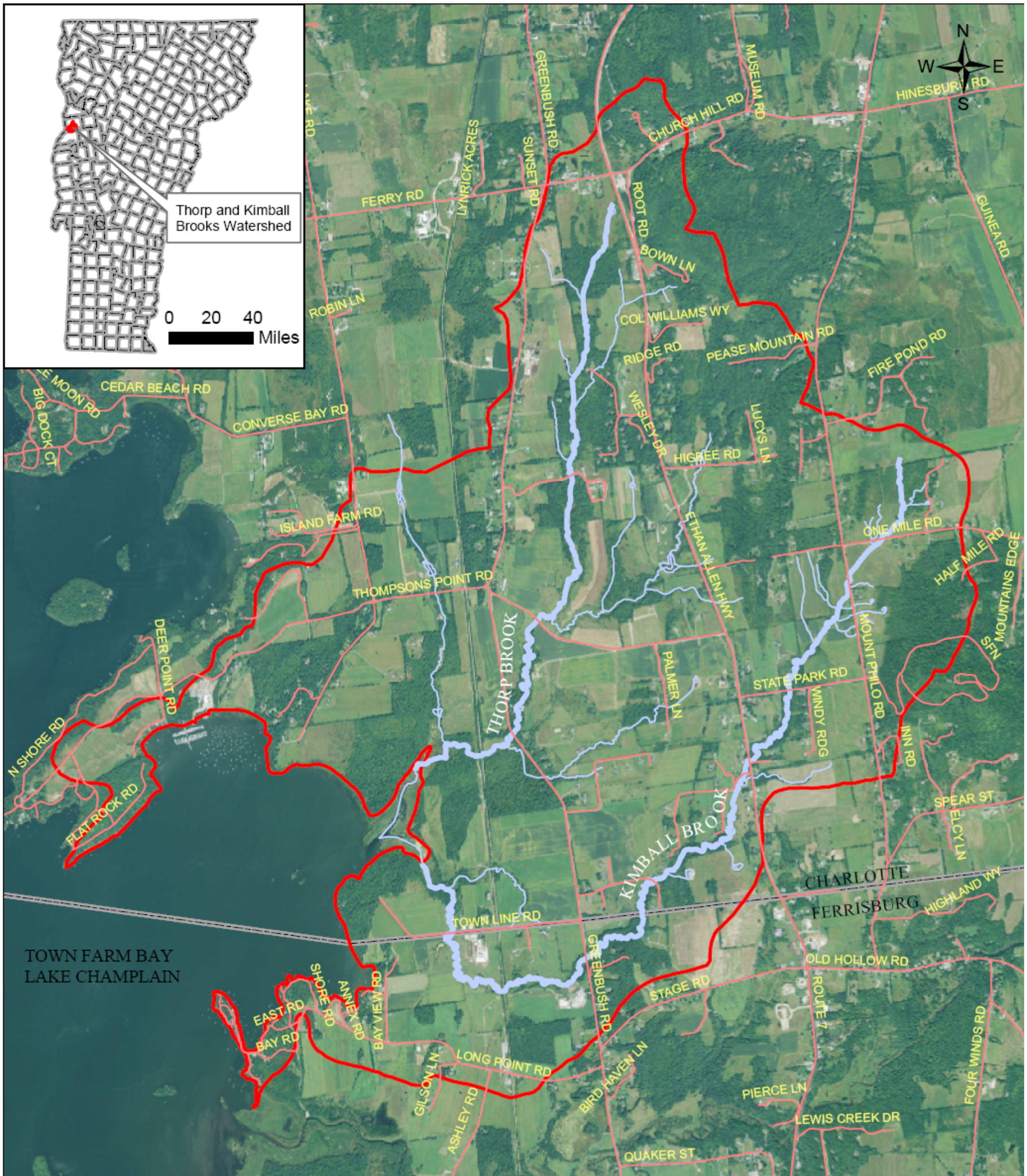
Water quality has been monitored in the Thorp-Kimball watershed through a volunteer effort since 2008. These data illustrate high nutrient and sediment concentrations for freshwater streams, yet concentrations are not relatively high compared to other regional data on larger tributaries of Lake Champlain. Some local potential hotspots of nutrients have been identified where high concentrations were observed.

Stream gauging is needed to support on-going water quality monitoring so that measured concentrations (mass / volume) can be converted to loads (load = concentration x flow = mass / time) and yields (yield = load / area = mass / time-area). Facilitating future calculation of the nutrient and sediment yield is a primary objective of this study to understand how significant this and other small direct drainages are to the health of bays and Lake Champlain relative to other larger watersheds draining to the lake. Gauges have been established as part of this project to calculate flow each trip to sample sites.

Another important objective of this study is to determine the location of the transition zone between lake and stream over the hydrologic year. This information is essential to understand the results of existing monitoring, guide future monitoring efforts, and create appropriate near-lake management strategies.

A refined monitoring program to improve assessment and planning in the Thorp and Kimball Brook watershed and other direct drainages to bays and Lake Champlain is needed. With shrinking monitoring and analysis budgets, it is essential to understand which watersheds are most problematic to water quality in order to accomplish the most improvement with available restoration funds. If the direct drainages are found to have significant nutrient yield (as expected), than future monitoring should work towards identifying problem areas for restoration.

Milone & MacBroom, Inc. (MMI) was retained by the Lewis Creek Association (LCA) to document the physical setting of the lake-stream transition zones on Thorp and Kimball Brooks, establish a flow gauge in each stream, and create a direct drainage assessment plan for the Thorp and Kimball Brook watershed. The plan will hopefully serve as an initial template for assessing other direct drainages. This report documents project methods, findings, and recommendations.



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1233 Shelburne Road, Suite 150 South Burlington, VT 05403 (802) 864-1600 Fax: (802) 864-1601 www.miloneandmacbroom.com	MMI#: 3452-07 MXD: sitewalk.mxd SOURCE: www.vcgi.org	**Watershed Area** **Thorp and Kimball Brooks**	DATE: 11/18/2010 SCALE: see scale bar SHEET: **Figure 1**

2.0 FIELD OBSERVATIONS

2.1 Kimball Brook

2.1.1 Low Stream Flow / High Lake Level Observations

Kimball Brook was walked by Milone & MacBroom personnel on May 7, 2010. During the stream walk, lake levels were near seasonal highs (Elevation 98.35 feet NGVD29, USGS 04294500 Lake Champlain at Burlington). Stream characteristics were documented with digital photographs, field-based water quality meters, and high-accuracy GPS (Figure 2). A YSI meter (Model 85, Yellow Springs, OH) was used to record temperature, dissolved oxygen, conductivity and salinity. Velocity measurements were recorded using a Marsh-McBirney (Flow-Mate Model 2000, Loveland, CO) portable velocity meter. GPS points were recorded to locate features and measurements (Trimble GeoXT, Sunnyvale, California).

The stream walk and water quality measurements (Table 1) were started upstream of Greenbush Road (Point 1) and continued to where the Lake was visible (Figure 3, see Appendix A for a photo-documentation of the stream walk). The discharge was 3.4 cubic feet per second just upstream of Greenbush Road (Point 2). No tributaries join Kimball Brook between Greenbush Road and the Lake so the discharge measurement applies downstream until backwatering from the lake takes place.

At and upstream of Greenbush Road, Kimball Brook has characteristics of a flowing-water environment (i.e., fluvial) with no signs of backwatering. In the vicinity of Greenbush Road, the stream has riffle-pool bedform with some point bar development and adjacent river floodplain with recent sediment deposits from overbank flows (E channel according to Rosgen and Silvey, 1996). The bed is dominated by silt and clay, with gravel and sand at the riffles. Immediately downstream of Greenbush Road, a large scour pool has formed, most likely due to erosion associated with jetting flow due to the undersized culvert.

Downstream of Kimball Brook Farm (Points 5-7) dunes and ripples became more common and channel sinuosity increases. Gravel deposits are almost absent. The channel remains free-flowing with no signs of backwatering. The lower channel slope through this section contributed to a lower water velocity and deeper water. The remains of a small laid up stone dam (Point 8) controlled the water surface elevation in this section. The temperature gradually increased through this section due to the lack of tree canopy.

Downstream of the remnant small stone dam the channel flows into woodlands. The channel is wider and the velocity lower. Large sand and silt deposits covered the stream bed. The channel follows an active cattle crossing under the railroad that seems to be causing some backwatering in the section upstream. The altered

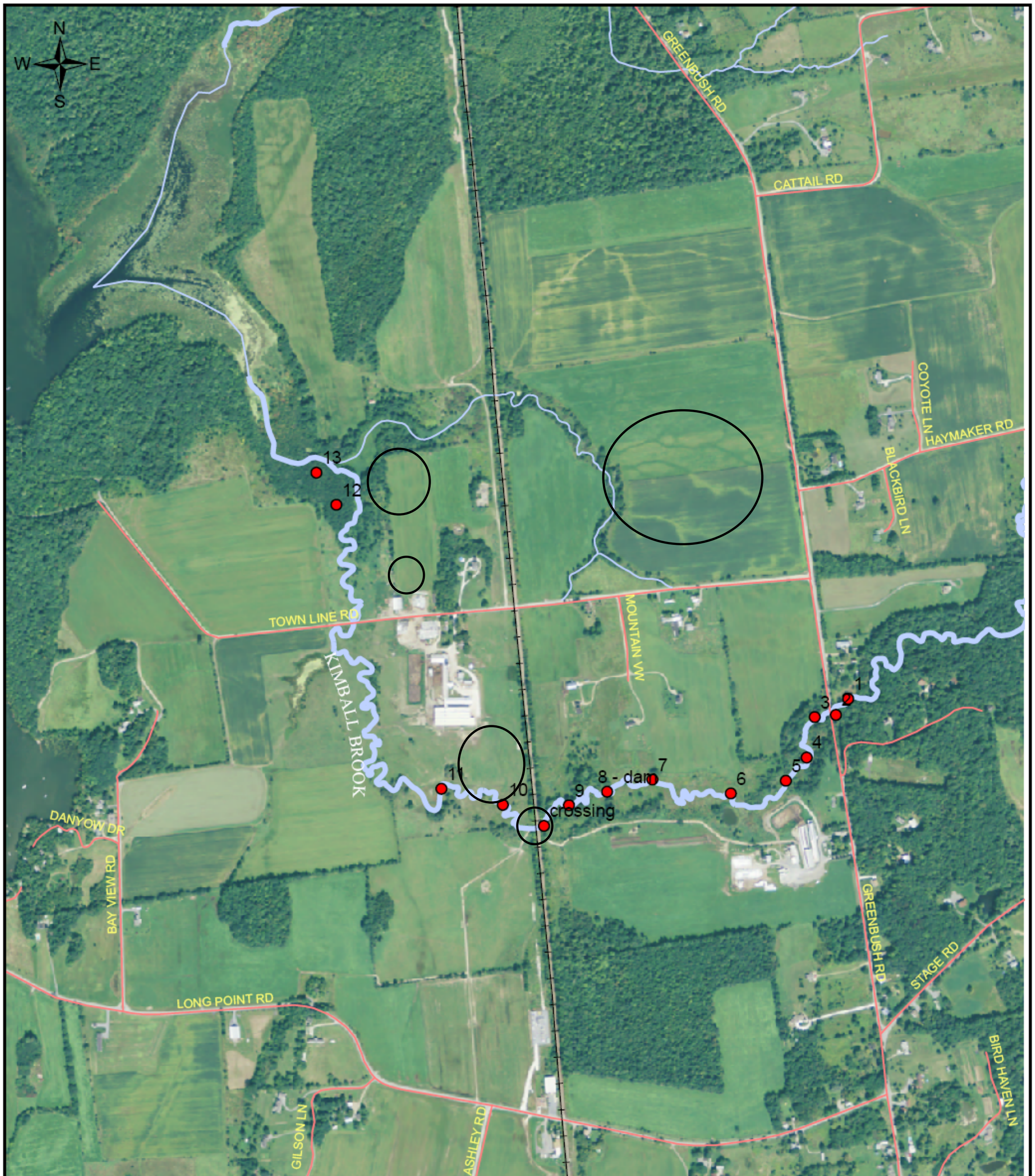

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Figure 3a: Kimball Brook upstream of Greenbush Road (Source: MMI, May 7, 2010).

Figure 3b: Kimball Brook at the Lake Champlain floodplain forest (Source: MMI, May 7, 2010).

channel form in this location is trampled and muddy. Downstream of the cattle crossing the channel narrows, has lower banks, and is well-connected to floodplains.

As the channel widened and deepened upstream of the farm on Town Line Road, the water in the channel became turbid (Point 11). The channel appears to have been historically altered in this location as a berm exists that unnaturally creates a wide flat channel. The channel approaching Town Line Road is wide, shallow, has wetland characteristics, and is ponded in locations. The channel form is poorly defined likely due to historic pasturing or maintenance of the channel to support local farm operations. The channel is currently confined to one side of pasture, with cattle fencing keeping animals from grazing the low floodplain. Meander scars are visible in the field around the stream that illustrate a greater sinuosity and lower slope approaching Town Line Road in the past.

Algae clog much of the channel in this area and turbidity is high. Kimball Brook is ponded upstream of Town Line Road where a culvert and small headwall exist. Signs of water overtopping are evident along the lowest part of the road. The culvert under the road was full during the site walk, yet no visible signs of moving water were present – a fully backwatered condition. The temperature continued to increase through this section with a corresponding decrease in dissolved oxygen.

Downstream of Town Line Road the channel flowed through a pool that appeared excavated and full of fine sediment. The channel was not well-defined and flowed overland through a stand of cattails. Water sheeted across a grass wetland with no distinct channel visible and entered a lake-edge floodplain forest (Thompson and Sorenson, 2005) (Point 11). Silver maple, American elm, green ash, and red maple dominated the forest. Moving downstream the depth of ponded water increased and the understory became minimal. The forest was flooded to lake level. A distinct high water mark was visible on trees, 1.3 feet above current water level. The standing water was deep and very wide, and the edge of Lake Champlain was visible downstream (point 13). The temperature decreased relative to the open pasture section upstream. The dissolved oxygen levels were low in the standing water amongst the flooded forest.

Dissolved oxygen levels decreased approaching the lake-edge floodplain (Table 1) likely due to respiration by the large standing crop of submerged aquatic vegetation symbolic of high biological oxygen demand. Temperatures reflected the difference between canopy cover on the stream. Conductivity measurements did not vary much during the stream walk and thus did not provide evidence of the change between the lake and stream environments.

During the site walk, possible impacts to water quality were noted.

- The small pasture adjacent to the channel upstream of Greenbush Road has disturbed ground, a steep slope, and no buffer.

- The Town Line Road Culvert is undersized and may be leading to excessive local erosion.
- The cattle crossing under the railroad has direct input of manure and has a highly disturbed streambed.
- The farm on Town Line Road contributes agricultural runoff and disturbed soils to the edge of Lake Champlain.

Table 1: Kimball Brook Field Water Quality Data

GPS Point	Max. Depth (feet)	Max. Velocity (feet/sec)	Temp. (Celsius)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Specific Cond. (uS)	Salinity (npt)
1	0.6	0.7	11.2	106	11.6	449	0.2
2	0.5	1.0	11	94	10.4	448	0.2
3	0.5	2.5	11.3	96	10.4	350	0.2
4	0.9	1.1	11.6	105	11.4	445	0.2
5	1.0	0.8	11.9	104	11.1	375	0.2
6	1.0	0.9	12.3	91	9.8	463	0.2
7	1.2	0.5	13.0	100	10.8	464	0.2
9	1.0	0.6	13.6	110	11.5	460	0.2
10	1.0	1.2	14.2	120	12.3	457	0.2
11	1.4	0.2	14.4	105	10.7	465	0.2
12	0.6	0.1	17.2	85	8.3	444	0.2
13	1.2	0.0	13.7	48	4.9	441	0.2

2.1.2 Low Stream Flow / Low Lake Level Observations

A stream walk during low flow conditions was planned, yet initial observations revealed shallow stagnant water in the channel for much of the summer. Select observations were instead made at key locations identified during the initial site walk. The region was experiencing extreme seasonal low flows during summer 2010 observations (Figure 4).

Kimball Brook was visited on July 13 and August 10 when lake levels were approaching seasonal lows (Elevation 96.3 feet NGVD29, USGS 04294500 Lake Champlain at Burlington). During the low flow summer period the stream flow was just a trickle. Riffles and dunes were almost dry and small shallow pools existed. Sections of the stream downstream of Greenbush Road the streambed was moist yet no visible flow was present. The stream was not observed to be completely dry and is therefore not considered to be intermittent. Low flows made it difficult to pinpoint the downstream transition between lake and stream, yet field observations suggest it is within the lake-edge floodplain forest.

Figure 4: Kimball Brook with mostly dry streambed near Kimball Brook Farm manure pit. (Source: MMI, July 13, 2010).

2.1.3 High Flow / High Lake Level Observations

There were no high flow events observed during high lake levels. These extreme events would typically occur during spring snow melt rain events and did not occur during this study period. Field observations suggest that the extreme upstream limit of the lake backwater would be at the Railroad Arch Culvert. Backwatering would typically be further downstream, most commonly in the vicinity of Town Line Road.

2.1.4 High Flow / Low Lake Level Observations

High flows were observed on October 1 and October 15, 2010 (Figure 5). Lake levels were near the seasonal low (Elevation 95.2 feet NGVD29, USGS 04294500 Lake Champlain at Burlington). Both rain events produced approximately bankfull flows. The precipitation event occurred after an extended dry period. Water filled the channel and flowed on the floodplain upstream of Greenbush Road and downstream through the Kimball Brook Farm property. The stream flowed freely without influence of the lake backwater in the vicinity of Greenbush Road and Kimball Brook Farm.

Figure 5: High flows in Kimball Brook upstream of Greenbush Road culvert on (Source: MMI, October 15, 2010).

2.1.5 Survey

Although originally planned, survey was not performed to profile the Kimball Brook channel as it will not provide useful information due to the historic channel disturbance and control at the Town Line Road culvert. Survey was performed to record the elevation of the staff gauge, Greenbush Road culvert geometry, and local reference points to reset the staff gauge when it is washed out (see Section on Stream Gauging).

2.1.6 Summary

The transition between stream and lake is dynamic depending on lake level and discharge. The channel appears to transition from stream to lake most of the year at the farm along Town Line Road during high lake levels. The precise location of the lake-stream transition is difficult to locate as the channel in this area has been altered and is not clearly defined, the floodplain has been altered due to past farming, and the Town Line Road culvert controls flow up- and downstream. Field data suggest that the transition zone during high lake levels and large flood events could extend approximately a quarter of a mile upstream from the obvious edge of the lake-edge floodplain community to the Railroad Culvert. During dry periods the lake recedes, streamflow declines, and flow disappears in many locations. The stream-lake transition under these conditions is typically within the lake-edge floodplain forest.

2.2 Thorp Brook

2.2.1 Low Stream Flow / High Lake Level Observations

A stream walk and water quality measurements (Table 2) were completed on Thorp Brook from Greenbush Road downstream to where the lake was visible on May 7, 2010 (Figure 6, Figure 7, and Appendix B for photo-documentation). Discharge was measured upstream of Greenbush Road to be 3.9 cubic feet per second (Point 1). Additional observations were taken upstream of Greenbush Road (Points 9-10) on May 13, 2010 when discharge was measured to be 2.6 cubic feet per second.

The channel upstream of Greenbush Road has a gentle slope, distinct banks, and deposit of fine sediments. Channel bed features of riffles and pools are evident. The bed is primarily silt and clay, with fine gravel in riffles and thalweg cross-over locations (upstream of Point 9). The stream walk extended upstream to a private driveway culvert crossing (Point 10). This location has obviously flowing water, with a 1+ foot drop at the outlet of the culvert. There is a 1+ foot dam upstream of this location. This section of channel appears to be outside the effect of the Lake. Large debris jams cause accumulation of sediments upstream of Greenbush Road and provide channel grade control and instream habitat.

Immediately upstream of Greenbush Road, sediments indicate periodic backwatering by the culvert under the roadway, but channel characteristics indicate that this location is dominated by a flowing-water environment. Downstream of Greenbush Road a large scour pool has formed. The pool elevation is controlled by a downstream riffle that serves as a distinct tailwater control. Downstream of Greenbush Road, the channel has a triangular cross section and clay bottom with no signs of backwatering (Point 2).

The channel enters an open field upstream of a stone masonry Railroad Bridge (Points 3-4). The channel has a clay bottom, low velocity, low sinuosity, and is very flat. Upstream of the bridge the channel depth increases and velocity decreases to the point where it is hard to tell if the water is flowing. Backwatering appears to be taking place in this location. The water surface elevation is flat through the Railroad Bridge and thus this backwatering does not appear to be caused by the crossing structure but a downstream location. The outlet pool downstream of the railroad has a flat water surface elevation. The channel downstream is a very flat, meadow channel with low velocity (E channel, Rosgen and Silvey, 1996). The channel is well-connected to its floodplain.

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MXD: sitewalk.mxd
SOURCE: www.vcgi.org

Data Collection Locations
Thorp Brook
May 7, 2010

LOCATION:
Charlotte & Ferrisburg, VT

DATE: 11/18/2010
SCALE: see scale bar

SHEET:
Figure 6

Figure 7a: Thorp Brook just downstream of the Greenbush Road Culvert looking downstream (Source: MMI, May 7, 2010).

Figure 7b: Thorp Brook at beginning of lake influence downstream of the railroad crossing (Source: MMI, May 7, 2010).

The channel transitions from a distinct channel (Point 5) to a flooded cattail marsh (Point 6). The adjacent floodplain becomes increasingly lower and wetter, until there is little difference between the channel and the adjacent marsh. The marsh transitions to a flooded lake-edge floodplain forest (Thompson and Sorenson, 2005) (Point 7). The forest is dominated by silver maple, American elm, black willow, and red maple. Royal fern is abundant on the dry islands of the floodplain floor. As the edge of Lake Champlain became visible, water was too deep to wade (Point 8).

Water quality impacts possible on the walked stream segment is the inputs from the mowed lawn upstream of Greenbush Road, drainage along the roadway itself, and the undersized culvert possibly leading to excessive local erosion. A vegetated buffer exists around the brook over much of the observed area. The main sources of nutrient loading to Thorp Brook are located upstream of Greenbush Road.

Water quality parameters did not show distinct signals between stream and lake (Table 2). Specific conductivity and salinity measurements were likely increased due to the suspended clay particles mobilized during the stream walk.

Table 2: Thorp Brook Water Quality Data

GPS Point	Max. Depth (feet)	Max. Velocity (feet/sec)	Temp. (Celsius)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Specific Cond. (uS)	Salinity (npt)
10	0.1	1.7	--	--	--	--	--
9	0.4	1.4	--	--	--	--	--
1	0.5	1.4	16.4	115	11.3	479	0.2
2	1.0	1.0	16.4	120	11.8	527	0.3
3	1.5	0.2	16.4	100	10.1	518	0.3
4	1.9	0.1	16.1	113	11.1	520	0.3
5	1.5	0.7	15.8	104	9.8	518	0.3
6	1.3	0.7	16.0	112	10.9	517	0.3
7	1.4	0.0	17.4	120	10.7	503	0.2
8	0.8	0.0	17.1	113	13.1	509	0.2

2.2.2 Low Stream Flow / Low Lake Level Observations

Flow in Thorp Brook was extremely low during the dry summer of 2010 (Figure 8). The brook was observed on July 13 and August 10 at select locations. Flow was very low, almost non-existent.

During the summer period thick grasses grew over the banks and emergent wetland vegetation began to grow in the channel. Although barely moving, the water was turbid due to suspension of clay particles. The water was clearly not backwatered by the lake at the Greenbush Road culvert and immediate area. The transition between lake and stream likely exist downstream of the Railroad Culvert in the vicinity of the lake-edge floodplain forest.

Figure 8: Thorp Brook at low flow on (Source: MMI, July 13, 2010).

2.2.3 High Stream Flow / High Lake Level Observations

There were no high flow events observed during high lake levels. These events would typically occur during spring snow melt rain events and did not occur during this study period. Field observations suggest that lake backwatering would extend up to and through the Railroad Culvert during high flows. The extreme upstream limit of lake backwatering during large flood events at high lake levels is likely just downstream of Greenbush Road.

2.2.4 High Stream Flow / Low Lake Level Observations

High stream flows were observed in Thorp Brook on October 1 and 15, 2010 (Figure 9). Flow was freely flowing downstream in the channel with significant flow on the floodplain downstream of Greenbush Road. The transition between lake and stream likely exist downstream of the Railroad Culvert.

Figure 9: High flows at the Thorp Brook staff gauge location, looking downstream (Source: MMI, October 1, 2010).

2.2.5 Survey

Survey to profile the channel was not completed as it will not provide very useful information as originally anticipated. Survey was performed to record the elevation of the staff gauge and local reference points to reset the staff gauge when it is dislodged (see Stream Gauging Section).

2.2.6 Summary

The channel appears to transition from stream to lake in the vicinity of the Railroad crossing. The lake may have influenced approximately halfway between the railroad and Greenbush Road (Point 3). The low-gradient channel may allow lake influence as far back as the Greenbush Road culvert during higher lake levels where a riffle exists downstream of the structure.

3.0 STREAM GAUGING

Staff gauges were placed on Kimball and Thorp Brooks and rating curves were developed to allow for flow to be calculated during future water quality sampling. Stream flows are necessary to identify when low and high flows are taking place during sampling, and are needed to convert parameter concentrations to loads.

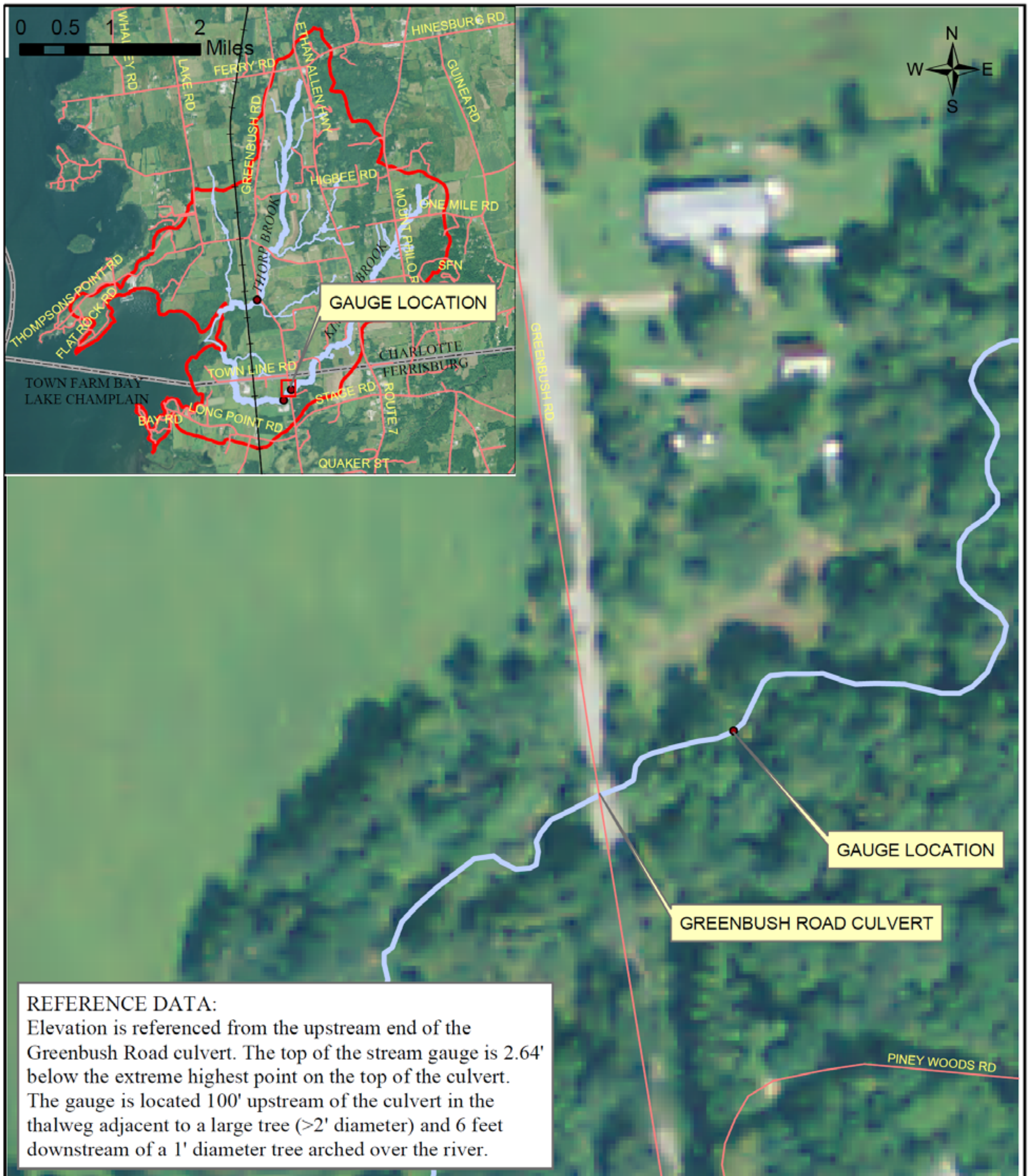
The staff gauges are 3.3 feet tall scales mounted on a post driven into the stream bed. Observers stand on the river bank and record the water level at the gauge in tenths of feet. A detailed description of the measurement techniques and a sample field record form that would be useful for water quality monitoring have been developed (Appendix C). Gauge height measurements would then be converted to discharge (cubic feet per second) with the rating curve (height versus discharge).

3.1 Kimball Brook

3.1.1 Gauge Location

Stream gauging on Kimball Brook was established near Greenbush Road to document watershed discharge. No significant perennial flow inputs were observed between Greenbush Road and the Lake. The ideal gauge location is a few hundred feet downstream of Greenbush Road in the straight, uniform stretch of channel along Kimball Brook Farm. A gauge was initially set up in this location, but then moved to upstream of the Greenbush Road Culvert due to difficulty accessing the initial gauge site.

The staff gauge was installed in the stream thalweg 100 feet upstream of the Greenbush Road Culvert (Figure 10). The backwater from the partially undersized culvert and road embankment does not influence flows at the gauging site except during large floods when the gauge is submerged. The gauge is adjacent to a very large tree (diameter > 2 feet) on the left bank (facing downstream). Survey was performed to document the staff gauge elevation in reference to permanent features so that it may be replaced when dislodged. The Greenbush Road Culvert (corrugate metal pipe, diameter = 6 feet) was used as a local survey reference. The highest point on top of the upstream end of the culvert is 2.77' above the top of the staff gauge and 2.64' above the top of the fence post. Therefore, the top of the culvert is equivalent to 6.1' on the staff gauge were it to extend that tall.



REFERENCE DATA:
Elevation is referenced from the upstream end of the Greenbush Road culvert. The top of the stream gauge is 2.64' below the extreme highest point on the top of the culvert. The gauge is located 100' upstream of the culvert in the thalweg adjacent to a large tree (>2' diameter) and 6 feet downstream of a 1' diameter tree arched over the river.

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	MMI#: 3452-07 **MXD:** sitewalk.mxd **SOURCE:** www.vcgi.org	**Kimball Brook Gauge Location**	**DATE:** 11/18/2010 **SCALE:** see scale bar	**SHEET:** **Figure 10**

3.1.2 Methods

Instantaneous stage and cross-sectional flow measurements were made upstream of the Greenbush Road culvert using the velocity-area method at 0.6 times depth (Leopold et al., 1964). Velocity was also measured in the culvert during high flows to provide an indirect measurement of discharge when wading is not possible in the channel (Bodhaine, 1982). The indirect discharge measurements in the culvert followed the procedures provided in the velocity meter user's manual (Marsh-McBirney, 1990) (Appendix D).

3.1.3 Results

Five discharge measurements were made to establish a rating curve on Kimball Brook (Figure 11, Appendix E). The staff gauge documents flows between 0.2 and 48.6 cubic feet per second.

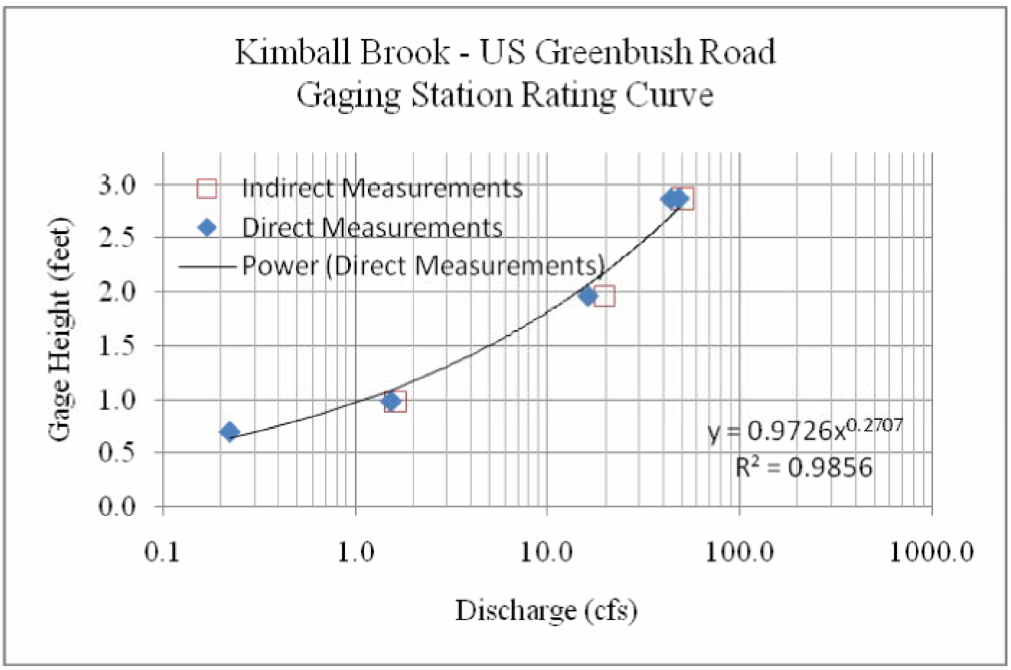


Figure 11: Kimball Brook staff gauge rating curve.

Local USGS gauges were used to track regional flows to know when to visit Kimball Brook for gauging. The LaPlatte River and Munroe Brook gauges were useful for tracking regional floods. Flows move through the relatively small Kimball Brook watershed much faster than in the larger watersheds (i.e., Kimball Brook is hydrologically flashy).

3.2 Thorp Brook

3.2.1 Gauge Location

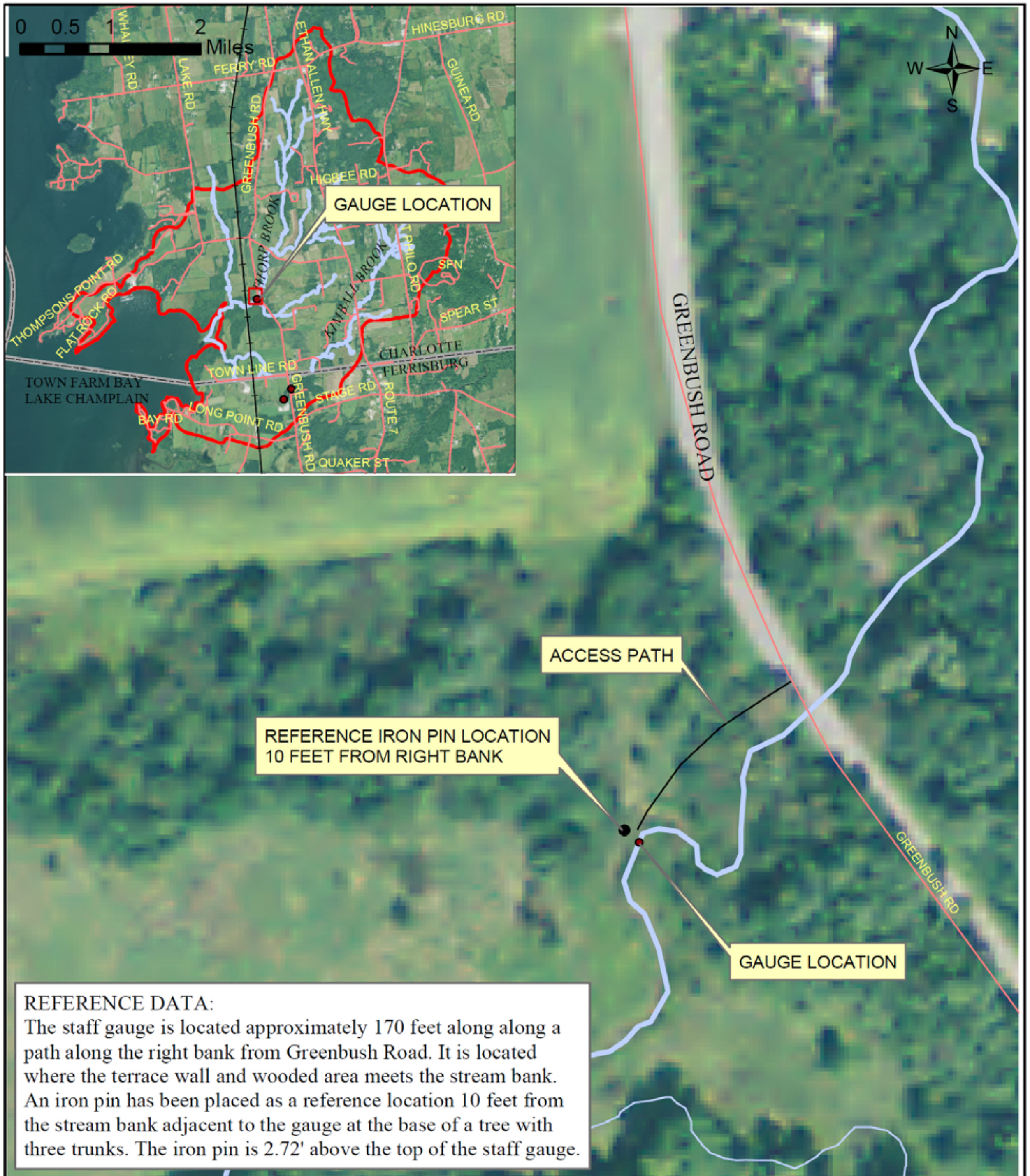
The uniform section downstream of Greenbush Road was selected for gauging to place the discharge measurement out of the lake-influenced area for most of the year other than during extreme flood events. Access to the gauge is through the path along the right side of the channel originating from Greenbush Road embankment.

The staff gauge was installed in the thalweg of the channel downstream of Greenbush Road on a 6-foot tall fence post (Figure 12). It is located approximately 170 feet downstream of Greenbush Road, walking southwest along right river bank. Upstream of the gauge there is a low herbaceous floodplain, immediately adjacent to the gauge the right bank slopes up and meets the shrub and tree-covered sloping terrace wall.

An iron pin has been set in the edge of the trees to serve as a local survey reference. The pin is located at the base of a small tree with three trunks, 10 feet from the right stream bank. The iron pin is 2.72 feet higher than the top of the gauge and 2.59 feet higher than the top of the fence post. Therefore, the iron pin is located at 6.02 feet according to the staff gauge were it to extend that tall.

3.2.2 Methods

Instantaneous stage and cross-sectional flow measurements were made upstream of the Greenbush Road culvert using the velocity-area method at 0.6 times depth (Leopold et al., 1964). Velocity was also measured in the culvert during high flows to provide an indirect measurement of discharge when wading is not possible in the channel (Bodhaine, 1982). The indirect discharge measurements in the culvert followed the procedures provided in the velocity meter user's manual (Marsh-McBirney, 1990), Appendix D).



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MMI#: 3452-07 MXD: sitewalk.mxd SOURCE: www.vcgi.org	**Thorp Brook Gauge Location**	DATE: 11/18/2010 SCALE: see scale bar	SHEET: **Figure 12**

3.2.3 Results

Five discharge measurements were made to establish a rating curve on Thorp Brook (Figure 13, Appendix F). The direct measurements documented flows between 0.3 and 20.7 cubic feet per second. The Greenbush Road culvert was used for an indirect flow measurement during a high flow event. A flow of 63 cubic feet per second was measured at the upstream side of the culvert.

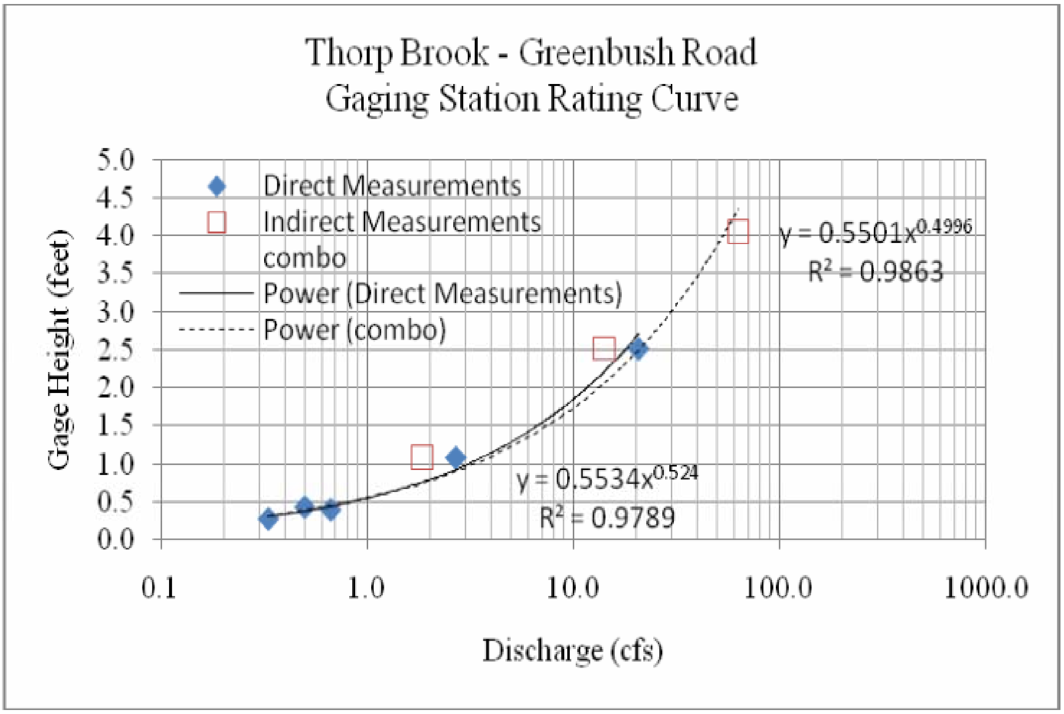

Figure 13: Thorp Brook rating curve.

4.0 EXISTING DATA

4.1 Kimball Brook

4.1.1 Geomorphic

The following watershed description was taken from the existing phase 1 stream geomorphic assessment for Kimball Brook (T8.S2.01-07) (LCA, 2008). "Kimball Brook begins northeast of the Mt. Philo Road and One Mile Road intersection. It flows southwest crossing Route 7 and Greenbush Road before turning northwest and enters Lake Champlain at the south end of Town Farm Bay. Watershed land use is field and cropland with increasing residential development, especially in the subwatersheds near Route 7. Many areas have little to no woody riparian buffer vegetation. Total watershed area is 2.5 square miles. Almost the entire stream appears to have been straightened historically with much current channel migration evident. Kimball Brook flows through 11 culverts and has one dam and one water withdrawal evident. Some roads and development encroach into the corridor. Some bank erosion was visible in the windshield survey. Invasive aquatic plants and algae are present in the bay."

The phase 1 data confirm field observations of a meadow stream dominated by dune-ripple bed downstream of Greenbush Road (Appendix G). However, the field walk indicates a broad transition area to riffle-pool morphology with well-defined small riffles existing downstream of Greenbush Road. All channel observations suggest widespread historic straightening of Kimball Brook and current lateral adjustment as meanders redevelop. Another key stressor is land use change near the channel and in the watershed.

4.1.2 Water Quality

Water quality monitoring has been conducted on Kimball Brook since 2008 by local volunteers concerned with algae blooms and increased turbidity impacting recreational uses in Town Farm Bay. Four stations have been monitored on Kimball Brook – Greenbush Road (K1: 2008-2010), Town Line Road (K2: 2008-2010), and near Vermont Route 7 (K3 and K4: 2008).

Field parameters included temperature, pH, dissolved oxygen, and secchi transparency. Water was also collected for laboratory analysis of total phosphorus, total suspended solids (2008 and 2009 only), turbidity and total nitrogen. Samples are collected roughly on a distributed schedule. Samples during dry periods are taken following storm events when there is enough flow in the channel to collect water.

Analysis of the water quality data generally indicates that total phosphorus concentrations are high in Kimball Brook for freshwater streams, but values are typical relative to other rivers and streams in the region. A local pulse of high concentration of total phosphorus was measured in 2008 near Vermont Route 7. The concentrations of nutrients tend to be higher at Town Line Road than at Greenbush Road (VTDEC, 2010).

Although flow data have not been collected until the current gauging effort, a review of precipitation records indicated that the nutrient inputs are most likely linked to uncontrolled farm runoff. Total suspended solids concentration tended to track phosphorus levels, yet the relationship was inconsistent. Solids and turbidity levels varied widely.

Sampling has also been performed at three monitoring sites in Town Farm Bay – near the mouths of Thorp and Kimball Brooks, mid-bay, and at the edge of the bay on Lake Champlain. Nutrient and chlorophyll concentrations tend to be higher closer to the mouths of Thorp and Kimball Brooks.

Additional data analysis and findings are available for Kimball Brook water quality sampling through Lewis Creek Association and Vermont Department of Environmental Conservation (VTDEC, 2010).

4.1.3 Field-Scale Hydrology

The proximity to Lake Champlain, flat terrain in the lower direct drainage watersheds, historic channel and floodplain alterations, and current land use dominated by agricultural fields suggests that field-scale hydrology is an important water quality consideration. Past and current field observations indicate that stormwater runoff from farm fields, barnyard areas, and road ditches enter Kimball Brook in numerous locations.

The Vermont office of the Natural Resources Conservation Service (NRCS) recently performed a GIS study to approximate the location of the farm field ditches (Appendix H). The GIS mapping exercise indicates that several flow paths likely exist on Kimball Brook that could be contributing high sediment and phosphorus levels previously observed. Several flow paths north and south of Town Line Road should be confirmed and addressed.

4.2 Thorp Brook

4.2.1 Geomorphic

The following watershed description was taken from the existing phase 1 stream geomorphic assessment for Thorp Brook (T8.02-05) (LCA, 2008). "Thorp Brook and its 4 tributaries flow mainly south from the Route 7 and Hinesburg Road area across East Thompson's Point Road and Greenbush Road, entering Lake Champlain in Town Farm Bay. Watershed land use is field and forest with increasing development. Many areas have little to no woody riparian buffer vegetation. Total watershed area is 3.8 square miles. One dam with pond is present along the mainstem with several more on tributaries. Relatively little straightening is evident, however the channel appears to be migrating, especially in the downstream reaches. The mainstem flows through 5 culverts with 10 more on tributaries. Relatively few roads and developments encroached into the corridor. Some bank erosion was visible in the windshield survey. Invasive aquatic plants and algae are present in the bay."

The phase 1 data confirm field observations of a meadow stream dominated by dune-ripple bed downstream in the vicinity Greenbush Road (Appendix G). Some well-defined small riffles existing downstream of Greenbush Road. The primary stressor is land use change near the channel and in the watershed.

A phase 2 assessment was previously performed on a small portion of Thorp Brook upstream of Greenbush Road (T8.03). The assessment documented a strong influence on the channel due to beaver activity. The channel was generally found to be in "good" condition in terms of geomorphic equilibrium and habitat quality (LCA, 2008).

4.2.2 Water Quality

Water quality monitoring has been conducted on Thorp Brook since 2008 by local volunteers to track inputs to Town Farm Bay. Six stations have been monitored on Thorp Brook – Greenbush Road (T1: 2010, 2009, 2008), East Thompson's Point Road (T1.5: 2010, 2009), East Branch (T2: 2010, 2009, 2008), two on tributary to the north (T3: 2010, 2009, 2008 and T3.5: 2010), and a tributary to the east (TW1). Similar parameters were collected on Thorp and Kimball Brooks.

Analysis of the water quality data generally indicates that total phosphorus concentrations are high in lower Thorp Brook for freshwater streams, yet typical of values observed on other streams and rivers in the region (VTDEC, 2010). The suggested sources for the increased phosphorus are bank erosion and polluted farm runoff. Cropland and roadside ditches were observed delivering sediment-laden runoff to Thorp Brook.

A local hotspot of high total nitrogen concentration was identified in 2010 on the north tributary that flows into the lake-edge floodplain (T3.5). The sample was collected during high flows following a large flood in October 2010 near the outlet of a farm pond. Farm fields are upstream of the sample locations. The concentration of total nitrogen at station T3.5 is the highest value recorded in the region.

Although flow data have not been collected until the current gauging effort, a review of precipitation records indicated that the nutrient inputs are most likely linked to uncontrolled farm runoff. Total suspended solids concentration tended to track phosphorus levels, yet the relationship was inconsistent. Solids and turbidity levels varied widely.

Water quality analyses were performed on Holmes Brook during 2010.

Additional data analysis and findings are available for Thorp Brook water quality sampling through Lewis Creek Association and Vermont Department of Environmental Conservation (VTDEC, 2010).

4.2.3 Field-Scale Hydrology

The Vermont office of the Natural Resources Conservation Service flow accumulation GIS study illustrates a few field runoff paths to the northeast of Greenbush Road (Appendix H). Several flow paths enter the large Thorp Brook wetland complex that could buffer the stream from water quality impacts. Again, the fact that the lower portion of the direct drainage watershed is inundated each year suggests a strong hydrologic connection to Town Farm Bay and Lake Champlain.

5.0 DIRECT DRAINAGE ASSESSMENT PLANNING

5.1 Monitoring and Study Recommendations

The field work and existing data review illustrate the water quality threats in the Thorp-Kimball watershed that directly drains to Lake Champlain via Town Farm Bay. The primary threat is pulses of sediment and nutrient loading associated with local storm events due to land use change, altered hydrology, and historic channel alteration. Channel flow, ditch flow, and field runoff are closely linked to Lake Champlain.

5.1.1 Hydrology

The staff gauges should be read each time any field observations are made or a water quality sample is collected. The rating curve will be used to convert the gauge reading to a discharge. The flow calculated from the gauge reading can be transferred to other locations on Thorp and Kimball Brooks by scaling by drainage area. Adding a flow value to water quality data will allow for separating samples into flood and low flow collections, and will allow for calculation of instantaneous mass. Flow measurements will also allow for estimation of where on the hydrograph a sample is taken (i.e., before or after the peak of the flood).

A long-term daily gauge record is needed to create a time series of daily load that can be used to estimate monthly, seasonal, or annual load. The gauge should be read by a volunteer who passes the gauge location for a select month-long or seasonal period. The gauge readings should span multiple water quality sample runs. The daily stage rating will be coupled with the water quality samples to estimate daily, seasonal and annual loads or yields.

The staff gauges must be checked and maintained after spring thaw and large floods. Any signs of movement should lead to resetting the gauges based on the local survey reference points.

Lewis Creek Association may want to periodically confirm or update the rating curve generated as part of this project. In the case of high flow events during water quality monitoring where the staff gauge is submerged or the gauge cannot be accessed due to floodplain inundation, water quality samplers should measure the depth of water at the upstream and downstream end of the culvert to make an indirect measurement of discharge during high flows.

5.1.2 Study of Loading During Floods

The flashiness of Kimball Brook, Thorp Brook, and other small direct drainages complicates water quality sampling as it is generally unknown where on the flood hydrograph a current water quality sample is collected. Water quality will vary between the rising limb, peak, and falling limb of the flood hydrograph (i.e., hysteresis). The varying seasonal flow levels can intensify the expected differences between samples taken during different parts of the hydrograph. For example, a summer thunderstorm following a prolonged period of low flow is likely to pass the primary load of pollutants during the rising limb or just before the peak of the storm during the first flush. A grab sample collected during high flows, yet after the first flush would underestimate loading where pollutants originate from a farm ditch. Sampling early in a storm during spring runoff may underestimate sediment loading due to bank erosion that tends to increase with saturation of bank material as a storm progresses.

A study is suggested to track flows and water quality parameters over a storm using an auto-sampler or high-frequency manual sample collection. The goal of this study would be to gain a better understanding of the temporal dynamics of flow and pollutant loading during storms at different times of the year. Collections should be performed in early spring during rain on snow or frozen ground (May), during a summer thunderstorm (June to July), and during a fall flood once transpiration by trees slows and groundwater levels increase (October to November). An important outcome of this study is to optimize high flow sampling when most loading occurs and when nutrient concentrations are most variable.

Samples should be collected every 30 minutes as a storm begins and continue until base flow returns. The water should be analyzed for total phosphorus, dissolved phosphorus, total nitrogen, nitrate nitrogen, and total suspended solids. At the same time, a water quality sonde should be installed to record temperature, pH, conductivity, turbidity, and depth at 30-minute intervals. Depth would be related to the staff gauge installed during this project so the rating curve could be used to calculate flows during the auto-sampling study.

During the auto-sampling or high-frequency sampling, a grab sample should be collected as part of the on-going volunteer water quality monitoring program following normal protocols (i.e., typical collection time, sample method, etc.). The objective of this sample is to illustrate how the grab samples relate to loading throughout a storm, and how this sample relates to other parameters measured during high-frequency sampling.

The storm loading study would be performed at Town Line Road (K1) on Kimball Brook if the existing culvert did not restrict flows too much to create ponding upstream of the road and if the lake level was not too high. If ponding does exist at Town Line Road, the high-frequency sampling should be conducted at Greenbush Road (K2).

On Thorp Brook the storm loading study should be conducted downstream of Greenbush Road (T1) and on the tributary to the north that flows into the lake-edge floodplain (T3). Sampling is needed in both of these locations to document the full loading during storms to Town Farm Bay.

High-frequency storm loading characterization is a good project for graduate students since they are conducted over short time frames that mesh well with an academic schedule and tell an informative story about the watershed. Students at University of Vermont and Green Mountain College should be considered to assist with implementing the study of storm loading on direct drainages. This project may be well-suited for the EPSCoR Vermont Streams Project.

5.1.3 Continued Lay Monitoring

The current water quality sampling has been effective to initially characterize the primary threats in the Kimball and Thorp Brook watershed, yet this monitoring protocol is not adequate to understand the dynamic runoff events and watershed yield. On-going water quality monitoring should be scaled back to one or two samples primarily to facilitate calculation of watershed yield. Samples should be collected monthly or following summer rains when ample flows permit sampling. Kimball Brook sampling should continue at Greenbush Road (K2) and Thorp Brook sampling should continue at Greenbush Road (T1) and the northern tributary with high nitrogen (T3).

Analysis should continue to be performed for total phosphorus, total nitrogen, and turbidity. Samples should also be collected and filtered to analyze for dissolved phosphorus as this is the nutrient component that is readily available in Town Farm Bay to produce algae blooms and impair local recreation. Monitoring would thus allow for comparing total and dissolved phosphorus loads that could improve the ability to develop appropriate management strategies.

Samples in Town Farm Bay should be continued at the outlet of Thorp and Kimball Brooks, and off of East Thompson's Point. Dissolved phosphorus should be added to sampled parameters to understand the threat to recreation due to algae blooms from excess nutrient loading. Sampling in the bay would also allow for comparing estimates of loading from the watershed to the loading in the bay to see if nutrients are originating in the local uplands or from other watersheds such as Little Otter Creek that circulate into Town Farm Bay.

5.1.4 Windshield Survey

Perform a windshield survey to locate frequently inundated areas that could potentially be critical source areas of nutrients and document obvious historic channel and floodplain alterations for restoration. Observations could be conducted by volunteer monitors or by the Charlotte Conservation Commission.

During moderate and large flood events observed inundated areas could be sketched on a map and eventually digitized by Lewis Creek Association to archive findings. The gauges should be read to document stream flow during inundation area mapping. Areas regularly inundated should be prioritized for working with landowners to buffer streams and naturalize hydrology. The windshield survey could also attempt to document altered channel and floodplains to identify potential restoration sites.

5.1.5 Stream Geomorphic Assessment

Phase 2 stream geomorphic assessment (VTANR, 2009) may be conducted in Kimball Brook upstream of Town Line Road and on Thorp Brook upstream of the Railroad Crossing. The channels appear to be mostly fluvial throughout the year in these locations and thus the protocols would apply. The assessment should be done during low to moderate flows.

Channels appear to be mostly stable with minimal erosion due to cohesive clay banks and gentle sloping streams, yet the assessment could expand documentation of baseline conditions of the channel and floodplains as increased incision is possible due to land development and the predicted increase in storm size. A critical element of the assessment would be to locate each stormwater input to the channel from overland flow paths from farm fields and ditch flow locations. Other needs of the assessment include confirming the transition between riffle-pool and dune-ripple stream types, verifying floodplain-channel connections, and documenting historic alterations of the channel and floodplains.

5.1.6 Update Watershed Delineation

Previous watershed delineation and mapping of the stream network at the boundary between the Thorp Brook and Holmes Brook watersheds shows the western tributary to Thorp Brook extending north beyond the watershed divide. This flat headwater location where farm fields exist needs to be visited to fine-tune watershed mapping. Field reconnaissance is also needed to map a drainage divide between the western edge of the Thorp Brook watershed and the local areas that directly drain to Town Farm Bay and Lake Champlain.

5.1.7 Apply Findings of Existing Studies to Direct Drainages

Several studies have been performed and are on-going that could be applied to Lake Champlain direct drainages such as Kimball and Thorp Brooks. The Lake Champlain Basin Program is sponsoring a critical source area identification project in the Missisquoi Bay Basin and a road ditch project in the region. Methods and findings from both of these projects could support efforts to improve water quality on direct drainages. Improving the quality of road ditch runoff is important for Kimball and Thorp Brooks. Critical source area identification could help focus in on problem areas near the lake.

The Vermont Water Quality Division performed a nutrient study in the Rock River watershed to explore phosphorus yield versus common GIS variables to try and create a quick method to estimate loading around the watershed.

Other studies exist and a workshop may be beneficial to share lessons learned and to continue to develop strategies to investigate and improve water quality in direct drainages of Lake Champlain.

5.2 <u>Implementation Recommendations</u>

5.2.1 Investigate Possible Water Quality Hot Spots

Based on past water quality sampling two sites stand out as possible sources of impairment – Kimball Brook near Vermont Route 7 (K4 and K5) and the tributary to the north of Thorp Brook (T3.5). Local landowners should be contacted and field investigation should be performed to try and identify the possible sources of nutrient inputs at the potential hot spots. Note that these sites were identified as areas of concern solely based on concentrations so the relative importance of the loads relative to other watershed locations is not known.

5.2.2 Investigate Impaired Locations

During site walks several sites appeared to be impaired or to be possible sources of nutrients. Local landowners should be contacted and field investigation should be performed to try and confirm the possible sources of nutrient inputs and explore project development to improve conditions.

On Kimball Brook the cattle crossing under the railroad needs improvement or to be moved to a new location to limit physical damage to the channel, excessive sedimentation, and direct input of manure. This project is a current priority.

Work is needed at the farm on Kimball Brook at Town Line Road to disconnect the flow paths between the barnyard and farm fields to the channels. Given its location near the permanent transition from stream to lake, this farm essentially sits on the edge of Lake Champlain and thus its activities directly influence the lake-edge floodplain and Town Farm Bay. Kimball Brook is highly altered around this farm and thus restoring the historic channel and floodplain while excluding cattle would be highly beneficial to water quality. Some cattle were excluded from the historic floodplain during the stream walk in this area yet it is unknown for how long.

The small pasture adjacent to the Kimball Brook channel upstream of Greenbush Road needs a vegetated buffer and runoff controls on the steep slope.

On lower Thorp Brook a vegetated buffer is needed adjacent to the mowed lawns upstream of Greenbush Road.

5.2.3 Investigation of Field-Scale Runoff Pathways

The NRCS field hydrology study reveals likely flow paths where sediment and nutrients are delivered to Kimball Brook, Thorp Brook, and tributaries (see circled areas on Figures 2 and 6). These potential runoff sites should be field verified with local farmers and efforts should be made to employ best management practices to separate runoff from farms during floods from the brook and lake. Priority areas to investigate on lower Kimball Brook include:

- The co-located cattle/stream crossing under the railroad;
- The north to south farm field flow path that enters Kimball Brook before the channel turns north towards Town Line Road;
- The flow path draining the barnyard area adjacent to Town Line Road; and

- The field flow paths that enter the tributary of Kimball Brook that flows into the lake-edge floodplain.

Priority areas to investigate on lower Thorp Brook include:

- The east to west field ditch that flows into Thorp Brook to the east of Greenbush Road; and
- Thorp Brook tributary and the documented flow paths from farm fields entering the channel north of Thompson's Point Road.

5.2.4 Promote Implementation of Agriculture BMPs

Continued effort is needed to work with local farmers in the direct drainages to implement agriculture best management practices (BMPs) to naturalize land cover and field hydrology. Land use conversion on regularly inundated areas is a primary threat to water quality in the bay and lake. Adjusting cropping plan based on field inundation (i.e., changing the wettest areas from corn to hay), cover cropping, conservation tillage, injection spreading, row cropping, and other practices should be discussed with farmers to reduce nutrient-rich runoff.

5.3 Guiding Principles for Improving Direct Drainages

5.3.1 Naturalize Hydrology

The hydrology of Thorp Brook, Kimball Brook, and other direct drainages needs to be naturalized through reverting land cover to natural vegetation or implementation of best management practices that mimic the functions of vegetation (e.g., absorb and slow runoff). With the pervasive land use conversion more water is now moving through the drainages at much faster rates than before. The result is a more rapid movement of nutrients from fields to bay and lake, and an increase in erosion. This is especially true given the fine clay particles that once mobilized may be transported downstream, into bays, and out to the lake.

Increased erosion leads to more sedimentation and sediment-associated nutrients. Naturalizing watershed hydrology to slow the movement of water through the direct drainages is especially important given the likely increase in the size and frequency of storms expected in the region (Collins, 2009). Naturalizing hydrology is also important to retain soil to grow crops on land and limit the growth of algae in the bays and Lake Champlain.

5.3.2 Restore Natural Channel Planform

Channel alternation is pervasive in the Thorp and Kimball Brook watersheds. Many channels have been straightened and moved to the sides of valleys to create agriculture fields. Small culverts convey channels under roadways. Channels in the direct drainages generally need more space to reform their sinuosity, decrease slope, and allow for stable natural channels to form. This will reduce erosion from bank erosion and channel avulsion.

5.3.3 Naturalize Floodplain Vegetation

Floodplain connection appears to be good in Thorp and Kimball Brooks, and this should be preserved to limit flood water velocity and reduce erosion in the channels in direct drainages. Floodplains that are inundated the most should be reverted to natural vegetation. Ditches should be plugged to rehabilitate overland flow through natural vegetation. The duration of floodplain inundation should be explored as this is an important determinant of the biophysical nature of channels (Shields et al., 2008).

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