PLANNING for EXTREMES

Adapting to impacts on soil and water from higher intensity rains with climate change in the Great Lakes basin

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Executive Summary

A number of studies indicate a trend since 1970 towards heavier rain events and more frequent intense events in the southern Ontario part of the Great Lakes basin. This is consistent with observations of increased precipitable water in the lower troposphere and general theory linking observed higher temperatures to greater water vapour in the lower atmosphere. These phenomena, in southern Ontario and many other parts of the world, are linked to climate change driven primarily by increasing greenhouse gas concentrations especially since about 1970. Such trends will continue for some decades to come.

Maximum intensities for one day and for 30 to 60 minute durations have been rising, on average, at rates of 3 to 5% per decade, although not all stations exhibit this upward trend. Climate models project continued increases of this order. Another study shows that heavy one-day rains above a certain high threshold have been increasingly frequent in this region since 1950. Increases in frequency have been greatest in summer but have also been substantial approximately 4% per decade, in early spring (March, April, May). A further preliminary analysis for a few stations suggests a shift to heavy rainfall events earlier in the season especially May. Total precipitation has increased by a lesser amount, except for increased snowfall in the lee of the more ice-free and warmer Great Lakes.

An analysis of implications of these precipitation changes for erosion of agricultural lands suggests that increases in spring rain events may be most important, but very severe storms in summer can also be significant. About 85% of annual in-field soil erosion occurs in spring and summer. In summer, a single event, causing the greatest soil loss, can account for 60% (±40%) of the total loss. In both spring and summer large sediment loads from eroded lands are event driven. However, the seasonal pattern of river sediment loads suggests that effective surface runoff/overland flow transport exists only in late winter and early spring. In addition, in rolling upland areas most of the soil erosion and stream suspended sediment is generated in small percentages of total watershed areas.

Using erosion models, (See Chapter 3), the possible changes since 1970 with the changes in rainfall regimes noted above could be summarized as:

RAIN CHANGE	EROSION OR SEDIMENT CHANGE	
Increase in intensity or frequency of heavy events	**Increases**	
4% per decade (March, April, May)	Localized soil loss Total spring soil loss	20% – 30% 13% - 19%
5% - 7% per decade (June, July, August)	Localized soil loss Total summer soil loss	25% - 50% 14% - 20%
4% per decade (March, April, May)	Spring sediment loads Contribution to annual soil loss	13% - 19% 9% - 13%

Potential trends of these orders of magnitude are likely to continue in future decades unless significant erosion prevention measures are undertaken. Water quality implications in the Great Lakes and its major tributaries arise from the sediment particles themselves, chemicals (phosphorous, pesticides, trace metals, bacteria), attached to the particles or in solution in increased surface runoff events. Benthic invertebrates in water bodies are an important link in the aquatic food chain and they are threatened as sediment transported from eroded soils would cover their natural habitat. Data to determine such trends quantitatively could include data archived from water treatment plants intakes or satellite imagery. These data sets are either not available or not yet analyzed for this purpose.

Other aspects of climate change, especially higher air and water temperatures, longer ice free seasons and later snowmelt also affect water quality and ecosystems in the waters of the Great Lakes basin. We anticipate deeper mixing zones and greater hypolimnetic oxygen depletion especially in the central basin of Lake Erie. As a consequence, the summer refugia for cold water fish will be restricted between deeper warmer waters and oxygen depleted deep waters. The effects of more high intensity rains interact in complex ways with these other aspects of change.

Dry periods and lower lake levels expose some sediments to oxygen resulting in the reoxidation of reduced sulfur compounds in the sediments with the next rain, high levels of sulfate and acidity will be released. Such conditions are expected to contribute to higher levels of methyl mercury, the form of mercury that accumulates in food chains leading to man.

For some lakes in agricultural areas, more frequent events that move nutrient-rich fertilizers and manure from farmland more often would result in greater biological production and the trend towards a more eutrophic state. But other lakes are becoming clearer as a result of less dissolved organic carbon export from the drainage basins. This results in greater penetration of light and ultraviolet radiation. Consequently, algal primary production will be inhibited and shifts to more noxious blue green algae may occur. Such conditions also impact the zooplankton grazing community as well. With increased water clarity, increased growth of weed beds will result. Boating will become difficult in some areas. Due to the near shore circulation patterns in the Great Lakes, the coastal waters, where most uses are concentrated, will be more frequently turbid after heavy rains.

Adaptations or Remedial Responses

Progress has been made in Ontario in steps to limit erosion losses. By 2004, 40% of Ontario farms had been part of the Environmental Farm Plan Program. Earlier estimates suggested water erosion risks were reduced by the order of 21% by actions on the land between 1981 and 1996, but that 60% of the land area still contained “intolerable risk cases”. No till adoption increased dramatically between 1991 and 2001, with greatest adoption rates, as high as 50% of farms in Lambton and Essex Counties,. Nevertheless, the few sampling stations from which trends in sediment loads for southern Ontario could be inferred suggest little change.

Question: Have improved land use practices approximately offset increased erosion and sediment potential with the changing rain regime? A 2005 Agri-Environment Canada Report suggests that this may be so.

Successful programs to reduce pesticide use, and changes in crops, have resulted in a 52% overall decline between 1983 and 2003 as measured by active ingredient. However, glyphosphate-based pesticide use, especially on soy beans, has increased 58%.

Actions Recommended

1. Develop a relatively simple methodology for identifying and mapping those portions of rural watersheds (at a field scale) that constitute critical source areas for surface runoff, stream sediments and associated contaminants, with particular attention given to winter and spring runoff conditions.
2. Expand the implementation of nutrient, pesticide and bacteria control measures in all agricultural regions of the province, with particular attention given to those portions of rural watersheds that constitute i) critical source areas for surface runoff and stream sediments, and ii) critical source areas for groundwater recharge, with a primary focus on winter and spring conditions.
3. For all farms, move towards:
    a. further reduction of pesticide use by 30% (IJC 1998 recommendation),
    b. providing for adequate containment of manure and elimination of winter spreading, and minimization of chemical nutrient application especially in spring,
    c. minimized non-growing season chemical and nutrient application,
    d. installation of buffer strips or set back zones, where beneficial,
    e. expanding wetlands where they can be effective in reducing peak flows.
4. Develop a plan for compensation to farmers for conservation measures to reduce sediment and pollutant transport to waterways, to protect soil and water quality, and sequester greenhouse gases.
5. Conduct programs to increase areas of forest and wetlands in critical source areas to reduce movement of sediment and contaminants into waterways and the Great Lakes.
6. Monitoring and Assessments to understand trends in the Great Lakes basin related to climate change:
    a. Reinstate systematic sediment transport monitoring on major tributaries to Great Lakes[1] and ensure that large runoff/erosion events are measured,

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[1] In its program on "Watershed Evaluation of Best Management Practices", Agriculture and Agri-Food Canada has instrumented the South Nation watershed, tributary to the Ottawa River.

b. Provide for a more extensive network of recording rain gauges and keep up-to-date the analyses of intensity-duration-frequency data,

c. Institute a long-term small watershed study in an agricultural region tributary to the Great Lakes, with instrumentation to determine impacts on sediment transport and runoff with various agricultural practices, and trends of extreme events,

d. Measure and assess near shore Great Lakes water quality in late winter and spring each year for chemical composition, turbidity, bacterial contamination and biological production, and

e. For the Great Lakes, use satellite imagery to assess sediment transport and dispersion, and analyze water quality from water intakes to assess near shore contamination.

7. Greenhouse Gas Mitigation

Agricultural areas should be managed to increase carbon sequestration in soils, vegetation and products, and everyone should participate at personal, business, municipal, provincial and federal levels to reduce greenhouse gas emissions.

Note: The above recommendations are primarily for consideration of and action by Ontario and Federal agriculture and environment departments, and Ontario Conservation Authorities. Some may be undertaken in the framework of new programs and legislation such as those for Nutrient Management and Source Water Protection.

Chapter **1**

Introduction

By James P. Bruce

The changing climate, due mainly to increases in greenhouse gases in the global atmosphere, is manifest in a number of ways. Higher temperatures at earth's surface and greater amounts of water vapour in the atmosphere are two fundamental changes being observed over the watershed of the Great Lakes and in much of the world. These factors are combining to produce heavier storm rainfalls at many locations for durations ranging from 30 minutes to 24 hours.

It has long been recognized that for a given soil, slope and vegetative cover, the frequency and intensity of such heavy rain events is a primary trigger for erosion. For example, in the revised universal soil loss equation (RUSLE), developed by U.S. Department of Agriculture scientists (Renard, K.G. , et al., 1997), and adapted to Canada, (Wall et al., 2002) is widely used to estimate erosion losses. Soil erosion rates are proportional to E, the total storm energy, times I_{30} the maximum 30 minute rain intensity. E is related to the amount of rain from a given storm and I_{30} to the peak intensity for a 30 minute period. Other techniques to estimate erosion rates from rain are also used, but they all include some measure of the energy of the rain, closely related to intensities over short periods of time. Surface runoff also occurs during and after storms of high intensity and/or snowmelt events. Studies by Soil and Water Conservation Society (SWCS) and Nearing using U.S. data show that relatively small increases in the rainfall index can result in substantial additional erosion losses and surface runoff (SWCS 2003, Nearing 2004).

Sediment particles, particularly those from cropland, are often transported to the nearest waterway and from there to major rivers and lakes. Not only is the sediment itself, especially suspended sediment, an undesirable pollutant, but the sediment particles usually have attached to them toxic substances, such as pesticides, and nutrients particularly phosphorus and nitrogen. Where manure is spread on fields, pathogens can also be swept into water systems by runoff from heavier rains, adding to the burden due to dissolved chemical pollutants in agricultural runoff.

Thus an increase in the rain intensity regime of a region will result in increases in erosion rates and storm runoff and thus augment the input of toxics, nutrients and pathogens to rivers and lakes and perhaps to wells and groundwater. In the U.S. portion of the Great Lakes basin, and elsewhere in most of the U.S.A., rain regime trends towards higher intensities have been documented and their impacts assessed, in an initial way, by the Soil & Water Conservation Society (2003). This present study is being undertaken to determine the extent to which these phenomena are also occurring in the Canadian portions of the Lake Huron-Georgian Bay, Lake Erie and Lake Ontario watersheds. An initial study by Adamowski et al. (2003) of short duration rain intensities in Ontario indicates that increases have occurred in the past 30 to 40 years. This is the period over which greenhouse gases became the dominant factor in changing the global climate. With the full climatic effects of greenhouse gases already released to the atmosphere still to be experienced, and global emissions of such gases continuing to increase, the trend towards heavier rains at many locations, experienced in the past four decades, is likely to continue in coming decades.

This report provides information to quantify the rainfall regime changes to date and assess projected changes into the future. Estimates are made of the implications for soil erosion and runoff in Ontario and impacts on water quality in the affected Great Lakes and their main tributaries.

A review is also presented of policies and practices in soil erosion prevention and control measures in Ontario in order to assess their adequacy in the near term future. A set of recommendations is then presented on modifications needed to erosion control and prevention practices, and design criteria, to cope with the changing climate and to minimize future soil losses, and water pollution. At a later stage, these results in the Canadian portion of the Great Lakes Basin, will be inter-compared and integrated with similar data and analysis in the U.S. part of the basin, by the SWCS. This will afford an overview of past trends and likely future trends with climate change, of pollution of the Lakes as a whole from agriculture sources, due to changes in rainfall regimes.

Chapter 2

Trends and Projections of Intense Rain Events

By James P. Bruce

Factors Affecting Rain Intensities

Since the late 1960s trends towards warmer climatic conditions have been driven dominantly by increases in greenhouse gases from human activities (Intergovernmental Panel on Climate Change, IPCC 2001). Before then, natural climate forcing factors, such as changes in the sun's energy, earth's albedo and volcanic emissions, were important factors, along with greenhouse gas changes, in driving changes in global and regional climates. But from the mid 1960s on, the effects of these natural factors have been overwhelmed by the rapidly rising concentrations of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Thus climate changes since the late 1960's are related primarily to forcing by greenhouse gas increases, and are a foretaste of climate of coming decades, which will undoubtedly be driven by increasing gas concentrations in the global atmosphere. Confirmation of IPCC's 2001 assessment on the relative importance of various forcing factors on the climate system, has been the outcome of much recent research (International Ad Hoc Detection and Attribution Group, 2005) (G. Meehl, et al., 2004).

The intensity of rain events are a product of:

- upward vertical motions caused by fronts, orographic effects and convection from surface heating,
- condensation processes, which may be stimulated by some forms of aerosols, natural or anthropogenic, and
- amount of water vapour in the atmosphere in the surrounding area that can be converted into rain (or snow).

In a generally warming climate the only lifting mechanism that may be changing is convection from surface heating probably increasing under certain circumstances. Condensation processes are likely not changing much, especially with emission control programs having some success in reducing aerosol emissions. However, the water vapour available for rain events is on the rise, from both theory and observations.

The theory of the relationship between temperature and the water holding capacity of the atmosphere is expressed by the long-used Clausius-Clapeyron equation. With reasonable assumptions, this suggests that for each 1ºC rise in lower atmosphere temperature, a 7% increase in column water vapour or precipitable water (P_w) could occur. Heavy rainfall rates greatly exceed evaporation rates and depend on low level convergence of water vapour from surrounding areas. Trenberth, et al. (2001) argue that the increased water vapour would result in higher intensity rains in rain events, rather than more total rainfall. They also conclude that greater potential evaporation occurs in a warming climate which can lead to drought between heavy rain events.

An analysis has been made of trends in water vapour measured in the atmosphere between 1973 and 1995 by Ross and Elliott (2001). They show general increases over most of North America, with the Great Lakes basin and southern Ontario P_w having increased more than 3% over that period. This is at a somewhat slower rate than would be suggested by the observed 1.5ºC temperature rise in the basin since 1970, and the Clausius-Clapeyron equation. However, this indicates that the direction of the process is correctly understood. Heavy rain events can, of course, be greater than the increase in P_w since both strong low level convergence can feed water vapour into a storm, and the latent heat release in the rain producing process, can itself reinforce rain intensities.

It may be noted that the observed and projected increases in precipitable water in the warming climate may call into question the safety of estimates of probable maximum precipitation for dam design. Most estimates made use of older (pre-1970 or 1980) measures of P_w.

Observed Trends

TABLE 2.1
Seasonal Precipitation Trends
mm change / mean over 10 year %

TIME OF YEAR	Winter		Spring		Summer		Autumn	
PRECIPITATION	**Snow**	**Rain**	**Snow**	**Rain**	**Snow**	**Rain**	**Snow**	**Rain**
Great Lakes St. Lawrence (Lake Huron plus LowerLakes basins)	-1.5	+2.6	-3.8*	+2.6*		+1.6*	-0.1	+2.9*

* Significant Trend (1895-1995) *Mekis and Hogg, 1999*

Seasonal Total Rainfalls

In a comprehensive study by Mekis and Hogg (1999) the precipitation records for a number of Canadian stations were adjusted to allow for changes in observing methods, particularly a new standard rain gauge in early 1970, and to important changes in sites at some stations. These authors also examined the trends in total precipitation over the period of record from 1895 to 1995. The changes observed over this period for the region and seasons of interest are given in Table 2.1.

Thus, in the basins of Lakes Huron, Erie and Ontario total rainfall has risen over the past century in spring, summer and autumn by modest but statistically significant amounts per decade. At the same time, the spring and autumn snowfalls have declined, as temperatures have risen. It is late winter, spring and early summer seasons when agriculture lands are most susceptible to erosion in high intensity rainfall. In the period 1940 to 1995, these authors found that over much of the southern lakes Huron, Erie and Ontario basins, there has been a small increase in the fraction of precipitation falling in heavy (>90th percentile) events. They also reported a slight decrease in the fraction of precipitation in heavy events over the Georgian Bay, northern Lake Huron basins in this period (1940-1995.)

One-Day Rainfalls

The impact of the generally warming climatic trend on intense rain events can be seen in data for the contiguous United States (SWCS 2003). The linear upward trend in the frequency of intense daily rain events for the period 1910 to 1970 was 0.9% per decade for “very heavy” events, those less frequent than the 1 percentile occurrence. For the same “very heavy” events the upward trend from 1970 to 1999 was 7.2% per decade. For “extreme” events (<0.1 percentile) the upward trend for 1910 to 1970 was 1.5% per decade but from 1970 to 1999 it was 14.1% per decade. This illustrates the rapid increase in trends towards heavier one day rain events since 1970 over U.S.A.

Another study (Kunkel, K., et al., 1999) assessed North American heavy rainfall trends, from 1951 to 1993 for Canada as a whole, and 1931 to 1996 for U.S.A. This analysis was for 1 to 7-day large precipitation events with a 1 year or longer recurrence interval. For Canada overall there was only a small upward trend on an annual basis, not statically significant, but for the spring period (M, A, M) a large upward trend was recorded, with a sharp break to more intense events after 1970. In the U.S.A., upward trends in the extremes were most pronounced in the region of the Great Lakes basin (Figure 2.1), even though the annual total precipitation increase was not pronounced in this area, except for the central Michigan peninsula. The upward trend for heavy events was greater than that for total amounts.

A study by Groisman et al. (2001) examined potential flood-producing 3 day rain events in U.S.A. and analyzed the trend in occurrence of 50 mm (or 2 inches), of rain on the third day. The analysis covered the whole 20th century, not differentiating the period from 1970 on. It showed a 36% increase in these events in the “mid-West” which included the U.S. portion of the Great Lakes basin. T. Karl and R.W. Knight (1997) showed upward trends in the percentage of the total annual precipitation occurring in heavy events for five countries: Austria, Canada, China, Russia, The Canadian data were from 1940 to 1996.

L.V. Alexander (Australia), X. Zhang (Canada), T. C. Peterson (USA) and others assembled and analyzed global data on one day temperature and precipitation. A strong increase in numbers of warm days in winter, but especially warm nights was documented for the Great Lakes region, suggesting earlier snowmelt episodes. This region also showed more heavy precipitation days, greater contribution to annual precipitation from very wet days, and increases in daily intensities. The seasonal charts suggest that the seasonal maximum 5 day amounts have been increasing over a larger part of the Great Lakes basin in spring (MAM) than in other seasons. Data for the analyses were from 1951 to 2003.

A Canada-wide analysis of frequency of one day rain events in several intensity ranges was undertaken by Stone, Weaver, and Zwiers (2000). For Southeastern Canada, including the Canadian portion of the Great Lakes watershed the study found that increases in total accumulation observed in spring and summer (AMJJ) were driven mainly by an increase in heavy event frequency (Figure 2.2). The average increase per decade in heavy rain frequency in May, June, July was 7% from 1960 to 1990. The frequency of April-May-June heavy events increased by 5%/decade on average and March-April-May rains by 4%/decade. (Figure 2.2) In Chapter 3 the much greater impact on erosion of intense rain events in spring is discussed. A smaller increase in total accumulation in autumn (S,O,N) was driven by events of both intermediate and heavy nature. Heavy rain events were defined as ≥ (5.0 + 5.0 x n) mm/day where n is the highest amount that results in at least 5 heavy events per year over the 1960 to 1990 period of the study.

An examination of the dates of heaviest rainfall for Ontario stations in the Great Lakes basin is an imperfect way of detecting trends but may be suggestive. The problem is that there were probably fewer observing sites prior to 1968 than later. Nevertheless the network was quite extensive in the early 60s and before then. At any rate, of 47 recorded one day rainfalls greater than 100 mm, 37 were from 1968 to 2000. Of the extreme amounts, greater than 140 mm, all 5 recorded were in the 1970-2000 period (see data in section on recent severe storms) (Emergency Management Ontario-Met Service Web site).

For this report an analysis was undertaken of trends in amounts of maximum annual one day rainfall amounts from 1970 to 1996, and for 3 stations where records had been abstracted to 2002. These annual maximum values were provided by Meteorological Service, Environment Canada (Robert Morris 2005, personal communication). These data were fitted with least squares trend lines. For 14 stations in the basins of Lakes Huron, Erie and Ontario, only three had negative trends. The latter were all due south of Georgian Bay in a pattern similar to that noted in figure 16 of Mekis and Hogg (1999). Average results for all 14 stations gave an upward trend of 2.6 mm per decade. When expressed as a percentage of the initial amounts of the trend lines, averaging 49mm, this represents about a 5% increase per decade, as an average value over the study area. An example of data and trend lines are given in figure 2.3 for Bowmanville. For the long term stations with one day data to 2002, Chatham (1966-2002) showed a downward trend of 1.3 mm/decade, and St-Thomas (1926-2002) a small increasing trend of 0.3 mm/decade. In extreme southwestern Ontario relatively low annual maxima were recorded from 1999 to 2002 resulting in the small trends observed at Chatham and St-Thomas. However the trend 1970 to 1996 was positive at both locations.

Short Duration Intensities

Rainfall of hourly or shorter durations must be measured by automatic recording rain gauges, which are operated, in Canada, at fewer locations than ordinary rain gauges which are read once or twice a day. In recent decades the Meteorological Service of Canada has not been able to keep up to date with processing all data from recording rain gauge charts. Thus it has been of great value that K. Adamowski and colleagues in the Department of Engineering at University of Ottawa took on the task of analyzing short duration data from some 15 stations in Ontario. Four of these stations are outside the Great Lakes drainage (Big Trout Lake, Moosonee, Chalk River and Timmins). Table 2.4 indicates the stations used, their locations and period of record. It should be noted that the majority of records begin in the years 1968 to 1971 and end mostly in 1997 or 1998, so they cover the period in which heavy one day rain events were increasing most rapidly in the U.S.A. and changes were driven mainly by greenhouse gas increases.

Adamowski, et al., (2003) summarized the impacts on the intensity-duration-frequency curves from the beginning of the record (generally about 1970) to the end (about 1998). The results are summarized in Figure 2.5 where changes in the intensity duration frequency (IDF) curves are presented. It will be noted that the largest percentage increases over the approximately three decades is for the 15 and 30 minute durations. The latter is generally considered critical for erosion of soil. The percentage increases for the most rare, 50 year return period events are less than for the more frequent 2 year heavy rains. Increases range from a low of 7% for 5 to 10 minutes rains of a 50 year return period to 16% for 2 year return period events for 15 to 30 minutes duration. For 60 minute rains, increases of 8-13% for various return periods were determined. (Figure 2.5) Thus for the erosion-producing 30-60 minute high intensity rains, an increase in amount of 3-5% per decade has been observed.

In a further analysis for this study, annual maximum 30 minutes rainfall amounts provided by the Meteorological Service, Environment Canada were examined. The data for 1970 to 1996 (27 years) were analyzed for 14 stations in the region of interest (Canadian parts of Lakes Huron, Erie and Ontario basins) Table 2.5. Most were station data sets additional to those analyzed by Adamowski, et al., (2003). Three stations (Kingston, Bowmanville and Preston) for which data were analyzed by that University of Ottawa group were re-analyzed, with essentially the same trend results. Both 30 minute and one day trend analyses for Bowmanville are shown in Figure 2.3, as an example.

Using both sets of analyzed trend data, provided 20 stations. Of this number 6 had negative trends over the 1970 to 1996 period. The remaining 14 locations exhibited increasing annual maximum values. If all of the trends are averaged over the basin, the mean rate of change was 1.05 mm/decade. This represents a 5%/decade increase over the initial average value of 20 mm.

There was no apparent geographic pattern to the locations where negative trends were recorded. From this it is assumed that severe convective storms which result in large 30 minute rainfalls are distributed fairly randomly and thus it is quite possible for some stations to have missed the heavier rains of later years in the period or to have been visited by heavy events early in the period, resulting in negative trends. However, the probability of increasing heavy falls, on average over the region, is quite evident in the data, and can be used in planning for erosion, runoff and water quality control measures

It must be recognized that, in the southern Ontario climate, some soil erosion and polluted runoff also occurs in periods of snowmelt, especially during rain on snow events on thawing ground. In a warming climate these conditions are likely to occur more frequently over winter months, as well as during the usual spring freshet. The major snowmelt event is tending to occur earlier, but generates increasingly less runoff, since in recent years much of the snowpack tends to melt during the warm episodes in the winter leaving less snow for the spring freshet. Using data up to the early 1980s, Madramootoo (1988) calculated rainfall and runoff erosion indices for Southwestern Ontario. He estimated that about 20% of the total annual erosivity index occurred in the four winter months D.J.F.M. A preliminary analysis of 15 to 360 minute maximum amounts on a monthly basis, for a few stations, suggests large increases in May since 1975, but negative trends in summer months.

Recent Severe Storms

To emphasize the somewhat random geographical distribution of very heavy rainfalls and to strike a cautionary note about projections from the least squares trend lines mostly to 1996 used in this study, it is instructive to consider some intense rain events of the year 2000 and following. Unfortunately these could not betaken into account in the general trend analyses since annual maximum data from 1996 on were not available for most stations.

Data for heaviest rainfalls in 2000 and 2004 were provided by Meteorological service, Environment Canada (Joan Klaasen, 2005, personal communication). These data are given in the following table 2.2.

For the 12 May, 2000 (Walkerton) storm the nearest long term station is at Owen Sound, a station with a decreasing trend line for 30 minutes rainfalls. The 56 mm 30 minute fall recorded at Goderich in this event far exceed the greatest (33 mm) in the Owen Sound 27 year record. In the 9 July, 2000 storm, Thorndale recorded a 1 day fall of 172 mm. It is close to London Airport where the 27 year record (indeed the 50 year record) maximum was 89 mm in 1986. On 31 July, 2000, the 141 mm in a day recorded at Dorset MOE greatly exceeded the previous high of 97 mm in 1980. In July 2004, Peterborough experienced severe flooding. The rains recorded at the Trent University gauge on 15 July, far exceeded those in the period of record 1970 to 2002 at Peterborough airport on the other side of the city. A similar vary high amount recently (June 2005) occurred at Barrie. This illustrates the point that there is a small radius of correlation for the most intense rain events which are due to local convective storms.

Heavy rains in eastern Ontario occurred on 9 Sept. 2004 as the remnants of hurricane Francis passed through. The daily amount at Ottawa’s airport of 137 mm exceeded the previous 27 year high of 116 mm set in 1981. The intense thunderstorm rainfall at Barrie in June 9, 2005 was reported (newspaper) as 100 to 130 mm. The previous 24 hour maximum since 1968 was 113 mm in 1986. The Grand River Conservation Authority reported one-day rainfall in excess of 200 mm on 13 June, 2004 in the northwestern part of the basin. (personal communication)

The data from these storms suggest that much higher amounts than the general trend lines indicate, have recently occurred, and also show how geographically concentrated these intense convective rain events can be. Remnants of hurricanes such as Francis and Hazel in 1954, can produce record 24 hour rainfalls over larger areas, but rarely result in record short duration amounts. Recent research suggests that hurricanes are increasing in intensity and longevity with warming oceans, and thus the Great Lakes basin can probably expect more frequent heavy rains generated by the remains of hurricanes. (K. Emmanuel, 2005) (Webster, P.J., 2005)

TABLE 2.2
Rainfall (mm)

Date	Location	30 min	60 min	1 day
12 May 2000	(Walkerton) Goderich (Owen Sound)	56	75	
	Orangeville	24	26	
	Summer Hill Markland Valley CA		48	
	Greenock-Sauger Valley CA		57	
9 Jul 2000	Thorndale-Upper Thames CA		61	172
31 Jul 2000	Dorset MOE	34	61	141
15 Jul 2004	Trent University (Peterborough)	46.4	87	240
9 Sep 2004	(Hurricane Francis) Ottawa CDA	17.4	29	116
	Ottawa, Macdonald Cartier Airport			137
	Proctor Creek (Lower Trent CA)		40	

Data from Joan Klaasen, MSC

Future Trends

In its 2001 review of the world's scientific literature on climate change, the IPCC (Intergovernmental Panel on Climate Change) expressed its confidence in the finding that "more intense precipitation events" are becoming "very likely, over many areas." The period of most significant increase in recorded rain intensity in several regions (1970 to date) coincides with the period in which greenhouse gas concentrations have dominated global climate change. The climate of coming decades will also be driven overwhelmingly by greenhouse gases with concentrations still on the increase. Thus a continuing trend of greater and more frequent intense rain events is "very likely," as IPCC has phrased it.

There were a number of climate projections into the future, as well as the trends of recent decades, which IPCC cited to support their assessment of likelihood of future heavier rainfalls. Among these were studies by Dessens (1995) which linked rising night-time temperatures, observed and predicted in a warming climate, to more intense convective activity and rainfall. Continued increases in short duration, convective rain intensities would require greater instability over land and greater water vapour content of the atmosphere as discussed above.

In considering changes in erosivity due to rain and runoff events there are two main aspects of rainfall to consider. One is the total rainstorm kinetic energy and the other is the highest intensity fall over a short period, 30 to 60 minutes.

Data for the trends since 1970 of the 30 minute and 24 hour intense rainfalls have been documented above. Projections for the future are primarily for seasonal and daily rainfall changes. The storm kinetic energy is related more to these changes in longer duration rains of 24 hours or more.

Global Climate Models have been used to project changes in annual precipitation over the Great Lakes basin between now and the period 2040 to 2060. For 30 different models and various future greenhouse gas global emission scenarios, the great majority of results show 2 to 6% increases in annual precipitation (including snow) by the time of the two decades about 2050, along with 2 to 4 ^{0}C temperature increases over the Great Lakes basin (Bruce et al., 2003).

Thus, it appears that in a greenhouse gas forced climate from 1970 onwards, increases in annual total rain and snow fall over the basin that have been about 5% or less for 30 years and are likely to continue at a rate of about 5% over the coming 5 decades, perhaps 1% per decade on average. For seasonal totals, table 2.1 shows that for the long period from 1895 to 1995, the increase in spring, summer and fall rainfall has been significant, but snowfall in these seasons has declined and some winter snowfall has become rain.

Increases for one day and shorter period intense rainfalls have been and are projected to be greater than for changes in annual or seasonal totals. There have been a few attempts to use Global Climate Models to project future shorter duration (i.e. one day) rain events as well as annual and seasonal changes. These have concentrated on one day rain events since data are insufficient, and models not of fine enough scale, to address intensities in convective rainstorms for hourly periods or less.

The most frequently quoted projections of future extreme daily rain amounts were undertaken by the Canadian Centre for Climate Modelling and Analysis (CCCma) (Zwiers and Kharin 1998, Kharin and Zwiers 2000). These model results show over the Great Lakes basin, a 15mm increase by 2090 in 20 year return period one day amounts over the 1975-1995 values. Increases in such extreme events are larger than increases in annual or seasonal values in a changing climate, according to both past experience and the models. Over the Great Lakes basin, the increase by 2080 to 2100 of 15 mm, represents a 30% or about 3%/decade increase over the 1975-1995 values for a 20 year return period amount over the Canadian part of the basin. The 2040 to 2060 period value for the Great Lakes basin is projected to be about 15% greater according to these model results with again a rate of increase of about 3% per decade.

Another projection of future one day rain events over USA and by implication southern Ontario was included in a U.S. State Department report on climate change (2002). In this study (Figure 2.7) the changes in frequency by 2080 to 2100, in one day rain amounts ranging from very light to very heavy were derived by two climate models—one the Hadley Centre 2 (United Kingdom) model, and the other the Canadian Centre for Climate Modelling and Analysis (CCCma) model. The Hadley Centre results showed declining frequency in the light and moderate one day rain categories, but increases of 57% in amounts in the heaviest category (i.e. those with a probability of occurrence only 5% of the time). Somewhat more modest increases are shown by the CCCma model, with, in general, small increases of 0.1 to 9 % for light to moderate rains respectively, and a 23% increase in amounts in the heaviest category. Thus for the CCCma result the average increase in amount of very large daily rainfalls would be about 2 ½% per decade and for the Hadley Centre projection 6% per decade over the century.

Summary and Conclusions

A generalized summary of the above cited results is given in table 2.3. Increases in frequency and amounts, which are closely related, are combined in this table.

TABLE 2.3
Summary of Results
all positive averaged over the region

INCREASES	OBSERVED TRENDS 1970-2000	PROJECTED TRENDS to 2050
Increases in 30 minute extreme amounts	3-5% per decade (Adamowski) 5% per decade to 1996 (SWCS)	
Increases in daily extremes	7% per decade (May, June, July) (Stone) (frequency) 5% per decade (April, May, June) (Stone) (frequency) 4% per decade (March April, May) (Stone) (frequency) 5% per decade (annual) to 1996 (SWCS) (amounts)	(models results) 3% per decade – yearly amounts (20 year return period) 2 ½% - 6% per decade (rainfalls with probability <5%)
Increases in annual rainfall	1% to 3% per decade	1% per decade (model projection)

Thus it appears that changes in the short duration intensity factor, as well as changes in daily falls are affecting the “R” erosivity factor in the soil loss equation. Overall we could expect a combined EI_{30} factor (RUSLE and RUSLEFAC equations) to increase by the order of 5 x 3 = 15% per decade, with the future rate of change to 2050 not significantly different from that experienced in the 1970 to 2000 period. From an erosion perspective it should be noted from the studies by Stone et al. (2000) and by Zhang et al. (2000) that the greatest one day (and probably shorter duration) increases have been in late Spring and early Summer, with lesser but significant increases in the March to May period, and this is likely to continue. At a few stations monthly analyses of short duration amounts show by far the greatest increases in May over the period 1975-2003.

TABLE 2.4
Stations Used in the Analysis
(Adamowski et al. 2003)

Station	ID	Latitude	Longitude	Record Length	Time
Bowmanville	6150830	43°87′	78°24′	30	1968-1998
Burketon	6151042	44°02′	78°48′	30	1969-1998
Delhi	6131982	44°52′	80°33′	34	1962-1995
Kingston	6104175	44°14′	76°29′	38	1961-1998
Orillia	6115820	44°37′	79°25′	27	1965-1991
Oshawa	6155878	43°83′	78°94′	29	1970-1998
Port Colborne	6136606	42°85′	79°15′	34	1964-1997
Preston	6146714	43°24′	80°25′	25	1971-1995
Sarnia	6127514	43°00′	82°18′	28	1970-1997
Sudbury	6068150	46°37′	80°48′	20	1971-1990
Waterloo	6149387	43°29′	80°31′	28	1971-1998

TABLE 2.5
Slope of Annual Extremes
Linear trend (mm)

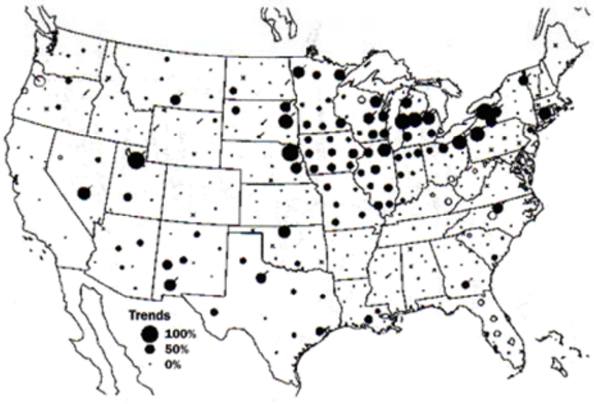
#	Location	Period	24 hour	30 minute
1	Windsor Airport	1970-1996	.63	-.20
2	Chatham	1970-1996	.31	.36
3	St. Thomas	1970-1996	.55	.12
4	London Airport	1970-1996	.87	.-10
5	Stratford	1970-1996	-.09	.11
6	Owen Sound	1970-1996	.10	-.16
7	Hamilton RBG	1970-1996	.48	.01
8	Preston	1971-1996	-.44	.50
9	Toronto	1970-1996	.08	-.16
10	Toronto: Lester B. Pearson	1970-1996	.05	-.23
11	Bowmanville	1970-1996	.54	.24
12	Trenton Airport	1970-1996	.02	-.02
13	Belleville	1975-1997	.42	.38
14	Kingston Pumping Station	1970-1996	.18	.10
15	Sarnia *			.18
16	Oshawa *			.30
17	Port Colborne *			.02
18	Waterloo *			.36
19	Delhi *			.12
20	Sudbury *			.18

Data to 1996 provided by Meteorological Service of Canada – R. Morris
* Stations from Adamowski, 2003

Figures

FIGURE 2.1
Heavy Precipitation Events Over Contiguous U.S.A. (Kunkel et al.)

Linear trends in frequency of heavy precipitation events over the contiguous United States, 1931 to 1996.

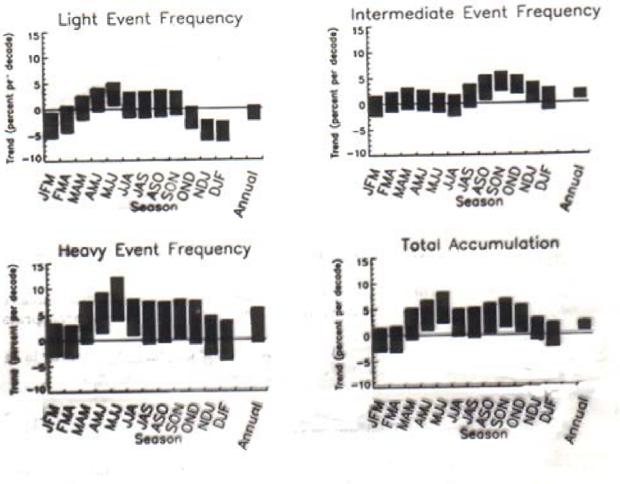


United States climate division trends in frequency of precipitation events of 7-day duration exceeding a 1-year recurrence interval. Shaded circles indicate upward trends while open circles indicate downward trends. The magnitude of the trend is given in terms of the percent increase or decrease over the period 1931-1996 relative to the 1931-1996 mean. As indicated in the key, the magnitude of the trend is linearly proportional to the radius of the circle. A tail attached to the upper right indicates positive trends with local significance at the 5 percent level. A tail attached to the upper left indicates locally significant negative trends. An "x" indicates a climate division with no stations with complete records for the period 1931-1996.

Source: Kunkel et al. 1999a. Copyright held by the American Meterological Society.

FIGURE 2.2
Seasonal Trends Southeastern Canada 1950-1995 (Stone et al.)

Figure 2: Southeastern Canada


Light Event Frequency

Intermediate Event Frequency

Heavy Event Frequency

Total Accumulation

D. A. Stone et al., Atmosphere Oceans, 2000

FIGURE 2.3
Daily and 30-Minute Annual Maximum Rainfall Trends – Bowmanville

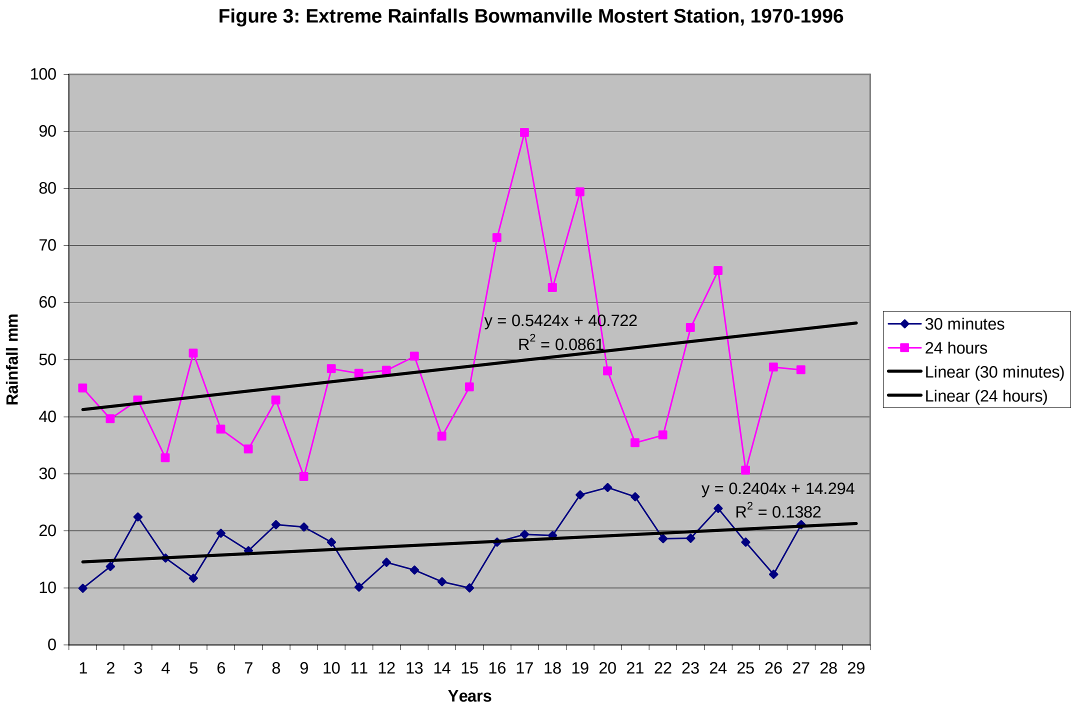


FIGURE 2.4
Pollutant Transport in Erosion and Runoff Events

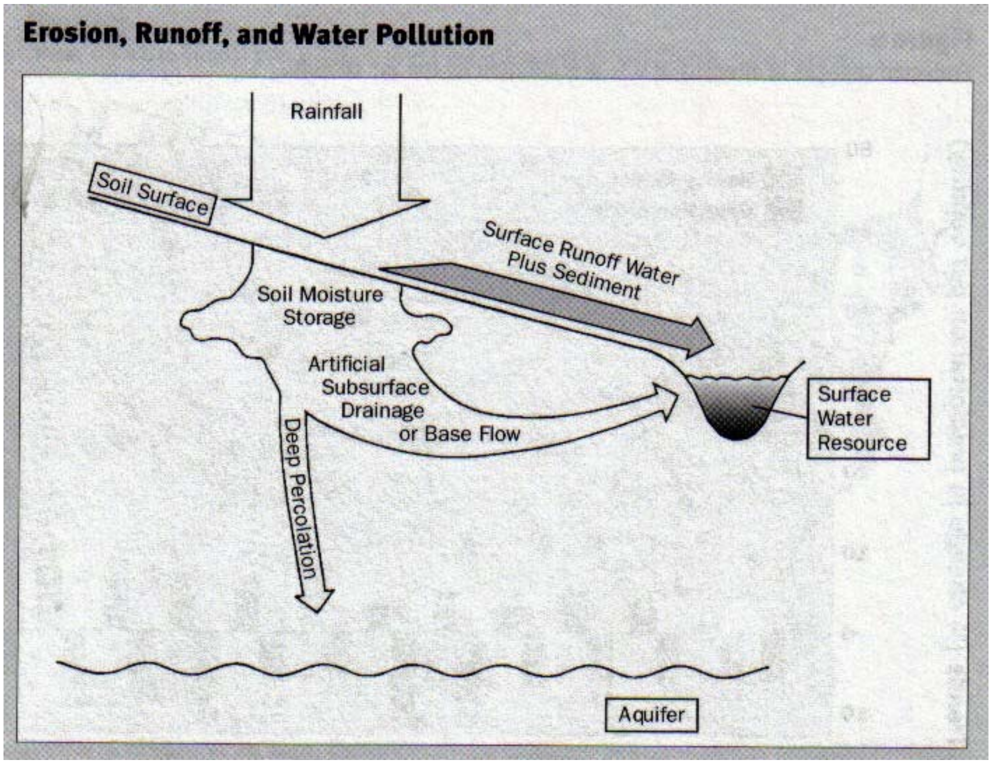
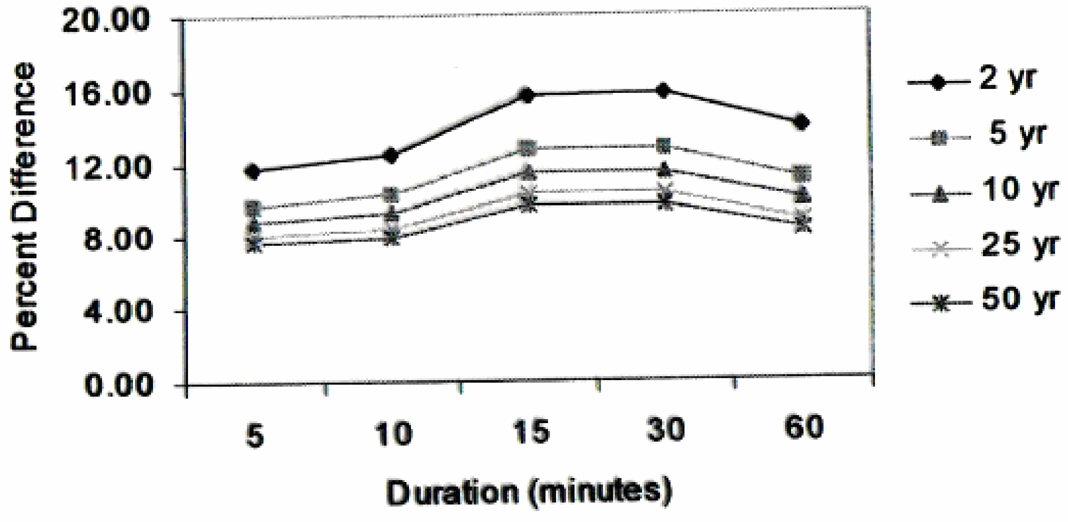
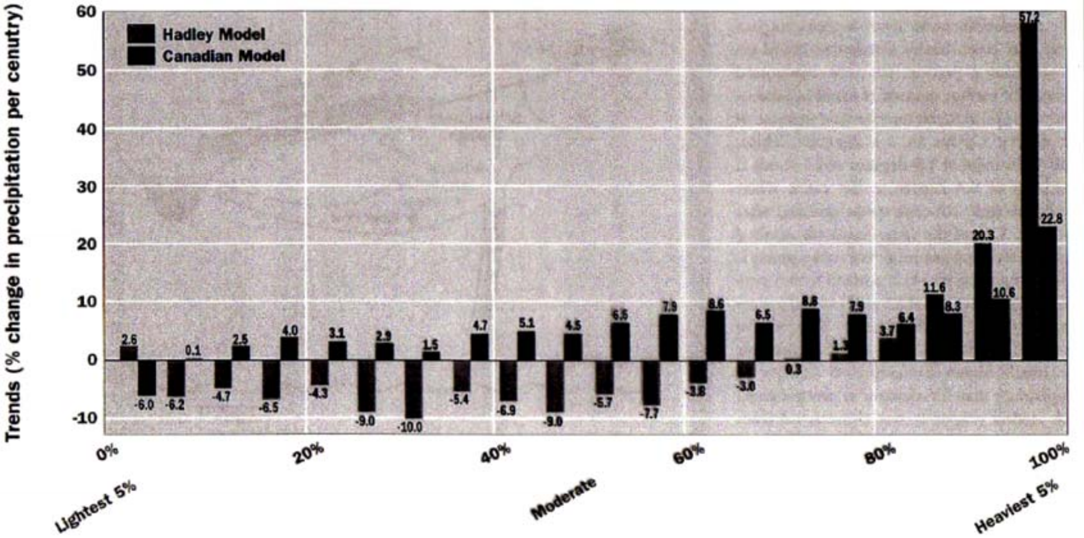


FIGURE 2.5
Average Percent Increases in IDF Curves-Ontario (Adamowski et al.)



Adamowski, et al. (2003)

FIGURE 2.6
Projected Daily Rainfall Changes Over 21st Century (Hadley Centre and CCCma models)



The projected changes in precipitation over the United States as calculated by two models indicate that most of the increase is likely to occur in the locally heaviest categories of precipitation. Each bar represents the percentage change of precipitation in a different category of storm intensity. For example, the two bars on the far right indicate that the Canadian Centre model projects an increase of over 20 percent in the 5 percent most intense rainfall events in each region, whereas the Hadley Centre model projects an increase of more than 55 percent in such events. Because both historic trends and future projections from many global climate models indicate an increase in the fraction of precipitation occurring during the heaviest categories of precipitation events in each region, a continuation of this trend is considered likely. Although this does not necessarily translate into an increase in flooding, higher river flows are likely to be a consequence.

Source: U.S. Department of State, 2002.

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Chapter **3**

Possible Impacts on Soil Erosion and Sediment Yield

by W.T Dickinson, R.P. Rudra, G.W. Wall & S.M. Kazim

Context

Chapter 2 presents evidence that precipitation patterns appear to be changing in the Great Lakes Basin in conjunction with climate change, including possible increases in storm rainfall intensities and amounts, primarily for durations of 1 day or shorter, and including spring months. Soil erosion rates occurring in agricultural fields and associated suspended sediment yields to watershed streams may be expected to change in response to increases in rainfall as a result of associated changes in soil moisture conditions, surface runoff and the erosive power of rainfall and runoff.

Much has been learned regarding rainfall, soil erosion and sediment load regimes which have been the norm in past decades in southern Ontario. Particularly relevant to this study are the seasonal variability of rainfall extremes, seasonal patterns of soil erosion and suspended sediment loads, and expected spatial patterns of soil erosion and suspended sediment yield. This context is briefly presented as a prelude to consideration of possible impacts of increases in rainfall intensity on soil erosion and sediment yield.

Seasonal Variability in Rainfall Extremes

An analysis of monthly rainfall extremes for various durations over 35 to 50 years of data (up to 1975) for southern Ontario stations revealed a pronounced seasonal pattern in the extremes (Dickinson, 1976). The amount of rain expected for a selected probability of occurrence during the summer months of June through September was found to be considerably greater than (i.e. almost double) the rainfall that might be expected to be equaled or exceeded at the same probability level during spring and fall months, the extent of the variability varying with storm duration. This seasonal pattern, illustrated in Figures 3.1 and 3.2, is undoubtedly linked to the occurrence and frequency of short-duration convective thunderstorms during the early to mid 1900s.

Further study of the Ontario rainfall data (Dickinson, 1977) revealed that the extremal probability distribution for annual rainfall extremes could be linked directly to and determined from extremal distributions for monthly extreme values. From this analysis it is clear that a slight increase in annual extremes, as noted to have occurred from 1951 to 1993 by Kunkel and Andsager (1999), could have been caused by slight increases in extremes in a number of the months, or by more significant increases in the extreme values occurring in one or very few months. In terms of Figures 3.1 and 3.2, significant increases in spring rainfall extremes could cause the March, April and/or May extremal distributions to look more like the June through September distributions of the past. Such shifts, if confirmed, would mean a virtual doubling of intensity at the shorter rainfall durations for a selected return period. As this scenario could have particularly significant implications for erosion and sediment transport during spring months, it will receive serious attention later in this chapter.

The seasonal pattern in rainfall extremes is reflected in the seasonal distribution of rainfall erosivity, with about 15, 75 and 10% of the annual erosivity occurring in the spring (February through May), summer (June through September) and fall/winter (October through January) periods respectively. Consideration of snowmelt conditions shifted these values to 30, 60 and 10% (Wall et al., 1983).

Seasonal Soil Erosion

Although soil erosion rates have been found to be linked to rainfall intensities and/or depths (Ateshian, 1974; Cooley, 1980; Meyer, 1981), estimated seasonal soil loss amounts in Ontario do not match the pattern of rainfall extremes presented above. The upland component of the field-scale GDVFS model (Rudra, 2005)) has been used to estimate seasonal soil losses for 1 hour spring, summer and fall rainfalls of 20, 40 and 20mm respectively (i.e. rain amounts with 25 year return periods prior to 1975 in months in the respective seasons) on a loam soil on a 7% slope and on a clay soil on a 1% slope. The model input includes seasonal variations in soil erodibility (Rudra et al., 1989), cropping factor (Wischmeier & Smith, 1978), and runoff curve number (U.S Soil Conservation Service, 1997). The sample output shown in Table 3.1 reveals that localized soil loss on slopes and in fields can be expected to occur primarily during the spring and summer months for a range of cropping practices, accounting for about 85% of the total annual erosion; and that spring and summer erosion amounts can be expected to be comparable in magnitude.

The spring soil loss estimates presented above correspond closely to earlier estimates and measurements made during the PLUARG studies (Coote et al., 1978; van Vliet and Wall, 1979); and the frequency, amount and conditions specifically relating to winter and spring soil erosion events in southern Ontario have been discussed by Rudra et al., 1989. The number of significant soil loss events during the late winter and early spring has been found to be relatively few; and the occurrence and amount of soil loss during this period has been linked primarily to moderate to heavy rainfall alone, or such rainfall on snowmelt conditions, particularly when the surface soil has thawed but frost continues to be present in sub-surface soil layers.

Summer runoff and soil loss measurements are available for more than 3 decades for hillslope plots in Guelph, Ontario (Rudra et al. 1985). This monitoring involved a variety of soil and crop management techniques, and the data were collected primarily for the period from May through September. These erosion data have revealed that the number of soil loss events likely to occur each summer in Ontario exhibits a wide range (i.e. from 0 to 28), with an extremely small mean value of 2 (i.e. just 2 soil loss events in 5 months). The events result from moderate to heavy rainfalls; and the event each summer which generates the greatest soil loss usually accounts for a significant portion if not most of the total seasonal accumulation, the range being 21 to 100%, with a mean of 60% (McArthur, 1971).

The research results relating to seasonal soil erosion in Ontario reveal that soil loss is clearly an extreme event-oriented process, with soil loss events linked to not only the occurrence of moderate to heavy rainfalls but also highly variable seasonal soil erodibility and runoff conditions. Spring soil losses are comparable to summer values, despite lower spring rainfall intensities; and the relative seasonal erosion values tend to depend primarily on the occurrence or lack of occurrence of a single significant rainfall event, summer or spring.

Seasonal Sediment Loads

Suspended sediment concentrations and loads in Ontario streams also exhibit a seasonal pattern, roughly following the seasonal trends of discharge, although sediment concentration is not singularly determined by discharge. In general, the lowest concentrations and loads are observed during the low-flow winter period, with the highest concentrations and loads observed during the spring period. Concentrations and loads decline in summer and sometimes rise slightly in the fall (Dickinson et al., 1991).

The spring portion of the annual load cycle contributes the bulk of the annual suspended load (70 to 80%), this pattern somewhat paralleling the seasonal distribution of flood occurrences. Significantly smaller portions of load are contributed during the summer (10%) and fall (10 to 15%) periods. The loads are associated with only a few events each year, the most and the largest of them clearly in the spring, when virtually all loads are associated with rainfall or rainfall on snowmelt events occurring when the ground surface has thawed but frost layers remain in the subsoil. Further, 70 to 80% of the annual sediment load is contributed by daily loads equaled or exceeded 10% of the time, 55 to 85% contributed by loads equaled or exceeded only 5% of the time.

A comparison of the seasonal patterns of soil erosion and sediment loads reveals that the delivery or transport of suspended sediment from field to stream is very different in the spring and summer periods in Ontario: the erosion occurring in the spring translating into a spring sediment load that constitutes a significant portion of the annual load; and the comparable amount of erosion occurring in the summer translating into an almost insignificant amount of summer sediment load. Calculations undertaken during the PLUARG studies regarding seasonal sediment delivery from several small agricultural watersheds in southern Ontario indicated that spring watershed sediment delivery ratios could be substantial, up to 40% for rolling upland basins and close to 100% for a flat lowland basin (Coote et al., 1982; Wall et al., 1982). In contrast, summer sediment delivery ratios were close to zero for both upland and lowland basins.

The seasonal patterns of sediment loads and associated delivery ratios discussed above reveal that an efficient and effective surface runoff/overland flow transport system exists in Ontario only during the late winter and early spring months, and implies that the extensive network of surface waterways which carry overland flow intermittently remain virtually dry during the summer months. The same conclusions have been drawn from studies of surface runoff in Ontario (Card, 1966; Dickinson & Whiteley, 1970).The runoff coefficients (i.e. the ratio of runoff to contributing rainfall) for spring events were found to be as high as 0.60 to 0.70, indicating that the minimum area contributing runoff was 60 to 70% of the watershed area, while the coefficients for summer rainfall events were typically less than 5% and more often 0 to 3%. Since the perennial stream surface area is approximately 2% of the watershed area in parts of southern Ontario, an area equal to or not many times larger than the perennial stream itself can generate the surface runoff from most summer rainfall events. The vast majority of fields in southern Ontario watersheds simply do not generate surface runoff during the summer months; and hence localized soil erosion occurring during that period has no overland flow system for transport to streams (Dickinson et al., 1987).

Spatial Patterns of Soil Erosion and Sediment Yield

Soil erosion rates can be quite spatially variable in upland watersheds in southern Ontario, due to the spatial variability of the contributing factors of slope, soils and crops. An example of this variability is shown in Figure 3.3, developed from an application of the distributed GAMES model for spring conditions (Cook et al., 1985). With such spatial variability, a major portion of soil eroded in upland fields moves in a relatively small percentage of the area. For the example given, 90% of the soil erosion occurs in about 50% of the area. In flatter lowland areas of the province, near Lakes St. Clair and Erie, erosion rates are not only lower but also much less spatially variable, for example 56% of the soil loss occurring in 64% of the area (Dickinson and Pall, 1982).

As for soil erosion, sediment yielded to the stream by rolling upland fields can be quite spatially variable in the spring of the year, as shown in Figure 3.4. Further, the prime sediment source areas do not necessarily correspond to the areas with greatest soil erosion, since the delivery ratio from field to stream is not spatially constant, particularly across rolling upland watersheds, indeed varying from 0 to close to 100% (Dickinson and Pall, 1982). In such watersheds, about 75 to 85% of the spring sediment load is estimated to be generated by only 15 to 20% of the area, 50 to 65% being generated by 5 to 10% of the area. In contrast, in flatter lowland areas, most of the area yields sediment to the stream during spring events, albeit at very low unit area rates. In the summer period, only relatively few fields immediately adjacent to the stream play a role in yielding sediment to the stream in both upland and lowland watersheds.

The Ontario rainfall-soil erosion-sediment context can be summarized as follows:

1. Rainfall extremes vary considerably from season to season – being greatest in the summer months of June through September and much lower in spring and fall months.
2. Soil erosion occurs relatively infrequently, and is linked to not only moderate to heavy rainfall events but also highly erodible soil and runoff conditions particularly prevalent during late winter and early spring periods. As a result, spring and summer soil loss amounts are comparable for many cropping systems, and the accumulated erosion from these 2 seasons constitutes most of the annual loss.

3. The majority of stream suspended sediment is transported in a very short period of time during relatively few surface runoff events during the spring of each year.
4. In rolling upland areas, most of the soil erosion and most of the stream suspended sediment load is generated in relatively small percentages of the watershed area; and the areas experiencing most significant erosion do not necessarily match the areas yielding the most sediment.

In a sentence, soil erosion and suspended sediment yield are highly event-oriented and extreme-event oriented; and they occur relatively infrequently and over a relatively small percentage of much of the southern Ontario landscape.

In light of this context, the question for this chapter becomes: How might increases in rainfall intensities attributable to climate change possibly alter amounts, and temporal and spatial patterns, of soil erosion and sediment yield in southern Ontario?

Possible Changes in Soil Erosion

The upland field component of the GDVFS model (Rudra, 2005) was used to explore possible changes in localized soil erosion in fields 1 hectare in area with a uniform slope of length 50 metres due to changes in extreme rainfall intensities. This model includes a variety of algorithms which can be selected for the estimation of runoff and soil erosion (Foster et al., 1977; Williams, 1975; Knisel, 1980).

The model runs included consideration of:

- an upland and a lowland field, the upland field located on a loam soil at a 7% slope (characteristic of rolling upland areas of southern Ontario) and the lowland field on a clay soil at a 1% slope (characteristic of lowland areas near Lakes St. Clair and Erie), including variations in soil erodibility for spring and summer conditions;
- 3 soil and crop management systems: corn with conventional tillage, small grains with conservation tillage, and pasture, along with associated spring and summer cropping factors;
- spring and summer rainfall events: spring and summer rainfall intensities of 20 and 40 mm per hour respectively, for a duration of 1 hour (i.e. intensities representative of 1 hour storms with 25 year return periods for spring and summer months in southern Ontario); and
- wet and dry antecedent soil moisture conditions for spring and summer events respectively, as reflected in the associated SCS curve numbers.

Three basic storm event scenarios were examined:

A: pre-1975 spring rainfall on spring soil, crop and soil moisture conditions;

B: pre-1975 summer rainfall on summer soil, crop and soil moisture conditions; and

C: pre-1975 summer rainfall on spring soil, crop and soil moisture conditions;

and, for each scenario, increments of 5, 10, 15, 20 and 25% were added to the rainfall intensities.

Sample outputs from the model runs are presented in Tables 3.2, 3.3 and 3.4, showing the estimated impacts of increments of rainfall intensity on runoff and soil loss events from the upland and lowland fields. A number of interesting observations can be made from these results.

The outputs involving scenarios A and B reveal:

1. percentage increases in localized soil loss (Table 3.2) can be expected to be 2 to 3 times the percentage increases in event rainfall intensity for all conditions explored. In most cases the percentage increases in soil loss are slightly higher than increases calculated to be proportional to the square of rainfall intensity (i.e. 2.05 to 2.25). The values in Table 3.2 fall within the median range of model sensitivities reported by Nearing et al. (2005), which involved models and soil loss algorithms also used in the present study.
2. percentage increases in localized runoff volume (Table 3.3) can be expected to vary more widely than those for soil loss, ranging from being almost the same as (i.e. 1.3) to 3 times the percentage increases in event rainfall intensity, for those cases when the basic runoff volume was greater than 5 mm. When the runoff amount was less than 5 mm, the percentage increases in runoff could be quite large (e.g. 22.2), although the final runoff estimates remained very small i.e. less than 5 mm.

The outputs involving scenario C (shown in Table 3.4) reveal:

1. localized soil loss which can be expected to result from a pre-1975 summer-type storm occurring in the springtime, even before consideration of percentage increases in storm intensity, may well be 4 to 5 times the soil loss presently experienced from pre-1975 spring storm events. If this storm were to not only occur during the spring but also increase in intensity by up to 25%, the expected soil loss amounts could be expected to reach 5 to 9 times soil losses presently experienced during significant spring events.

Clearly the impact of increased rainfall intensity on seasonal and annual soil loss experienced on slopes and in fields is dependent on the frequency of occurrence of storm events exhibiting increased rates. For example, consider a seasonal distribution of erosion percentages of 45, 42 and 13 for spring, summer and fall, and the likelihood that the soil loss from a single significant spring rainfall in the past constituted about 60% of the loss for that season (as noted earlier). If the rainfall intensity of only the most significant spring rainfall event were to increase by X%, the localized soil loss for the event could be expected to increase by 2.5X%, the total spring soil loss to increase by 1.5X%, and the annual loss by 0.7X%. For example, for a 4%/decade increase in March, April and May daily rainfall extremes for the past two to three decades (a possibility noted in Chapter 2 in Table 2.3), potential increases in localized soil loss may have been 20 to 30%, with a 13 to 19% increase in total spring soil loss. Such possible increases may have been offset by the implementation of remedial practices in some regions of southern Ontario, as noted in Chapter 5.

If the rainfall intensity of only the most significant summer rainfall event were to increase by X%, the localized soil loss resulting from that event could also be expected to be 2.5X%, the total summer soil loss to increase by 1.4X%, and the annual summer loss by 0.6X%. Given a possible 5 to 7% increase per decade in summer heavy rain events over the past 2 to3 decades (Table 2.3), the potential increases in localized soil loss could have been 25 to 50%, with a total summer soil loss of 14 to 29%. If significant storms in both spring and summer were to increase by X%, the localized total annual soil erosion could be expected to increase by 1.3X%. Favis-Mortlock and Boardman (1995) also used an approach which incremented only the most significant rainfall events during the year.

If a summer storm were to occur during the spring season (with no increase in rainfall intensity), the localized soil loss from that event might be expected to increase 4 to 5 fold, the total localized spring soil loss to increase by 3 to 4 times, and the annual loss to increase by 2 times. Clearly, a change in rainfall regime which caused what we have known as summer-type storms to become more frequent during the spring season would result in major increases in localized soil loss.

The analysis conducted here suggests that with an increase in rainfall intensity for the most significant seasonal storm events, a resulting percentage increase would be realized in localized soil loss across all cropping systems. Such a result would continue to yield a highly variable spatial distribution of localized soil loss, all amounts having increased by some percentage; and a large percentage of the total erosion occurring over a watershed would continue to be generated in a small percentage of the area.

Possible Changes in Sediment Yield

The possible changes in amounts of suspended sediment transported from fields to streams in a watershed become a function of the possible changes in both localized soil erosion, seasonally and spatially, and the sediment delivery ratio from field to stream, seasonally and spatially. Since the delivery ratio algorithm considered for this analysis (Cook et al., 1985) does not take into account differences in storm event rainfall or runoff, even though it does allow for variations from season to season and from field to field, the possible changes in sediment yield will first be explored on the assumption that delivery ratios from field to stream will not vary with increases in rainfall intensity and associated runoff.

The possible percentage change in total spring sediment load can be expected to be equivalent to the percentage change in spring soil loss, and the percentage change in total summer sediment load equivalent to the percentage change in summer soil loss, given that the watershed sediment delivery ratios for spring and summer do not change. For an X% increase in the rainfall intensity for a significant spring event, the spring sediment load could be expected to increase 1.5X%, and the annual load to increase by 1.1X%, given that the initial spring sediment load is likely to have constituted about 75% of the annual load. For example, for the 4% increase per decade in spring heavy rains estimated to have occurred over the past few decades (Table 2.3), a 13 to 19% increase in spring sediment loads and a 9 to 13% increase in annual loads may have resulted. Again, remedial actions on Ontario farms may have offset possible rainfall-induced changes in erosion in some areas of the province.

If an X% increase were to occur in a significant summer rainfall event, the summer sediment load could be expected to increase by 1.4X% (i.e. the same as the increase in summer soil erosion), and the annual load by 0.2X%, the initial summer sediment load likely to have accounted for only about 10% of the annual load. For the situation when the total spring soil erosion might increase 3 to 4 fold as a result of a previous summer-type storm occurring in the spring, the spring sediment load could be expected to increase by a similar amount (if delivery ratios did not change), and the annual load by almost 3 times.

For small to moderate percentage increases in rainfall intensities in spring storms, the field to stream sediment delivery ratios which are expected to occur across a watershed in the spring months may not change very much. That is, the area contributing runoff and suspended sediment during spring events, and the transport capacity of the associated overland flow network, may not increase substantially. In fact, for lowland areas in which the watershed sediment delivery ratio approaches 100% for spring events, delivery cannot increase. For rolling upland areas, some of the field to stream delivery ratios may well increase at some point with increasing rainfall intensity in the spring; and it is very likely, for the scenario involving the occurrence of a summer-type storm in the springtime, that field to stream delivery ratios in upland watersheds will increase markedly, leading to increases in spring and annual downstream sediment loads even greater than those noted above.

For small to moderate percentage increases in rainfall intensities in summer storms, the field to stream sediment delivery ratios across watersheds in southern Ontario – most of which are presently zero – again may not change very much. However, at some threshold of moisture level which has net yet been determined, these delivery ratios may begin to increase, causing associated increases in downstream sediment loads greater than those discussed above.

Up to the point when field to stream sediment delivery rations begin to increase, the spatial pattern of sediment yield can be expected to remain similar to the existing pattern as illustrated earlier in Figure 3.4, with percentage increases in the absolute numbers associated with increases in rainfall intensity. Further, a large percentage of the downstream sediment load will continue to be generated by a small percentage of much of the landscape, particularly in upland areas.

Implications for Sediment-Borne Contaminants

The International Joint Commission report on "Pollution in the Great Lakes Basin from Land Use Activities" (International Joint Commission, 1978) reported: "PLUARG finds that the Great Lakes are being polluted from land drainage sources by phosphorus, sediments, some industrial organic compounds, some previously-used pesticides, and potentially some heavy metals. … Sediment affects the Great Lakes System primarily as a carrier of phosphorus and the other contaminants, contributing to the overall pollution of the lakes." In Ontario, suspended sediments have been found to be a carrier of phosphorus (Depinto et al., 1981; Culley et al., 1983), trace metals (Ihnat, 1982) and pesticides (Miles & Watson, 1977) from farmlands to streams to lakes.

With any increases in soil erosion and associated sediment yield, the pollution associated with sediment-borne contaminants is very likely to increase. Concentrations and loads of sediment-borne contaminants are functions of not only the quantity and particle sizes of the eroded soil and subsequently-transported sediment but also of the loading rates associated with each contaminant at the source (Rudra et al., 1990; Sharpley, 1980). Therefore, the extent of possible increases in such contamination must be explored more fully for each contaminant of concern. This issue is addressed further in Chapter 4.

Conclusions

As the analysis in this chapter is based on many assumptions and the outputs of hypothetical model runs, the results themselves are highly speculative. Nonetheless, it seems clear that increases in rainfall intensity attributable to climate change are likely to cause increases in soil erosion and sediment loads yielded by agricultural watersheds. The percentage increase in erosion from localized hillslopes and fields may be expected to be more than the percentage increase in rainfall intensity for small to moderate percentage increases in the intensity of individual significant storms both spring and summer. The resulting percentage increases in seasonal and annual soil loss may be closer to the percentage increase in storm intensity. The sediment yielded by watersheds could also be expected to increase as a result of such increases in rainfall intensity, but more for increases in spring than summer rainfalls.

For a very significant increase in rainfall intensity, e.g. for the doubling of intensity that might be expected if summer-type thunderstorms are beginning to occur in spring months with the same frequency that they have occurred to date during summer months, then localized storm, spring and annual soil erosion is likely to increase by several orders of magnitude. Storm, spring and annual sediment loads could also be expected to increase very significantly under this scenario of change in rainfall regime. As the increased frequency of occurrence of severe thunderstorms in spring months offers by far the greatest threat of increased soil loss and sediment yield, this possibility needs very careful monitoring.

The spatial patterns of soil loss and sediment yield which commonly occur in rolling landscapes of southern Ontario are likely to remain highly variable, meaning that most of the soil erosion and sediment yield are likely to continue to occur in relatively small portions of those regions.

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TABLE 3.1
Estimated seasonal soil loss and runoff from upland and lowland fields in Ontario under various cropping and tillage systems.

Physiography	Crop Tillage System	Season					
		Spring (F,M,A,M)		Summer (J,J,A,S)		Fall / Winter (O,N,D,J)	
		Soil Loss tonnes/ha	Run Off mm	Soil Loss tonnes/ha	Run Off mm	Soil Loss tonnes/ha	Run Off mm
Upland	Corn	7.0	8.6	5.7	0.7	2.3	0.4
	Small grain	3.2	6.5	3.8	0.2	1.3	0.2
	Pasture	0.1	3.1	0	0	0	0
Lowland	Corn	1.1	15.0	0.6	6.2	0.2	3.6
	Small grain	0.5	13.0	0.4	3.5	0.1	0.2
	Pasture	0.02	5.6	0.04	1.3	0	0

TABLE 3.2
Estimated percentage increase in soil loss per percentage increase in storm rainfall intensity for spring and summer storm scenarios on various cropping and tillage systems in upland and lowland fields in Ontario.

Physiography	Crop / Tillage System	Storm Scenario	
		A Spring Rain on Spring Conditions	B Summer Rain on Summer Conditions
Upland	Corn	2.3 to 2.5	2.3 to 2.5
	Small grain	2.5 to 2.8	2.2 to 2.5
	Pasture	2.9 to 3.0	-
Lowland	Corn	1.9 to 2.0	2.5 to 2.7
	Small grain	2.0 to 2.3	2.2 to 2.7
	Pasture	2.2 to 2.3	2.1 to 2.3

TABLE 3.3
Estimated percentage increase in runoff per percentage increase in storm rainfall intensity for spring and summer storm scenarios on various cropping and tillage systems in upland and lowland fields in Ontario.

Physiography	**Crop/Tillage System**	**Storm Scenario** **A** **Spring Rain on Spring Conditions**	 **B** **Summer Rain on Summer Conditions**
Upland	Corn	1.8 to 1.9	8.3 to 10.8
	Small grain	2.1 to 2.2	14.8 to 22.2
	Pasture	2.9 to 3.2	-
Lowland	Corn	1.3 to 1.3	2.9 to 3.2
	Small grain	1.4 to 1.4	3.7 to 4.2
	Pasture	2.2 to 2.3	5.8 to 7.1

TABLE 3.4
Comparison of soil losses estimated to be generated by spring and summer rainfalls occurring on spring soil and crop conditions for various crop and tillage systems in upland and lowland fields in Ontario.

Physiography	**Crop/Tillage Systems**	**Soil loss (tonnes/ha)** **20 mm Spring Rain on Spring Conditions**	 **40 mm Summer Rain on Spring Conditions**	 **50 mm Summer Rain on Spring Conditions**
Upland	Corn	7.0	30.1(4.3)*	46.9 (6.7)
	Small grain	3.2	14.8 (4.7)	23.5 (7.4)
	Pasture	0.1	0.7 (5.3)	1.2 (8.7)
Lowland	Corn	1.1	3.8 (3.5)	5.6 (5.3)
	Small grain	0.5	1.9 (3.7)	2.9 (5.7)
	Pasture	0.02	0.1 (4.9)	0.1 (6.9)

* Ratio of soil loss from summer rain on spring conditions to soil loss from spring rain on spring conditions

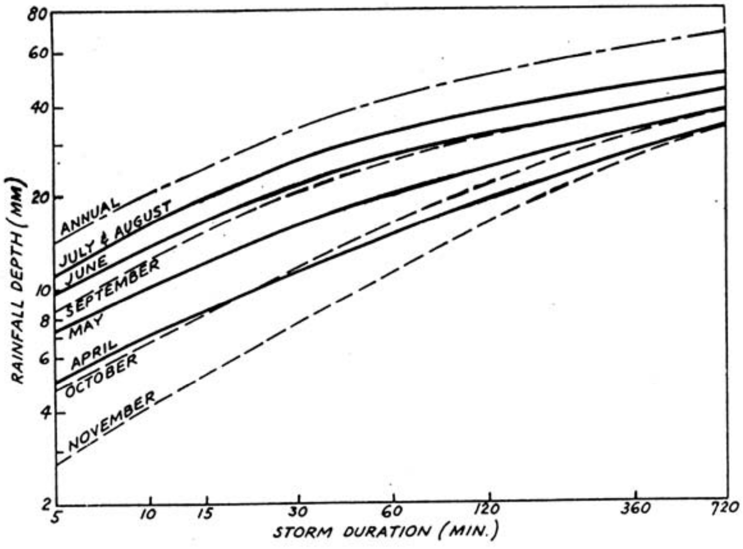

FIGURE 3.1
Monthly and annual depth versus duration curves for storms of 10-year return period in southern Ontario (Dickinson, 1976)

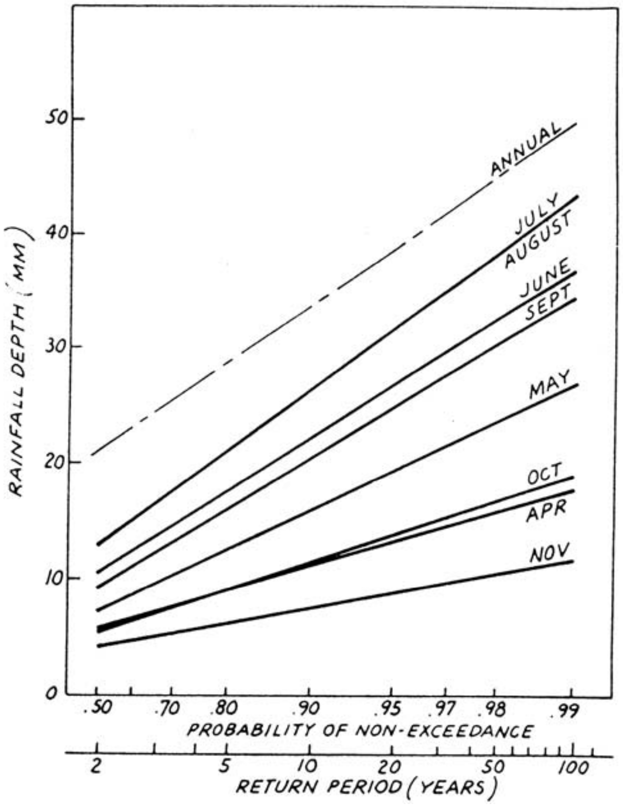

FIGURE 3.2
Monthly and annual extreme value distributions for 30-min storm rainfall in southern Ontario (Dickinson, 1976)

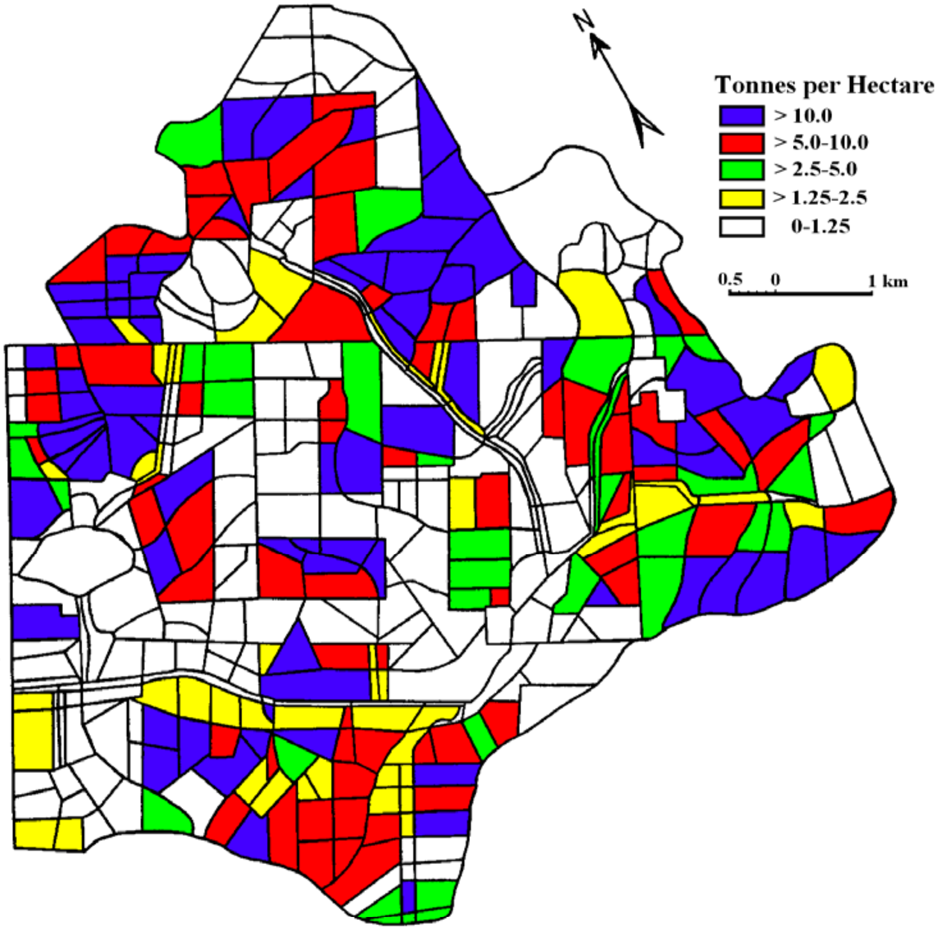

FIGURE 3.3
Spatial distribution of estimated spring soil loss for an upland watershed in southern Ontario (Dickinson et al., 1987)

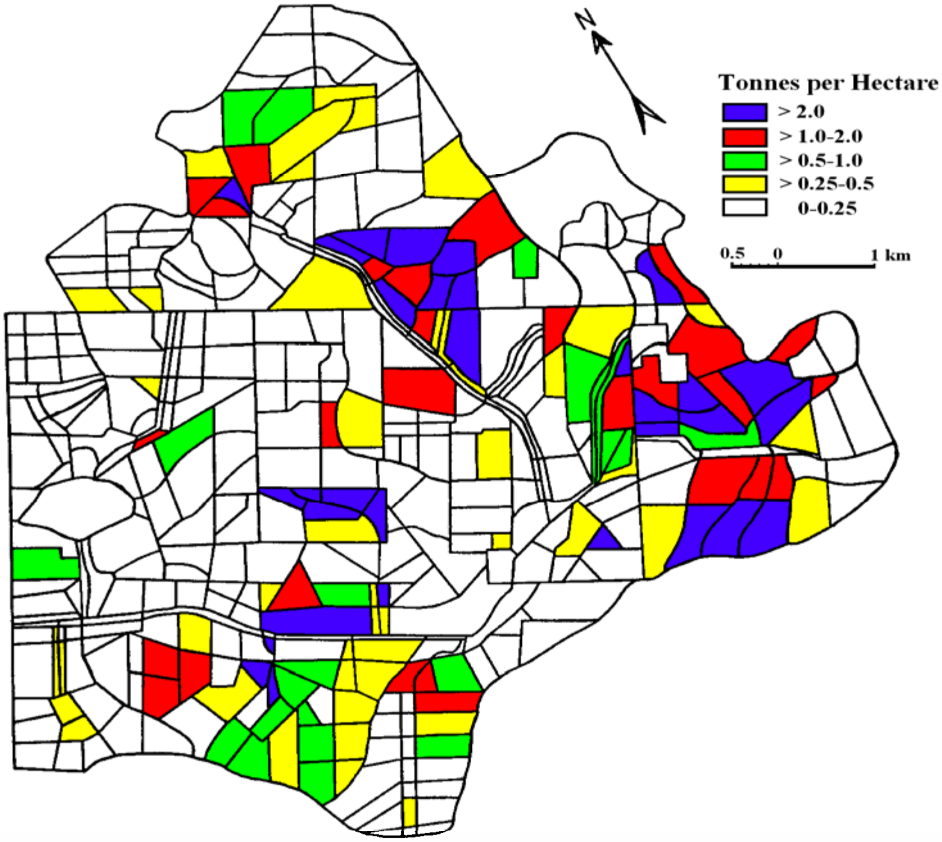

FIGURE 3.4
Spatial distribution of estimated spring sediment yield for an upland watershed in southern Ontario (Dickinson et al., 1987)

Chapter **4**

Water Quality in Aquatic Ecosystems: Influence of Warmer-Drier Conditions followed by High Intensity Rains

by David Lean, Emmanuel Yumvihoze, Victoria Renner and Jeff Ridal

Water Quantity and Timing of High Volume Flow Conditions

The term climate change covers so many aspects of this global issue that the volume of information can hide critical aspects that deserve immediate attention. Here, we focus mainly on the influence of the increase in the intense and very intense summer and spring storms (see Chapter 2) on the downstream aquatic ecosystem integrity.

The geographic focus is the temperate region of Southern Ontario in the basin of the Laurentian Great Lakes. Consideration must also be given to areas a little further north on the Canadian Shield since they provide some of the water to Southern Ontario through a series of drainage and control structures along rivers, lakes, and canals (e.g. the Trent- Severn Canal System).

Forest vegetation promotes infiltration and the formation of a layer of litter which is capable of intercepting surface flow, stabilizing soil and reducing erosion. Evapotranspiration from the forest also reduces runoff. Consequently, with deforestation rivers rise rapidly after heavy rains, then quickly return to base flow. In the past few hundred years the landscape has been altered dramatically by forest removal and wetland draining for farming and urban development. In this “new” landscape, the spring freshet is shorter and steeper making rivers “flashier” (Allen and Hinz 2004). This results in a greater number of high flow events and a reduction in the number of low flow events. Low flow events that do occur tend to be of shorter duration. The rate of rise of flow after heavy rain events is significantly faster than that found in the earlier records.

It is widely held that wetlands can act as sponges for water;they also trap nutrients, metals and other pollutants. Consequently, constructed wetlands are now commonly used in urban areas to dampen urban runoff. However, some reaction to their use has occurred. They become breeding grounds for insect borne diseases and often retain heavy metals and contaminants to be taken up by wading bird populations. The role of wetlands should not be oversimplified. They can be groundwater discharge or recharge areas, or discharge areas in part of the year and recharge at other times. They can serve as nutrient traps or sinks or can export nutrients. Wetlands play an important role in that they dampen flow from intense storms and reduce pollution to downstream lake and river ecosystems. In urban areaswetlands and storm water ponds have created to dampen storm events and reduce sudden surges of water into small creeks draining the watershed.

Some land management of farming practices should be reexamined to reduce the potential for erosion (see Chapters 3 and 5). We need to create conditions that make our soils less vulnerable to impacts of high intensity rain events, for example conservation tillage is recommended. In chapter 3, it was shown that the historical pattern of overland flow following snow melt resulted in the highest annual sediment concentration and load in rivers. Climate change is leading to alterations in runoff patterns due to earlier frost free soils, reduced spring snow depth and an increase in rain and winter freezing rain. Soil erosion can be severe in the springtime and occasionally in the summer (Chapter 3). Forest removal, wetland draining and the use of tile drains in agricultural areas as well as climatic changes, have compressed timing of the spring freshet to earlier and shorter periods in March and April. Rivers that once supported sawmills throughout the year are often almost dry in the summer. In the springtime, when the soils are wet and still partly frozen, overland flow can occur and at these times the soils are vulnerable to erosion. If no vegetation is reestablished, these sites will continue to further erode in the summer. Later in the year, a higher fraction of precipitation is retained in the soils and seeps to groundwater. Runoff is restricted to that falling on the rivers themselves and immediately adjacent land, and base flow of the rivers in the summer is sustained almost entirely by groundwater sources. When groundwater reserves are depleted the rivers can become completely dry.

Since the annual average precipitation has changed little but the frequency of high intensity rains for a day or less (Chapter 2) have increased, there would have to be longer dry spells in between. With higher temperatures and thus greater evapotranspiration, dry spells would become more intense and surface soil moisture levels would drop.

There are data on quantity and timing of flow from the headwater systems of the watersheds in southern Ontario, but more extensive data analysis specifically directed to this issue has not been published. Data from rivers in Michigan show a marked trend towards greater flashiness(Allen and Hinz 2004). Data from water intakes for treatment facilities and satellite imagery would also provide some of the critical information needed to illustrate the rapid response to high intensity rain, volume flow, turbidity, microbial abundance, and nutrient levels. This coupled with more specific information on declining late winter snowpack and timing of snowmelt, would increase our understanding of the factors that influence the volume and timing of the spring freshet and recharge of groundwater.

Currently, lake levels feeding the Trent Severn Waterway are controlled to retain much of the spring input for use later in the season. Discharge from these waterways may provide some measure of long-term trends and identify critical flow patterns through both drought and extreme rain events. Overall, the problem is partly a water quantity problem as well as a water quality problem. If there is less frost in the ground, there may be more infiltration from rain and snowmelt events – leading to more groundwater recharge, and in fact a more sustained flow response. Reliable water budgets for watersheds are required if we are to make informed decisions.

Long-term monitoring activities on aquatic ecosystems have been conducted principally on the Canadian Shield and there is a vital need for similar programs to be re-established in sedimentary drainage basins using methods consistent with those used historically. There was much more lake and river monitoring in the 1970s and 1980s and these investigations need to be reactivated. Almost all the useful recent information on inland lakes was collected on the Canadian Shield and may not be relevant to lakes downstream. For the present report, these monitoring data have been used to make some predictions for the Great Lakes and other smaller lakes.

It is well known that the contour of stream banks is a direct consequence of the volume of flow. Fluctuations between low flow and high flow conditions causes stream bank erosion and sediment re-suspension. Intense rainfall events, sufficient to cause the flow velocity to exceed the critical velocity for particle suspension, cause rivers to be more turbid with increased levels of suspended solids from sediments within the riverbed, from the banks and from field erosion. Even in areas where the forests still exist, a heavy rain can cause a lake to become turbid with eroded soils and floating debris (detritus, pine needles and leaves).

Stream bank subsidence during dry periods is another potential problem. In some areas, where ground waters have been depleted, dry riverbeds will become common. (Piggott 2004). As noted above, many of the streams in farming areas are now dry in the summer but would flow throughout the year as recently as 70 years ago when the forests and wetlands were intact.

Following low flow periods, of even a few weeks, sediments in wetlands, rivers, streams and shallow regions of lakes will become dried out, reduced sulfur compounds will be re-oxidized and with the next rainfall event, high levels of sulfate will be found in the rivers. In regions where the waters are poorly buffered, low levels of pH will also occur (Eimers and Dillon 2002, Eimers et al. 2004a,b; Yan et al. 1997). This problem also relates to removal of dams and restoration of watercourses. As part of an investigation conducted under contract with Ontario Power Corporation we showed that drying and rewetting sediments (to simulate rain events) resulted in an increase in sulfate export by an order of magnitude. The influence of higher sulfate on increased methyl mercury formation by sulfate reducing bacteria requires further investigation (M.Sc. thesis M.V. Nugent 2005 Department of Earth Sciences and K. Hindle 2005, Department of Biology, University of Ottawa).

As indicated in the Chapter 3, based on historical information, suspended sediment concentrations and loads in Ontario streams exhibit a seasonal pattern following the pattern of discharge but factors other than discharge may also be important. Soil type and organic content limit the potential for erosion. In addition, the dryness of the soils will alter its texture. Hard packed soils are not easily eroded and do not allow as much infiltration as soils with more organic matter.

Currently, an estimated $3 biollion in nutrients are stripped from over 600 million tons of cropland topsoil from the Great Lakes States each year (Great Lakes Commission 1987). Between 5-6 million cubic yards of sediments must be dredged annually from navigation channels in the Great Lakes and tributaries. The US Corps spends over $20 million annually for dredging and $300 million on confined disposal facilities for contaminated sediments. A study by Ohio State in the Maumee River Basin concluded that soil conservation efforts to reduce the sediment load by 15% would reduce the costs of dredging and confinement by $1.5 million per year

(Sohngen 2001). Additional costs include potable water treatment and clean-up for industrial uses.

Models for soil erosion and runoff related to changes in precipitation and cover include those discussed by Nearing *et al.* (2005) and those discussed in Chapter 3. They show that soil erosion and runoff are affected by changes in rainfall and cover. They further note that the increase of percent erosion and runoff will likely be more than the percentage change in rainfall intensity.

Water Quality Problems Related to Intense Spring and Summer Storms

Bacterial Contamination

The selection of appropriate indicators of fecal contamination and methods to rapidly identify pathogens are prerequisites for the identification of problems related to intense spring and summer storms. Kistemann *et al*. 2002 suggest that regular watercourse samples collected for monitoring purposes are not representative of microbial contamination in watercourse systems. Their studies showed that following extreme rainfall and runoff events numbers of coliforms, fecal coliforms, *E. coli*, *Clostridium perfingens* and fecal streptococci increased substantially, as did counts of the intestinal parasites *Giardia* and *Cryptosporidium.* Recent studies along the Raisin River, near Cornwall, Ontario, showed a 10-fold increase in *E. coli* values following an intense summer storm.. At the same time, higher concentrations of nitrate, ammonium, phosphorus, methyl mercury and total mercury were also recorded (Ridal and Lean, unpublished).

Coliforms, fecal coliforms and *E. coli* are typically used as indicator bacteria to assess the safety of drinking and recreational waters (APHA, 1995). "An indicator is an organism or substance whose presence and concentration signals the occurrence of another entity in a matrix under examination" (Tamplin, 2003). Higher concentrations of indicator bacteria are believed to signal a greater contamination with fecal matter and thus a higher risk of waterborne disease (Tamplin, 2003). Human fecal contamination carries the greatest risk, however feces from domestic and wild animals may also contain human pathogens (i.e. *Cryptosporidium*, *Campylobacter*, *Salmonella*). Although some indicators may be pathogenic, drinking waters are monitored for presence of indicators as an 'early warning system' for potential problems (i.e. inadequate treatment, cross-connections or inability to maintain a sufficiently high chlorine residual throughout the system) (LeChevallier, *et al*., 1996). Their presence in streams, rivers and lakes is worrisome to policymakers and the public; however, there is a growing body of evidence that the presence of these bacteria is not always indicative of recent fecal contamination.Many of these bacteria are exploiting an ecological niche and actually growing. Nevertheless, their presence has closed public beaches (IJC 2003) and created unsafe drinking water (Walkerton, May 2000, see Table 2.2) The Walkerton tragedy occurred after an intense rain event. These events are becoming increasingly frequent.

Coliforms are gram negative, non-spore forming, anaerobic, rod-shaped bacteria able to ferment lactose, with gas and acid production within 48 hours at 35^0C (APHA, 1995). This group of bacteria includes the genera: *Citrobacter*, *Enterobacter*, *Escherichia*, *Klebsiella*, *Kluyvera*, *Rahnella*, *Serratia*, and *Yersinia* (Krieg and Holt, 1984). Mammals eliminate approximately 2 x 10^9 coliforms per day per capita (Tamplin, 2003). These organisms are known to be widely distributed, metabolically diverse, and able to exploit a broad range of habitats (Krieg and Holt, 1984). Environmental strains of non-fecal origin have been reported in a variety of habitats: soil, bark, healthy wood, decaying wood, vegetables, plants, rain forest epiphytes, pristine stream habitats, biofilms, mill wastes and fish (reviewed by Archibald 1999). Coliforms of non-fecal origin often show a greater ability to survive in the aquatic environment than coliforms of fecal origin (APHA, 1995). These findings suggest that coliforms may not always be a specific enough indicator to be used to assess the sanitary quality of water (deBoer, 1998).

Fecal coliforms are a subset of coliform bacteria and they share all the same characteristics of coliform bacteria and are capable of fermenting lactose with gas and acid production within 24 hours at 44.5^0C (APHA, 1995). Although fecal coliform testing is more specific than coliform testing, fecal coliforms of non-intestinal origin have been detected (Archibald, 1999). Non-intestinal ‘fecal coliforms’ are most common in warm environments (for example, some industrial effluents).

Despite the negative attention *E. coli* received, most strains of *E. coli* do not cause disease. Instead, they live in a symbiotic relationship with their host. In exchange for providing habitat and a generous supply of nutrients, *E. coli* produce Vitamins K and B, help stimulate the normal development of the immune system in infants, and occupy many of the available gastrointestinal niches making it difficult for pathogens to establish themselves (Berg, 1996). Although the majority of *E. coli* are harmless, some strains are recognized as the agents responsible for human illness.

There are several distinct groups of pathogenic *E. coli*, including *E. coli* 0157:H7. This is the strain that caused internal haemorrhaging and death during the Walkerton tragedy. This strain of *E. coli* was first detected in the 1980s and has now been found to be endemic in about 10% of North American cattle (Coia, 1998; Solomon, *et al*., 2002). It is most common in the crowded conditions of the so-called factory farm. Outbreaks of O157:H7 are usually linked to unpasteurized milk, undercooked beef or contaminated water. This strain of *E. coli* is responsible for an estimated 73,000 cases of illness; 2,100 hospitalizations and 61 deaths per year in USA alone (CDC, 2005). Ironically, *E. coli* O157:H7 cannot be detected using standard fecal coliform or *E. coli* testing methods. Fecal coliforms are identified by their ability to grow at 44.5^0C, while O157:H7 does not grow at temperatures greater than 42^0C (Coia, 1998). *E. coli* are characterized by their glucuronidase activity, while typical O157:H7 strains do not produce an active version of this enzyme (Coia 1998). This issue was never fully explored during the Walkerton hearings and illustrates the need for more reliable tests. (Similar data to that in USA also exist for Canada but have not been published to our knowledge. Contamination of water with O157:H7 has been found in all provinces with highest values in Alberta and Quebec).

From the IJC Great Lakes Water Quality Board report on climate change (2003) the key implications for human health in the basin may include: increases in water borne disease, increases in health effects related to extreme weather events, intensified health effects due to air pollution, increases in the number of heat-related illnesses and deaths, more common occurrence of vector-borne and rodent-borne disease.

Pesticide Inputs

The term pesticide covers a wide range of chemical compounds used to kill unwanted pests. For registration, the Canadian Pesticide Management and Review Agency only considers data for specific organisms using the active pesticide ingredient and not the formulated product. However, the pesticide products contain a petroleum-based solvent such as xylene or toluene plus a surfactant as well as the active ingredient. Surfactants act to increase the penetration of the active ingredient through the cell wall of the pest (and non target organisms as well). Although the majority of surfactants are not identified, many are nonionic detergents such as nonyl and octyl phenol ethoxylates that break down to nonyl and octyl phenol, known endocrine disrupting substances now banned for use by the pulp and paper industry. Heavy summer rains would quickly wash the breakdown products nonyl and alkyl phenol into watercourses. Even very small quantities of these chemicals can disrupt amphibian metamorphosis (Crump et al. 2002). This aspect of the pesticide problem has not received much attention but Howe et al. 2004 showed that the polyethoxylated tallowamine (POEA) surfactant used in glyphosate-based herbicides such as Roundup Original, resulted in toxic effects (reduced length, at metamorphosis, increased time to metamorphosis, tail damage and gonadal abnormalities) to four North American frog species. The authors thought that the effects may be caused by disruption of hormone signaling because thyroid hormone receptor ß mRNA transcript levels were elevated after exposure to formulations containing glyphosate and POEA.

Models for quantifying transport and accumulation of the active ingredient of pesticides have reached an advanced level of reliability through efforts of Dr. Don MacKay at the Trent Modelling Centre in Peterborough (Mackay 2001). In general, herbicides used to control weeds (e.g. atrazine, 2,4D and Round-up) are more water-soluble and are often found in drinking waters, streams, and rainwater. Simple chemical partition coefficients along with such properties such as vapor pressure, and lipid (octanol) solubility provide reliable modeled values for pesticide fate and transport. Persistence is an important consideration. For example, we are often told that 2,4D has a very short half-life in the environment. This is based on attempts to find it after it has been used but this should not infer that it has been broken down to carbon dioxide and water. In fact, the actual breakdown products are rarely measured.

Many pesticides are persistent and take part in volatilization from water bodies and long-range transport to colder waters. Through cold condensation, they are found in cold regions including the Arctic and high mountains. Through food chain biomagnification the top predators reach very high concentrations. As waters warm in temperate region lakes, the process of volatilization and transport to the North will accelerate.

Higher intensity spring and summer rainstorm events will certainly increase soil erosion and any pesticide associated with it (Fawcett 1996). Two possible pathways exist for food chain contamination. One is through dissolution of pesticides and reabsorption to food used by invertebrates. This pathway is unlikely because most insecticides are tightly bound to soil particles. Alternatively, filter-feeding invertebrates do not discriminate in their source of food and filter all particles of a certain size. Soil particles of comparable size to either a bacterial or algal cell will be eaten directly. This is the likely pathway for contaminant uptake by invertebrates to enter the food chain. The pesticides would then move to higher levels of the food chain to be ultimately eaten by fish and other top predators including man. Increased soil erosion will indeed increase the contamination of biota in our rivers and lakes with pesticides.

For Ontario, successful programs to reduce pesticide use, and changes in crops, have resulted in a 52% overall decline between 1983 and 2003, as measured by active ingredient. However, glyphosphate-based pesticide use, especially on soy beans, has increased 58%.

Lake Ecosystem Response

The influence of climate change on water quantity and quality has not been addressed in many of the current textbooks (e.g. Wetzel 2001), but Kalff (2002) provides some predictions. Despite the deficiency of recent reliable data, initial predictions can be made from patterns observed during relatively short periods of change from a relatively stable climate. Clearly, the value of long term monitoring sites to link variables that can be used to develop reliable models of a changing environment is vital for our future.

One example of a long-term study was conducted at the Experimental Lakes Area (ELA) in northwestern Ontario on the Canadian Shield. This program was originally designed to determine the role of phosphorus in eutrophication of lakes. The site was then used in acid rain studies, studies on heavy metals and persistent organic pollutants. Despite the change in focus, a long-term monitoring activity was maintained andthe effects of the modest climate change could be documented (Schindler et al. 1990, 1996 and 2004). Although the data were only for one lake (Rawson Lake, Lake 239), they provide a template for other studies and illustrate how limnological and climatic variables are interrelated. Since 1970, when the studies were initiated, average annual air and water temperatures have increased by 2^{o}C and snow depth has declined by at least 50% (from 40 cm measured at the end of March 1970). The increase in air and water temperatures, along with the reduction in precipitation both in winter and summer, resulted in a 20 day increase in the length of the ice-free season. With less snow covering the lake ice, spring melt occurred earlier as did summer stratification of lake waters. There was an increase in the depth of mixing from the surface, and less oxygen in the hypolimnion. These conditions stressed cold-water fish. Small streams (first order) becoming dry during the summer increased from 10 to about 40 days. The reduced runoff increased water residence times and chemical solutes such as calcium and sulfate increased. The lake became clearer with less dissolved organic carbon (DOC). This was likely due to a combination of less export from the drainage basin, increased degradation by solar radiation and increased aggregation and sedimentation. Phosphorus, the limiting nutrient for phytoplankton abundance, and silica, needed for diatom production, both declined. A compounding factor was the increase in forest fires causing forest soils to lose their organic material and the ability to retain water.

DOC has been considered to be a master variable in the control of water quality. It is called dissolved because it is the fraction that will pass through a membrane filter of pore size 0.45 µm. However, much of it is of colloidal size. Many lakes and rivers that appear turbid are in fact coloured by DOC. It acts as the principal carrier of nutrients, metals, pesticides and controls the penetration of ultraviolet radiation and visible light wave bands (see below).

In another study on the Canadian Shield at the Ontario Ministry of the Environment location at Dorset Ontario, Dillon *et al*. 2004 also showed that from 1978 to 1998 there was a strong relationship between amount of total phosphorus, DOC, total iron and dissolved organic nitrogen (DON) exported from the drainage basin with precipitation. The fraction of DOC retained in the lakes also increased. With extended dry periods, water tables would decline and redox conditions of wetlands would increase. These authors predict that lakes would become much clearer with more penetration of visible and UV radiation to greater depths.

As noted earlier, the spring freshet will be, on average, of lower volume and will be earlier in the season. The traditional spring erosion periods will occur earlier in the year. With longer, warmer summers, the wetlands, rivers and lakes will have lower water levels (Mortsch, L., et al., 2003). Report to IJC) and the period of stratification as well as the water renewal time will be longer. In other words, the water renewal time for a lake volume to be replaced will increase. This will result in a greater retention of phosphorus and nitrogen with the net effect of lowering the level of nutrients being delivered to downstream ecosystems. This may be viewed as "good" in areas of high nutrient loading, but in remote areas it could lead to the desertification of the lakes.

Clair *et al.* 1996 related discharge, DOC and DON, from terrestrial basins with changes in climate over a ten year period (1983-1992) in 15 river basins in Atlantic Canada. The importance of evapotranspiration and precipitation was emphasized because even substantial increases in annual precipitation can lead to decreasing discharge when accompanied by higher temperatures and evaporation. Warmer, dryer conditions resulted in lower DOC export, while wetter conditions required lower temperatures for DOC to increase. The export of DOC from the drainage basin to the waterways is ultimately controlled by soil moisture content and the degree of infiltration into the soils. If water travels through the surface soils and litter zone, DOC values will be high. If it penetrates through the topsoil, DOC values will then be lower.

In conclusion, as we experience warmer winters with gradual late winter snowpack depletion, followed by warmer spring and summers interspersed with intense precipitation events we can expect lakes to lose ice earlier, stratify sooner and deplete oxygen more quickly deep waters. Lakes will be less productive, some with lower nutrient input and less DOC. As discussed below, this will permit greater UV radiation penetration.

Influence of soil erosion on productivity of aquatic systems through absorbance of solar radiation

With soil erosion, the downstream waters are usually much more turbid. This is a potentially increasing problem with an estimated 13 to 19% increase in spring sediment loads due to heavier rains since 1970, although this is probably offset in part by the greater use of conservation tillage (Chapter 3). Intuitively, we suspect that this loss is due to "soil" particles but it may include considerable organic detritus as well. Associated with these particles are fertilizers, including nitrogen, phosphorus and potassium.

The environmental impact of eroded soils varies from site to site and soil to soil. There are very few reliable studies that have determined the bioavailability to aquatic ecosystems of nutrients from fertilizers or pesticides except under controlled laboratory conditions. Extrapolation to field conditions should be done with caution. First of all, the nutrient phosphorus that is associated with the soil particles may or may not be bioavailable. Through a series of extractions, it is commonly held that non-apatite inorganic phosphorus is available on a time scale that is significant but under oxic conditions, soil particles may even remove phosphorus from the water column making lakes less eutrophic and productive. All particles tend to sink out of the euphotic zone so the impact on surface waters is often short lived unless conditions are sufficiently turbulent to keep the particles in suspension.

While in suspension, the particles absorb light across the visible spectrum rather than at specific wave lengths. Consequently, the suspended particles compete directly with phytoplankton for light. As a result, chlorophyll levels drop in zones of high turbidity as does overall productivity in the surface waters. In regions where eroded particles settle, the sediments become smothered. Invertebrate organisms that depend on the nutritious substrate in the sediments will be buried and will be exposed to lower levels of oxygen. The invertebrates both in the sediments and the water column that depend on filter-feeding algae and other microorganisms from the water will be challenged with additional particles in their food. The relative proportions of the soil to planktonic particles will determine the outcome and survival of this trophic level. We should recall that in most inland lakes about 75% of the energy used to sustain fish comes from consumption of benthic invertebrates.

Recently, many cottagers have made the casual observation that "my lake seems to be clearer". We intuitively think that the brown color of our lakes is due to suspended particulate materials due to soil erosion. In many cases this is correct but some of the "colour" is due to dissolved rather than particulate materials. The suspended particulate materials will absorb all wavelengths of the solar spectra but the dissolved materials are particularly important for absorbance in the UV region.

During periods of drought and warmer conditions there is less export of DOC from drainage basins (Schindler 1996; Clair *et al*. 1998; Dillon *et al*. 2006). Hudson *et al*. 2003 goes further by showing that DOC concentrations in the same lakes studied by Dillon *et al.* 2004 are influenced mostly by precipitation especially in the winter months, sulfate deposition (acid rain) and intensity of solar radiation (cloud free days). In general, DOC is refractory as most of the substrate that is useful for microbial activity has been depleted. It is persistent and at higher levels also gives some water bodies a tea color. The absorbance at 435 nm is commonly referred to as "colour" but at lower wavelengths the absorbance levels increase exponentially from 400 to 300 nm corresponding to absorbance of ultraviolet A (320-400) and ultraviolet B (300 - 320) radiation (Scully and Lean 1994). With reduced DOC export UV penetration increases (Schindler *et al*.1996B) with all of the problems associated with these damaging wavebands (Perin and Lean 2004).

As pointed out by Yan *et al*. (1997) in a lake near Sudbury that was recovering from acid deposition and showing signs of increased DOC levels, the effect of several very dry years resulted in an oxidation of reduced sulfur compounds which were released into the lake following several wet years. This resulted in increased acidification and depletion of DOC such that the increased UVB penetration would be sufficient to harm the zooplankton community. It is well known that UVB can lower primary production and shift the algal population to more tolerant species such as the *Cyanobacteria sp.* or blue-green algae, known to be poor food for zooplankton growth. Less DOC will increase underwater UVB radiation far more than the increase expected from stratospheric ozone layer depletion (Lean 1998a,b).

With lower DOC levels, there is a greater penetration of visible light. As a result the depth at which macrophytes are able to grow increases. As a result, cottagers, especially on the Canadian Shield, have already noticed weed problems that are associated with clearer waters. However, for water bodies affected by agricultural areas with heavy use of chemical fertilizer and manure, more intense surface runoff events can transport nutrients into the waters resulting in greater biological production and a trend towards eutrophication.

Projected Changes in the Great Lakes

With the changing climate, there are projections of declining water levels in the Great Lakes, connecting channels and the St. Lawrence River. (Mortsch, 1998) This will result in exposure of large mud flats especially in shallow areas such as Lake St. Clair, and require an increased need for dredging in order to get ships into major ports. This will further create problems in that the lower water flow will now be channeled through the deeper portions of the river resulting in less flow in the near shore zone. Furthermore, the increased velocity in the deeper regions will cause increased sediment transport from riverbeds to downstream areas in the main stem of the rivers.

It is striking to see the patterns of turbid river plumes as they reach the large lakes like Lake Ontario and Erie following intense summer storms. When the plume reaches the lake it makes a sharp turn, usually to the right. This is due to a current called the coastal jet that usually travels counterclockwise around the lake out to where depths are almost 40m. The coastal jethas a flow volume about 10 times the volume of the St. Lawrence River (Simons and Schertzer 1987). Inflowing water will be confined to this region and since the flow velocity is usually high during the summer, small particles would be kept in suspension for some time. It is in this region where most recreational activities take place.

Detailed information on the bioavailability of nutrients, heavy metals and organic contaminants is required before reliable predictions can be made, but certainly competition for light would occur and consequently primary production would be reduced especially in the coastal currents. Furthermore, removal of particles by filter feeding organisms would likely be the main pathway into the coastal food web. The overall pathway from inflow to final fate is unknown but certainly the coastal food web would be compromised. Ultimately, many of the refractory particles would find their way to the deepest region of the lake through sediment focusing. Here they would add to the accumulating sediments and perhaps smother the invertebrate population so important for benthic feeding fish.

The greatest stimulus for research on the Great Lakes was the discovery in 1967 that Lake Erie was "dying". A long-term trend for oxygen levels in the deep water of the Central Basin seemed to show that there was an increase in the depletion of oxygen since the first measurements were made in 1929. As a consequence, research activities between Canada and USA were stimulated and formalized through the International Joint Commission and the 1972, 1978 and 1987 Water Quality Agreements.

On further examination, four important conclusions were reached, three of which relate to issues of climate change. The first is that some of the data used for the early assessment were from waters much too warm to be considered a hypolimnetic sample. When these data were removed, the oxygen depletion rate was greater. The second discovery was that the depletion rate was higher in years when the water depth was less. Charlton (1998a,b) reasoned that the volume of the hypolimnion was less during low water years and consequently the volumetric depletion rate was greater. The third critical observation was that the rate of depletion of oxygen was always about the same for years of similar water depth and that the time of stratification in May started the clock for the summer depletion. Early stratification resulted in much greater depletion than when stratification occurred later in the year. Rogers (1987) showed that the date for stratification in Lake Ontario was a function of winter temperatures and not of the spring warming rate. This is likely a general phenomenon that would mean that warmer winters would result in earlier stratification in lakes.

These observations can be used to make predictions about the impacts of intense summer storms. If water levels are lower, hypolimnetic oxygen depletion will be greater. As winter temperatures rise, the date for summer stratification is earlier and depletion will be greater by the end of summer. If the water is more turbid, less light will penetrate, reducing plankton productivity, and the amounts of oxygen in the deep water will be less.

Overall, in large lakes, the influence of intense spring and summer storms will impact the coastal regions the most. It is here where the high velocity coastal jet will carry the turbid material around the lakes principally in a counter clockwise direction. There will be less productivity due to shading of the suspended particulate materials and also greater penetration of damaging UV radiation. Eventually the sediment load will be transported to deeper regions and the benthic invertebrate community will likely be covered over. Stratification will come earlier, and persist longer resulting in greater oxygen depletion and possibly in the Central Basin of Lake Erie, the stratification may not last through the summer and the entire water column would mix.

Summary and Conclusions

Soil erosion from agricultural lands is a major source of sediments, nutrients, and contaminants to the Great Lakes. These problems were documented in the Pollution from Land Use Activities Reference Group (PLUARG) report in 1978. In 1996, it was estimated that 26,000 tonnes of pesticides were being used annually in the Great Lakes basin (IJC 1998) with row crop herbicides being the largest component. PLUARG identified several toxic metals and other organic contaminants being discharged to the Lakes from diffuse sources both agricultural and urban. In a more recent report in 2005, the U.S. Great Lakes Tributary Modeling Program documented that soil erosion and excessive sediment loadings are causing billions of dollars in added costs, including: loss of topsoil and nutrients from cropland, increased fertilizer costs, damaged roads and structures due to stream bank erosion, additional treatment requirements for water supplies, loss of storage capacity in flood protection impoundments, loss of water based recreational use, degradation of Great Lakes water quality and destruction of aquatic habitat.

With an increase in intense rains, an increase in erosion is expected both from soils and within rivers where sediments will be resuspended and riverbanks altered as stream banks are shaped by the volume and velocity of water flow. This will result in more turbid conditions with greater loads of eroded soils, bacteria, nutrients and pesticides. Benthic invertebrates, an important link in the aquatic food chain, would be impacted as sediments collect in pools and lakes downstream.

Since extreme storms often follow dry spells, a reduced export of dissolved organic carbon may occur. This will result in clearer water in downstream lakes and with increased light penetration, macrophytes in weed beds will grow at greater depths capitalizing on nutrient rich sediments that have accumulated. In water bodies affected by agricultural activity, high rates of fertilizer and manure application would result in increased nutrient export with more intense rain events. Whether the nutrients actually influence the growth of algae remains poorly understood and may vary from soil to soil. Further investigations should be aimed at developing reliable predictions to relate overall nutrient export with changes in downstream water quality. Although we expect that an increased algal biomass would be developed with increased loading of nutrients this may in part be offset by the highly turbid conditions that would compete with algae for light and that eroded soils might actually take nutrients out of the surface waters as they settle. With increased sediment accumulation, oxygen depletion can be expected.

Climate change is also manifest in higher temperatures, especially in winter months. Due to melt periods during winter months, less snowpack would continue to be present at the end of winter and the spring freshet would likely have a lower volume, occur earlier and decline faster. If there is less snow and less frost, we might well expect changing patterns of flow and infiltration. Reliable budgets for watersheds are required if we are to make informed decisions. Since the spring freshet provides about 70% of the input to lakes each year, we should be prepared for lower water volumes in rivers and lakes.

With an overall warming trend, lakes will have longer ice-free periods, and thus a longer period of stratification. This will in turn result in increased oxygen depletion in the deeper zones. This is especially important for Lake Erie where critical hypolimnetic oxygen levels are experienced on a regular basis.

If soil is drier, runoff will move through deeper strata, rather than through litter and surface soils. Consequently, less dissolved organic carbon will be exported and this will result in greater penetration of visible and ultraviolet radiation. With clearer lakes, the mixing depth would increase, decreasing the amount of oxygen available in the deeper, cooler waters. Fewer cold-water fish would be able to find a suitable habitat. Also in the coastal zones of the Great Lakes, where most human uses are concentrated, the water would become more turbid in episodic events.

Along with the increase in erosion and surface runoff, higher levels of bacterial contamination are expected. Wells and rivers can become polluted from areas where large numbers of animals are contained without adequate manure storage facilities. While conventional bacterial enumeration provides some guidance, there are many false positives, and a great deal of confusion regarding the actual health risk posed by a positive result. For example, some forms of *Escherichia coli* are killers while others (the majority) are benign. This points to the need to increase our ability to identify pathogenic organisms using more sensitive and precise techniques (i.e. PCR-based techniques, microarrays, enzymatic assays, and others).

Additional information and data would be valuable in follow-up studies. These include water export data from controlled waterways and rapid monitoring data from intakes of water treatment plants coupled with satellite imagery. Measurements of water quality following intense and very intense spring and summer storms are needed.

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Chapter **5**

Remedial Responses and their Effectiveness

By W.T. Dickinson, R.P. Rudra, A. Huber and G.J. Wall

Remedial Responses

The erosion and loss of productive agricultural soil was one of the significant concerns which prompted the formation of Conservation Authorities in Ontario in the 1940s and 1950s. The need for remedial measures and programs to curb erosion was noted in the foundational conservation reports (e.g. Department of Planning & Development, 1952; Department of Energy & Resources Management, 1965). The response to this need was relatively low key at that time, and primarily involved educational materials including “fact sheets” prepared by the Ontario Ministry of Agriculture, Food and Rural Affairs and sections in County Soils Reports (e.g. Hoffman & Richards, 1962).

In the 1970s, the need to control soil erosion became more environmentally based, and was related to concerns regarding suspended sediment concentrations and loads downstream of agricultural areas along with associated contamination involving phosphorus, heavy metals and pesticides. These concerns led to quite significant studies undertaken under the sponsorship of the Reference Group of the International Joint Commission regarding “Great Lakes Pollution from Land Use Activities” (PLUARG), leading to recommendations for substantial remediation (International Joint Commission, 1978). This undertaking clearly identified soil erosion and the associated yield of sediment from intensive agricultural operations to be the major diffuse source of contamination in the Great Lakes system.

The Ontario Institute of Pedology, at the request of the Plant Industry Branch of the Ontario Ministry of Agriculture and Food, undertook a joint study to estimate annual water and wind erosion costs to Ontario agriculture (Ontario Ministry of Agriculture and Food & Ontario Institute of Pedology, 1982). The total annual costs attributed to yield reductions of 40%, nutrient losses of 45% and pesticide movement of 12% were approximately $68 million, with more than 80% of the costs occurring in the southern and western regions of the province. Costs associated with water erosion dominated the damages (approximately 98%), with wind erosion accounting for the remainder. Shortly thereafter, the Standing Senate Committee on Agriculture, Fisheries and Forestry (SSCAFF) submitted a report on soil conservation to the Senate of Canada (SSCAFF, 1984). This committee also concluded that soil degradation was costing farmers a very significant amount of money, and that soil conservation could not be dealt with in isolation from related issues such as water quality. The Committee recommended that both federal and provincial governments develop soil and water conservation policies.

A multitude of environmental legislation, statutes and programs emerged in Ontario in the years following the PLUARG studies and the reports noted above. Agnew et al. (2005) prepared a review regarding this material, providing a basis for the summary presented in Table 3.1. This summary reveals that there has been a flood of responses in the past 20 years aimed at the remediation of agri-environmental issues, including the control of soil erosion and sediment yield, with the development and implementation of programs and projects costing millions of dollars. It should be noted also that many of these programs have been voluntary, the farm communities being required to take their own initiatives.

Program Uptake and Evidence of Change on the Land

There is some evidence that the uptake of remediation programs by the farming community has been quite good, particularly given the voluntary nature of the programs. For example, for the Environmental Farm Plan, about 8 million hectares of farmland were covered by plans in 2004, representing 40% of farms in Ontario; and "adoption of the EFP has been increasing with time as the reputation of and respect for the program has increased in the community" (Fitzgibbon et al., 2004). Currently there has been a move towards regulation of some such programs, but many farm organizations are attempting to ensure that a segment of voluntarism remains (Wells, 2004).

Some reports have stated that there was a decrease in water-erosion risk after 1981, that decrease being attributed primarily to improved cropping and tillage practices. Wall et al. (1995) estimated the decrease in erosion risk in central Canada to be 16% from 1981 to 1991; while Shelton et al. (2000) estimated the overall reduction in Ontario to be at least 5% between 1981 and 1996. These reports further stated that about 60% of Ontario's cultivated land required further implementation of conservation management practices, with 40% of cropland still in intolerable risk classes.

Canadian census data also provides a useful base for exploring the extent to which remedial measures advocated in the programs noted may above have been adopted and implemented on the land. Ontario responses to a number of the census questions relating to topics addressed in remedial response programs and potentially affecting soil erosion and sediment yield are summarized in Figures 5.1 and 5.2. These data reveal that farming practices advocated for soil conservation have been adopted in a relatively small percentage of farms and cropped areas in the province as a whole. "No till" appears to be the only conservation practice which has increased substantially, although the percentage of overall cropped land involved remains less than 20%. The areas where strip cropping, contour cultivation and winter cover crops have been practiced have remained low and perhaps dropped; and grassed waterways continue to be used to a very limited extent.

Considerable light is shed on the adoption of no till practices in different areas of the province in Figures 5.3 and 5.4. Figure 5.3 reveals that adoption of no till has been extremely variable across the Census Agricultural Regions in Ontario. The uptake of no till appears to have risen dramatically between 1991 and 2001 in the Southern Region; and in that region, practices involving reduced tillage may have become implemented in more than double the percentage of cropped land of any other region in the province. The spatial variability in the adoption of no till is also evident at the county scale within the Southern region, as shown in Figure 5.4. Once again the practice of no till is seen to vary spatially more than two fold, the adoption rates achieving remarkably high levels, i.e. approaching 50%, in Essex and Lambton Counties in 2001.

There is evidence therefore that some soil conservation practices have been adopted in recent years in Ontario. The percentage of cropped land or farms across the province in which most such practices have been implemented however remains quite limited i.e. less than 15%. Nonetheless, the portion of cropped land on which no till practices have been used appears to have increased substantially from 1991 to 2001 in at least one region of the province (i.e. the Southern Region) and more specifically in a few counties in that region (i.e. Essex and Lambton). Increased adoption of no till is very likely attributable to the many programs focused in this direction in the late ‘80s and throughout the ‘90s. The areas of the province experiencing the highest adoption rates of conservation practices, no till in particular, probably reflect a sustained presence of highly qualified and committed field personnel and significant initiatives undertaken by small groups of “innovative farmers.”

Impacts on Stream Sediment

Unfortunately, there are virtually no data bases in the province regarding suspended sediments or associated extreme-event oriented variables which can be examined meaningfully for time trends. Stations monitored by the Sediment Survey of Canada, and for which there were detailed records of suspended sediment concentrations and loads (Dickinson et al., 1991), were discontinued in the mid 1980s; and the Provincial Water Quality Monitoring Network (PWQMN) operated by the Ontario Ministry of the Environment is based on a sampling program which involves the taking of only 8 samples per year with little or no sampling during peak flow events (Ministry of the Environment, 2005). Time trends in suspended solids concentrations, based on the PWQMN data base, have been prepared (e.g. Grand River Conservation Authority, 2005; Upper Thames Conservation Authority, 2004; Ministry of the Environment, 1999), revealing in general very little if any change. However, as most of the events involving significant sediment loads are not likely included in this data base, the apparent trends do not provide reliable indicators of possible changes in suspended sediment concentrations let alone loads.

The Enhanced Tributary Monitoring Program (ETMP) (Eddie & Onn, 1982; Ministry of the Environment, 1999) was established by MOE in 1980, and involved the monitoring of 16 stations near mouths of rivers in the Great Lakes Basin with the collection of 20 samples per year at each station and an emphasis on the spring freshet i.e. when a significant proportion of annual suspended sediment and associated contaminant loads occur. Unfortunately, this program has involved only 8 stations in recent years, and only 3 of those stations (on the Humber, Don and Grand Rivers) are in southern Ontario. Further, only the station on the Grand River at Dunnville involves a watershed with a significant agricultural component. No time trend analysis is presently available for this station for either suspended solids concentrations or loads.

The Case for Targeting Remedies

In light of the wide spatial variability of both soil erosion and sediment yield which occurs in many agricultural watersheds in southern Ontario, as noted in Chapter 3, it would seem both highly efficient and economical to target remedial responses to the most critical areas. It has been claimed that targeting assistance for soil erosion control could more than triple the amount of soil saved through the Agricultural Conservation Program in the U.S, (Henry, 1981). Lee at al. (1985) concluded that there would be substantial savings from targeting erosion control within watersheds, in terms of soil loss reduction per dollar of program cost; and Runge et al. (1986) noted that more accurate targeting could reduce on-site productivity losses and minimize the area affected negatively by restrictive land use practices. In a joint statement, the Ontario Chapter of the Soil Conservation Society of America (now the Soil and Water Conservation Society) and the Ontario Institute of Agrologists (1986) recommended that lands with erodible features should be considered as target lands for subsidization of forage crops or new productive woodlots, combined with cross compliance.

The Nonpoint Source Control Task Force strongly recommended that areas within watersheds that have a higher potential to deliver pollutants be identified and that implementation of controls be given priority in these areas (International Joint Commission, 1978). This recommendation acknowledged that only a small number of nonpoint programs had been targeted to those areas that contribute a disproportionately large share of the pollution load, and that it is necessary with a scarcity of resources to identify priority management areas and to target control expenditures.

An example of the possible effectiveness of targeting remedial responses for soil erosion and sediment yield control in a range of Ontario conditions is summarized in Figures 5.5 and 5.6 (Dickinson et al., 1990). The estimates of soil loss and sediment delivery were generated by application of the GAMES model in upland and lowland watersheds, and the strategies for implementation of remedial measures which were explored included selecting fields for remediation in each watershed in increments of 10 percent of the watershed area: A - at random, B - selectively from targeted portions of each watershed, those fields with the greatest soil loss and sediment yield rates being treated first, and C - at random from targeted portions of each watershed.

The evidence suggests that the targeting of remedial soil and water conservation measures is likely to be a highly efficient approach for reducing basin sediment yields and associated pollution. For example, as shown in Figure 5.5, implementing remedial measures in the most critical source areas of an upland basin, constituting only 10 to 15% of the watershed area, might well reduce downstream sediment loads by 50% or more. In lowland conditions (Figure 5.6), remediation in the most critical 20% might reduce loads by up to about 40%. It is also clear, given apparent adoption and implementation rates of 10 to 15%, that unless remedial measures associated with soil erosion and sediment yield are targeted to critical areas, the likelihood of downstream sediment and associated contaminant loads being reduced significantly is extremely small i.e. implementing remediation at random on 10% of the area might reduce loads by 5%.

The economics of targeting remedial measures have been clearly established (Fox & Dickson, 1990; Fox et al., 1995; Qiu, 2003). This evidence also reveals that, without targeting, the solution of nonpoint source problems remains slow and expensive, if achievable at all.

Conclusions

There certainly has been an abundance of legislation and programs in recent years directed at agri-environmental issues in Ontario, including a focus on remediation of soil erosion problems and associated contamination of rivers downstream with suspended sediments and sediment-borne pollutants. Participation in some of these programs has been active, and there has also been an increase in soil conservation oriented tillage practices during the same period of time, particularly those involving no till. Although these trends are very positive, the extent to which soil conservation practices are being implemented across the Ontario landscape as a whole remains limited; and the risk associated with water erosion remains significant. Upwards of 50% of the cultivated land in the province is estimated to remain at intolerable levels of soil erosion risk.

There is no evidence that concentrations or loads of suspended sediment in Ontario streams have decreased in the province as a result of implementation of remedial measures directed at reducing soil erosion and sediment yield. In fact, until improved monitoring of stream sediments is undertaken, there will continue to be no reliable data base for ascertaining changes in sediment concentrations or loads. There is also reason to believe that unless or until soil conservation practices are targeted at critical contributing source areas, sediment contamination in Ontario streams will not be significantly altered.

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TABLE 5.1
Summary of environmental legislation, statutes and programs related to agriculture in Ontario (After Agnew, 2005).

Legislation, Statute or Program	Description
Environmental Legislation & Statutes in Ontario	
Environmental Assessment Act (1990)	* Issued by the MOE * Primary environmental planning statute * Provides for: - assessment of major public or designated private projects - evaluation of ecological, social, cultural and economic impacts
Public Lands Act (1990)	* Administered by MNR * Regulates the use, management, sale and outlook of public lands and forests
Ontario Water Resources Act (1990)	* Administered by the MOE * Protects the quality and quantity of surface and ground water resources in Ontario * Standardizes sewage disposal * Forbids the discharge of materials that may impair water * Regulates "water taking"
Environmental Bill of Rights (1993)	* Provides for: - protection, conservation & restoration of the environment - sustainability of the environment - protection of the right to a healthful environment - assurance of public participation in environmental decision-making - increased citizen access to the courts for environmental protection
Agriculture Policy Framework (2001)	* Administered by AAFC * All provinces have signed * Considers business risk management; food safety & food quality; science, innovation, environment & renewal qualities * Involves sector-wide consolidation to eliminate redundancy and duplication * Establishes universal standards of environmental quality * Provides for improvement of environmental planning tools and management systems to achieve sustainability
Agriculture Code of Practice (2001)	* Administered by OMAF, MOE & MAH * Provides guidelines for livestock operations to minimize the potential for land, water & air pollution * Provides for issuing of Certificate of Compliance
Nutrient Management Act (2002)	* Administered by MOE & OMAF * Provides for control of on-farm nutrients from entering surface or ground waters * Facilitates the regulation of nutrient management through farm plans and strategies

Safe Drinking Water Act (2002)	* Administered by MOE * Relates to treatment & distribution of drinking water * Provides protection of human health through the control and regulation of drinking-water systems and testing * Provides legally-binding standards for contaminants * Mandates the use of licensed laboratories for the testing of drinking water, and the reporting of adverse test results
Sustainable Water Quality Management Legislation (2002)	* Administered by MOE * Requires municipalities to assess the costs of water, and to develop plans to charge appropriate rates and generate revenue
Greenbelt Plan (2004)	* Administered by MAH * Provides for - protection of the agricultural land base, greenspace and ecological features, and the containment of urban sprawl - the improvement and enhancement of quality of life for both rural and urban residents
Drinking Water Source Protection Act (2004)	* Identifies "multi-barrier" approach to the provision of a safe supply of drinking water * Phase 1: Evaluation of potential sources of contamination, the quantity of water available, and vulnerable bodies of water * Phase 2: Creation of programs, policies & initiatives to minimize the risk of contamination, and to ensure long-term protection
Past Agri-Environmental Programs	
Ontario Soil Conservation & Environmental Protection Assistance Program (1983-1988; 1988-1991)	* Involved 2 parts: OSCEPAP I & OSCEPAP II * Administered by OMAF * Provided grants to farmers who voluntarily: - adopted erosion control practices (soil conservation component) - constructed/installed manure storages, covers etc. (environmental component) a total grant of 25.5 million dollars being available during the 1st 5 years * Provided soil conservation advisors, beginning in 1985, to improve program uptake and to promote soil conservation practices including conservation tillage
Soil & Water Environmental Enhancement Program (SWEEP) (1986-1993)	* Involved Canadian & U.S. Governments * Provided for control of phosphorus pollution from entering the Great Lakes from agricultural and industrial sources
Land Stewardship Program (LS) (1987-1990; 1990-1994)	* Involved 2 parts: LS I & LS II * Provided grants to farmers who adopted conservation farming practices: - total grant of 2.25 million dollars during 1st 3 years, for maintenance, training & equipment - total grant 38 million dollars during past 3 years
Great lakes Water Quality Program (GLWQ) (1989-1994)	* Involved Canadian & U.S. Governments * Focused on agricultural chemicals and their reactions within the environment * Included water quality issues and conservation practices

National Soil Conservation Program (NSCP) (1991-1993)	* Provided for: - assistance for implementation of on-farm conservation measures - research & monitoring * Promoted awareness of benefits of the program
Clean Up Rural Beaches Program (1991-1996)	* Administered by MOE * Provided financial and technical assistance to rural landowners who voluntarily implemented BMPs * Focused on control of non-point source pollution * Promoted increased public awareness of the possible impacts of agricultural activities on water quality
Land Management Assistance Program (LMAP) (1992-1994)	* An extension of NSCP * Funds were provided for Rural Conservation Club programs, and the development of BMP booklets * Federal funds totaled 15.242 million dollars * Provided assistance for pilot project for the EFPs, and a workbook/video package
Environmental Sustainability Initiative (ESI) (1992)	* Focused on: - sustaining agriculture's natural resource foundation and competitiveness - the adoption of sustainable farming practices as a means of increasing long-term returns to producers * Initiated the EFP pilot project
Green Plan (1992-1997)	* Provided federal funds for research (30%), farmers & farm organizations (45%) and technology transfer (25%) * promoted use of community consultation to identify issues and to develop methods of action
Healthy Futures for Ontario Agriculture (2000-2004)	* Encouraged partnerships in Ontario's agriculture and food sectors to: - improve the quality and safety of Ontario food products through the adoption of new & upgraded technology and/or BMPs - capitalize on marketing & export opportunities - safeguard rural water quantity and quality
Current Agri-Environmental Programs	
Clean Water Program (2001-present)	* Administered by UTRCA, in concert with Oxford, Middlesex and Perth Counties, and rural parts of London, Stratford and St. Marys * Provides financial and technical assistance to landowners to share the cost of implementing BMPs that improve water quality
Rural Water Quality Program (1995-present)	* Administered by GRCA * Facilitates the response to particular water quality issues on farms * Provides financial and technical assistance to landowners to share the cost of implementing BMPs that improve water quality
Environmental Farm Plan (1998-present)	* Led by OFA, CFFO, OFAC & AGCare * Provides method for farmers to identify environmental strengths and concerns, and to prepare goals and timetables for the improvement of environmental conditions

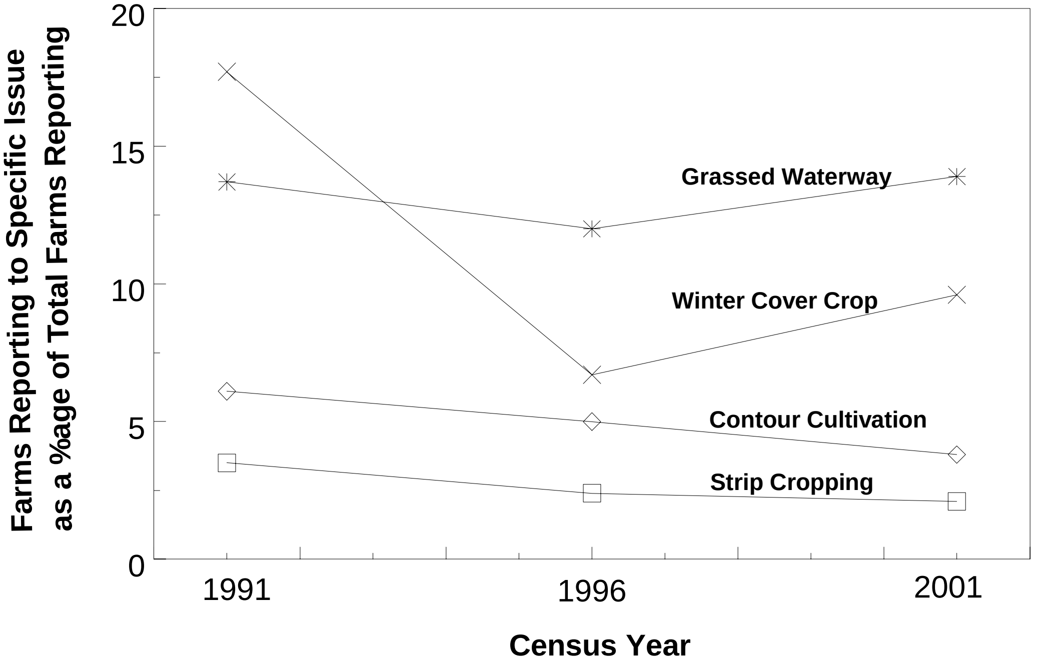

FIGURE 5.1
Trends in number of farms in Ontario reporting use of various conservation practices.

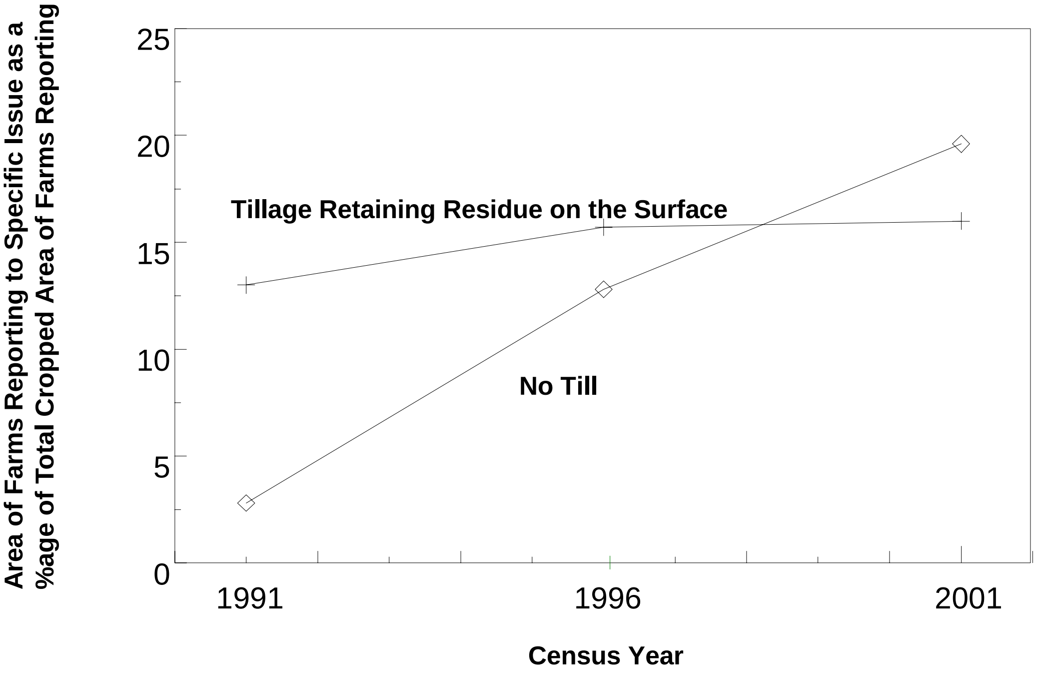

FIGURE 5.2
Trends in area of farms in Ontario reporting various soil conservation measures

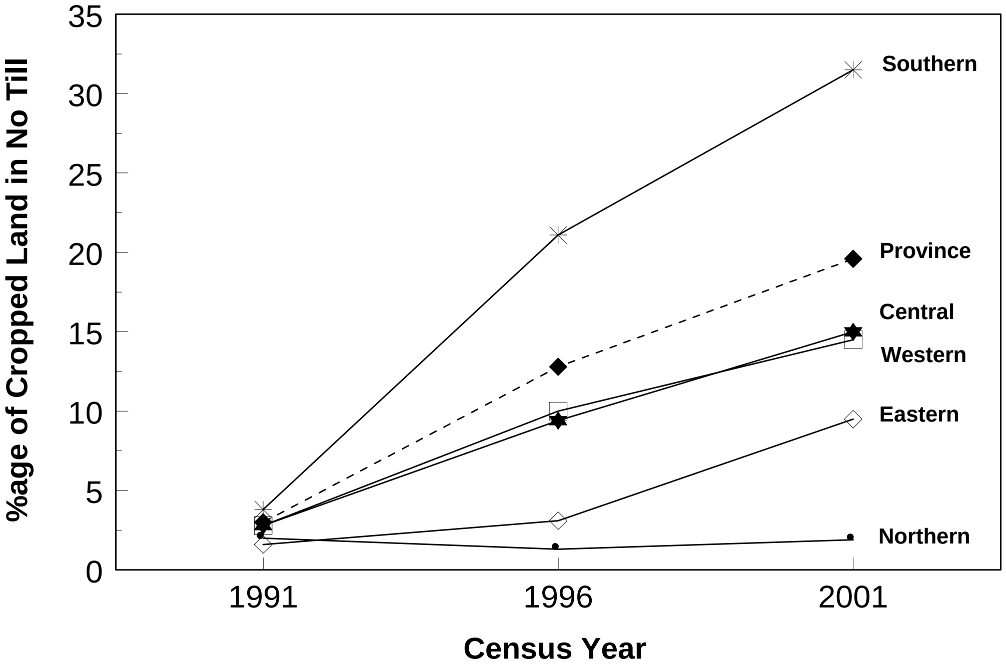

FIGURE 5.3
Trends in percentage of cropland in "no till" for Census Regions in Ontario.

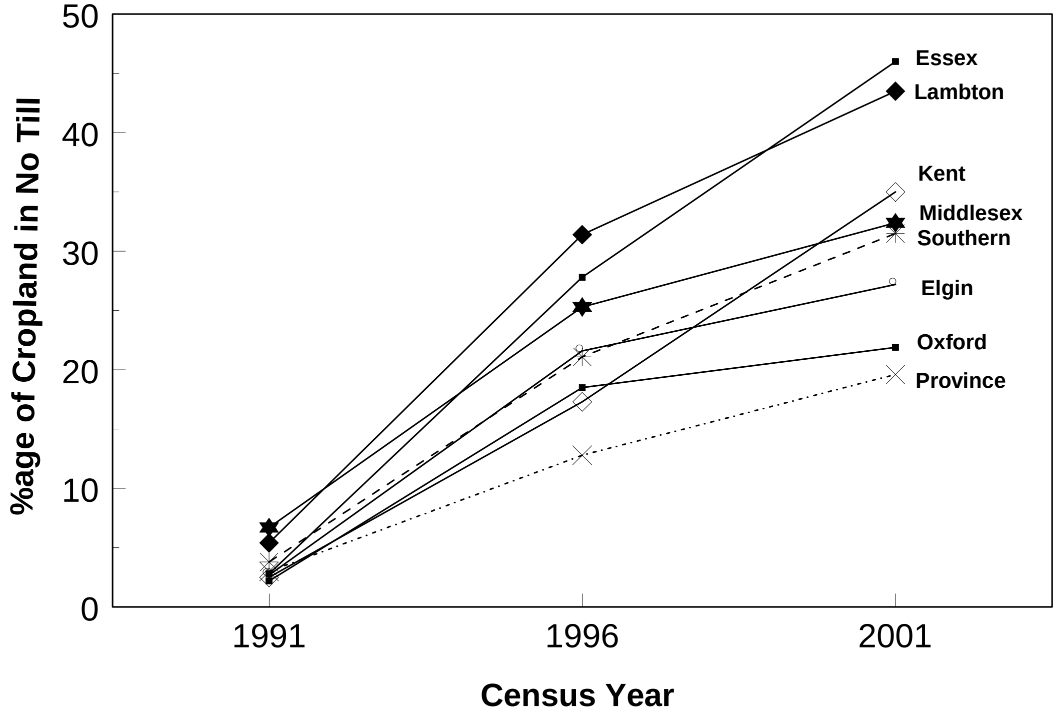

FIGURE 5.4
Trends in percentage of cropland in "no till" for counties in the Southern Census Regions in Ontario.

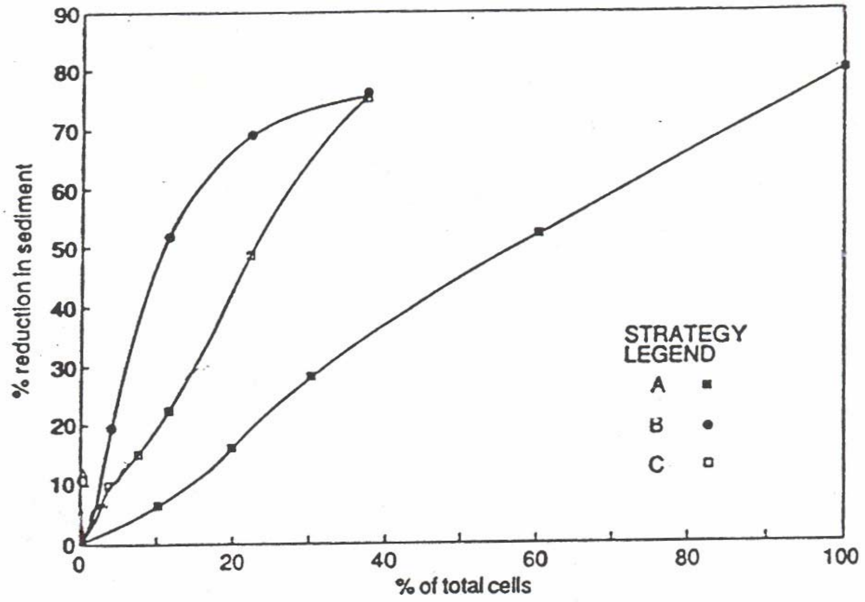

FIGURE 5.5
Reduction in sediment yield from an upland basin as a result of the application of various management strategies (Dickinson et al., 1990).

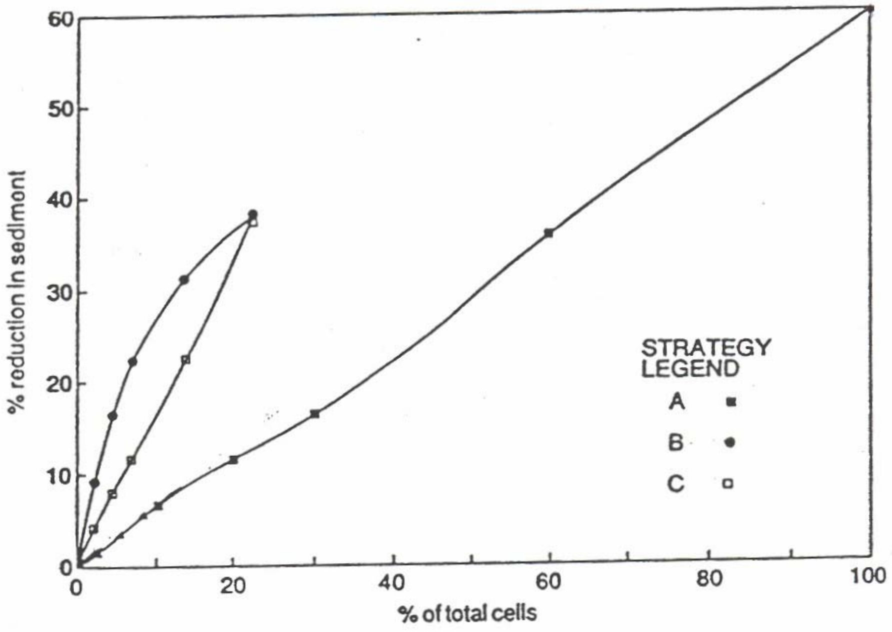

FIGURE 5.6
Reduction in sediment yield from a lowland basin as a result of the application of various management strategies (Dickinson et al., 1990).