Sydenham River
Fluvial Geomorphology Assessment

Submitted to: Ontario Ministry of Natural Resources and,
St. Clair Region Conservation Authority

Attention: Alan Dextrase

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Submitted by:

PARISH geomorphic

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1.0 Introduction

The Sydenham River is a large river system that drains 2900 km^2 of southwestern Ontario into Lake St. Clair (Figure 1). At least 42 rare and uncommon species of flora and fauna have become adapted to the unusual habitats that exist in the Sydenham watercourses, however numerous species populations are declining in number. Possible contributing factors include stresses on the biological, chemical and physical attributes of the system. Invasive species and impairment of water quality by agriculture and industry represent two possible biological and chemical stresses, respectively. Stresses upon the physical aspects of the river's environment include changes in flow regime and sediment supply, turbidity and degradation of structural habitat caused by instream and riparian alterations. Examples of localized channel alterations that disrupt the physical equilibrium of rivers include: channel relocation to accommodate road and bridge alignments, dams, urban development, livestock grazing impacts, tractor crossings and depositing of fill in the channel or floodplain. Climate change would also impact the system if precipitation levels, and hence runoff, change.

1.1 Study Purpose

The focus of this fluvial geomorphology study is the physical attributes of channels in the Sydenham River system. Changes over time in physical elements, such as channel lengths, will be documented, with an emphasis on sections of the channel that support populations of rare species. The report consists of a presentation of baseline information regarding the physical structure of the river and its main tributaries. Given the large size of the watershed, the study is broad-based in nature and focuses on the rudimentary elements of river morphology, namely: sinuosity, substrate size, bankfull width and gradient.

Very little is known about the physical nature of the watercourses in the Sydenham River basin, particularly in the North Branch and Bear Creek systems and other smaller tributaries. This report will address questions pertaining to the key physical attributes of the watercourses and how they relate to the health of the system within a physical context. The study will provide a foundation upon which specific areas in the watershed can be identified for potential restoration efforts.

1.2 Objectives

Overall Goal: Conduct a broad-based assessment of the physical state of watercourses in the Sydenham basin.

Objective 1 Delineate the Sydenham River and its largest tributaries into representative reaches.

Objective 2	Review historical information (maps, air photos, reporting) to assess channel changes over time throughout the reaches.
Objective 3	Conduct field assessments of representative reaches using established rapid geomorphological assessment protocols.
Objective 4	Provide analysis and interpretation of the physical characteristics operating in the watercourses, as well as commenting on the active processes and areas that are experiencing change.

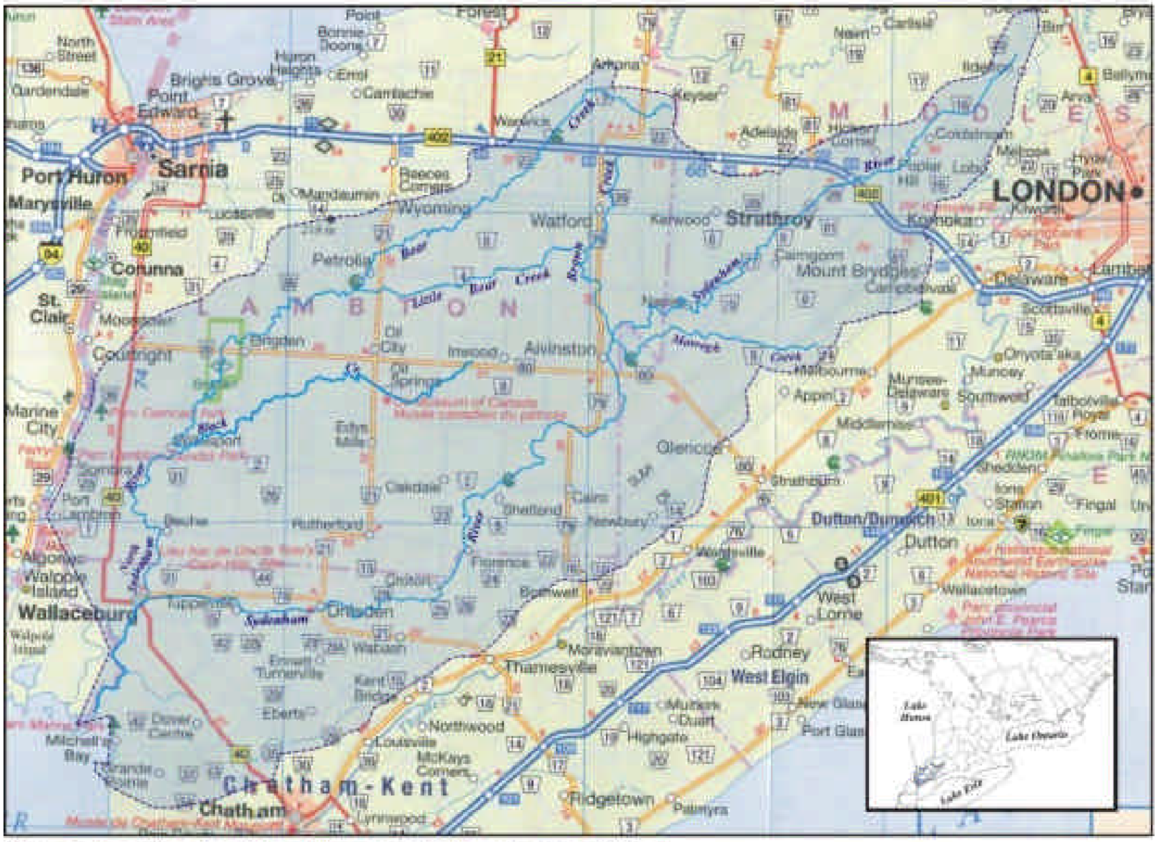

Figure 1. Location of Sydenham River watershed in southwestern Ontario.

2.0 Background Information

Physical data for the Sydenham watercourses is limited but basic information has been collected along the larger main stem channels (Table 1). Hunter and Caron (1979) collected substrate data between Napier and the mouth of the Sydenham River at Lake St. Clair as well as the North Branch below Wilkesport (Figure 2a). Staton (2000) expanded upon this work during a survey of the East Branch, collecting information pertaining to substrate, riparian characteristics, channel depth and wetted width between Alvinston and Dawn Mills (Figure 2b). These background data were combined with the field data collected in this study (Figure 2c) to produce a comprehensive map of the dominant substrate types in the watercourses of the Sydenham basin.

Flow data were also obtained for seven gauging stations in the watershed, four in the East Sydenham River at Strathroy, Alvinston, Florence and Dresden and three in the North Sydenham/Bear Creek system at Petrolia, Brigden and Wilkesport (Environment Canada, 1995). Data utilized include flow volume and maximum instantaneous (peak) flow and were investigated to assess the effect of flow regulation on hydrology. Information regarding geology was also incorporated to identify its influence on the physical aspects of the watercourses, such as gradient and width.

Annable (1996) completed detailed geomorphological investigations at two sites in the Sydenham watershed, namely: Bear Creek below Brigden and the Sydenham River at Alvinston. The Brigden station is located 1.3 km west of town on Regional Road 80. The author surveyed 1375 m of channel immediately downstream of Moore Township Rd. 9-10 (Table 2). This area is typical of the clay bed channels in this area. The Sydenham River at Alvinston is bedrock controlled. The plan characteristics (i.e. gradients) indicate the low relief present throughout the watershed. Bankfull depths are substantially less in the Sydenham River, a condition due in part to the bedrock control. Entrenchment ratios are sufficiently high (> 2.2) to permit adequate access of flood flows to the flood plain. The fact that high flows are able to access the floodplain is, at least in part, responsible for the relative stability of the channels.

Table 1. Summary of background information used in the fluvial geomorphological assessment.

Type	Year	Scale	Identification	Source	Information supplied
Satellite Imagery	1998-9	Variable	---	MNR	Land use and riparian conditions
Topo maps	1969	1:25,000	NTS 40-J/9, J/16, I/12, I/13, P/3	Energy Mines and Resources Canada	Gradients, 1969 reach lengths
Topo maps	1993	1:10,000	Digital OBM	MNR	1993 reach lengths
Report	2000	---	Sydenham River Aquatic Habitat Survey	Staton, *et.al*	Substrate, depth, wetted width, riparian conditions.
Report	1979	---	Sydenham River Substrate Survey	Hunter and Caron 1979	Substrate (East Sydenham downstream of Napier).
Reports	1965 1968	---	Sydenham Valley Conservation Report	Ont. Dept. Energy and Resources Mgt.	General description of watershed and historical problems relating to the streams
Flow Data	1945-95	---	---	Environment Canada	Maximum instantaneous discharge and total flow volume for East Sydenham River and Bear Creek
Geo-morphic data	1996	---	Database of Morphologic Characteristics	Annable	Detailed descriptions of fluvial geomorphology at water survey streamflow gauges (Bear Creek below Brigden and Sydenham River at Alvinston)

Table 2. Fluvial geomorphology data collected at two water survey gauges in the Sydenham watershed (source: Annable, 1996).

Data	Bear Creek below Brigden	Sydenham River at Alvinston
Bankfull Discharge (m^3/s)	27.94	84.9
Watershed area (km^2)	533	730
Geology	clay and silty clay	bedrock
Plan Characteristics		
Riffle length (m)	15	24
Interpool distance (m)	69	109.3
Stream gradient (%)	0.033	0.07
Riffle gradient (%)	0.187	0.25
Pool gradient (%)	0.0178	0.04
Profile Characteristics		
Bankfull width (m)	25.67	48.7
Bankfull depth (m)	2.38	1.79
Bank height (m)	3.38	1.17
Morphological Relationships		
Width to depth ratio	10.8	27.2
Entrenchment ratio	4.06	3.50
Sinuosity	1.25	1.06

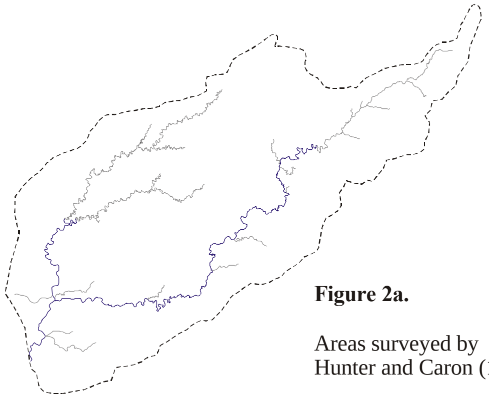

Figure 2a.

Areas surveyed by
Hunter and Caron (1979)

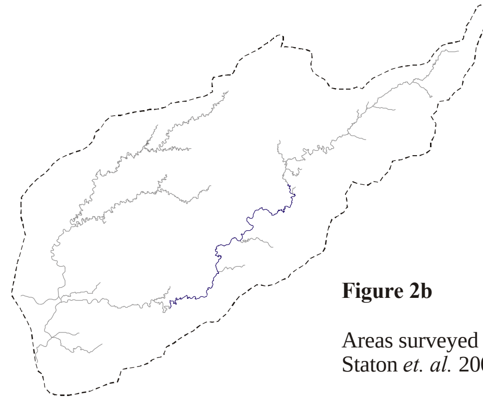

Figure 2b

Areas surveyed by
Staton *et. al.* 2000

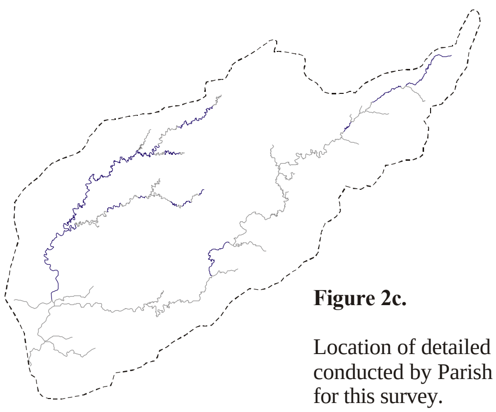

Figure 2c.

Location of detailed field work
conducted by Parish Geomorphic
for this survey.

3.0 Basin Characterization

The Sydenham River drains most of Lambton County, as well as a small area in western Middlesex and northern Kent Counties. There are numerous physical aspects that define or "characterize" the function of this watershed and its channels. These range from natural phenomena, such as climate and geology, to those caused by human activities, such as land use. The Sydenham is an agricultural watershed with numerous rural settlements with Wallaceburg and Strathroy representing the largest centers. There are two principal watercourses, the East and North Sydenham with the confluence located in Wallaceburg. The watersheds of both branches are relatively long and narrow and therefore most tributaries tend to be small (Figure 3).

3.1 Climate and Geology

Climate and geology are the chief aspects of the physical environment that control channel form and process. Climate, and specifically precipitation, provides the energy for the system and directly influences basin hydrology. Geology and physiography act as constraints to the level of fluvial activity and, in part, determine the nature and quantity of sediment supplied to the watercourses.

The location of the Sydenham River watershed within the Great Lakes Basin serves to modify local climate. Precipitation averages 760 mm in the southeast and 890 mm in the northeast where the effect of elevation and Lake Huron is more pronounced (Ont. Dept. Energy and Resources Managaement, 1968). Rainfall in summer (June-August) is approximately 200 mm with drought conditions occurring frequently. Summer thunderstorms are common and result in locally heavy rainfalls that occasionally result in flooding events.

The Quaternary geology of the basin exhibits marked variation in surface deposits (Figure 4). The Pleistocene glaciers deposited till with high silt and clay content across the northern and central portion of the region (Barnett, *et al* 1991). Glacial and post-glacial lake transgressions reworked and subsequently buried these deposits under glaciolacustrine clays. Both branches of the Sydenham River, for much of their length, flow across these deposits. Deposits along the East Sydenham vary considerably, consisting of a variety of parent and surficial materials. Outcrops of shale bedrock are also common in the reaches between Shetland and Florence. The geology of the North Sydenham/Bear Creek and Black Creek systems is less complex with both channels cutting into deposits of till and lacustrine clay. Relict beach deposits and shoreline scarps are widespread and have been subsequently cut by the modern watercourses. Across the southeast part of the watershed, the Caradoc Sand Plain is the principal geological feature, providing a source of sand for the East Sydenham. This river corridor also crosses glaciofluvial and recent fluvial deposits consisting of silt, sand and gravel.

3.2 Relief

Relief over the watershed is low (0.06%) and drainage poor as a result (Chapman and Putnam, 1984). Historically, approximately 95% of the watershed has experienced drainage problems and flooding has long been a hazard to communities along both major branches, including the upper portion of the watershed in Strathroy (Dept. Energy Resources Management, 1968). The Darcy McKeough Dam and Diversion Channel above Wilkesport was constructed as a dry dam (SCRCA 2000). Its sole purpose is to attenuate flood flows in the North Sydenham River to reduce flooding in Wallaceburg. It does not impede flow at any other time and remains open to allow passage of the North Sydenham River. The design of this structure was unique in the province owing to the exceptionally low gradient of the watershed. The traditional “dam and reservoir” solution would have required a flood storage volume too large and impractical to store floodwater.

The North Sydenham splits into Bear Creek and Black Creek at Wilkesport located approximately 20 km upriver of Wallaceburg, whereupon Bear Creek is the principal channel. The entire North Sydenham/Bear Creek system covers an area of 1150 km^2 and is 160 km long. The headwaters rise between the Wyoming and Seaforth Moraines near the village of Arkona (Chapman and Putnam, 1984). There are three large tributaries in this system: Black Creek (340 km^2), which is over 70 kilometres in length, Little Bear Creek (110 km^2) and Otter Creek (140 km^2). Valleys throughout the North Sydenham system tend to be narrow and shallow with low gradients.

The East Sydenham River is the larger (drainage area 1450 km^2) of the two principal branches and extends approximately 200 kilometres above Wallaceburg toward its source located between the Seaforth and Lucan Moraines near Ilderton. There are numerous tributaries but they tend to be relatively minor in comparison to the main stem channel. The substrate is typically a mix of bedrock, clay, silt, sand or gravel depending on local geology. This material, in combination with the exceptionally low gradient, has created unique stream habitats.

3.3 Land Use

The Sydenham watershed is largely agricultural with the original forest cover cleared in the 1800’s. The flat terrain is suitable for farming, although drainage and erosion of the fine-textured soils have long been a concern (Dept. Energy and Resources Management 1968). Pockets of forest cover have remained (or have re-colonized) the riparian corridors along the larger channels, particularly along the central portions of Bear Creek and the East Sydenham. Much of this cover has been removed along the lower reaches and smaller tributaries and tilling practices were observed to the water’s edge.

Channel realignments were evident in the small tributaries as well, as indicated by straight channels on topographic maps. This work has often been employed to improve drainage. Prior to European settlement, the southern tier of the watershed was wetland that has since been drained for agriculture (Dept. Energy and Resources Management 1968). The topographic maps (1969, 1993) indicate that many of the streams in this area, such as Little Bear Creek below Wallaceburg and Maxwell Creek, have also been straightened. These watercourses function as municipal drains and flow into the Chenal Ecarté before entering Lake St. Clair. It should be noted that drainage works have been in place in this part of the province for over a hundred years. Review of municipal drain reports from the Sarnia area, as part of another study in the area, revealed similar work being undertaken as long ago as the late 1800's.

3.4 Water and Sediment Discharge

Discharge of the river follows a seasonal pattern, as dictated by precipitation trends across the watershed. According the flow records for the Sydenham River at Dresden, mean monthly flows attain a maximum of 34.4 m^3/s in March then gradually fall to around 2.52 m^3/s during August (Figure 5). A similar trend was observed in the North Sydenham/Bear Creek System at Wilkesport, also with a maximum in March (16.9 m^3/s) and minimum in August (0.559 m^3/s).

There are no sediment discharge records for any of the channels in the Sydenham basin. Records for the adjacent Ausable River at Springbank, located 12 km northwest of Strathroy, were utilized to provide a picture of sediment delivery to the watercourses in this part of the province. The geology of this area is similar to the Sydenham basin, being a continuation of the clay plains and Rannoch Till (Barnett, *et al*, 1991) The drainage area above the Springbank gauge is 862 km^2, and comparable in size to the East Sydenham watershed above the Alvinston gauge (730 km^2). "Sediment" in this case refers to "suspended sediment" and includes wash load and bed material load. Wash load consists of material considered too small to settle out on the channel bed, and therefore has limited influence on morphology, although it will contribute to turbidity. Bed-material load is the coarser fraction of the sediment load that periodically settles on the channel bed. According Figure 6, water and sediment delivery is moderate during the winter freeze up but both values peak simultaneously in March, when runoff volumes are greatest. Almost half of the total sediment load passes through the system in the months of March and April. Sediment delivery drops to its lowest values in the summer months when vegetation becomes established, but rises again in the fall when the vegetation dies back.

A potential physical disturbance that may affect rare species is the alteration of base flows. Such alteration may be possible through ditching and tile drainage. This potential alteration was investigated by examining low flow records (Environment Canada 1995) at Alvinston and Petrolia (i.e. minimum instantaneous discharge). Although these values were found to fluctuate considerably, by roughly an order of magnitude, there was no long term increase or decrease in minimum discharges observed at either gauging station.

Gauging records in the Sydenham River basin also indicate that flow volumes have remained stable in both main stem channels but that peak discharges have decreased (Figures 7 and 8). The stable flow volumes suggest that precipitation and runoff across the watershed have not changed throughout the discharge record. The reduction in peak flows was observed at all records except Dresden, although the data record here is limited to only 15 observations. In the East Sydenham at Strathroy and Alvinston, where the data record is longest (25 years), peak flows have been reduced by 20-30%. A similar reduction was found in Bear Creek at all three gauging stations. While the flow regime is changing, it was greatly altered by land use change that occurred in the 1800's. Both flow volumes and peak flows would have increased. While peak flows are decreasing, the values are likely higher than levels prior to European settlement of the region.

A reduction in peak discharge has implications for sediment transport and channel morphology. For instance, bars composed of coarser material may become "stranded" as flows lack the competency to transport sediment. According to Schumm (1969) decreased peak flows will result in reduced channel width and depth, width to depth ratio and meander wavelength. Stream gradients would tend to increase as sediment gradually accumulates. However, it is important to consider that this observation is based on 25 years of flow data. Rivers function at numerous time scales and the observed reduction in peak flows may be a short to medium-term phenomenon, particularly if the changes are a result of fluctuations in climate trends.

There are a number of possible reasons for the reduced peak flows, including land use changes, flow regulation and changes in precipitation patterns. Land use change from pasture to cash crop with concomitant tile drainage may effect flows. However, the goal of tile drainage is to improve drainage, thereby reducing the time it takes water to reach the channel. Thus, if the impacts of tile drainage were evident, they would most likely appear as an *increase* in peak flows, a situation not observed at any of the gauging stations.

Decreased precipitation and runoff represents another possible cause of the reduction in peak flows. Analysis of flow records for the Maitland River below Wingham revealed that peak discharges have also decreased in this watershed by approximately 10% during the period of record (1954-95). This river is unregulated, meaning changes in peak flows are more likely attributable to regional alterations in precipitation patterns. However, if decreased precipitation were the cause, lower flow volumes would also be expected, a phenomenon not observed at any of the Sydenham streamflow gauges.

Another possibility is the redistribution of precipitation events, for example, large events being replaced by two or more smaller ones. To determine if this was occurring, a continuous hydrograph was plotted for two ten-year periods at the beginning and end of the Alvinston discharge record (1948-1957 and 1986-1995; Figure 9). The 1948-57 hydrograph shows several discharge peaks rising above the bankfull discharge of 84.9 m^3/s (Annable 1996). The 1986-95 chart indicates that there has been a reduction in the number of peak flow events. During this time, there are several small events, often occurring in the summer months. Detailed examination of precipitation records, which was beyond the scope of this investigation, would confirm this assertion.

Dams and reservoirs are also known to dampen peak discharges; often it is one of their primary functions. Currently, there is only one dam in the watershed that is designed to regulate flows, this being the Darcy McKeough Dam and Diversion Channel above Wilkesport (Bear Creek/North Sydehnam system). This dam is open at all times and does not obstruct flow except when downstream flooding in Wallaceburg is imminent (SCRCA 2000). At such times, the sluicegates are closed and floodwaters are diverted directly to the St. Clair River. Since its construction in 1984, the diversion has been used six times for a few days at a time. Elsewhere in the watershed, the Conservation Authority has constructed smaller dams and reservoirs along main stem channels and larger tributaries (SCRCA 2000; Figure 10). These include dams at Coldstream (1969) and Strathroy (1973) along the East Sydenham River and at Warwick (1971) and Petrolia (1967) along Bear Creek. Two dams have been constructed in smaller tributaries, one in 1971 along Morrogh Creek near Alvinston and another in 1981 along Stonehouse Drain at Petrolia. Although these dams are not intended for flow regulation, they still affect the hydrograph by backing up water during extreme events. Even a reservoir with high siltation can be expected to back up water to some degree during a bankfull event.

An initial survey of the 1:50 000-scale topographic mapping of the watershed indicated that there may be numerous smaller dams located along the small tributaries. For example, the mapping indicated that Morrogh Creek had a total of eight structures or inline ponds along its main stem and 1st order tributaries. While the effects of small individual dams on the watershed may be minor, the effect on flows may become more pronounced when the cumulative effects of several hundred structures are considered, if such numbers exist. Small dams may have the potential for big effects, even in the "steeper" headwater channels, due to the unusually large volume capacities that would result from the low gradients in the watershed. Even structures such as tractor crossings, if sufficiently high, would also function as dams, particularly after their culverts become clogged with sediment. At present, it appears as though a combination of small dams, coupled with a change in precipitation patterns, are two contributing factors that would explain the reduction in peak flows observed across the Sydenham basin.

3.5 Erosion and Deposition

Erosion is a natural and necessary in all watercourses and the Sydenham River is no exception. The clay-rich soils are prone to wind and water erosion. Disturbances caused by agricultural practices (e.g. livestock access), bridge crossings and construction activity also induce local stream bank erosion. Sheet and rill wash increases fine sediment loads and gives rise to the turbid conditions that prevail in the watercourses, even during periods of low flow. Gully erosion is also common (Dept. Energy and Resources Management, 1968), and is particularly evident where the valley is well developed, such as in the vicinity of Alvinston (Chapman and Putnam, 1984).

Depositional processes are also widespread throughout the East Sydenham. Hunter and Caron (1979) observed deposits of silt along much of the watercourse ranging from 2 mm in the upper reaches to 20 mm in areas near Wallaceburg where flow velocities are very low. Their survey also documented three major substrate types in the East Sydenham River. Sand dominated the bed between Napier to 4.5 km upstream of Alvinston. From

Alvinston to Dawn Mills the substrate is typically shale. The remainder of the channels, including the lower Sydenham and North Sydenham, contain a mixture of sand, silt, clay and detritus. The substrate data were incorporated with field observations made during this investigation to generate a substrate map of the Sydenham reaches (Figure 11).

3.6 Rare Species

Several rare species of mussel and fish inhabit the watercourses in the Sydenham basin. Mussels prefer a variety of habitats ranging from riffles with medium to coarse substrate and swift currents to quieter backwater areas with finer substrate (Dextrase *et al*, 2000). The principal physical factors limiting the species are loss of habitat, siltation and, in some cases, turbidity. Rare fishes are also found in a variety of habitats with a general preference for the fine-grained substrates that characterize many of the watercourses in this watershed. As with mussels, the loss or alteration of habitat is likely a serious threat to rare species. Certain fish species, e.g. *Opsopoeodus emilae*, *Lepisosteus oculatus and Fundulus notatus*, have a preference for aquatic macrophytes. Channel changes that disturb vegetation growth, such as straightening, pipeline crossings, would degrade the habitat of these species by disturbing vegetation and through mechanisms of turbidity and sedimentation.

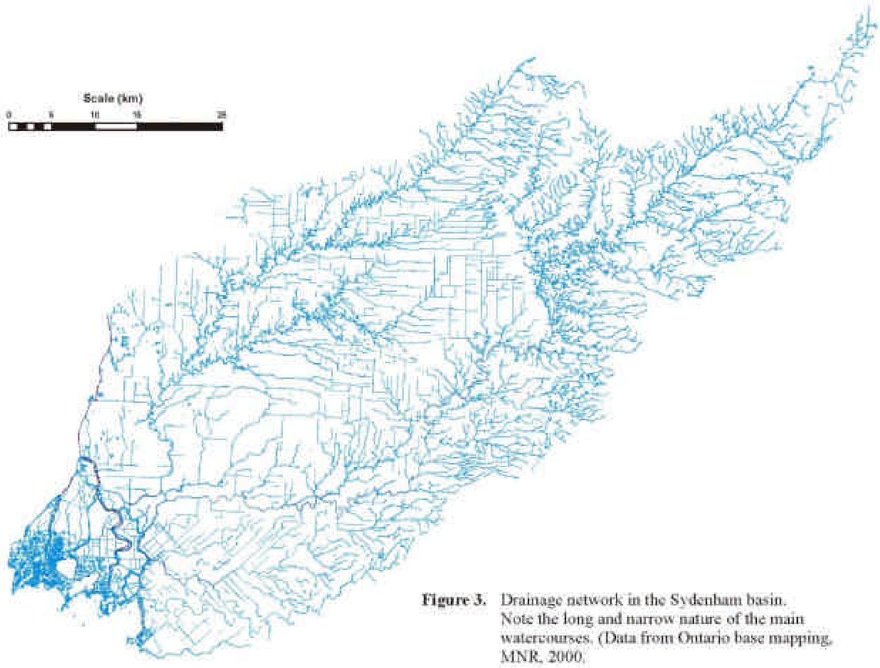

Figure 3. Drainage network in the Sydenham basin. Note the long and narrow nature of the main watercourses. (Data from Ontario base mapping, MNR, 2000.

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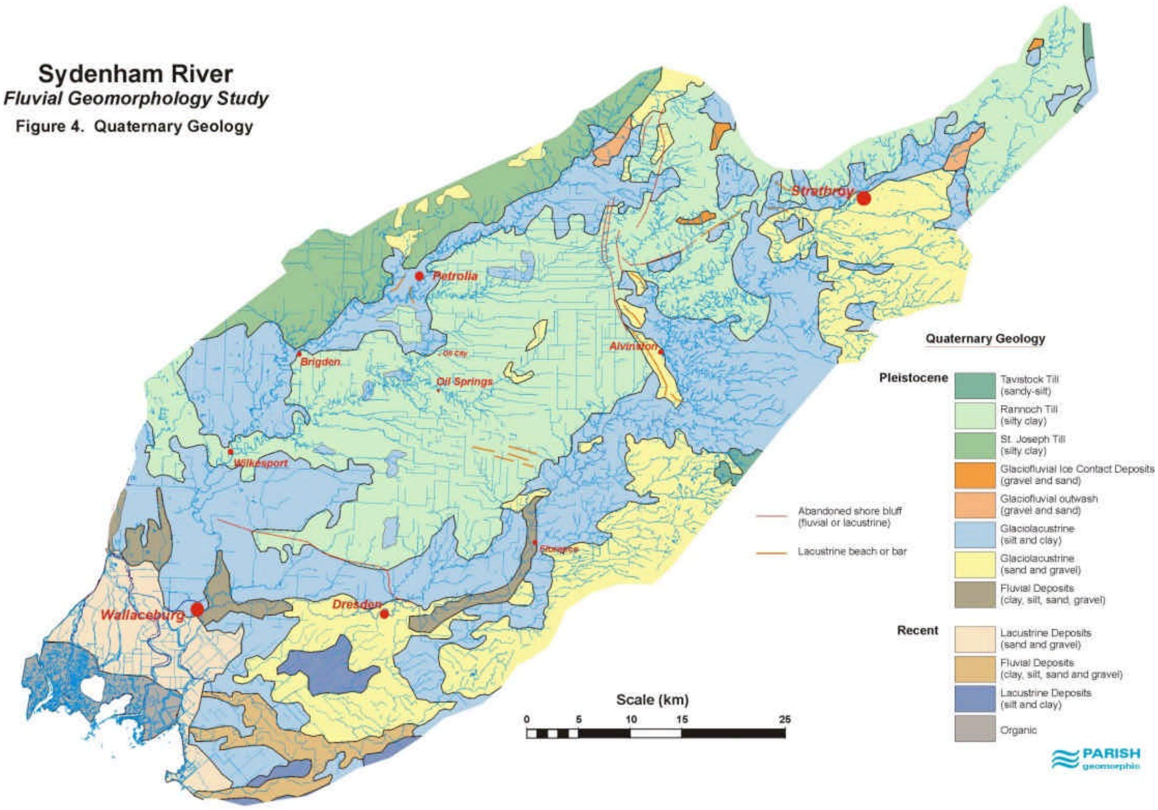
Figure 4. Quaternary Geology



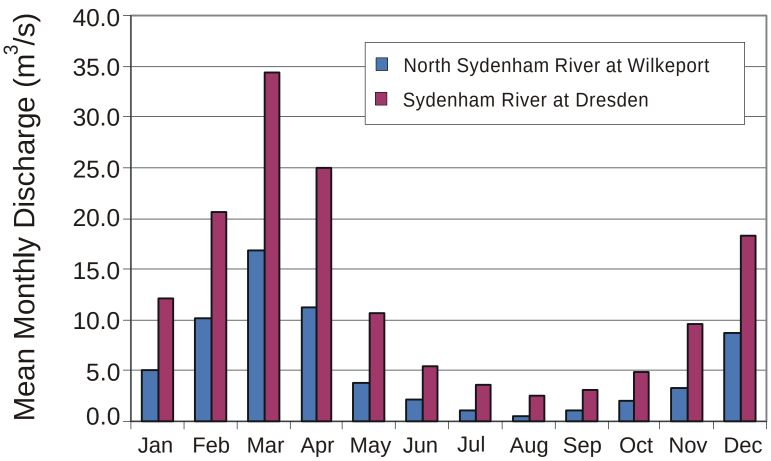


Figure 5. Mean monthly discharges for the North Sydenham River at Wilkeport and the Sydenham River at Dresden (Environment Canada, 1995).

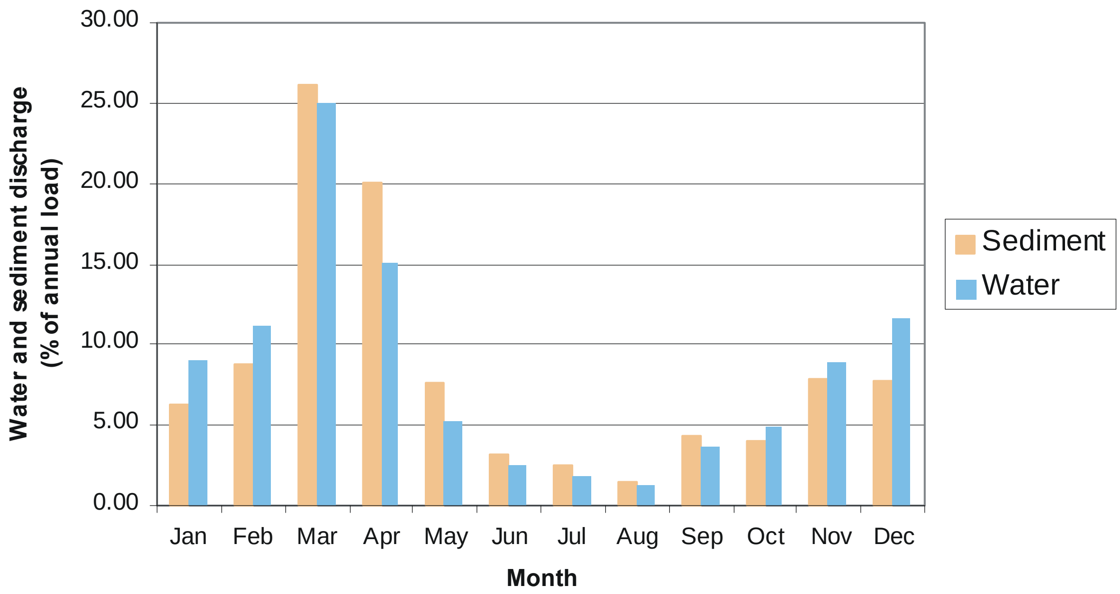
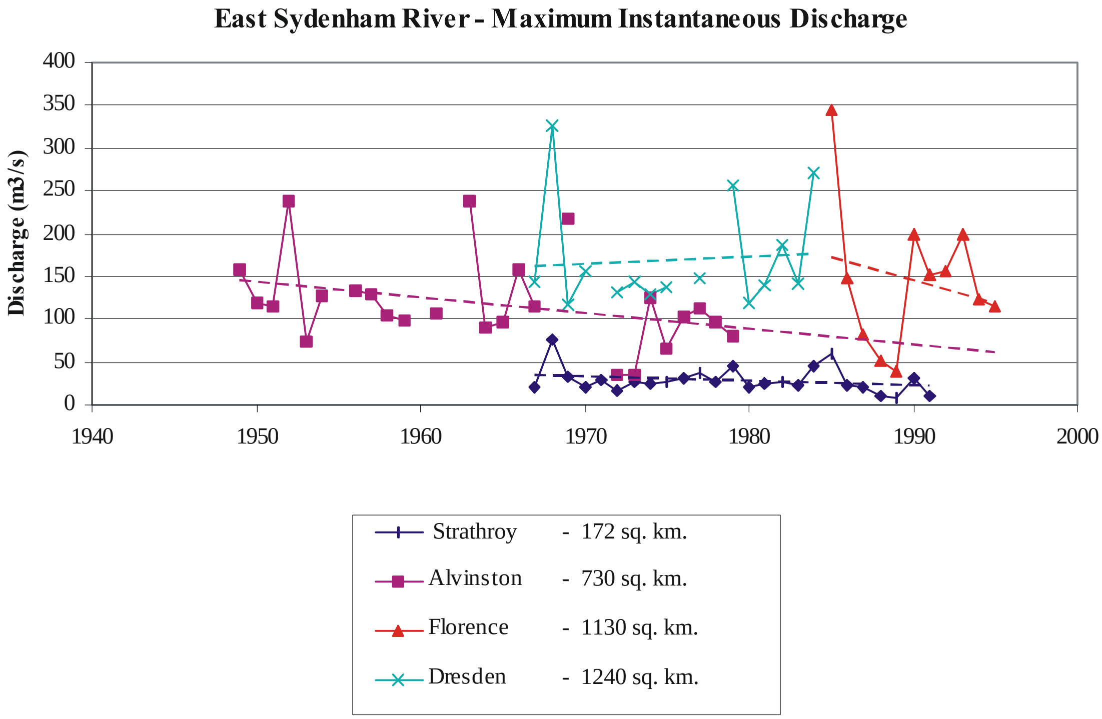


Figure 6. Water and sediment discharge of the Ausable River at Springbank. Peaks occur in March. A similar regime can be expected in the Sydenham watershed. Sediment load based solely on suspended sediment measurements (1970-94) and include wash load. (Environment Canada 1995).



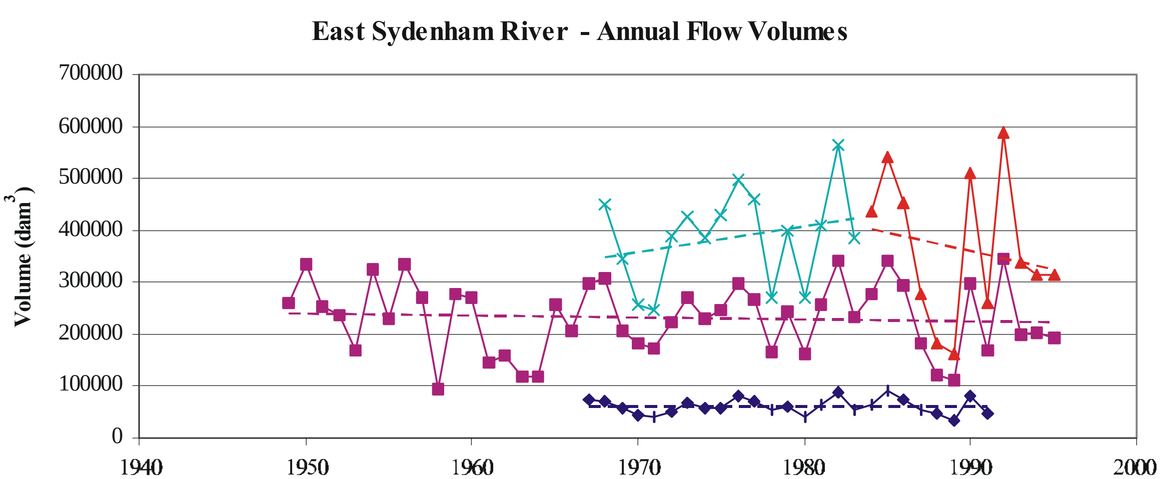
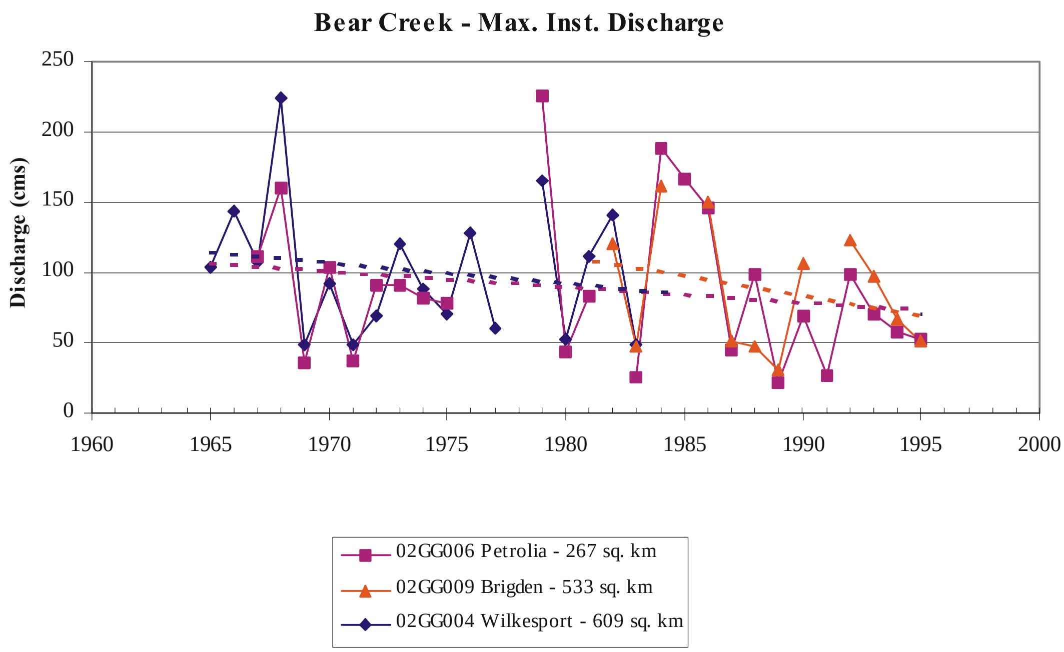


Figure 7. Mean annual flow and Maximum instantaneous discharge for four gauging stations along the Sydenham River. (Environment Canada, 1995)



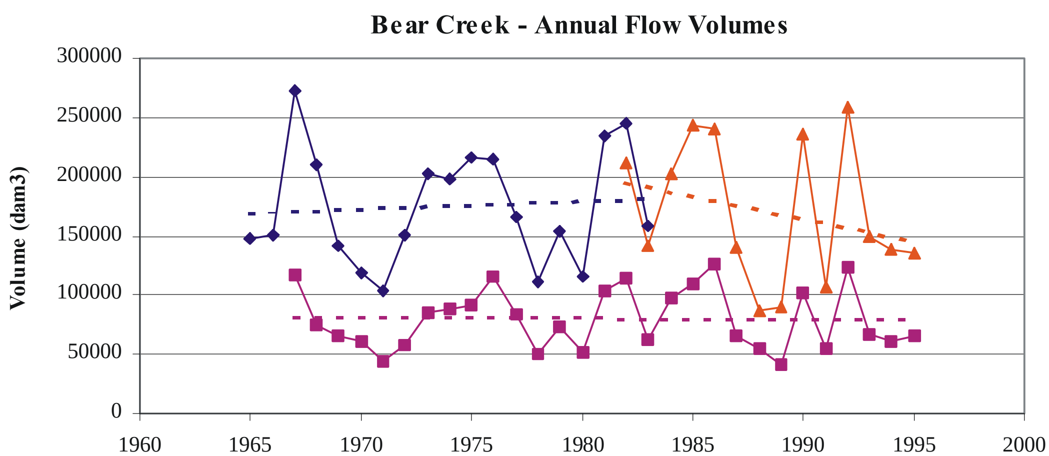


Figure 8. Mean annual flow volume and maximum instantaneous discharge for 3 stations along Bear Creek (Environment Canada, 1995).

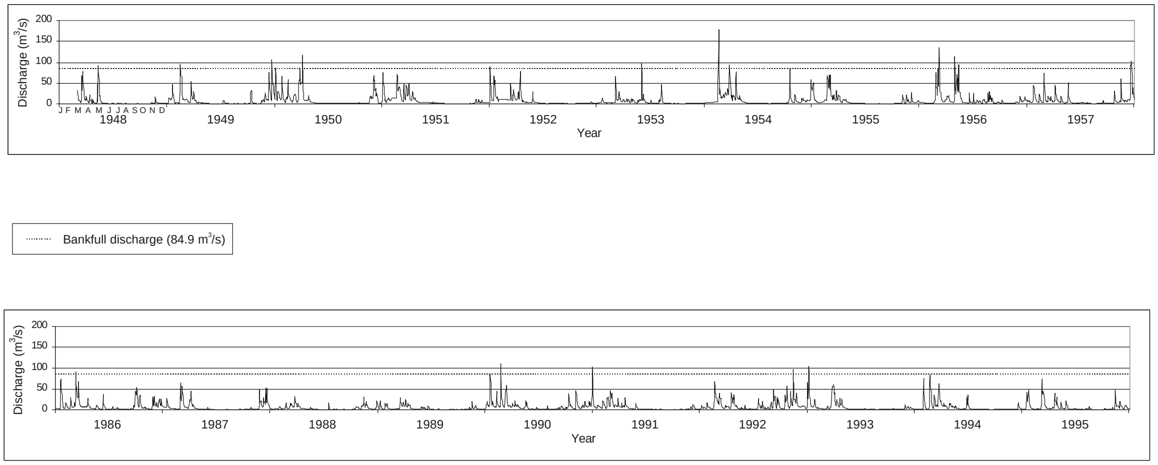


Figure 9.

Continuous hydrograph for Alvinston gauge
for two time periods: 1948-1957 and 1986-1995.
Bankfull discharge has been included as a reference.

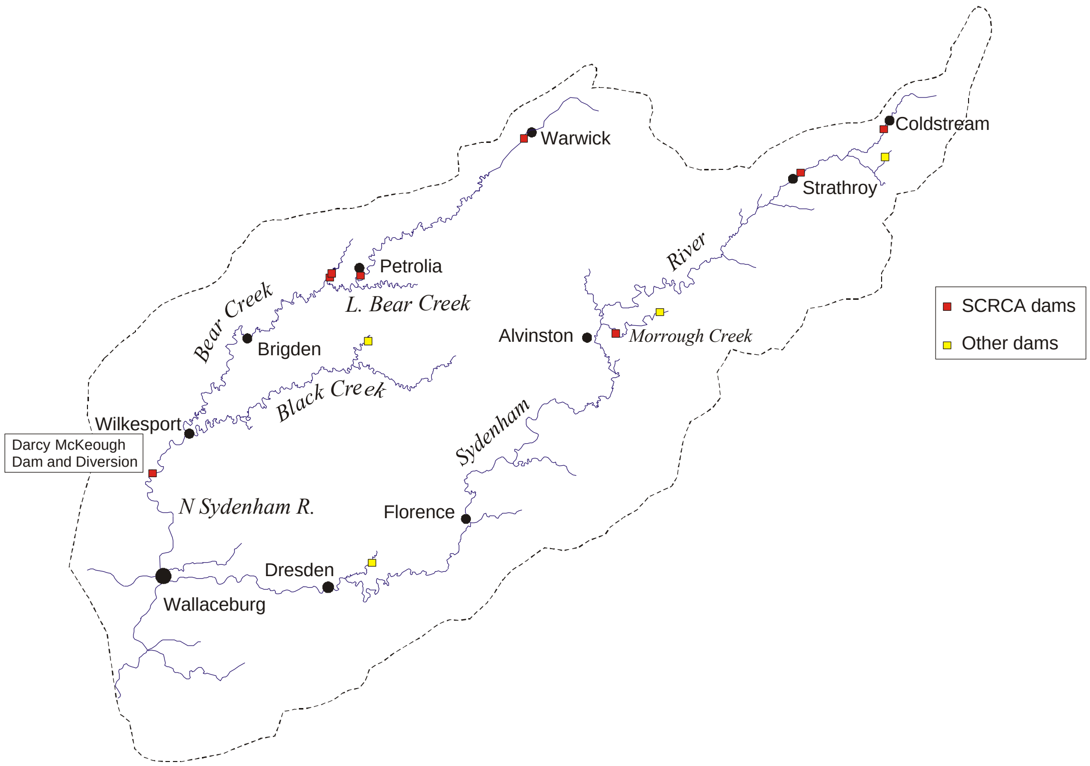


Figure 10. Location of dams and reservoirs in the Sydenham River basin. Numerous smaller dams in headwater streams have not been shown.

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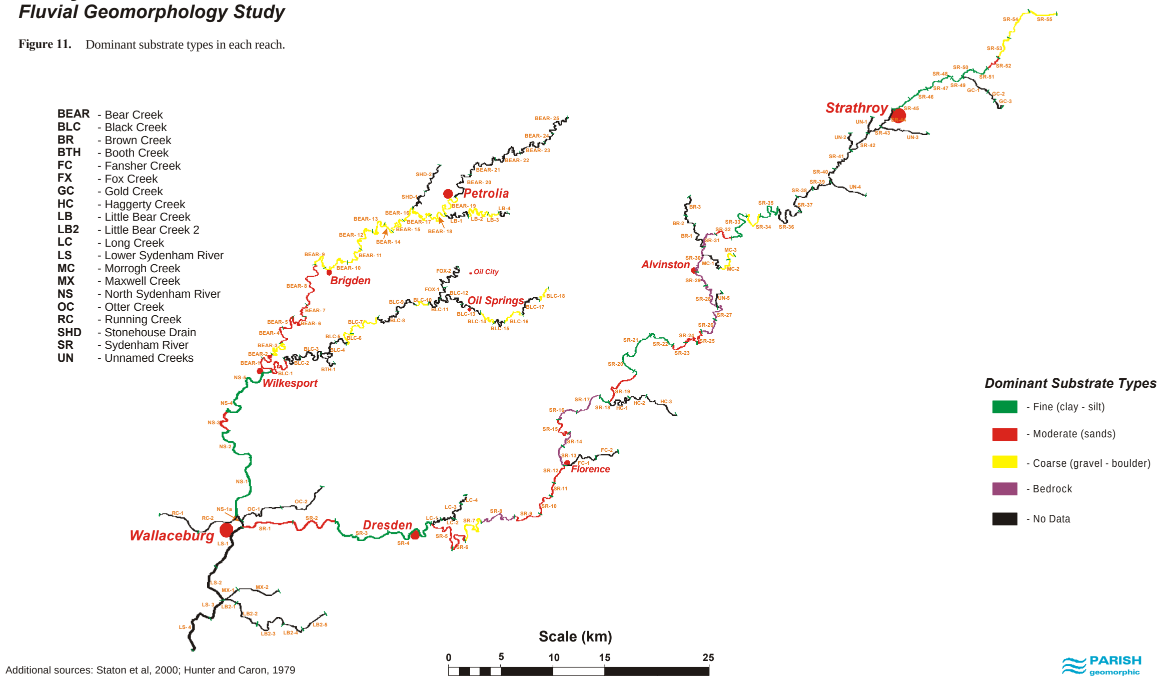
Figure 11. Dominant substrate types in each reach.



4.0 Methods

There are three principal components of the study: the delineation of channel reaches, historical assessment of these reaches and field reconnaissance of representative reaches.

4.1 Reach Delineation

The first task of the basin assessment was to characterize the watercourses in terms of their physical attributes. This was accomplished by partitioning channels into reaches. Channel reaches are sections of channel with relatively uniform physical attributes, such as gradient, sinuosity and geology. This information was obtained from 1:10,000 digital OBM mapping (5 m contours). The analysis concentrated on the larger channels, generally 3rd order and larger. Supplementary topographic mapping (scale 1:25,000) was used to measure gradient due to a better contour interval (i.e. 3 m).

All reaches were categorized according to sinuosity and gradient. Three classes of each attribute were developed and a 3 by 3 matrix used to group the 152 reaches of the basin into nine representative units. The classification ensured that an appropriate number of representative field sites were assessed.

4.2 Historic Assessment

Due to the large number or watercourses and reaches in the basin, the historic assessment was restricted to changes in channel length. These measurements were derived from the historical (1969) topographical maps and compared with 1993 digital OBM mapping. Reach lengths were measured directly from the topographic mapping with care taken to ensure that the reach boundaries were consistent between the digital (1993) and hard copy (1969) mapping. Measurements on the digital OBM maps were determined using Design CAD whereas measurements from the hard copy maps were made directly with a ruler.

Four classes of change were documented: Class 1: 0-5%, Class 2: 5-10%, Class 3: 10-20% and Class 4: >20%. Measurement error was estimated to be approximately +/- 5%, therefore reaches falling into the Class 1 category are inferred not to have sustained any substantial change in length. Approximately 10% of the reaches were re-measured to check for measurement error.

4.3 Rapid Geomorphic Field Assessment

The objective of the field assessment was a rapid inventory of the geomorphological and sedimentological conditions of the channels. The rapid assessment also included scores of channel health and stability, which can be applied to develop a better understanding of the physical condition of each reach.

The field assessments were largely conducted from canoe, which enabled entire reaches to be observed thus providing a comprehensive account of physical characteristics and disturbances. Bear Creek, the North Sydenham River and the section of the East Sydenham between Shetland and Florence were assessed in this manner. Photographs (Appendix A) and detailed descriptions were obtained. Substrate was assessed by hand or by probing the bottom with a paddle. The remaining reach surveys were completed by walking 400-500 m lengths of channel with access provided at bridge crossings. In several areas, the channel had been realigned at the crossing and the bed scoured at or below the crossing for up to 100 m. The reach assessments were conducted beyond these locally disturbed areas.

The assessment consisted of two parts. The first was the Rapid Geomorphic Assessment (RGA, MOE 1999), which involved observations of instability, such as exposed tree roots, to calculate the reach stability index. This index is a quantification of the occurrence of four channel changes: aggradation, degradation, channel widening and planimetric form adjustment. The greater the number the greater the stress on the channel. Index values between 0.0 and 0.2 indicate a stable channel, whereas values greater than 0.2 indicate a channel in adjustment. Indices between 0.2 and 0.4 represent a transitional area that indicates the channel is in adjustment, but is close to the threshold of stability. The technique was developed to assess reaches in urban channels. Although not well suited to the large reaches and relatively natural conditions in the Sydenham, the RGA was conducted to document the occurrence of geomorphic activity in the watercourses.

The second assessment was the Rapid Stream Assessment Technique (RSAT, Galli 1996) and involved a broader, qualitative assessment of the health of the reach. This included observations of channel stability, scour/deposition, instream habitat, water quality, riparian conditions and biological indicators, such as the abundance and species of benthic invertebrates present. Each indicator was given a number with lower values indicating poorer stream health. In a completely healthy stream, these numbers will sum to 50. The values of the RSAT provide a relative estimate of stream health between the reaches in the Sydenham basin. Also included were general observations of channel dimensions, such as bankfull width and depth, substrate size, bank height, vegetation cover, channel hardening and other disturbances. The location of bank erosion sites and channel disturbances were also documented to supplement the assessment.

Supplementary observations were also made of substrate, bankfull width and depth, bank height, angle and material and documentation of channel disturbances. The entire length of Bear Creek was canoed from Petrolia to Wilkesport over a period of four days. The sampling effort concentrated on this area for three reasons. The abundance of rare species and the occurrence of several different reach categories were paramount. In addition, physical data collected from this river would fill a substantial data gap for this portion of the watershed.

The existing physical data record is more complete in the East Sydenham River. Here, the sampling effort was concentrated in areas where rare species were present and, if possible, where data gaps could be filled to supplement existing physical data. Thus, the sampling effort focused upon the upper portion of the river, roughly between Coldstream and Strathroy. To ensure RSAT scores coincided with the previously collected data, five additional reaches were evaluated along the lower Sydenham between Shetland and Florence. This area was selected because of its diverse geology, substrate, habitats and profusion of rare species. Supplementary photographs and measurements of bankfull width were made at 16 additional locations to provide a comprehensive picture of 150 kilometres of channel between Coldstream and Dawn Mills. A sample of the data collection sheets used for both types of assessment appears in Appendix B

5.0 Results

5.1 Reach Delineation

As part of the basin assessment the watercourses were partitioned into reaches. A total of 152 reaches were delineated in 504 km of channel within the Sydenham watershed. The main stems of the East and North Sydenham contained two-thirds of the reaches with the remaining third distributed among 20 smaller tributaries. Figure 12 identifies reaches and associated categories. Reach numbering began at the downstream end of each watercourse and proceeded upstream.

Sinuosity and gradient measurements were used to classify the reaches into nine categories (Table 3). This information was then used to ensure that representative samples of reaches were investigated in the field. Only five field surveys were conducted in category 1 reaches. This reach type, characterized by low gradient and low sinuosity, was common to the lower portion of the watershed (i.e. Little Bear Creek 2 and Maxwell Creek) that also appear to have been artificially straightened. These habitats contained fewer rare species and therefore the sampling effort was concentrated in reaches where these species were more concentrated (main stem Bear Creek and East Sydenham River).

Reach sinuosity tended to be high, averaging 1.35 and occasionally exceeding 2.00 in areas characterized by tortuous meanders (e.g. Bear Creek reach 3). Both large main stem channels and small tributaries contained reaches with high sinuosity. The high sinuosity and low relief resulted in very low stream gradients. Only 14 reaches exceeded a gradient of 0.1% and none were greater than 0.2%. However, these values are indicative of the entire reach. Riffles would offer areas of locally steeper gradients.

Although not investigated per se, geology was also noted to have an impact on channel planform. The East Sydenham River between Strathroy and Alvinston traverses deposits of sand, till and clay. Radii of curvature were approximately double in till than in sand (upstream) or lacustrine clay (downstream). Surface topography across the till, although subtle, may also influence planform by exerting a stronger influence on valley form and, in turn, the course of the channel. The influence of local geology on planform will need to be considered if large-scale restoration efforts (e.g. re-establishment of meanders) are implemented.

Table 3. Proportion of reaches surveyed during the field reconnaissance program.

Reach category	Sinuosity	Gradient	Total number of reaches	Number of reaches surveyed	%
1	1.00-1.24	0.0-0.030	33	5	15
2	1.00-1.24	0.031-0.060	15	9	60
3	1.00-1.24	>0.060	13	5	38
4	1.25-1.50	0.0-0.030	17	7	41
5	1.25-1.50	0.031-0.060	19	5	26
6	1.25-1.50	>0.060	20	5	25
7	>1.50	0.0-0.030	12	7	63
8	>1.50	0.031-0.060	17	7	41
9	>1.50	>0.060	6	4	67
Total	-	-	152	54	35.5

5.2 Historic Assessment

A total of 145 reaches were assessed for change in length between 1969 and 1993. Seven reaches could not be assessed due to incomplete coverage of 1969 mapping. Change to reach length was grouped into four categories: 0-5%, 5-10%, 10-20% and greater than 20% change. The 0-5% category represents minimal change and, at the scale employed, it was difficult to ascertain if the change was actual or related to measurement error. Over 80% of the reaches investigated fell into the 0-5% category. Thus, 20% of the reaches are considered to have experienced a quantifiable change in length over the 24-year time period (Figure 13). A summary of the data is presented in Table 4 to illustrate the magnitude of the changes.

Table 4. Summary of reaches exhibiting substantial changes in length between 1969 and 1993. Negative values indicate a reduction in reach length.

Reach	Length (m)		Change	
	1969	1993	Length (m)	Percent
SR-12	2030	2160	130	6.4
SR-17	3240	3420	180	5.6
SR-18	1110	1180	70	6.3
SR-25	2140	2310	170	7.9
SR-31	2600	2840	240	9.2
NS-5	4575	4830	255	5.6
SR-20	2380	2150	-230	-9.7
SR-34	3000	2760	-240	-8.0
SR-38	2350	2110	-240	-10.2
SR-41	5050	4550	-500	-9.9
SR-42	5375	3820	-1555	-28.9
SR-44	3600	3320	-280	-7.8
SR-46	4200	3890	-310	-7.4
SR-47	3200	2640	-560	-17.5
SR-48	2225	1980	-245	-11.0
SR-49	3075	2460	-616	-20.0
SR-50	2750	2580	-170	-6.2
SR-52	2125	1930	-195	-9.2
SR-53	3325	3010	-315	-9.5
BEAR-10	4000	3550	-450	-11.3
BEAR-21	6375	4910	-1465	-23.0
BLC-3	4150	3930	-220	-5.3
BLC-13	3525	3190	-335	-9.5
FX-2	7000	6420	-580	-8.3
GC-1	3550	3150	-400	-11.3
UN-4	4500	3800	-700	-15.6
MC-3	2050	1610	-440	-21.5

Approximately 16% of the reaches have been shortened, probably as a result of channel realignments to improve drainage or eliminate multiple bridge crossings. Much of the change was observed in the vicinity of Strathroy with 8 of the 10 reaches in this area exhibiting a reduction in length of 5% or greater. Abandoned oxbows were evident on the mapping, particularly reach BEAR-21 upstream of Petrolia where the channel has been shortened a total of 1.5 km to accommodate three bridge crossings.

These human alterations should not be confused with the natural process of meander development and cutoff that have created the extensive oxbow lake wetland complex located in the Strathroy area. A combination of hydrology, gradient and geology has given rise to conditions that promoted the tortuous meander development found here; the oxbow lakes in this area are the legacy of thousands of years of gradual erosion and deposition. This complex extends across sand and clay plains, with the “pace” of meander development controlled to a large extent by geology and climate but also by the amount of vegetation cover. Protecting this vegetation, particularly in erosion sensitive sand-bed systems, is an important consideration in the continued protection of rare species.

According to Table 4, stream length in the reaches surveyed has decreased by 10 kilometres compared to only 1 kilometre gained, representing a net 1.8% decrease over the period investigated. Assuming a mean wetted width of 10 m, this corresponds directly to a loss of 9 hectares of instream habitat. However, channel shortening not only affects local habitats but also adjacent areas as the channel responds to the increase in gradient and energy resulting in more erosion and sediment transport.

5.3 Rapid Geomorphic Field Assessment

A total of 54 reaches were investigated in the field to complete the RSAT and RGA information sheets: 16 in the East Sydenham and 28 in the North Sydenham/Bear Creek system. An additional 6 were obtained in Black Creek with the remaining 4 coming from smaller tributaries. Composite plots of the observations were completed for the East Sydenham, North Sydenham/Bear Creek and Black Creek systems. The charts contain information regarding channel gradient, width and depth, RSAT scores, geological controls and the location of cultural reference points. A summary of the data appears in Appendix C.

RGA scores were also determined and found to be high (i.e. indicative of instability) in the reaches of both the North and East Sydenham basin. This result is believed to be a systematic error rather than an actual indication of the physical state of the watercourses. RGA’s were developed for short reaches (100-200 m) in urban settings and document the basic presence or absence of geomorphological activity. Reaches in the Sydenham were 3-4 kilometres in length and thus were found to exhibit many of the parameters indicative of change and instability listed on the RGA bench sheet. As a result, the RGA scores were considered to be inappropriate indicators and thus were not included in the analysis. RSAT scores are more appropriate for rural areas and larger reaches.

5.3.1 East Sydenham River

The upstream reaches of the East Sydenham River were in fair condition whereas observations between Shetland and Florence indicated the physical state of the channel was good (Figure 13). Of the 11 reaches investigated in the upper portion of the river, only three scored in the “good” category whereas all five of the lower reaches were rated as good. The “fair” rating in the upper reaches appear attributable to disturbance from livestock grazing and widespread erosion and bank slumping observed during the field survey. The cause of the erosion may also be linked to reductions in channel length. Dams at Coldstream and Strathroy also degraded the stream resulting in deposition upstream and excessive erosion immediately downstream of the structures. The localized effects of urbanization around Strathroy and limited storm water management may also have contributed to the fair rating in the upstream reaches.

The 13.3 km canoe reconnaissance between Shetland and Florence indicated that the physical condition of this part of the watercourse was in good shape. Although Hunter and Caron (1979) did not complete RSAT scores (the concept has only been recently developed), present conditions in this part of the watercourse appear similar to those encountered 20 years ago. As in 1979, habitat in this area was found to vary considerably in response to varying substrates, flow strengths, depths and in the type and amount of cover available. A contributing factor to the excellent habitat diversity, and hence the potential abundance of ecological niches, was the well-developed bed morphology. A large number of pools and riffles were present with local variations in flow velocity, water depth and substrate. Riffle sediment appeared to be relatively stable (i.e. well packed) and embeddedness was relatively low (i.e. interstitial spaces between larger sediment clasts had not been completely filled with smaller sediment). These conditions are important for many species, such as the mollusc *Epioblasma triquetra* that is intolerant of siltation. Bank vegetation, macrophytes, substrate, and current velocities were also found to vary considerably along the length of channel surveyed. However, bank erosion was evident in areas where livestock had access to the channel. The water was slightly turbid with visibility limited to a depth of approximately 50 cm. As in 1979, a thin (few millimetres) layer of fine, unconsolidated sediment was observed on much of the coarse substrate in this part of the river.

Figure 14 illustrates the physical aspects of the East Sydehnam basin (geology, gradient, channel dimensions). Gradients were steepest (0.25%) in the upper 20 kilometres of the watershed. Below Coldstream, gradient drops and remains constant at approximately 0.05%. A notable knickpoint is located near Alvinston where the channel has cut into bedrock. Below Dawn Mills, the gradient is essentially flat and backwater conditions prevail. As expected, channel widths increase in the downstream direction. Geological material varies considerably along the river with numerous crossings of sandy facies. Substantial increases in width appear to correspond to the occurrence of sandy deposits. Outcrops of shale were also observed along the channel boundary (Staton *et al*, 2000) and were observed during the field reconnaissance between Shetland and Florence. In some areas, bankfull widths exceeded 100 metres and large mid-channel bars have formed. Vegetation has colonized the bar deposits in the form of grasses, tall herbs and shrubs. The bars shown on the 1969 topographic maps were present in 2000 and have not migrated downstream. The bars appear to have formed when peak flows were higher or when there was abundant sediment supply.

5.3.2 North Sydenham River/Bear Creek

The 46.5 km reconnaissance canoe trip along Bear Creek provided considerable insight into the form and function of this system. Overall, the habitat conditions did not appear to be as diverse as those observed in the East Sydenham River (Figure 16). Water levels were extremely low during the field reconnaissance and, although hampering travel by canoe, they afforded a good opportunity to clearly observe substrate. Channel morphology was generally poorly developed along much of the channel with few riffles observed. Those observed consisted of gravel or small cobbles and were embedded with silt. Riffle substrate also tended to be tightly packed and difficult to dig into by hand. Pool substrate consisted of sand or silt, usually over coarser material or clay parent material and indicated that siltation was occurring. Numerous small channels and gullies drained into the river with fans of sediment at their mouth.

Bankfull widths along Bear Creek seldom ranged below 10m or above 20 m, despite the increase in watershed area in the downstream direction. The resistant nature of the clay parent material is partially responsible for the low widths. Another factor was the considerable amount of vegetation that further protected the banks. Bank erosion was evident in channel bends as indicated by exposed tree roots and leaning and fallen trees observed along the section surveyed by canoe. Numerous debris jams were encountered that considerably slowed the progress of the investigation. There were at least 20 jams that blocked the channel with backwater extending upstream a kilometre or more at some sites. Deep pools had been scoured into the resistant clay substrate at some locations, indicating that the debris jams have influenced the flow paths and hydraulic conditions immediately downstream.

Disturbances to the channel were also observed at sites used by farmers to ford the creek. In some areas, the crossing was essentially "unimproved" and the effects on the channel were minor. At other crossings, rubble, concrete blocks and culverts had been placed in the channel. These structures hindered the movement of water and sediment and thus their effects upon the channel are similar to those caused by dams. Backwater ponds as long as two kilometres were observed with substantial deposition of sand and silt immediately upstream of the structures. With sediment transport blocked, erosion was commonly observed immediately downstream as the channel worked to increase its sediment load. In reach BEAR-10, a tractor crossing has resulted in the creation of a one metre high knickpoint and substantial erosion as the channel tries to move around the blockage. Figure 15 shows the location of tractor crossings and areas heavily disturbed by livestock access along Bear Creek.

Erosion was also observed around the dam structure in Petrolia, which appears to have been further aggravated during the extreme flow events occurring in summer 2000. The effects of the dam downstream have been occurring far longer. The dam effectively blocks all coarse sediment and the channel downstream is effectively sediment "starved". The result is excessive erosion of the bed and banks for several hundred metres as the channel works to adjust to the disruption in sediment supply. Opening the dam to permit sediment transport would help to remedy the situation, but care must be taken not to inadvertently introduce large volumes of trapped material to the system. With careful consideration and planning, the dam in Petrolia should be able to function for purposes of recreation while at the same time maintaining the water and sediment budget for the river.

Additional field reconnaissance was conducted upstream of Petrolia at three additional reaches (BEAR 21, 22 and 23). Flows were high at this time and were inferred to be approximately 70-80% of bankfull discharge. Channels were shallow enough to wade and revealed clay substrates with occasional deposits of coarser lag. Flow velocities were moderate (approximately 0.5-1.0 m/s). Suspended sediment loads appeared to be high since the water was very turbid. Much of the suspended sediment was inferred to be very fine washload material (i.e. sediment that will not settle out and thus contribute to channel morphology). Bed load transport was not readily apparent owing to the cohesive “mucky” nature of the bed sediment. The apparently low sediment transport rates lends support to idea that bed morphology evolves slowly in the clay-bed systems found in this part of the watershed.

Bank erosion was evident where livestock had access to the channel. Bridge crossings in areas with clay substrate also experienced substantial bed scour. Pools with depths in excess of 2-3 m were commonly observed at bridge crossings. Some streams appeared to have been re-aligned and widened at stream crossings. Additional scour of the clay sediment would introduce a substantial quantity of fine sediment directly into the stream channel.

Figure 16 illustrates the basic physical attributes of Bear Creek and the North Sydenham River. As with the East Sydenham, the steepest portion of the North Sydenham/Bear Creek system was located in the headwater area above Highway 402 (gradient 0.2%). Between Warwick and Brigden, gradient was approximately 0.04%. Between the Bear/Black Creek confluence and Wallaceburg, the North Sydenham falls by approximately 20 cm (Chapman and Putnam 1984). The geology of this system is less complex than the East Sydenham River with lacustrine clay accounting for about 80% of the surface material. Equal proportions of till, sand and glaciofluvial deposits form the remaining 20%.

RSAT scores are generally better here than in the East Sydenham with 86% of the reaches scoring in the good category and the remainder being fair. The resistant nature of the clay parent material and predominance of forest cover likely contributed to the overall good physical state of this system. However, habitat in Bear Creek did not appear as good as that observed in the East Sydenham River, particularly the section between Shetland and Florence. The water was more turbid and siltation appeared to be occurring along the entire length of channel surveyed. Bed morphology was poorly developed with few pools thus rendering the habitat less appealing to species requiring larger sediment. This fact appears to be primarily a result of geological conditions since almost the entire watercourse passes through clay with few available deposits to contribute coarser material to the sediment transport regime. Tractor crossings and livestock access were also locally disruptive to the channel but over the length of the reach, their effects were considered to be relatively minor.

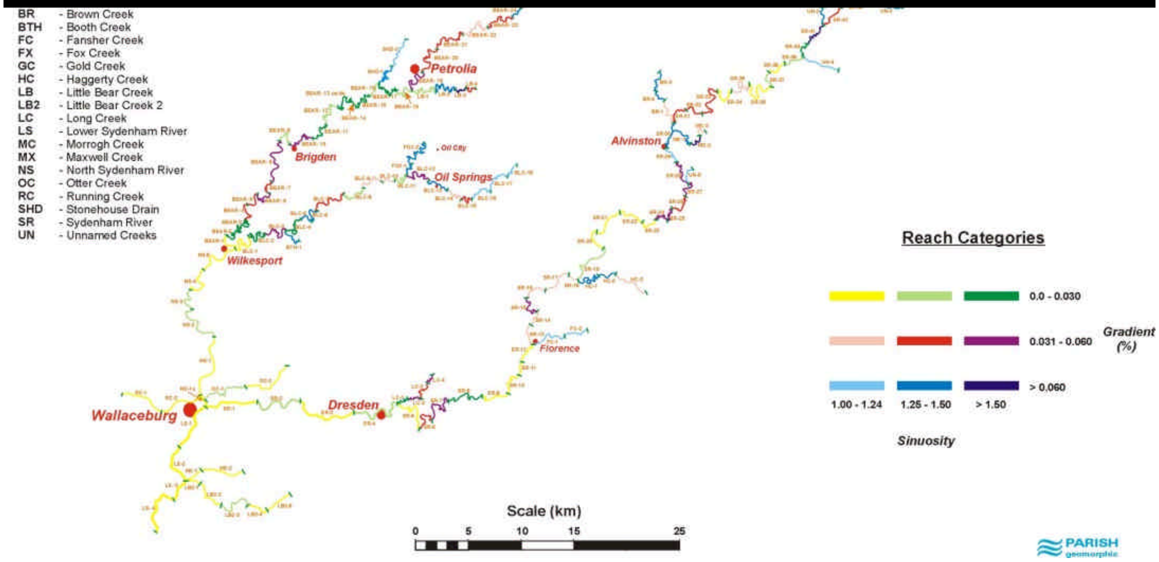
5.3.3 Black Creek and Other Tributaries

Black Creek is the largest tributary in the Sydenham/Bear Creek system and is home to three rare species of fishes and one rare species of mollusc (Dextrase *et al*, 2000) and, as a result, warranted investigation. The field reconnaissance involved detailed observations along six reaches distributed evenly along the stream (Figure 17). Local geology is almost entirely clay till or lacustrine clay plain with only one minor occurrence of sand in the headwater area. The channel profile is much flatter than the larger main stem branches of the Sydenham. Bankfull width and depth gradually increase in a downstream direction, as expected. The lower values generally coincided with heavy forest cover with the largest width occurring at the mouth where backwater effects were evident.

RSAT scores were generally good with fair scores occurring where bank erosion was prevalent. Reach BLC 16 scored the lowest. This reach appears to have been straightened and removed from its floodplain. The resulting high entrenchment has resulted in locally excessive bank erosion.

Four additional reaches were surveyed in other tributaries including: the lower reach of Brown Creek, a channelized reach of Morough Creek and two reaches along the Little Bear at Petrolia. Livestock had access to the surveyed section of reach BR-1 but dense forest cover and shrubs helped to limit erosion by impeding access and stabilizing the banks. Reach MC-3 scored low due to excessive bank erosion (slumping) induced by channel straightening and a tractor crossing. Little Bear Creek appeared to be in better physical shape although some areas lacked suitable riparian buffer zones and ploughed fields encroached upon the water’s edge. Considerable scour of the clay parent substrate was observed at bridge crossings along Black Creek and Little Bear Creek.

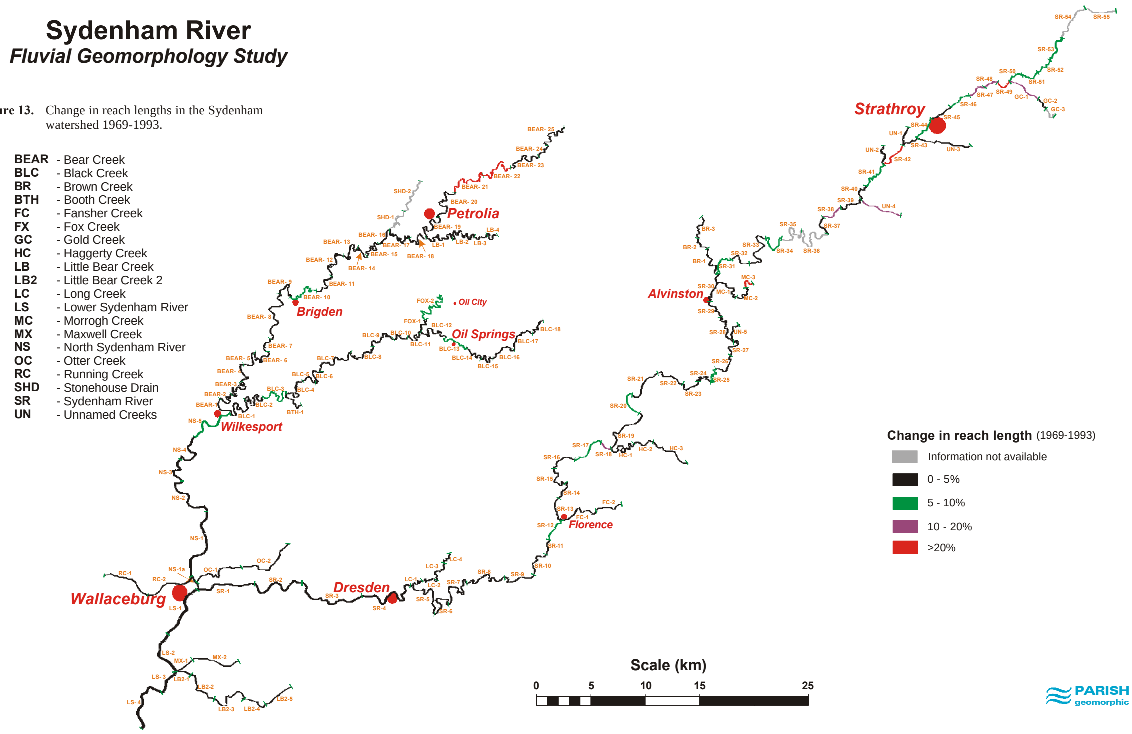
[redacted]



BR - Brown Creek
BTH - Booth Creek
FC - Fansher Creek
FX - Fox Creek
GC - Gold Creek
HC - Haggerty Creek
LB - Little Bear Creek
LB2 - Little Bear Creek 2
LC - Long Creek
LS - Lower Sydenham River
MC - Morrogh Creek
MX - Maxwell Creek
NS - North Sydenham River
OC - Otter Creek
RC - Running Creek
SHD - Stonehouse Drain
SR - Sydenham River
UN - Unnamed Creeks
Petrolia
Brigden
Oil City
Oil Springs
Alvinston
Wilkesport
Florence
Wallaceburg
Dresden
Reach Categories
0.0 - 0.030
0.031 - 0.060
> 0.060
Gradient (%)
1.00 - 1.24
1.25 - 1.50
> 1.50
Sinuosity
Scale (km)
0 5 10 15 25
PARISH geomorphic

Sydenham River
Fluvial Geomorphology Study

Figure 13. Change in reach lengths in the Sydenham watershed 1969-1993.



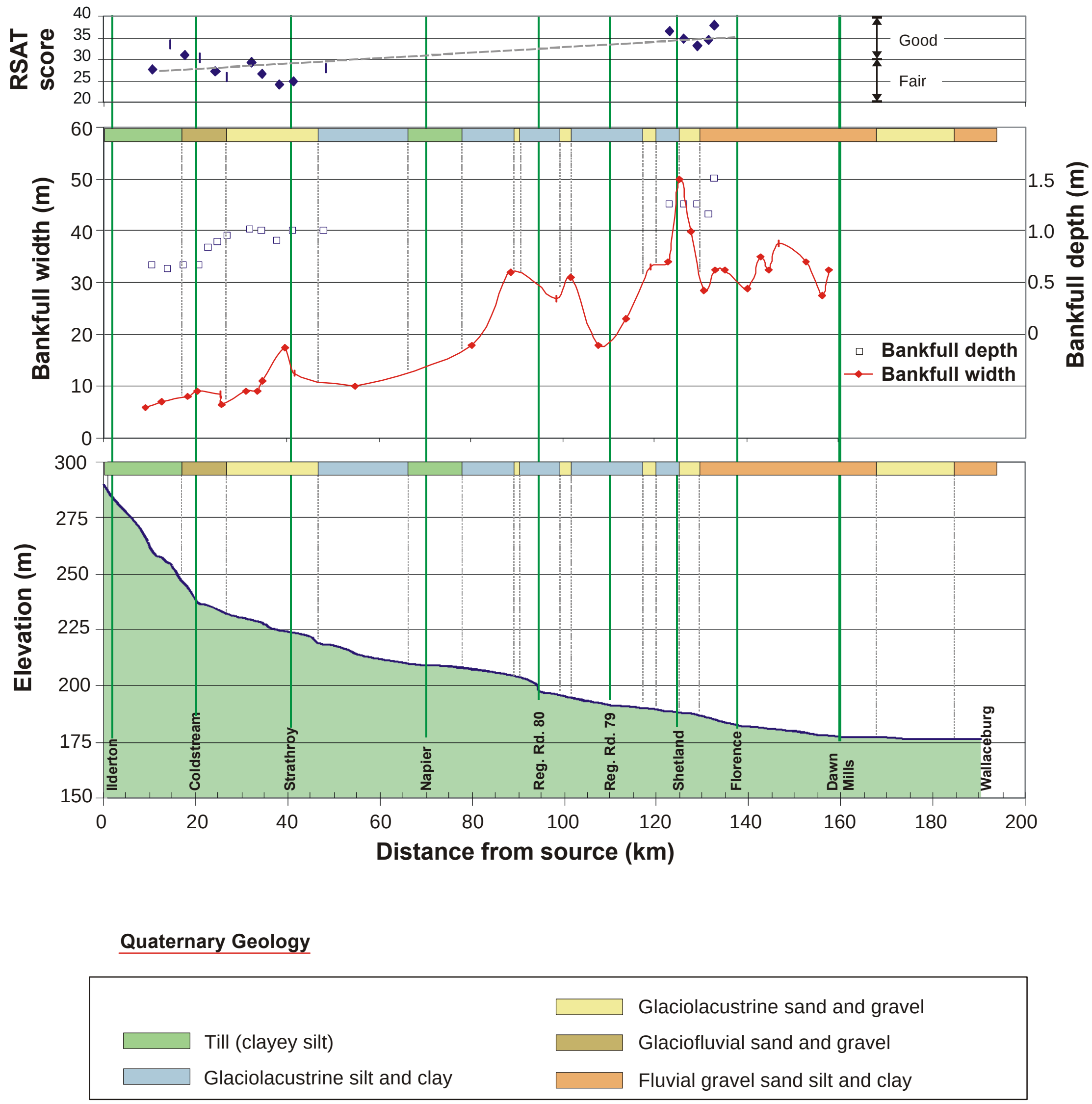


Figure 14. Relationship between gradient, bankfull width and depth and RSAT scores along the East Sydenham River.

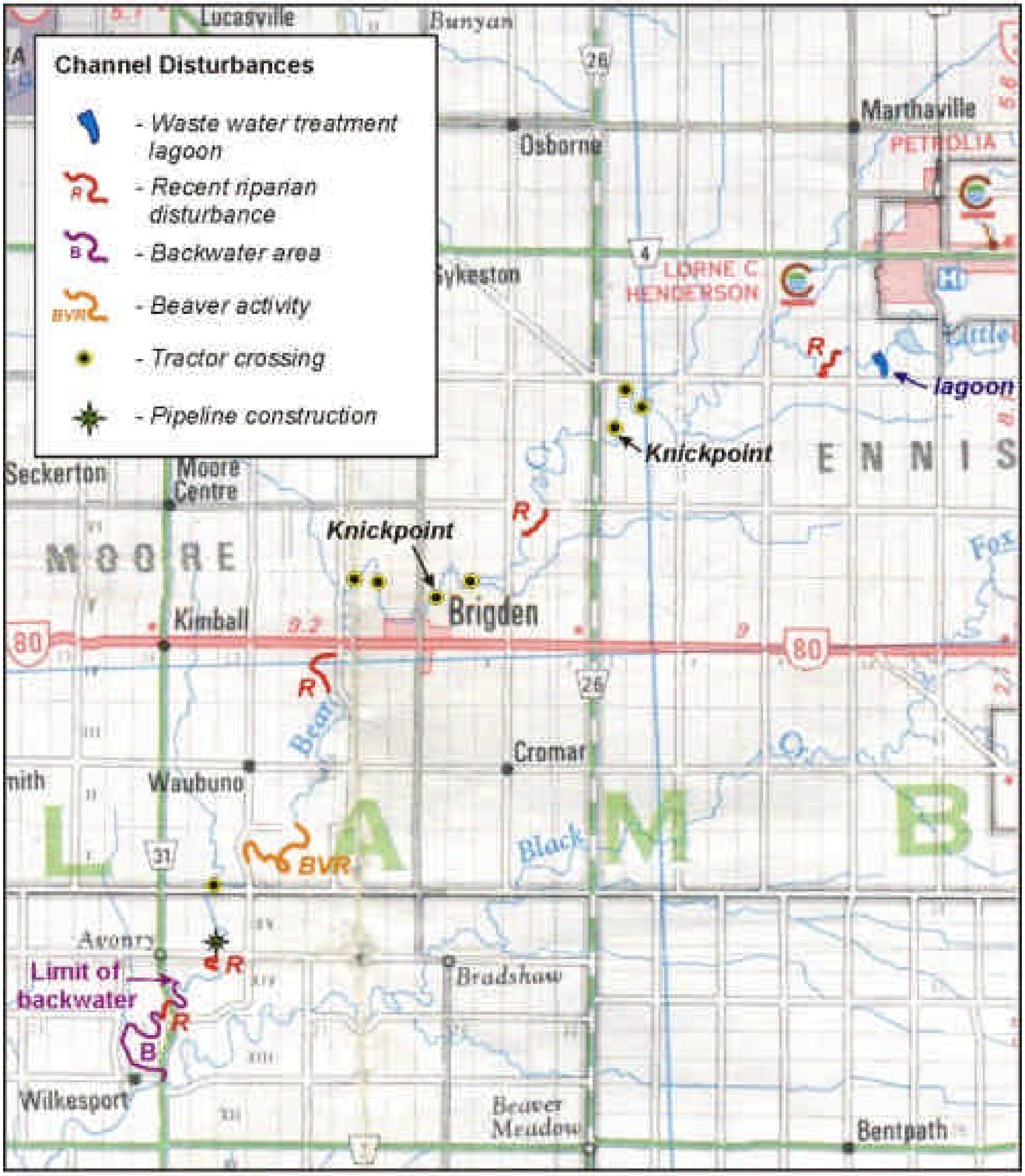


Figure 15. Location of channel and riparian disturbances along Bear Creek between Petrolia and Wilkesport.

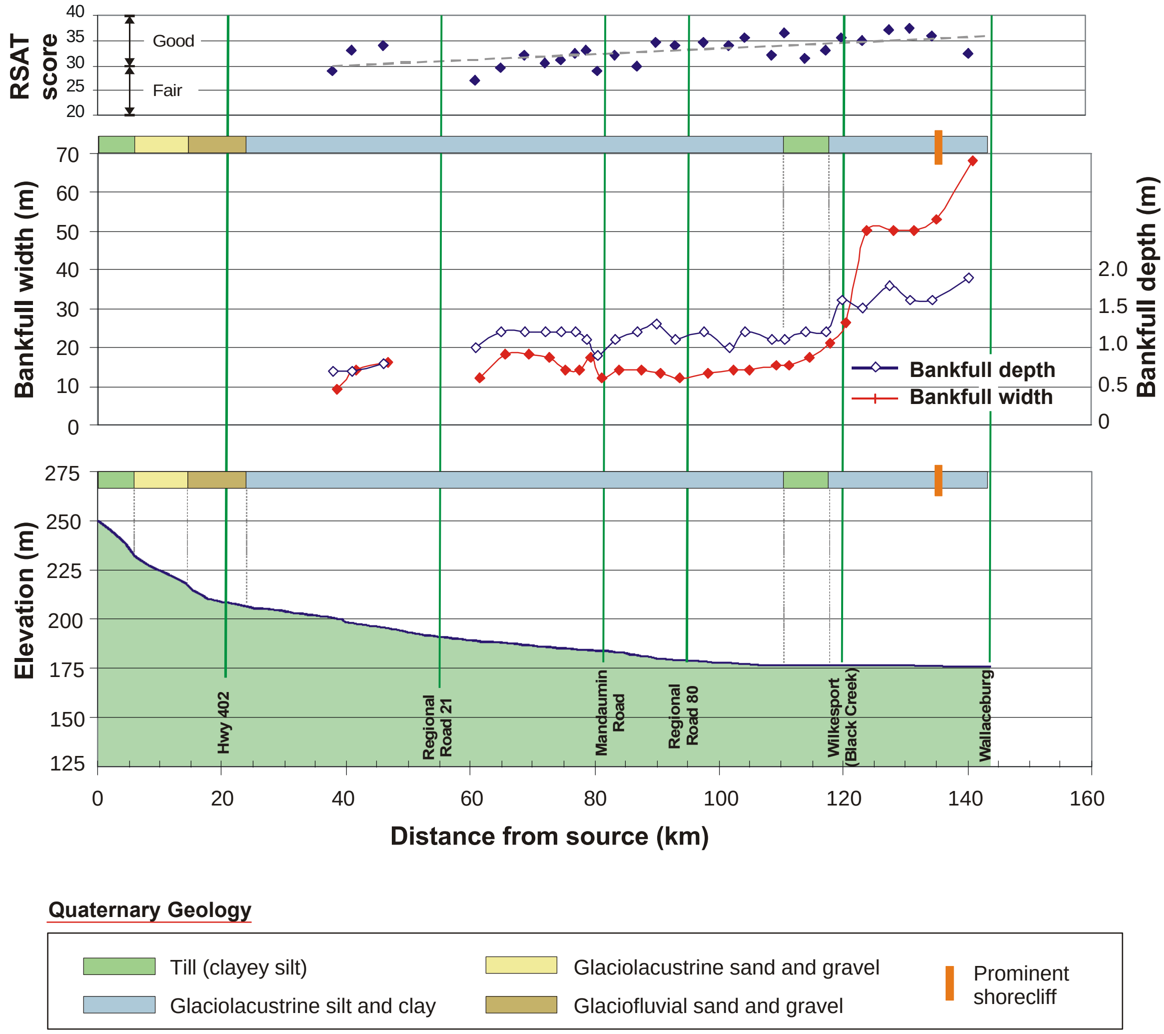


Figure 16. Relationship between gradient, bankfull width and depth and RSAT scores along the North Sydenham River/Bear Creek.

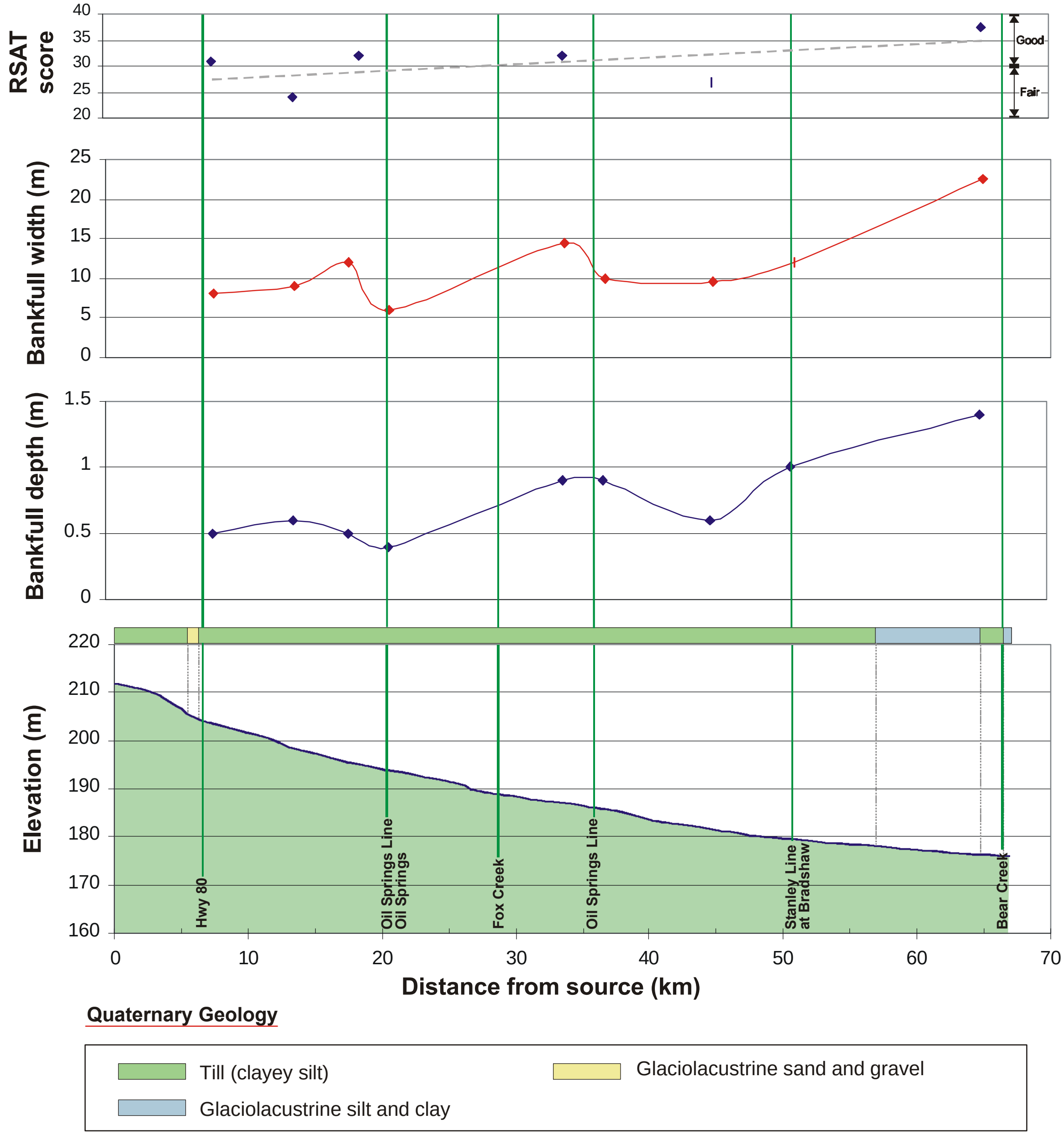


Figure 17. Relationship between gradient, bankfull width and depth and RSAT scores along Black Creek.

6.0 Discussion

6.1 Existing watercourse condition

Overall, the state of the Sydenham watercourses is considered to be fair to good with some reaches experiencing local disruptions to physical processes. The flow data indicate maximum instantaneous discharges have systematically decreased since records began in the late 1940's. This trend was also observed in the relatively close Maitland River watershed (unregulated), indicating that fluctuations in precipitation have likely had some influence on the magnitude of peak flows. The construction of dams and reservoirs and the cumulative effect of smaller dams may also have some influence.

With respect to the physical stability of the watercourses, leaning and fallen trees and exposed roots were a common occurrence, particularly in Bear Creek suggesting that erosion processes were evident. However, this activity was predominately located along the outside of meanders where it is to be expected as part of the natural process of channel migration. The tortuous meanders observed in many areas of the watershed further indicate that channel migration is an ongoing process. Excessive erosion was observed but in localized areas where cattle had access to the channel or in sections where construction activities were occurring, such as where land was being cleared for agriculture. The overall fair-good health of the system indicates that the complete recovery of the Sydenham system is a feasible goal.

Two activities that have impaired the physical health of reaches include livestock access to the channel and reductions in channel length. Livestock grazing tramples bank vegetation and macrophytes, destabilizes bed and bank material and morphology resulting in local widening or deepening of the channel. Grazing activity appears to have a greater impact in the upper reaches and tributaries of both North and East systems. Streams are smaller and shallower in these locations and livestock often have access to the entire channel. In the lower sections of the river, e.g. the North Sydenham, the water is too deep for livestock to cross and thus impacts are limited to the upper portion of the bank.

The reduction in channel lengths, most notable in the upper reaches of the East Sydenham, also impair channel function. The reduction in stream length is a form of channelization that involves "cutting off" one or more meander sequences to improve drainage and reduce the local effects of flooding. The harmful effect on streams has been well-documented (Emmerson, 1971; Brice 1981) and range from possible alterations to flow velocity to changes in hydrology and sediment transport regime (Table 5).

Table 5. Effect of straightening a reach by cutoffs (after Simons and Senturk 1977)

Local effects	Upstream effects	Downstream effects
1. Steeper slope 2. Higher velocity 3. Increased transport 4. Degradation and possible headcutting 5. Banks unstable 6. River may braid 7. Degradation in tributary	1. See local effects	1. Deposition downstream of straightened channel 2. Increased flood stage 3. Loss of channel capacity

Pipeline construction (dry crossing) was observed in Bear Creek during the field reconnaissance. Despite the amount of earth being moved during the procedure, there was no indication of excess sediment entering the channel during the procedure. Turbidity levels appeared identical both upstream and downstream of the crossing. Research (Anderson, *et al* 1997) on a small sand bed system in Eastern Ontario indicated that the impacts of wet crossings (more pronounced than dry crossings) were short term and limited to temporarily elevated sediment transport within 100-200 metres of the crossing. Fish and benthic populations were unaffected.

6.2 Trends

Trends can be grouped into spatial and temporal. Temporally, there was a 1.8% reduction of reach lengths between 1969 and 1993. If extended to include all watercourses in the watershed, this proportion would likely be higher as first and second order streams are more likely to have been straightened. Many smaller creeks appear to have been channelized prior to 1969, as indicated on the topographic maps. It is also possible that many first order streams were removed by ploughing. The implication for downstream reaches is increased sediment loads as the smaller tributaries work (i.e. erode) to become re-established. The RSAT data indicate that reaches in the upper portion of the watersheds are slightly more impaired in a physical context than reaches lower in the system. The trend is more pronounced on the East Sydenham River where channelization is more predominant.

In an effort to improve drainage, low order channels have been turned into ditches or removed altogether, being replaced by tile drainage systems. Low order channels serve an important function within any drainage network. During precipitation events, runoff begins to fill these channels until there is sufficient volume to promote flow. The lag time between the onset of precipitation and the downstream flow of water in the low-order stream lengthens the duration of the storm hydrograph and attenuates peak flow. Channel configurations continually adjust to the hydrologic regime of the drainage network therefore low order streams should be maintained and enhanced where possible to maintain the drainage density within the subwatershed.

6.3 Effect on rare species

There are several activities that disrupt the physical processes and structural habitat utilized by the rare species identified in the Sydenham watercourses. Anthropogenic disturbances include livestock grazing, channelization, tile drains, scour at bridges and downstream of dams, destruction of the riparian zone and instream activities, such as tractor crossings and pipeline construction. Land use, in particular row cropping, also contributes to erosion and the overall sediment load. The principal impact of these activities is habitat impairment or loss through increased erosion and sediment delivery. The high turbidity and embedded substrate in Bear Creek indicates that sedimentation is a continuing process in this portion of the watershed. Sedimentation was noted as a limiting factor for the survival or reproduction of several species of mussel. Fish also suffer as spawning beds are smothered and forage habitat is impaired.

Dams and reservoirs affect stream hydrology and, in turn, sediment transport. Upstream effects are considered minor (Knighton, 1984), with the effects being limited to an increase in the elevation of local base level extending upstream to where the water surface intersects the original bed. The elevation of the dam crest or spillway determines the increase in elevation. With a reduction in capacity and competence for sediment transport, a depositional wedge forms and channel gradient is locally lowered. Downstream of the dam, there is a marked decrease in sediment transport, especially reaches close to the dam (Petts, 1977). Stream energy below dams is greater than upstream, resulting in increased erosion potential.

Although large dams operated by the Conservation Authority are intended solely for recreation purposes, they still influence basin hydrology. Some degree of ponding could be expected during bankfull (or larger) events, and thereby have a dampening effect on the intensity of peak flows in the main channels. Sediment supply would have to come from bank erosion the main channels as little is coming from the tributaries. Lower peaks would mean flow competency would be decreased but this would not likely have a considerable effect on the channel as much of the sediment is fine grained.

7.0 Summary

The watercourses in the Sydenham basin are in generally fair to good physical condition. RSAT scores indicate physical processes such as sediment transport and flows have not been seriously impaired due to land use practices or direct alterations to the channel. The headwater channels and tributaries were more degraded and problematic. These channels are smaller and thus more sensitive to the effects of disturbances such as livestock grazing and trampling. The degraded nature of the tributaries is also manifesting itself on the main stem channels (e.g. increased turbidity and sedimentation). A recovery effort should therefore focus on the tributaries and local areas along the main channels.

A combination of climate change (fluctuations in precipitation) and dams appears to have reduced peak discharges in the Sydenham River basin. Decreased peak flows would decrease the channel's ability to transport sediment. Typically, a reduction in peak flow would result in reduced channel widths. Although indications of channel "narrowing" were not directly observed in the field, this process would have implications to channel biota as it would tend to decrease the amount of available instream habitat.

Direct evidence of habitat loss was observed due to a reduction in channel length. In a 24-year period between 1969 and 1993, nine kilometres of channel have been removed from the drainage network, likely through channel realignment works. This not only represents a substantial loss of habitat but also a potential source of sediment as the channels adjust (i.e. erode) to the altered energy state and flow regime. This activity was most notable in the upper reaches of the East Sydenham. In Bear Creek above Petrolia, 1.5 kilometres of channel has been cut off to accommodate bridge crossings.

Livestock grazing represents another harmful activity with both localized and basin-wide implications. The sensitive nature of the clay stream beds and banks compounds the effects. Locally, livestock access to the channel destroys habitat and destabilizes the banks through the physical process of trampling, whereas at the basin level, this activity impairs water quality and introduces additional sediment throughout the fluvial system. Tractor crossings present a further strain on the sediment transport regime by creating environments that promote accelerated erosion and deposition. These crossings create backwater areas that promote deposition and smoother habitat. At some crossings, the blockage of sediment has created substantial (1 m) knickpoints and localized bank erosion has the channel works to cut around the structures.

Additional erosion occurs at bridge crossings, particularly in areas where stream beds are composed of clay. Bridges appear to be too narrow to permit the passage of flow and areas of backwater develop. Since flows are confined laterally, stream energy is directed downward to the bed and scours the bottom. The amount of material by itself is not considered to be substantial but, when considered cumulatively with other sources, it represents an additional source of material that contributed to turbidity and sedimentation.

8.0 Recommendations for Future Work

This study was intended to present a broad-level assessment of the physical condition of the watercourses in the Sydenham basin and its importance with respect to the occurrence and abundance of rare species. In the course of this investigation additional information or knowledge gaps were noted. Recommendations for future work have been presented here to facilitate a better understanding of the dominant physical processes (e.g. erosion, sediment transport, sedimentation) that operate within the watercourses.

1. The link between land use and sediment delivery to the channels should be investigated further. Observations of bars at the mouths of small tributaries and gullies indicated excessive erosion of upland sources.

2. The magnitude and timing of sediment transport events may have shifted as a result of flow regulation. The potential effect upon rare species should be investigated.

3. Sections of channel that are in good physical condition and exhibit abundant rare species should be subject to detailed geomorphological investigations. This information would serve as a template to aid the rehabilitation of sections of the river destroyed or damaged by previous activities, such as grazing or channelization. The East Sydenham River near Shetland would likely be a suitable reference area. A similar investigation in an area with low abundance of species would permit comparison of physical attributes and the identification of those most important to rare species.

4. Areas disturbed by channelization (e.g. reach BEAR-21 and SR-42) should be also be investigated in detail to determine the effect of these changes on the channels.

5. The two sites where detailed fluvial geomorphology data were collected (Annable, 1996) should be reassessed to determine if any geomorphic change has occurred along the river.

6. Similarly, at least one reach located downstream of a dam should be investigated to determine the magnitude and extent of the impact of the structure on channel form and process and on structural habitat.

7. Channel migration rates should be measured to identify reaches where the channel has been particularly active. Based on the rate of channel migration and the grain size of bank material introduced into the streams, this information provides insight on the degree of sediment transport through the system.

8. Documentation detailing recovery projects in neighbouring watersheds (if available) should be complied and reviewed to help determine the influence of channel morphology, dams, land use and precipitation trends on the overall health of these watercourses.

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10.0 Glossary of Terms

Aggradation

The building up of the land surface (or river bed) by depositional processes.

Bankfull (depth, width, discharge)

Channel dimensions associated with flow events that typically recur every 1-2 years and are largely responsible for shaping channel form.

Bed load

Sediment transported within a stream channel that rolls or bounces along the channel bed.

Channel migration

The long-term lateral movement of a stream channel resulting from processes of bank erosion and deposition. Rates of movement determined from historic aerial photography.

Entrenchment

A channel condition characterized by the inability of flows to access the floodplain during floods, caused by excessive incision of the channel bed or artificial heightening of stream banks.

Entrenchment Ratio

A term describing the vertical confinement of a river channel. The entrenchment ratio is the ratio of the width of the flood-prone area to the surface width of the bankfull channel.

Flood-Prone Area

The width of the channel at an elevation that corresponds to twice the maximum depth of the bankfull channel as taken from the established bankfull water elevation.

Flow regime

The frequency, duration and magnitude of flood events for a given cross-section along a watercourse.

Knick point

A prominent break in slope along the course of a stream channel.

Lag

In erosion environments, the coarse sediment left behind after the fine material has been winnowed away.

Planform

The physical characteristics of a length of channel as seen in planview. These include meander characteristics such as amplitude, wavelength and radius of curvature.

Planimetric form adjustment

Changes to the planform variables that naturally occur in meandering river channels. Form adjustments may result from fundamental changes in the watershed processes (e.g. climate change) or be accelerated by human action (e.g. alteration of flow regime caused by urbanization).

Rapid Geomorphic Assessment (RGA)

A numerical score of stream health based solely on the presence or absence of geomorphological features whose presence or absence indicate stability or instability.

Rapid Stream Assessment Technique (RSAT)

A numerical score of stream health measured on qualitative observations of geomorphic activity, biological diversity and water quality.

Reach

A longitudinal section of a stream unique physical characteristics (slope, land use, bank materials, stream size, discharge) that distinguishes it from other sections of channel.

Sinuosity

A term referring to the amount of meandering exhibited by a stream channel. Values between 1.0 and 1.5 indicate sinuous channels whereas values greater than 1.5 represent meandering channels.

Stream order

A classification of a drainage system according to a hierarchy of orders of magnitude of the channel segments. The unbranched channels that terminate at the stream head are termed “first order”.

Appendix A. Photographs of the Watercourses

Photo 1. *North Sydenham, Reach NS-1.* The channel is wide and deep with no apparent morphological structure. The wakes from boat traffic have historically contributed to bank erosion at this location.

Photo 2. *Reach NS-2.* This reach is characterized by its wide channel width and very narrow riparian zone.

Photo 3. *Reach NS-3.* The Darcy McKeough Dam has influence on this reach. At the time of survey the floodgates were open.

Photo 4. *Reach NS-4.* A typically wide reach, with little bed morphology. At the time of the survey many large algae blooms were present in the channel causing large patches of "green water".

Photo 5. Confluence of Bear Creek (left) and Black Creek (right) where they become the North Sydenham River. Note the erosion occurring at the confluence.

Photo 6. *Reach BEAR 3.* This reach has many areas of erosion and a large amount of wood debris. Note the meander cut-off, which is occurring at the right of the photo.

Photo 7. *Reach BEAR 4.* Pipeline construction has blocked the channel and the flow is being pumped around the site and down the bank (center).

Photo 8. *Reach BEAR 6.* This reach is well vegetated which has allowed significant beaver activity to occur as indicated by several beaver dams.

Photo 9. *Reach BEAR 10.* An abandoned crossing is creating a large backwater area. The channel has begun to circumvent the crossing by eroding away the left bank.

Photo 10. *Reach BEAR 11.* This lower portion of this reach has well defined bed morphology as displayed by the above riffle. The riffles tended to be coarser indicating an increase in local gradient.

Photo 11. *Reach BEAR 11.* This photo typifies the effect of cattle access to the channel. The banks tend to be grazed bare and cattle movement up and down the banks exacerbates erosion.

Photo 12. *Reach BEAR 14.* Considerable garbage was observed in Bear Creek. The bridge in this photo was used to dump garbage.

Photo 13. *Reach BEAR 17.* A portion of this reach has experienced recent floodplain clearing and cultivation to the stream margin.

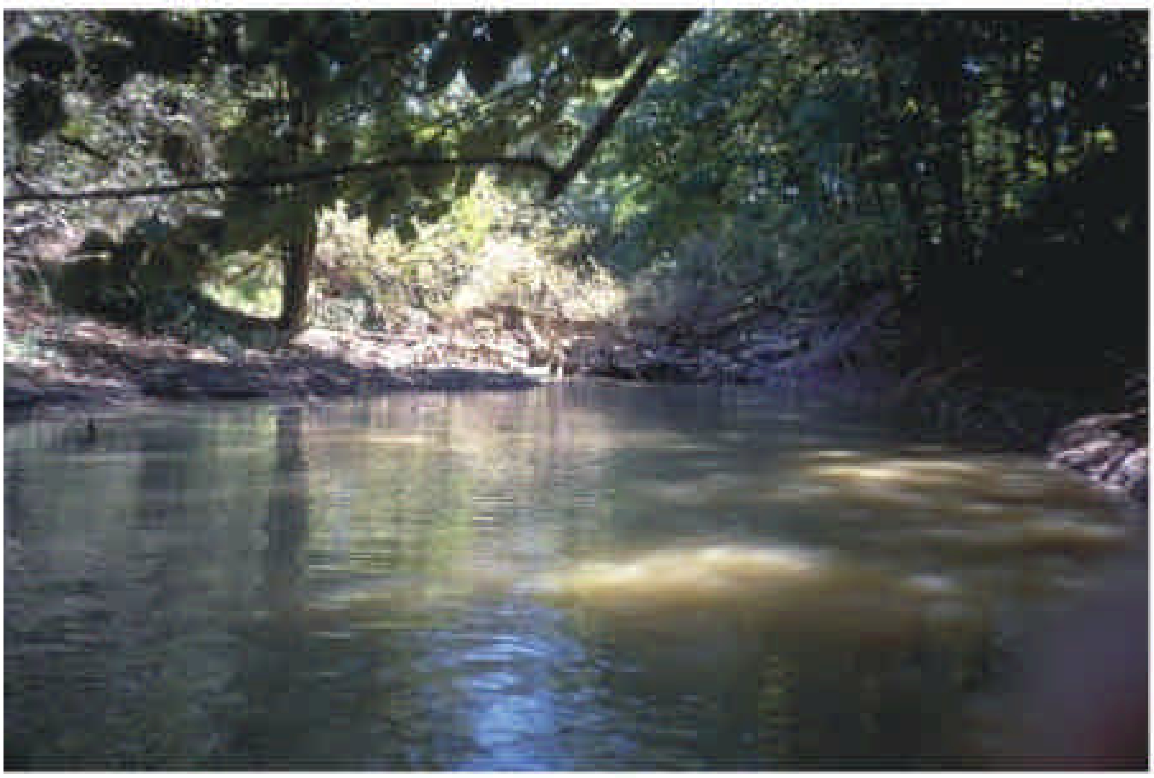

Photo 14. *Reach BEAR 19.* Near the town of Petrolia, this reach has extensive amounts of wood debris. Many trees were leaning or had fallen into the channel due to bank erosion.

Photo 15. *Reach SR 14.* Banks tend to be somewhat eroded with some leaning or fallen trees. Note thatch in the tree (top right) indicating the level of recent high flows.

Photo 16. *Reach SR 16.* Well-defined pool-riffle sequences, bedrock substrate and dense bank vegetation define this reach.

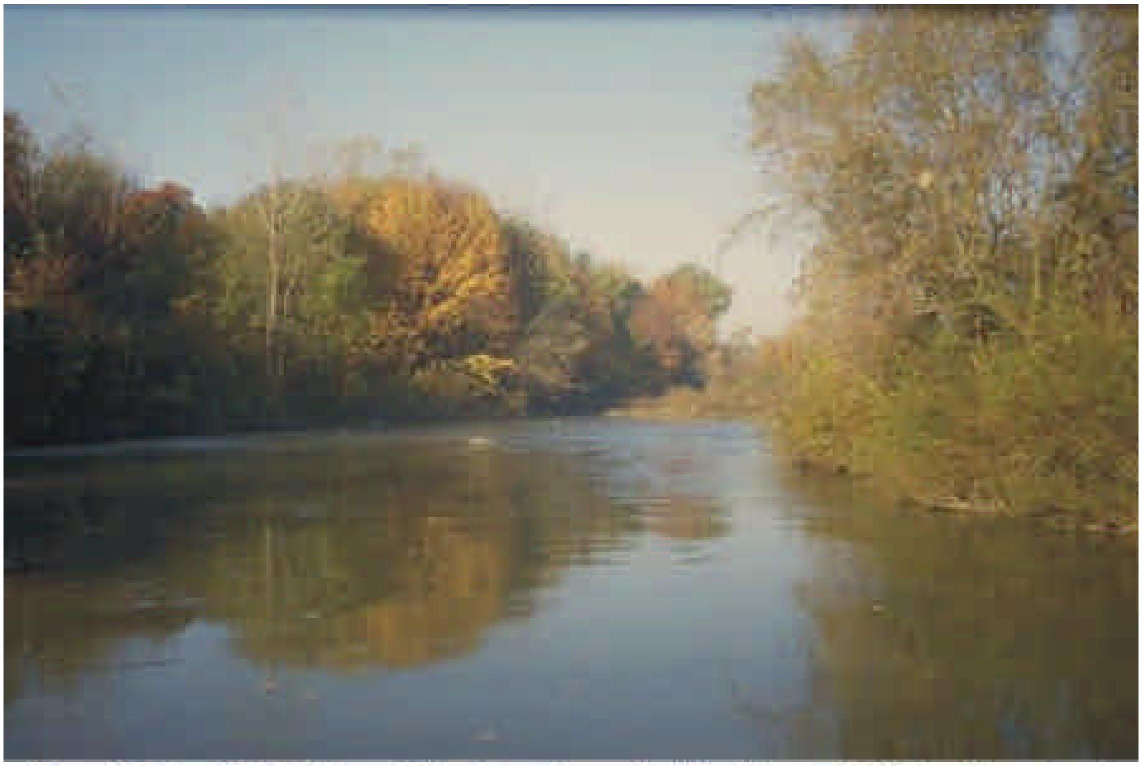

Photo 17. *Reach SR 17.* Several islands are located within this reach. Bedrock dominated pool substrate whereas coarse gravel and cobble was found in riffles.

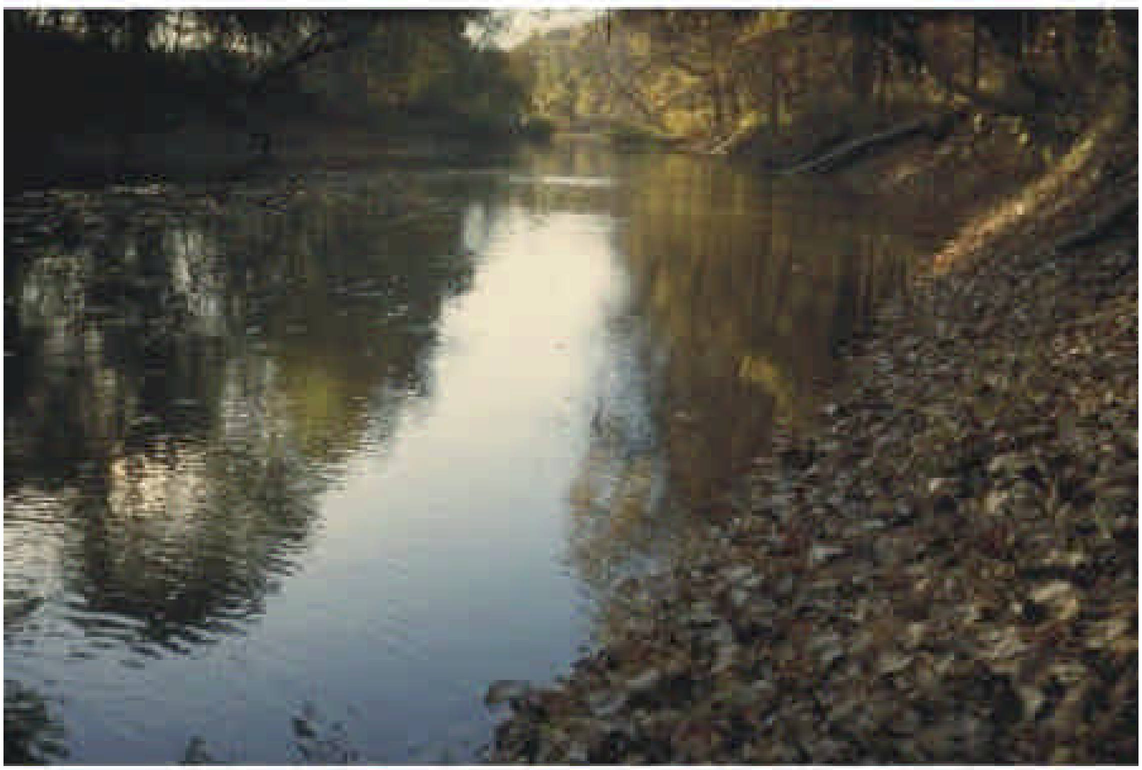

Photo 18. *Reach SR 26.* Located approximately 6 km downstream of Alvinston. Steep, clay banks dominate this part of the watercourse as the river flows across a lacustrine clay plain.

Photo 19. *Reach SR 33.* The bridge crossing and livestock activity have caused a local increase in channel width. Note narrower stream 100 m upstream of bridge (top right)

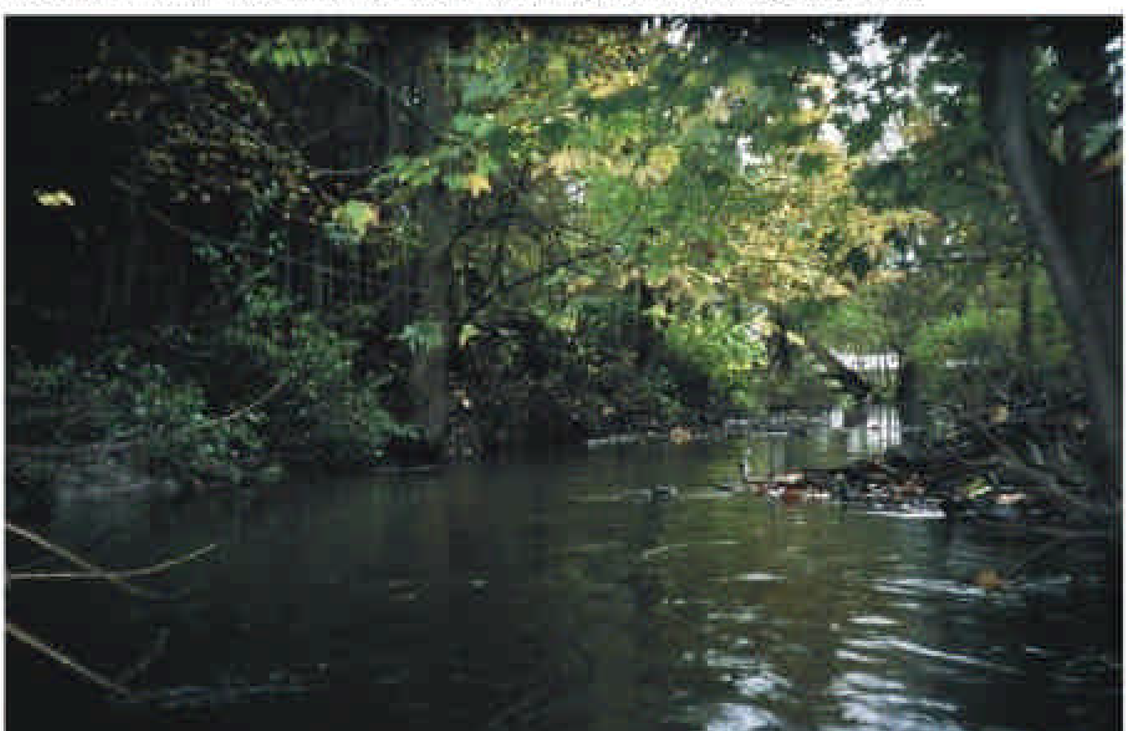

Photo 20. *Reach SR 41.* Forested portions of this reach contribute significant amounts of wood debris to the channel. Flows were approximately 60-80% of bankfull.

Photo 21. *Reach SR 45.* Park area downstream of Strathroy. Sandy soils increase the sensitivity of the banks to erosion. Vegetation has been mowed to the bank (above) which has contributed to increased bank erosion at this site.

Photo 22. *Reach SR 45.* Reservoir upstream of dam in Strathroy. Siltation is an ongoing process in this area.

Photo 23. *Reach SR 47.* Midway between Coldstream and Strathroy. The channel flows across lacustrine clay plain and is narrow and deep with significant woody debris.

Photo 24. *Reach SR 50.* Portions of this reach have been affected livestock grazing. Many banks exhibit signs of erosion and degradation.

Photo 25. *Reach SR 51*. This relatively narrow but deep reach has large amounts of woody debris within the wetted part of the channel .

Photo 26. *Reach SR 55*. Bank erosion and relatively high sediment loads were predominant in this portion of the watercourse, as illustrated by the bar deposits and undercut banks. View upstream.