# 2006 ASSESSMENT OF WATER QUALITY IN
# ALDER, INDIAN AND SUNDERLAND BROOKS, ESSEX TOWN, VERMONT

## Annual Report of the Essex Waterways Association to
## The Vermont Agency of Natural Resources, Department of Conservation

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PREFACE:
This report describes the results of a project carried out collaboratively by the Essex Waterways Association (EWA) and the Vermont Department of Conservation (VTDEC) during summer 2006. EWA sampled three Essex streams biweekly, measuring physical parameters with a Quasar Hydrolab and collecting water chemistry samples for subsequent analysis by VTDEC's LaRosa Laboratory (with analytical costs covered by a Lab Services Grant). In addition, water quality was assessed at one stream site over the course of a storm. Neil Kamman served as Project Coordinator for the VTDEC and Suzanne Levine as EWA's Project Manager. Jerry DiVincenzo oversaw laboratory activities. The stream sampling team included Suzanne Levine, Meaghan Lineman (responsible for the storm study), Erik Post, Ashley Wright and Sharon Zuchowski. Meredith Curling of the University of Vermont provided flow and precipitation data for sites with gauging stations, making possible estimation of downstream fluxes and analysis of water quality-flow relationships.

INTRODUCTION
Essex is the second most populated town in Vermont and one that continues to convert agricultural and forested land to residential communities and commercial zones at a rapid pace. Four streams drain most of the Town. In order of importance, these are the Browns River with its tributary Abbey Brook, Indian Brook, Alder Brook, and Sunderland Brook. The Winooski River, which defines the Town's southern boundary, also receives a small amount of direct runoff. All Essex runoff that doesn't evaporate eventually reaches Lake Champlain and influences its water quality. Indian Brook flows directly into the lake at Mallets Bay, while Alder and Sunderland Brooks are tributaries of the Winooski, and the Browns River a tributary of the Lamoille River.

Land clearing and development, along with historic channel manipulations and flow diversions, have taken a toll on Essex waterways. Phase 1 and 2 geomorphic assessment, completed for the main stems of all Essex streams between 2004 and 2006, indicates substantial in-stream erosion and sediment infilling within many reaches (Willard xx, Fitzgerald 2006 a,b,c). Indian Brook and Sunderland Brooks are on the USEPA 303d list of streams impaired by storm water, land development and erosion. Among the pollutants listed as contributing to degradation are sediment, nutrients, organics, metals, pathogens and unspecified toxics. In addition, all Essex (and Vermont) streams are impaired with mercury, which accumulates in fish making them unsafe for human consumption.

However the mercury source is largely atmospheric and thus not easily controllable by the Town or State.

To stem further degradation of its streams, Essex Town adopted a storm water ordinance in 2006 and will consider a riparian buffer ordinance in 2007. These ordinances pertain only to new development, however, and permit waivers and conditional uses. Delisting of the impaired streams will require improvements within already developed areas, including diversion of storm water runoff from the hundreds of pipes emptying into the streams to retention ponds, replanting of riparian buffers, and public education about the need to control fertilizer use, car washing, and pet waste.

The Essex Waterways Association (EWA) is a citizens group formed in fall 2005 to support and augment stewardship of the Town's water resources by Vermont State and Essex Town. The organization anticipates participation in water quality monitoring, public education, and stream/riparian zone restoration efforts. EWA received two grants in 2006, its first year of activity. An ANR River Management Grant financed geomorphic assessment of Alder Brook, the one Essex stream that had not yet been assessed. Fitzgerald (2006c) presents the results of this assessment. The second grant, from the VTDEC LaRosa Analytical Partnership Program, permitted assessment of water quality in Alder, Indian and Sunderland Brooks. The current report describes this activity and presents its results.

The project's major goal was to provide baseline data against which future measurements of water quality might be compared and the effectiveness of restoration and TMDL implementation assessed. Monitoring also might reveal hitherto unidentified issues, and provide clues about in-stream and watershed processes that influence pollutant behavior in these streams. Sites were chosen and the sampling schedule set up to address the following specific questions:

• What are current nutrient, suspended sediment, pH and salt levels in the streams at base-flow? How much variability is there in these parameters over the course of a summer?

• How does runoff following rainfall influence these constituents? (Assessed in Alder Brook only.)

• Is water quality altered by stream passage through developed areas? (Sites were chosen before and after developments draining to Alder and Indian Brooks.)

• How much suspended sediment, salt, and nutrient is exported downstream through these reaches, ultimately contributing to the pollution of Lake Champlain? (One site on each stream was located at a UVM gauging station, which meant that pollutant concentrations could be multiplied by water discharge to estimate fluxes.)

METHODS

Stream and Site Descriptions

Alder, Indian and Sunderland Brooks were chosen for analysis because they drain 77% of Essex Town, run through urban/suburban areas, and are small enough to be safely sampled at all flow rates without special equipment. In addition, other citizens' groups have formed to steward the larger Browns and Winooski Rivers, although neither of these rivers were sampled during 2006. Each stream is described separately below, while Table 1 provides additional information on physical characteristics.

Table 1. Physical characteristics of the three sampled streams.

| **Parameter** | ***Alder*** | ***Indian*** | ***Sunderland*** |
|---|---|---|---|
| *Length (mi)* | 11.7 | 16.7 | 6.4 |
| *Drainage Area (sq mi)* | 10.6 | 12.0 | 5.5 |
| *Overall channel slope (%)* | 1.1 | 0.8 | 0.4 |
| *Soil types (% A, B, C, D)** | 8.7, 18.8, 30.4, 40.6 | 12.5, 4.2, 16.7, 60.4 | 85.7, 14.3, 0.0, 0.0 |
| *Ave discharge at mouth (cfs)*** | 12.9 | 13.8 | 6.9 |

*A to D soils form a gradient from more permeable sands to impermeable clays. **Data from TetraTech (2005).

*Alder Brook*

This tributary of the Winooski River lies almost entirely within Essex Town and drains roughly the middle third of the Town's area. Its headwaters are in wetlands near the Essex-Milton boundary (Fig. 1A). From here, it initially flows north, but then quickly turns south for a long run through agricultural and forested land over relatively flat terrain underlain with soils of low permeability. The brook has a small floodplain in this reach. Up until 1820, Alder Brook turned east near Essex Center and emptied into the Browns River. The stream's course was changed when one of the Center's founders dammed the stream and diverted part of its flow through his sawmill and out into a small Winooski tributary. An unusually large spring freshet in 1820 sent high flows through the new passageway, which being underlain by sand, eroded deeply and captured the stream's entire flow. Within days, a chasm over 100 feet deep was created across Essex Center and down to the Winooski River. Mills, bridges and other structures in the Center were destroyed and travel across the village so disrupted that Town government moved to Butlers Corner for several years.

The sand that Alder Brook encounters in Essex Center is the remnants of an ancient delta lain down by the Winooski River as it flowed into prehistoric Lake Vermont several thousand years ago. The highly dissected ridge and ravine nature of this part of Essex Town attests to the high erodibility of this landscape feature, particularly when faced with running water on a slope. Along most of its course through the ravines, Alder Brook is now digging into a layer of clay below the sand. However sand produced through tributary incision and main stem widening continues to enter the stream. Groundwater moves readily through the sands but is retained by the underlying impermeable clay.

Consequently there are many seeps and springs where the sand-clay interface is exposed. Fluidization of sands along the interface contributes to mass wasting of stream banks.

Six Essex residential neighborhoods sit on the edge of the ridge-and-ravine terrain, with a few homes sited on sand ridges. Severe tributary incision is occurring where storm water outfalls from these neighborhoods empty directly into ravines (Fitzgerald 2006). Although the new Essex Towne Center and Essex Outlet Fair are largely in the watershed of Indian Brook, some parking lot runoff is directed into Alder brook. Alder Brook also receives runoff from the Circumferential Highway (I 289, the Circ), which was built alongside its course through the ravines in 1999-2000 and crosses over the stream twice, forcing stream flow through culverts. Although precautions were taken to minimize construction impacts, geomorphic assessment in 2006 identified large plugs of sediment migrating downstream from the sites of culvert installation (Fitzgerald 2006).

*A.* *B.*

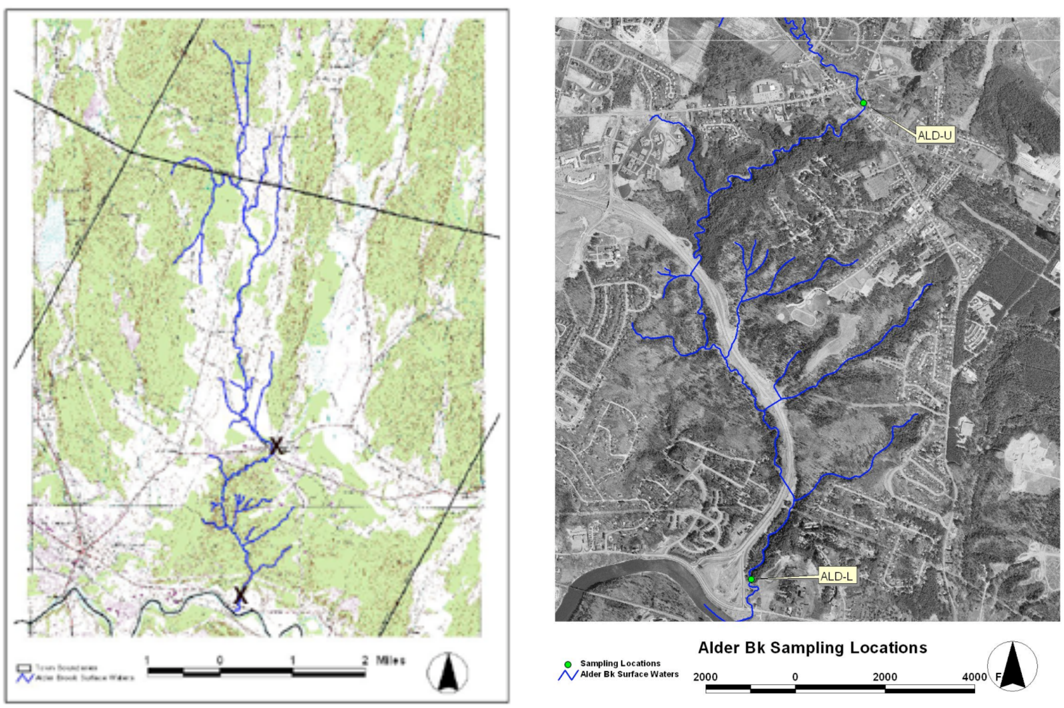



*Figure 1. Alder Brook. A. Entire stream course with sampling sites marked as Xs. B. Aerial photograph of the lower river, with ALD-U and ALD-L labeled (green dots mark locations).*

Despite geomorphic instability and substantial embedding in its lower reaches, Alder Brook is designated a Class B stream (VTDEC 2004). Its fish and invertebrate communities are typical of waters in fair to good condition. This status may be jeopardized by two aspects of the 2006 Essex Town Plan: the call to build a connector between the Circ and Hwy 15 through the ravines, and identification of the Lower Alder Brook watershed as a targeted “neighborhood growth center”.

EWA sampled Alder Brook at VTDEC Biomonitoring Site 490700000028 (see Figure 1B), at the beginning of the Essex Center gulch, behind the Essex Free Library, and at Site 490700000003, about a quarter mile upstream from the stream's confluence with the Winooski. The upper site (ALD-U) is cobble-bottomed and heavily shaded while the lower site (ALD-L) is more sandy-bottomed and open. Both are riffle reaches (generally a prerequisite for biomonitoring). The University of Vermont flow and precipitation gauging station is located about hundred yards downstream from ALD-L (installed June 2006).

*Indian Brook*
Indian Brook arises in the northwestern portion of Essex Town, where it passes through beaver ponds and Indian Brook Reservoir before heading roughly south through forested and agricultural lands (Fig. 2). Its bedform is primarily plane bed in this section, with the bottom material alternating between cobble, gravel and sand. Additional beaver ponds are traversed, probably with the result that flow variability is reduced and pollutants retained. The stream flows under the Circumferential Highway and past the Essex Outlet Fair and Towne Centre, which present a large amount of paved surface, before entering Essex Junction, and turning to flow northeast. In its flow through the village, the stream is fed storm water from 128 outfalls. This not only brings nutrients, road salt, grease, oil, pesticides and sediment into the stream; it also augments flow, increasing the potential for in-stream erosion, which already is high due to historic straightening of reaches and building encroachments that prevent the stream from spreading out. Leaving the Village, Indian Brook passes under the Circumferential Highway's Susie Wilson Bypass and through another built-up commercial/industrial zone before reaching Colchester Town. The final third of the stream's journey to its outlet at Mallets Bay is through largely undeveloped land providing flood plain access and many beaver ponds to reduce pollutant load.

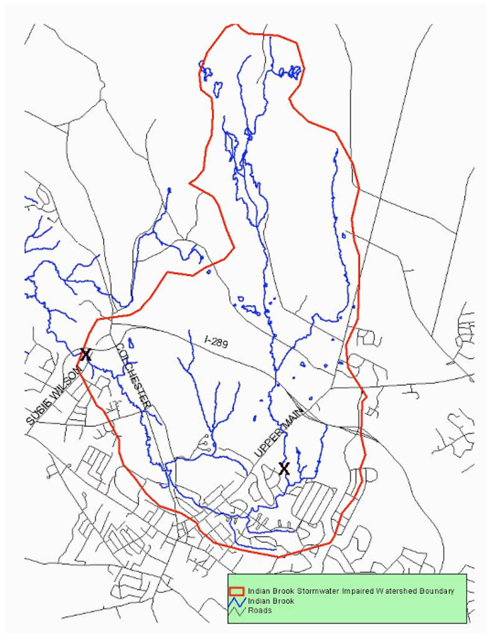
Over its urban reaches in Essex, Indian Brook is classified as "storm water impaired". Delisting of the stream will be a challenge. The 2006 Essex Town Plan calls for centralization of high-density residential and commercial growth in Essex at two locations, both of which lie in the Indian Brook watershed, the new Town Centre and along Susie Wilson Road.

Our upstream Indian Brook site, INDI-U, was VTDEC Biomonitoring Site 480000000095. It is on the outskirts of Essex Junction, about a quarter mile upstream from the Hubble Falls Road bridge (before a beaver dam). The site is unshaded with a rocky bottom, but enough sand to support prolific macrophyte growth. INDI-L is downstream of Essex Junction, at the outlet of the culvert under the Susie Wilson Bypass. This also is the site of a UVM gauging station (run by TetraTech, before 2006). The stream emerges to a cobble-bottomed riffle with an iron seep along one side. Iron seeps are common throughout Essex, and probably affected all three streams.

*Sunderland Brook*

Another tributary of the Winooski River, Sunderland Brook lies largely in Colchester Town, but its headwaters are in the built-up region around Susie Wilson Road (Fig. 3). Like neighboring Indian Brook, it is on the 303d listing of impaired streams, with

A.




*B.*

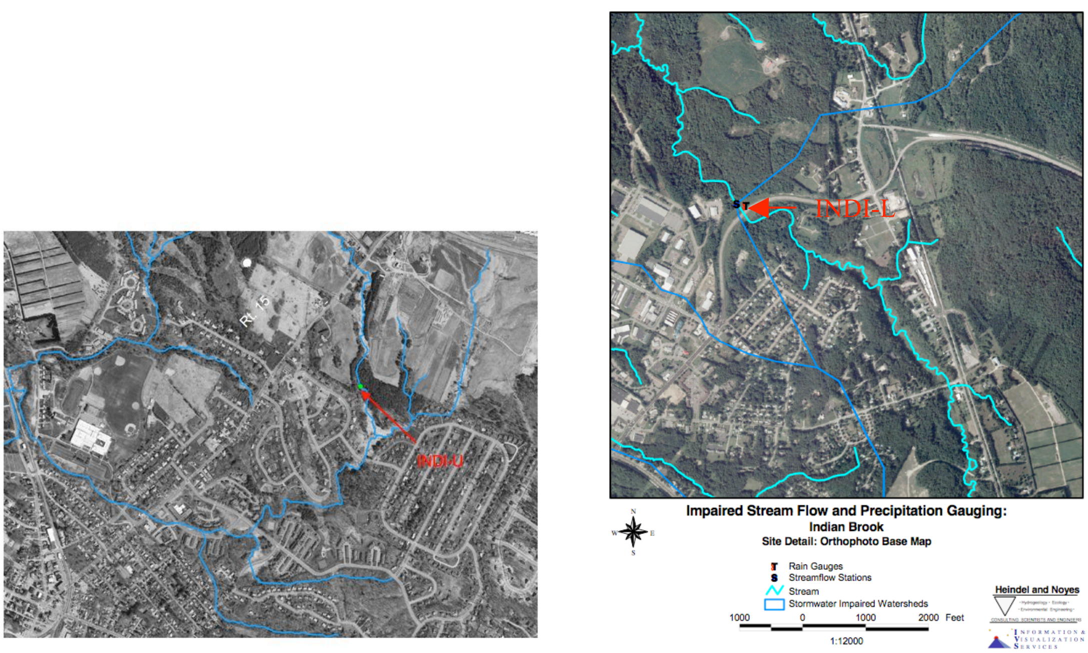
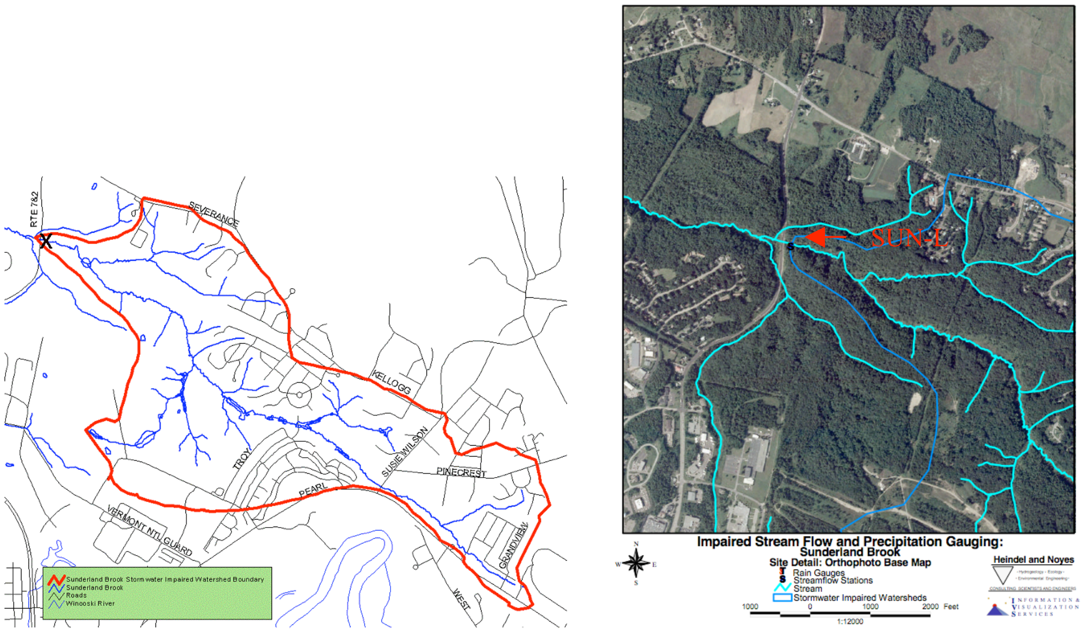



*Figure 2. Indian Brook. A. Map showing the two sampling sites as X's, and outlining the watershed of INDI-L in red. B. Aerial photographs.*

*Figure 3. Sunderland Brook. A. Course of the stream between its headwaters and SUND-L (X), with the area drained outlined in red. B. Aerial photograph.*

*A.* *B.*




*B. Aerial photograph showing the site location*

We sampled Sunderland Brook at just one site, the TetraTech/UVM gauging station, on the upstream side of the culvert carrying stream flow under Highway 7 (Figure 3B). An upstream beaver pond separates this site from a DEC Biomonitoring Site. Although this site was downstream from development, it was probably partially cleansed by passage through woodland and beaver ponds on its way to the sampling site. Should monitoring of Sunderland Brook be continued in 2007, we recommend addition of a site nearer to Susie Wilson road.

<u>Sample Collection</u>

The three streams were sampled Sunday mornings between June 4 and September 24, 2006. The LaRosa Laboratory supplied pre-cleaned bottles, which were rinsed and filled following procedures specified in our contract with the LaRosa Partnership Program. Most bottles were rinsed three times with stream water before filling to a specified level. Chloride samples could not contain particles however, and thus were obtained by drawing water into a syringe and pushing it through a glass fiber filter (pore size, 0.45 µm) in a screw-on filter holder. Chloride bottles were rinsed with this filtered water prior to filling. Separate bottles were used for each assay. One set of field duplicates were collected each week, holding the bottles together in the stream during filling. The location of duplicate collection rotated through the sites over the summer. Analytical duplicates were collected for phosphorus analysis monthly. All samples were collected mid-depth at the approximate center of the stream. Great care was taken not to enter the stream upstream of the collection site. Blanks were obtained by using distilled water supplied by the LaRosa Laboratory to rinse and fill bottles.

Water bottles were stored in a cooler on ice or in a refrigerator during the interval between sample collection and analysis in the LaRosa Laboratory. Samples normally were delivered to the lab within 24 hours of collection.

Storm sampling followed the same procedures as the biweekly sampling, but was focused over a 42-hour period from September 28-30. We sampled at base flow before rainfall began, three times during the storm, and 25 hours after rainfall ended.

In-situ Measurements

After bottle filling and taking notes about stream condition, we used a Quasar Hydrolab to measure temperature, dissolved oxygen, pH, specific conductance and turbidity at the site of sample collection. All probes were calibrated no more than 48 hours prior to sampling (generally < 24 h) using Hydrolab specified standards and procedures. Measurements were made mid-depth and with the unit's stirrer on.

Laboratory Analyses

All water chemistry was undertaken in the LaRosa Laboratory following the procedures outlined in the program QAPP. The assays performed included total suspended solids (TSS), chloride concentration (Cl), total phosphorus (TP), and total nitrogen (TN).

## RESULTS AND DISCUSSION

QA/QC

All field data met LaRosa QA/QC standards. Field blanks were consistently measured at the reporting limits for all measured parameters: Cl= 2 mg/L, TN = 0.1 mg/L, TP = 5 µg/L, and TSS = 1 mg/L. Mean relative percent difference values were well below LaRosa's precision target of ≤ 15%: Cl= 0.8%, TN = 2.0%, TP = 2.2%, and TSS = 6.9%. TSS was less precisely measured both due to the vertical and spatial heterogeneity of suspended material, and because 1 L samples were small when flow rates were low and little sediment in transit.

Biweekly Monitoring

Seasonal means for the measured parameters in each monitored stream reach are presented below in Table 2. Discussion of between-date variability follows.

*Temperature*

Stream temperature is a function of both the heat content of inflowing runoff and groundwater and of heat exchange with the atmosphere. In summertime, groundwater inputs tend to depress stream temperatures, while streams receiving substantial runoff from heated pavement and open fields tend to be warmer. Degree of canopy cover, and

*Table 2. Seasonal means for 2006 determined from biweekly sampling.*

| | Temp °C | DO % Sat. | Turb NTU | TSS mg/L | SpCond ms/cm | Cl mg/L | TN mg/L | TP µg/L | pH |
|---|---|---|---|---|---|---|---|---|---|
| **Alder** | | | | | | | | | |
| **Upper** | 18.54 | 88.8 | 16.6 | 10.07 | 0.254 | 22.6 | 0.53 | 46.6 | 7.55 |
| **Lower** | 16.43 | 102.1 | 25.3 | 22.37 | 0.480 | 77.3 | 0.76 | 41.0 | 8.12 |
| | | | (13.5)* | (5.8)* | | | | (24.9)* | |
| **Indian** | | | | | | | | | |
| **Upper** | 19.17 | 90.8 | 7.5 | 3.12 | 0.297 | 31.2 | 0.61 | 37.1 | 7.68 |
| **Lower** | 18.57 | 99.5 | 18.8 | 10.87 | 0.639 | 126.2 | 1.49 | 43.4 | 8.02 |
| **Sunderland** | 20.03 | 99.7 | 12.2 | 7.12 | 0.410 | 67.1 | 0.6 | 36.4 | 7.93 |

*Mean with 2 July, a high flow date, excluded.

thus the integrity of riparian zones, also influences stream temperature by determining how much solar heating occurs. Thus urban stream reaches tend to heat up through solar heating as well as runoff impacts. Because our study sites experienced similar air temperatures, seasonal patterns of warming and cooling were similar (Figure 4). In general, Sunderland Brook was the warmest of the three streams, and Alder Brook, the coolest. While this ordering could be related to differences in amount of impermeable cover in the stream watersheds, it also could result from differences in the contributions of cool groundwater to stream flow. The many seeps along Alder and Indian Brooks suggest substantial groundwater inputs, although these influxes have not been quantified. Groundwater inputs clearly are implicated in comparisons of temperature differences between the upper and lower sites on Indian and Alder Brooks. Temperature increases were expected due to the importance of urban/suburban landscape. Instead, Indian Brook's temperature generally fell by ~ 1°C, in passing through Essex Junction, while Alder Brook normally cooled by 2-4°C passing through the ravines. Alder Brook did not change temperature between sampling stations on July 2nd, however. Flow was unusually high and dominated by overland flow and storm runoff at this time.

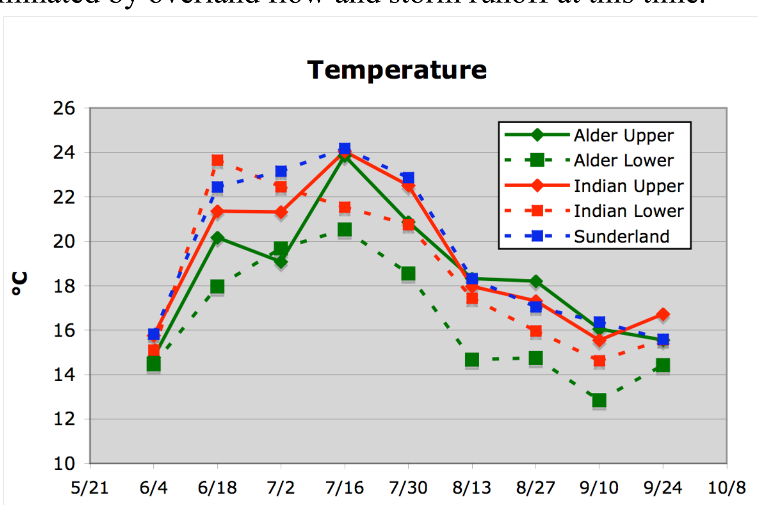



*Figure 4. Stream temperatures during summer 2006.*

*Dissolved Oxygen*

Although dissolved oxygen (DO) is critical for animal and microbial respiration, shallow streams have so much contact with the atmosphere that DO concentrations are maintained near saturation levels and rarely impact metabolism. We measured DO concentrations during this study primarily because our Hydrolab unit automatically reported them. Mean values are reported in Table 2 as percent saturation. These values changed little over season and thus are not plotted. Our upstream sites on Alder and Indian brooks were typically slightly undersaturated with DO, a situation that commonly develops in shaded reaches with plenty of leaf litter and other detritus to support microbial activity and invertebrate shredders, but little light to encourage plant and algal growth. ALD-L displayed the opposite trend, a tendency towards mild supersaturation. This condition develops where plants or algae are abundant and the food web strongly influenced by autotrophic production. In Alder Brook, diatoms attached to rocks appear to be the main primary producers influencing DO concentrations. Note that increases occurred over the two stream sections despite groundwater inputs. Groundwater is frequently somewhat depleted in DO due to its isolation from the atmosphere. The remaining two lower reaches, INDI-L and SUND-L, had average DO concentrations very close (within 0.5%) of the saturation values predicted from temperature and atmospheric pressure data.

*Suspended Sediment*

We used two estimators of suspended sediment load in the streams, total suspended solids (TSS), which involves filtering and weighing particles concentrated from stream water, and thus is a direct measure of particle concentration, and turbidity, which measures light scattering from suspended particles, and thus is less direct. Regression of turbidity on TSS for the biweekly data (all sites and dates; Fig. 5) yielded an $r^2$ of 0.96 and a P value of $<0.001$ (n= 45).

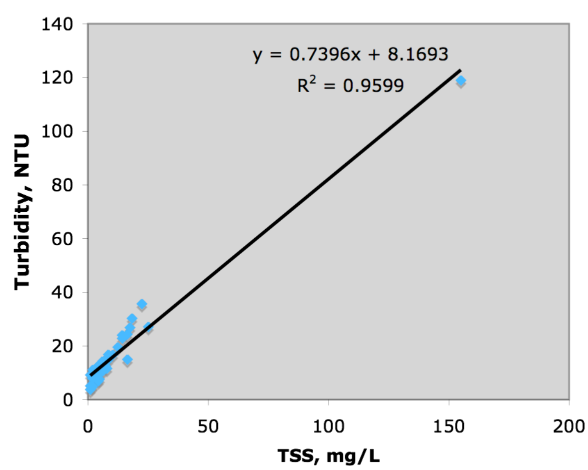



*Figure 5. Regression of turbidity on TSS concentration. Biweekly data from all sites included.*

We expected an increase in suspended sediment in Indian Brook during its passage through Essex Junction, partly because there is little riparian buffer intact to trap sediments in overland flow, but more importantly because storm water is piped into the stream here making it flashy and erosive. Both TSS and turbidity measurements confirmed that this was the case (compare INDI-U and INDI-L in Table 2, Figs. 6& 7). For TSS, the average increase was greater than three fold!

Alder Brook showed more complex sediment dynamics through Essex Center and the ravine reach. At low flow (all dates but July 2), TSS concentrations declined by 40%, on average. The severe embeddedness of this reach suggests that the improved clarity was largely related to aggradation, sand settling out at a fairly high fall velocity. However, high groundwater inputs may have improved water clarity through sediment load dilution, as well. At higher flow, the situation changed drastically, as the sandy bottom was set in motion. Although flow on July 2 was only modestly increased compared with levels during storms, TSS concentration at ALD-L was six times the value at ALD-U and 27 times the average for base flow conditions!

Although Sunderland Brook arises in an urban area and is stormwater impaired, it had substantially lower TSS concentrations and turbidity than the post-urban site on Indian Brook. In addition, it was much clearer than Alder Brook at high flow. Without an upstream site, we do not know whether suspended sediment load was reduced by passage through beaver ponds and wetlands.

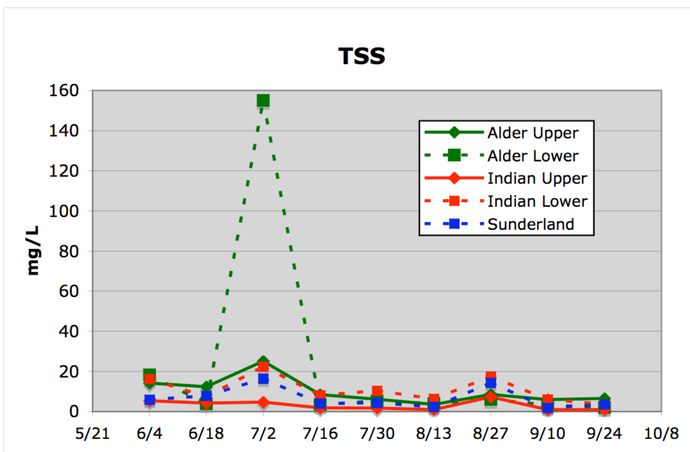



*Figure 6. Total suspended solid concentrations in the streams during summer 2006.*

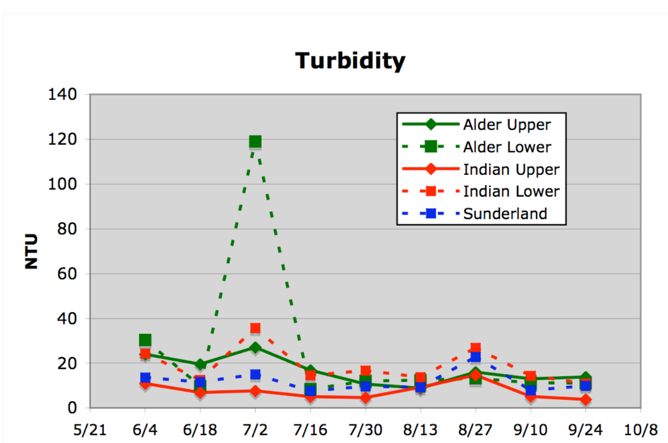



*Figure 7. Turbidity in the streams during summer 2006.*

*Salt Content*

Chloride concentration is a good measure of road salt (NaCl and $CaCl_2$) contamination since only small amounts of chloride are produced through rock weathering. Specific conductance (SpCond) is a poorer measure, because it includes all ionic material, minerals dissolved from rocks, for example, as well as road salt. However, SpCond has the advantage of being measurable instantaneously in the field. Figure 8 demonstrates that the two measures were reasonably well related in our study streams despite variations in geology ($r^2$ =0.95 with n=45, P <0.001).

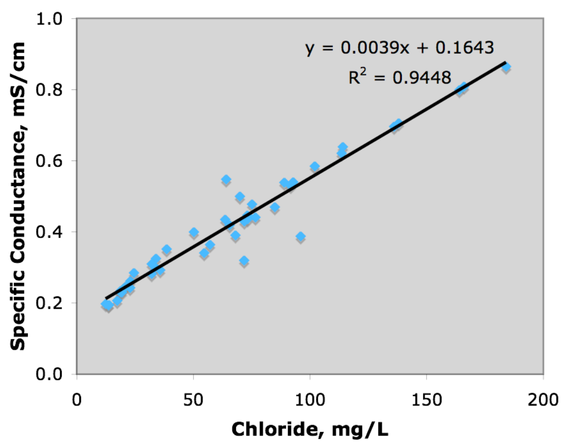



*Figure 8. Regression of specific conductance on chloride concentration. Biweekly data from all sites are included.*

In summer, roads are not salted, but the soil profile and groundwater store salt added in winter, and thus contribute salt to streams throughout the year. We expected chloride levels to be above pristine levels at all sites given the large amount of road salting done throughout Vermont, but anticipated especially high concentrations at the lower sites due to river passage through urban/suburban regions. In addition, we thought that salt added to the Circumferential Highway might result in chloride contamination of lower Alder Brook. The data, both chloride concentrations and specific conductance, confirmed that road salt is indeed a serious issue for the two streams.

Chloride concentrations increased by four fold on average between INDI-U and INDI-L, and by three fold between ALD-U and ALD-L (Figs. 9, 10). SUND-L also had high chloride concentrations, beaver ponds and wetlands being ineffective at removing conservative, dissolved substances.

*Nutrient Content*

Total nitrogen (TN) and total phosphorus (TP) include a potpourri of organic and inorganic dissolved and particulate substances. Because dissolved phosphate as well as many organic P compounds absorb strongly to fine particles, and especially to clay and silt, TP tends to be transported downstream primarily during storm events that erode the stream bottom. Ammonium and some dissolved N forms also cling to particles, but nitrate, the dominant N form in most streams, does not. These differences in N and P

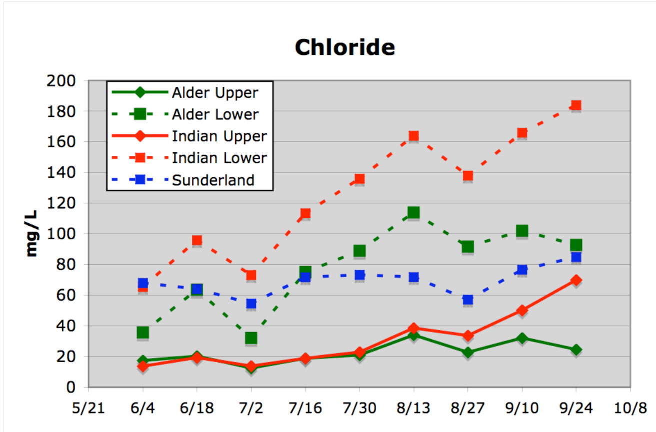



*Figure 9. Chloride concentrations in the streams during summer 2006.*

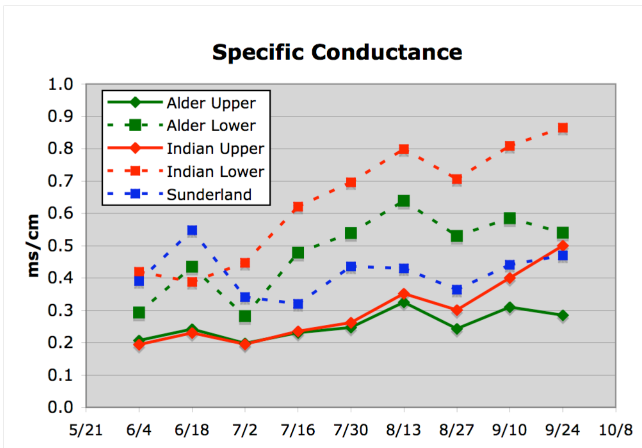



*Figure 10. Specific conductance in the streams during summer 2006.*

behavior were apparent during our study, particularly in Alder Brook. At base flow, TP, like TSS, decreased sharply between ALD-U and ALD-L (again by about 40%), whereas at high flow (July 2nd) TP concentrations (and TSS) increased phenomenally at the lower site (Fig. 11).

The relationship between TP and TSS was less strong in Indian and Sunderland Brooks, probably because their sediments have been exposed to high P concentrations for many years, and have become saturated with adsorbed nutrient. Thus much of the P moves downstream in dissolved form. In Indian Brook, TP increased by 17% on average between the upper and lower sites, despite a general 3 fold increase in TSS. If the P in Sunderland Brook were mostly particulate, it would be largely removed during wetland and beaver pond passage, and TP concentrations would be lower than at INDI-L. Instead, concentrations were similar for the two sites. Dissolved P is a more serious pollutant than particulate P. It travels downstream much more quickly, not requiring high flow for movement, and once in Lake Champlain, mixes readily into the epilimnion, while particulate P settles to the lake bottom.

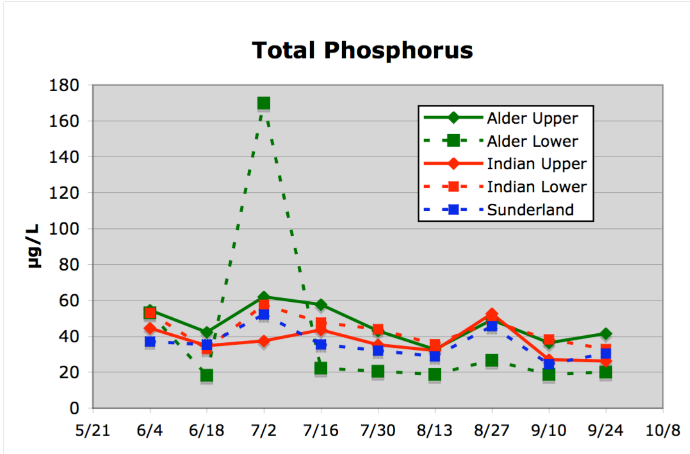



*Figure 11. Total phosphorus concentrations in the streams during 2006.*

Nitrogen is as serious a pollutant for Lake Champlain as phosphorus, despite getting less press. Algae in the troubled St. Albans and Missisquoi Bays are strongly N rather than P limited (Levine et al. 1997). Our study showed a doubling of TN concentration in Indian Brook during its passage through Essex Junction (Fig. 12). For Alder Brook, the impact of development was less severe; its TN concentration increased by 43% on receiving drainage from Essex Center neighborhoods and shopping centers. However one must keep in mind that Alder Brook's water chemistry is probably significantly impacted by groundwater inputs. Despite an urban origin, Sunderland Brook had TN concentrations more like those in at our upper, more rural INDI-U and ALD-U sites than those at INDI-L. Water passage through wetlands can lead to substantial denitrification of nitrate (conversion to $N_2$ gas, which vents to the atmosphere), as well as plant uptake.

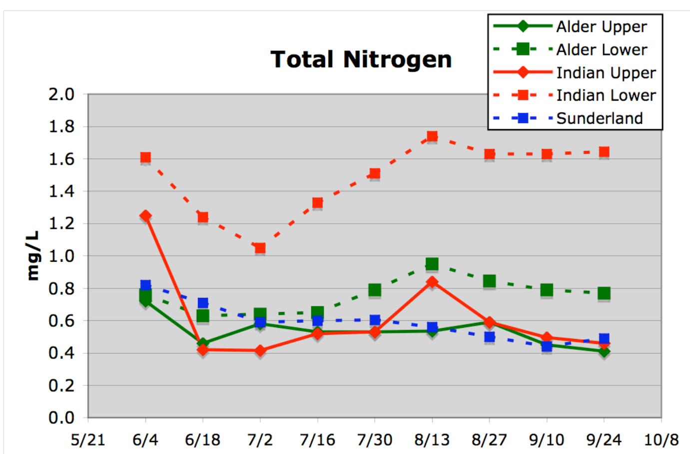



*Figure 12. Total nitrogen concentrations in the streams during 2006.*

*pH*

pH is a measure of $H^+$ ion (and $OH^-$) content. Vermont's precipitation typically is acidic, but its rocks contain neutralizing minerals that typically keep stream pH between 6.5 and 7.5. Photosynthesis raises pH through the production of $OH^-$ ion. Where algae or aquatic plants are abundant, it is not unusual for pH to exceed 8 or even 9 daytime. Respiration produces H+, and thus counters photosynthesis in lowering pH at night and in reaches that are primarily heterotrophic. In this study, pH was typically < 8 at INDI-U and ALD-U, where below-saturation DO concentrations suggested heterotrophy in excess of autotrophy. By contrast, pH was frequently >8 at ALD-L, INDI-L, and SUND-L, where DO concentrations suggested autotrophy was more important.

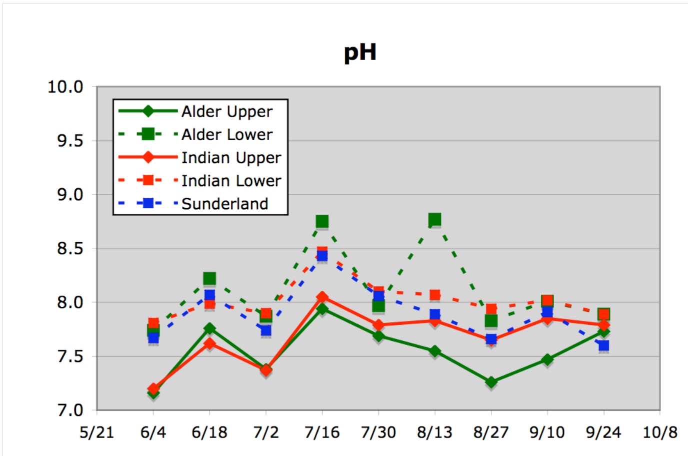



*Figure 13. pH in the study streams during 2006.*

*Discharge and Downstream Fluxes*

Stream discharge was tracked at ALD-L, INDI-L, and SUND-L beginning in mid-June. While the record was continuous, Figure 14 plots only discharge volumes at times of water sample collection (contact Meredith Curling, UVM, for a full record). The three streams were similar in discharge at base flow, but diverged markedly after rainfall. While Sunderland Brook, with its many beaver ponds and wetlands to store and slow excess water, showed little increase in flow during the post-rainfall sampling of July 2, the discharge in Indian and Alder Brooks was elevated by about 5 and 10 fold, respectively. The particularly flashy nature of Alder Brook was further explored during the September storm study (below).

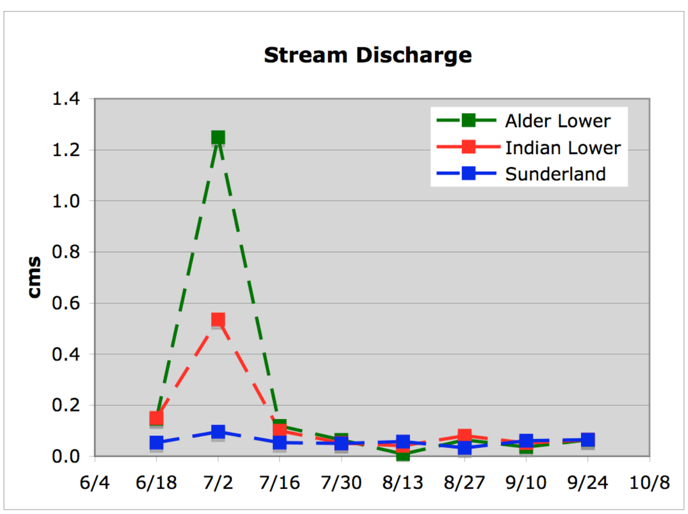



*Figure 14. Stream discharge at sample collection sites with gauging equipment at the times of sample collection. Data provided by M. Curling, UVM.*

Discharge values were multiplied by TSS, Cl, TN and TP concentrations to estimate the downstream flux of the four pollutants. The results tell a different story than concentrations values. While runoff dilution of groundwater reduced chloride and TN concentrations in Alder and Indian Brooks at high flow (July 2), the actual amounts of Cl and TN transported downstream per unit time increased several fold (Figures 15 & 16).

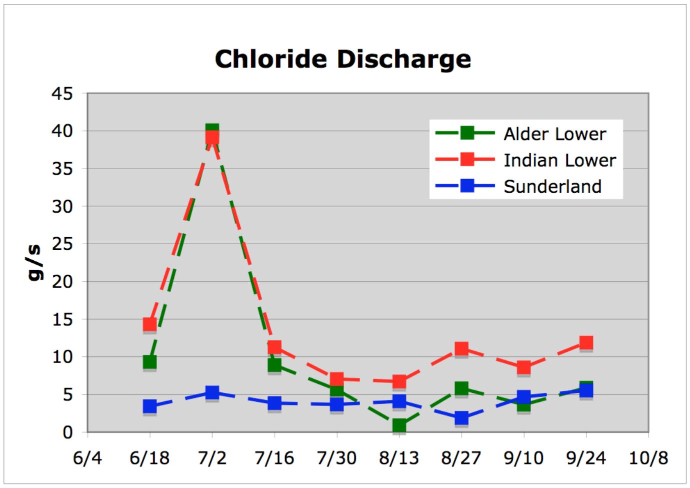



*Figure 15. Chloride mass transported past the stream sites per second, 2006.*

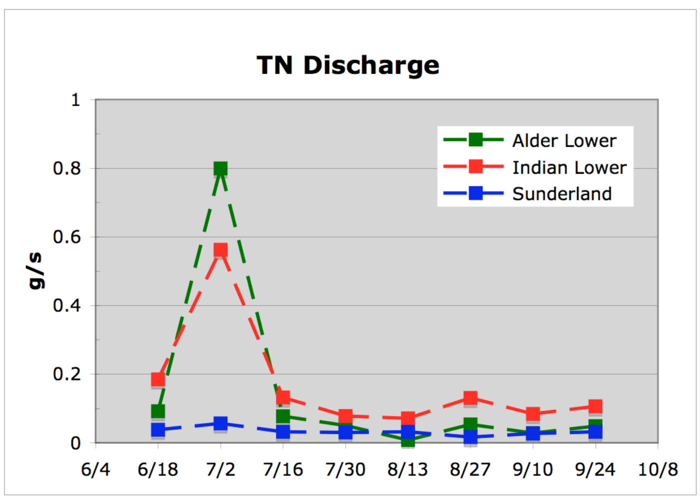



*Figure 16. Total nitrogen mass transported past the stream sites per second, 2006.*

Sunderland Brook, did not demonstrate this surge in salt and TN flux downstream after rainfall because its hydrological response was muted. At water flows < 0.1cms, Indian Brook clearly transported more salt and nitrogen than the other streams. When flow exceeded this threshold, however, Alder Brook's load was equal or greater.

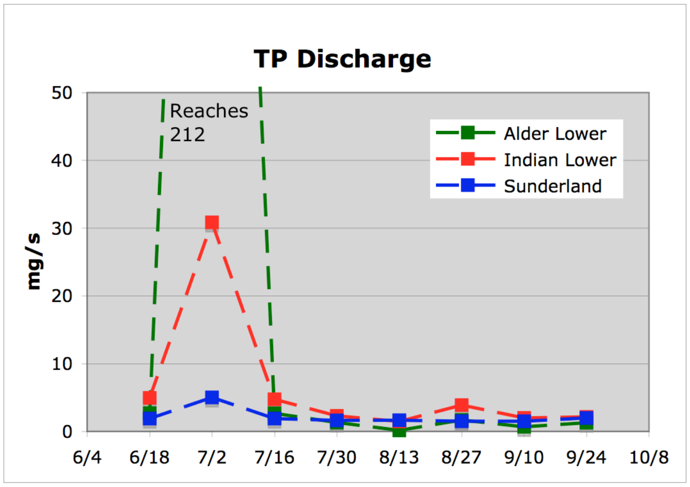



*Figure 17. Total phosphorus mass transported past the stream sites per second, 2006.*

The impact of high flow on TSS and TP fluxes downstream (Figures 17, 18) was greater than the impact on Cl and TN due to their association with sediment and the erosive power of flashy streams. On July 2, Indian Brook carried about ten times as much

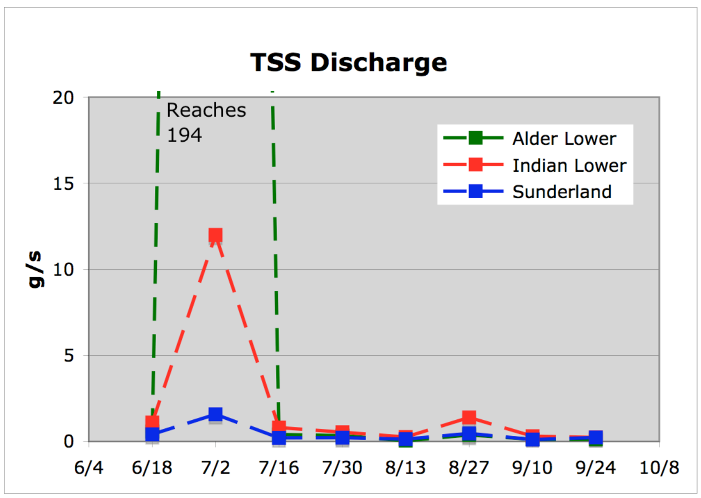



*Figure 18. Mass of suspended solids transported past the stream sites per second on the sampling dates, 2006*

suspended sediment and about thirty times as much phosphorus downstream as it did at base flow. Alder Brook outdid its impaired neighbor, moving about 300 times as much sediment (mostly sand) and 100 times as much P as at base flow!

Extrapolating the fluxes measured in grams per second to more easily appreciated daily rates, we found TSS transport in Alder, Indian and Sunderland Brooks to range from lows of 0.002, 0.022, and 0.009 metric tonnes per day, to highs of 16.73, 1.04, and 0.14 metric tonnes per day, respectively. Daily movement of chloride past the sampling sites ranged from 0.08 to 3.46 tonnes $d^{-1}$ in Alder Brook, 0.58-1.24 tonnes $d^{-1}$ in Indian Brook, and 0.16-0.48 tonnes $d^{-1}$ in Sunderland Brook. Again Alder Brook was far more variable in its behavior than the other streams. TN transport ranged from 0.7- 69.1, 6.1-48.6, and 1.4-4.9 kg $d^{-1}$ and TP transport from 0.01-18.3, 0.2-2.7, and 0.1-0.4 in kg $d^{-1}$, in Alder, Indian and Sunderland Brooks, respectively. For every contaminant assessed, Alder Brook had both the lowest and highest mass transport rates, largely because its discharge was most variable.

Storm Response of Alder Brook

*Rainfall and Discharge*
The storm study at Alder Brook took place before, during and after an 11.5 h rainfall event that deposited 3.48 cm (1.37 in) of rain. Rainfall began around 3:30 on September 29th and continued until 14:30, with three heavy showers at about 5:00, 8:30, and 12:30 (Figure 19). Only one light shower occurred on September 30th.

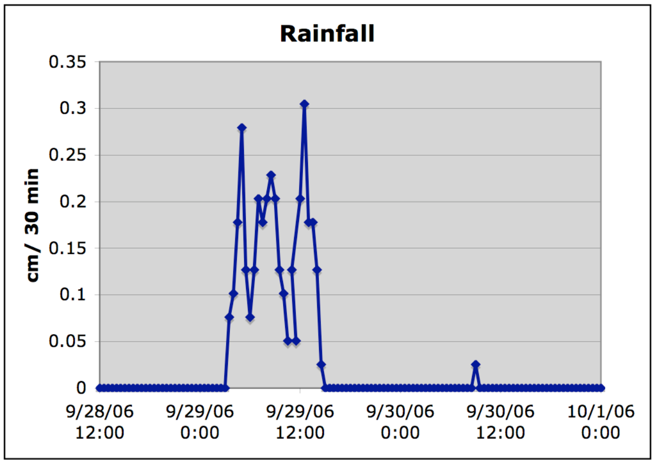



*Figure 19. Rainfall distribution between noon 9/28/06 and midnight 10/1/06.*

The stage recorder began to detect increased stream flow about 40 minutes after light rainfall began. The rise in flow was not bell-shaped as it would be with steady rain but showed three peaks representing the heavy showers recorded (Fig. 20). Mode travel time of surface runoff into the stream appeared to be 6.5-7 h, the time between peaks in rainfall and peaks in flow. Discharge in the stream peaked at ~21:15 on 29 September, 12.5 hours after the mid-point of the total rainfall period. This delay represents travel time of both overland and subsurface flow. The maximum stream discharge measured was 0.726 cms, twenty times the discharge measured on 28 September, 0.036 cms. Flow rates declined quickly for several hours after peaking, but then leveled off at 0.312 cms- half the storm flow, but ten times the discharge measured before the storm. The extra flow may be related to groundwater recharge during the storm. If water table height were elevated, groundwater seepage into the stream would increase.

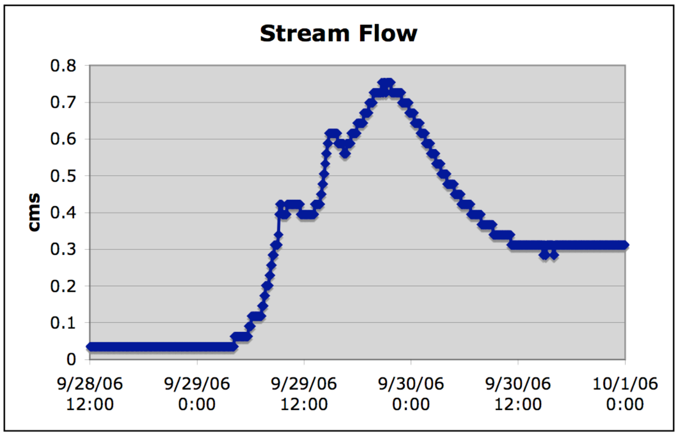
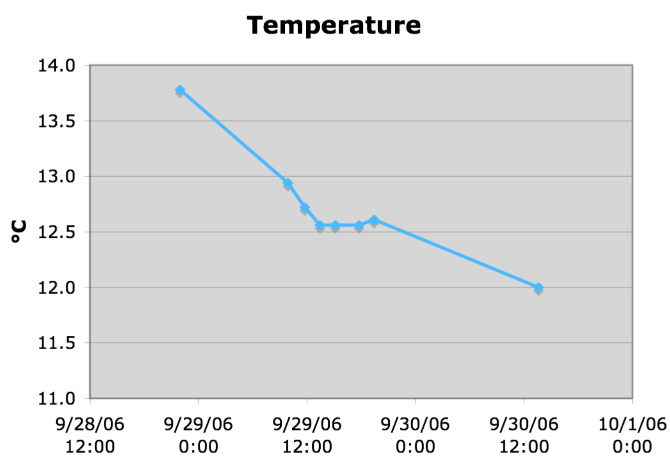



*Figure 20. Discharge at ALD-L between noon 9/28 and midnight 10/1/06.*

*Temperature*

On September 29th, the day of the storm, the water temperature in Alder Brook fell by about 1°C. It fell another half degree the following day as runoff continued to enter the stream. Stream cooling during autumn storms makes sense because the runoff passes through cooling air and land surfaces, while the moderating temperature of groundwater dominates at baseflow.

*Figure 21. Water temperature during the storm study. Rain fell from 3:20-14:05,*




*9/29/06.*

*Suspended Sediment*

The day before the monitored storm, ALD-L was clear, with a TSS concentration of only 1.9 mg/L, and a turbidity of 8 NTU. Six-and-a-half hours into the storm, TSS concentration was already up to 228 mg/L, more than a hundred times baseline, and turbidity was at 190 NTU. The stream was visually very muddy. Some of this suspended load apparently settled out between the first two heavy showers, when discharge declined temporarily (Fig. 22). The highest levels of TSS and turbidity measured were much greater yet, 344 mg/L and 373 NTU, respectively. These values were measured at about 13:00 on Sept. 29th, six hours before water discharge peaked. This suggests that easily

suspended sediment on the stream bottom was carried out of the stream early on, making erosion the principal source of newly suspended material later in the storm.
During our final post-storm sampling, TSS and turbidity were much reduced, but still 7 and 3 times pre-storm levels (13.5 mg/L and 24 NTU, respectively). That they did not return to pre-storm levels is related both to continued elevated water discharge and to the slow rate of silt and clay sedimentation once these small particles are brought into suspension.

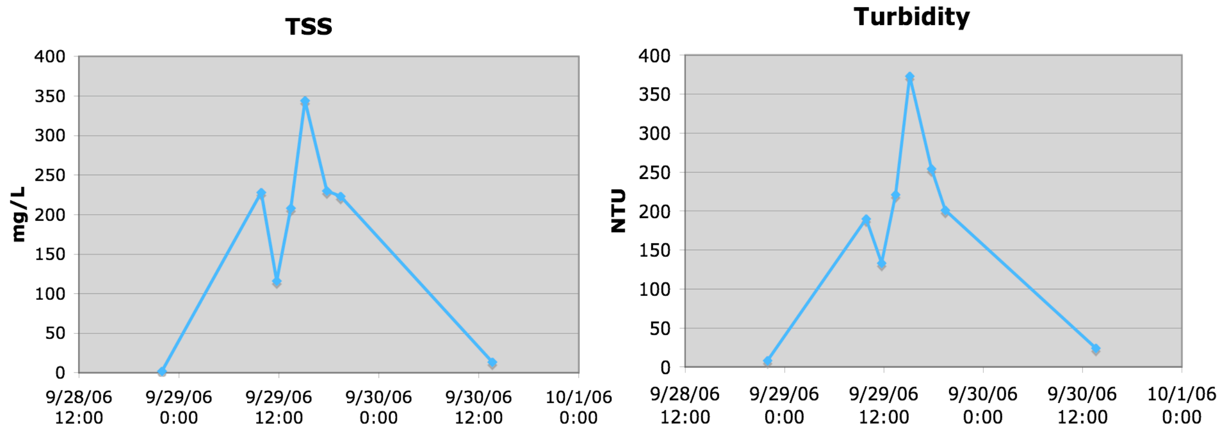



*Figure 22. TSS concentration and turbidity* at ALD-L *during the storm study. Rain fell from 3:20-14:05, 9/29/06.*

*Salts and pH*
Both chloride concentration and specific conductance declined steadily throughout the storm event (Fig. 23). This trend was expected since the main source of salt in early

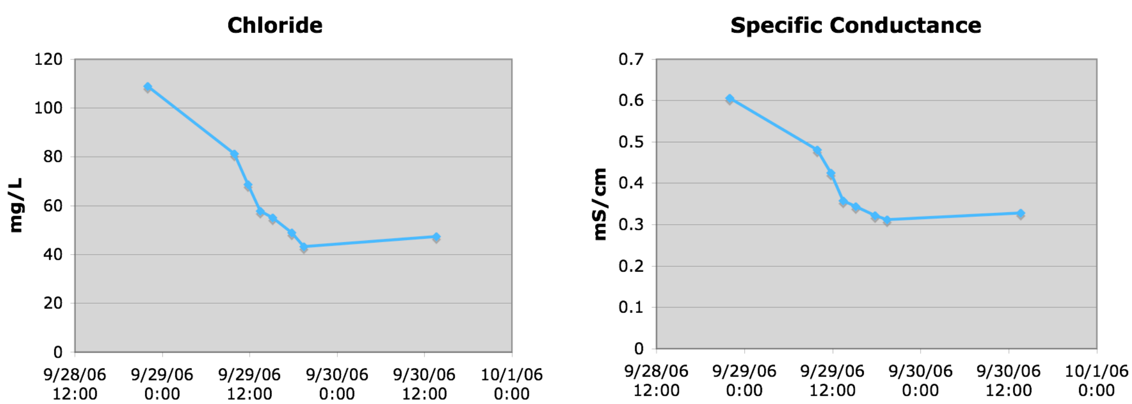



*Figure 23. Chloride concentration and specific conductance at ALD-L during the storm study. Rain fell from 3:20-14:05, 9/29/06.*

autumn is likely to be road salt that infiltrated into groundwater during previous winters rather than salt on the surface landscape. Runoff would dilute the salt contributed by groundwater. Regression of specific conductance on Cl concentration for the storm data confirmed that the two parameters are strongly related in Alder Brook (Figure 24). This indicates that road salting rather than mineral weathering is the major source of salinity for the stream. After the storm, chloride concentration and specific conductance rose slightly, as groundwater recaptured its role as major water source. Lack of return to pre-storm values may be related to storm flushing of salt from groundwater stores.

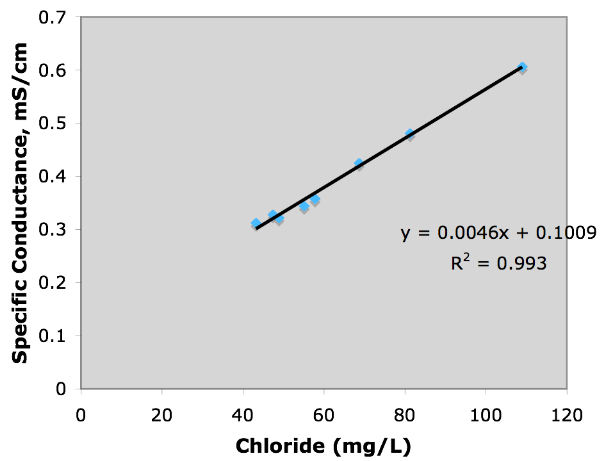



*Figure 24. Relationship between specific conductance and chloride concentration in Alder Brook for the September 29 storm.*

pH declined slightly during the rain event, but recovered by the Sept. 30th sampling.

*Nutrients*

Total phosphorus concentration showed dynamics similar to those of TSS over most of the course of the storm, attesting to the importance of particle-bound P (Figure 25). As the two rain events caused TSS to rise, fall, and rise yet again, TP followed suit, reaching the very high concentration of 428 µg/L during the second event. This value was 30 times the baseline level measured the day before the storm. TP departed from TSS in its dynamics post-storm, however. Its concentration was still 256 µg/L on September 30. The most likely explanation is that TP was absorbed primarily onto the smallest sediment particles (clays and fine silts), which settled more slowly than the sand accounting for the bulk of TSS. It also is possible that some P desorption occurred while sediments were in suspension.

Total nitrogen showed more complicated dynamics. On the whole, its concentration was depressed by runoff dilution, suggesting that its principal source is dissolved nutrient stored in groundwater. However, TN rose above its depressed level at peak TSS concentration, indicating that there also is a particulate component, possibly ammonium or organic materials absorbed on sediment particles.

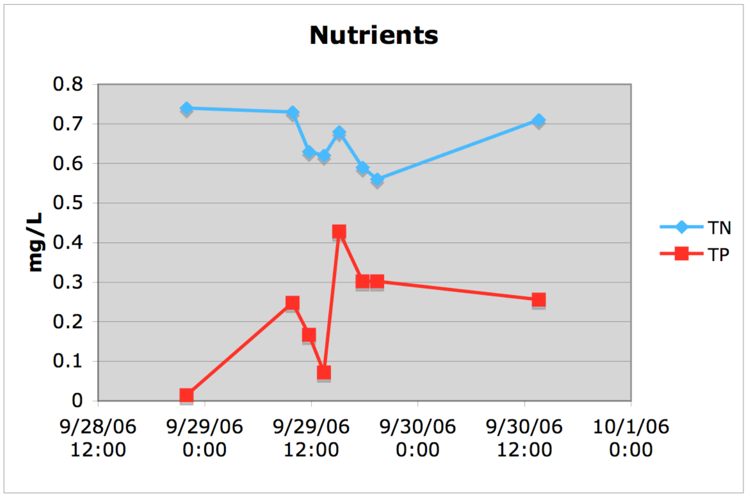



*Figure 25. Total nitrogen and phosphorus concentrations at ALD-L during the storm study. Rain fell from 3:20-14:05, 9/29/06.*

*Downstream Transport of Sediments, Salt and Nutrients*

Our sampling schedule missed peak flow. Thus we do not know what maximum rates of sediment, salt and nutrient transport were during the studied spate. However Figures 26-28 show the time course of the measurements that we have. Notice that even water constituents that were diluted in their concentrations during the storms moved downstream in augmented quantities at high flow, water volume more than making up for the dilution effect.

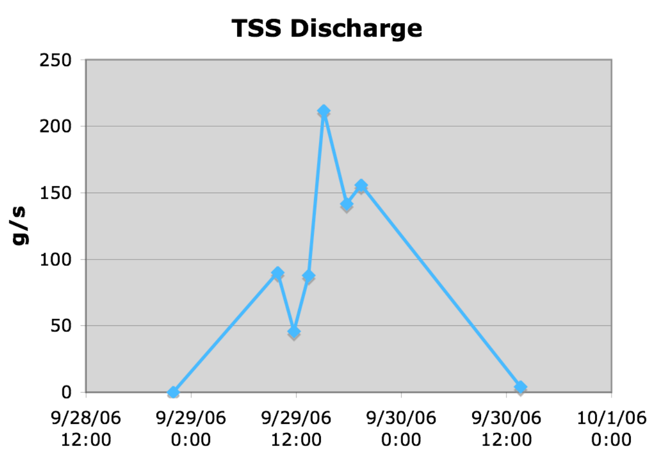



*Figure 26. TSS discharge (flux) past ALD-L before, during and after rainfall on 29 Sept.*

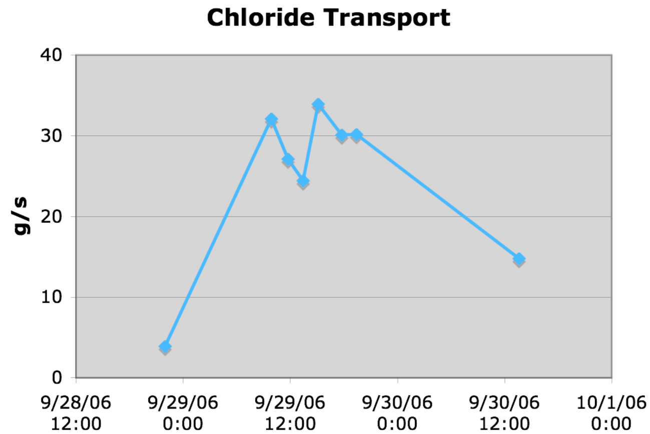



*Figure 27. Chloride discharge (flux) past ALD-L before, during and after rainfall on 29 Sept.*

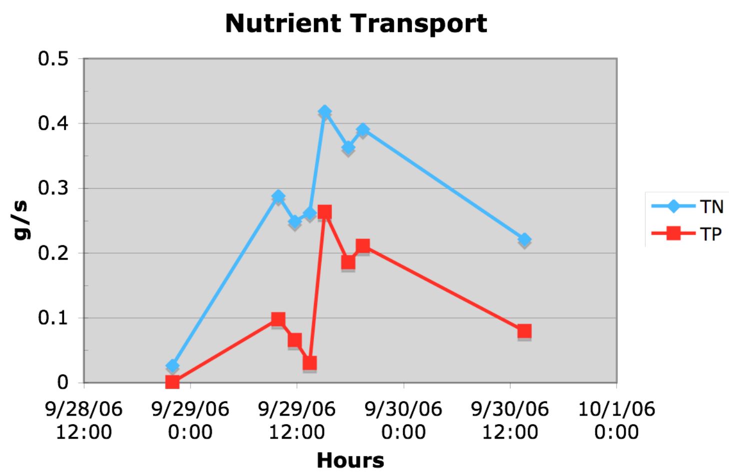



*Figure 28 . TN and TP discharges (fluxes) past ALD-L before, during and after rainfall on 29 Sept.*

Integrating under the curves (summing the areas of the trapezoids) yielded low estimates of mass transport past the study site over the 39.3-hour study period (some of which was pre-storm). For TN and TP, these estimates were 33.0 and 16.7 kg. For TSS and Cl, they were 11.5 and 3.3 metric tonnes! Nevertheless the highest transport rates measured during this medium-sized rain event were lower than those measured on July 2$^{nd}$.

## CONCLUSIONS AND FUTURE RESEARCH

This study added greatly to knowledge of the spatial and temporal patterns of water quality in Essex streams, and demonstrated the potential for more detailed assessment of streams through local community participation in monitoring. Because its manpower and resources are limited, the VT DEC assesses water quality in streams only occasionally, and generally at high flow. High-flow assessment is the rule because phosphorus inputs to Lake Champlain have been the major regional water quality concern, and P tends to travel with particles, the movement of which is flow dependent. Habitat value, on the other hand, is related more to water quality during the longer periods of low flow that prevail in streams. Many pollutants are diluted at high flow and thus most stressful for organisms during low flow. Total nitrogen and chloride were examples of such chemicals in the studied streams.

Increasing chloride concentrations in Vermont streams is a recent observation by DEC personnel that is raising red flags. Salinity has profound effects on water chemistry and the physiology of organisms, and in summer tends to be greatest at low flow, when salt stored in groundwater is released into streams. The need to determine the dynamics of this pollutant alone argues for routine sampling of Vermont streams at low as well as high flow. The lower, post-development, reaches of the Essex streams we studied typically carried more than 70 mg/L of chloride in late summer, and reached 184 mg/L in lower Indian Brook. These concentrations are less than the critical value set by EPA of 250 mg/L, but still alarming given that road salting had not occurred for several months when the measurements were made. Clearly sampling for chloride concentration should be extended into winter and spring.

The EWA data confirmed the association of phosphorus transport with sediment suspension at high flow. The surprise in our sampling was the very high sediment and phosphorus transport rates in the lower reaches of Alder Brook at high flow. Alder Brook is considered an "attainment" stream, while Indian and Sunderland Brooks are designated storm water impaired with phosphorus and sediment listed pollutants. These designations must be determined by conditions at low flow. Mass balance calculations using year around flow data should be performed to determine annual P transport in the three streams. If done, Alder Brook may show itself to be as serious a source of P to Lake Champlain as more urban Indian and Sunderland Brooks. The flashiness and heavy sediment load of lower Alder Brook following rain events is related to the sandy, steep ravines through which it flows. The river has been flowing through this section only since its 1820 diversion from its natural merger with the Browns River. The river may still be adjusting to this diversion. In addition, severe incision of tributaries is occurring as a result of storm water drainage directed into sandy streambeds (Fitzgerald 2006). Finally, construction of the Circumferential Highway alongside the stream through this reach seems to have added sediment despite measures to minimize inputs (Fitzgerald 2006).

Finally, the study provided information about limiting factors for algal and plant productivity in the streams. High primary productivity results in elevated DO (due to $O_2$ evolution) and pH (due to $CO_2$ withdrawal). Both Alder and Indian Brooks showed substantial increases in these two indicators of productivity between rural upstream and post-development downstream sites. Phosphorus concentration declined in Alder Brook between the two sites, while in Indian Brook it increased slightly. This suggests that algal growth is limited by a factor other than P. Nitrogen, which is greater in concentration at the more productive downstream sites, may be the limiting factor.

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