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The potential environmental consequences of utilizing sewage sludge as fertilizer on agricultural lands: A case study of the region of Waterloo (Ontario)

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THE POTENTIAL ENVIRONMENTAL CONSEQUENCES OF UTILIZING SEWAGE SLUDGE AS FERTILIZER ON AGRICULTURAL LANDS: A CASE STUDY OF THE REGION OF WATERLOO

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Abstract

With the advent of increased volumes of liquid sewage sludge being produced in the world annually, means of disposal and recycling have become a serious issue. The disposal of sludge onto agricultural lands has raised concern regarding its environmental implications. The concern stems from the presence of toxic substances often found in sludge which can be harmful to the environment.

The sludge utilization programme in the Regional Municipality of Waterloo has shortcomings in the areas of site evaluation and monitoring, and setting an application agenda tied in with a weather forecasting system. These shortcomings combined with the physical characteristics of the sludge sites may be considered as hindrances to the safe and proper application of sludge onto agricultural lands.

Comparing the guidelines which govern sludge utilization on agricultural lands and how they are implemented with those of other countries, suggests that in the Region of Waterloo (Ontario Ministry of the Environment) the standards for sludge quality permitted on land are high, however, implementation of guidelines must be rendered a more strictly monitored operation.

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CHAPTER 1

1.1 INTRODUCTION

Urban growth is an ongoing process in North America and the world. As these urban centres expand, the volume of sewage waste generated continues to rise substantially, taxing current disposal and recycling methods. As a result, disposal and recycling programmes have become issues of prime concern.

Sludge can be disposed of and/or, recycled in a variety of ways; however, each method possesses certain limitations. Incinerating sludge for example, depending on the efficiency of the facility, may in fact release harmful substances, e.g. $S0_2$, $N0_X$, HCl, particulates, heavy metals and other toxic organic compounds into the atmosphere most of which, in time, return to earth as atmospheric fallout (Dirkzwager and L'Hermite, 1989). Other disposal methods include direct disposal into the ocean, composting, lagooning, and landfills. Applying sludge onto agricultural land has been regarded for the most part as a disposal method. However, because of the nutrient value of sludge, it can be considered a form of fertilizer. As such, the use of sludge is referred to as a form of recycling. The limitation of this method is that soil can only absorb/adsorb a finite amount of sludge nutrients/metals within a given period of time. The amount of nutrients/metals adsorbed/absorbed by the soil depends on both sludge and soil chemical characteristics, the hydrological conditions, and temperature.

There are numerous advantages to applying sludge onto agricultural land. The low cost of recycling, sludge nutrient value, and its high moisture content are the most pronounced advantages. The high moisture is especially beneficial to soil during prolonged dry periods. Despite the advantages, there are environmental repercussions to consider. The concern stems from the presence of certain toxic substances commonly found in sludge examples of which are cadmium (Cd) and mercury (Hg) to name a few. A noteable portion of these substances, particularily Cd can enter the food chain. The presence of toxic substances in sludge makes sludge management an important component in the effort to protect both public health and the environment.

Management plans differ by the manner in which strategies are adopted to achieve a certain goal. Goals may be similar, but one manager may prefer a diverse plan which would include numerous disposal alternatives, whereas another manager may rely on a single disposal method and simply have a contingency plan in the event that the system fails, e.g. equipment failure.. Economics, ecology and public health are all prime considerations. Because of the toxic substances found in sludge, environmental protection is the common denominator of most waste management plans. However, due to economic constraints, and/or inadequacies in management procedures, actual implementation of management schemes may not always produce the desired results.

The purpose of this thesis is to examine the environmental implications associated with applying sludge onto agricultural land, as it is currently practiced in the Regional Municipality of Waterloo. Emphasis will be on reviewing management practices of the sludge utilization programme in the Region of Waterloo, and to highlighting areas in the management procedures which could be improved to optimize environmental protection.

An examination of the guidelines governing sludge spreading in Ontario in conjunction with comparing guidelines and sludge spreading practices of other countries will serve to put Ontario practices into perspective. This thesis will examine what impacts a selected few sludge constituents have on surface water quality, and how the physical characteristics of selected sites may raise the risk of potential environmental degradation.

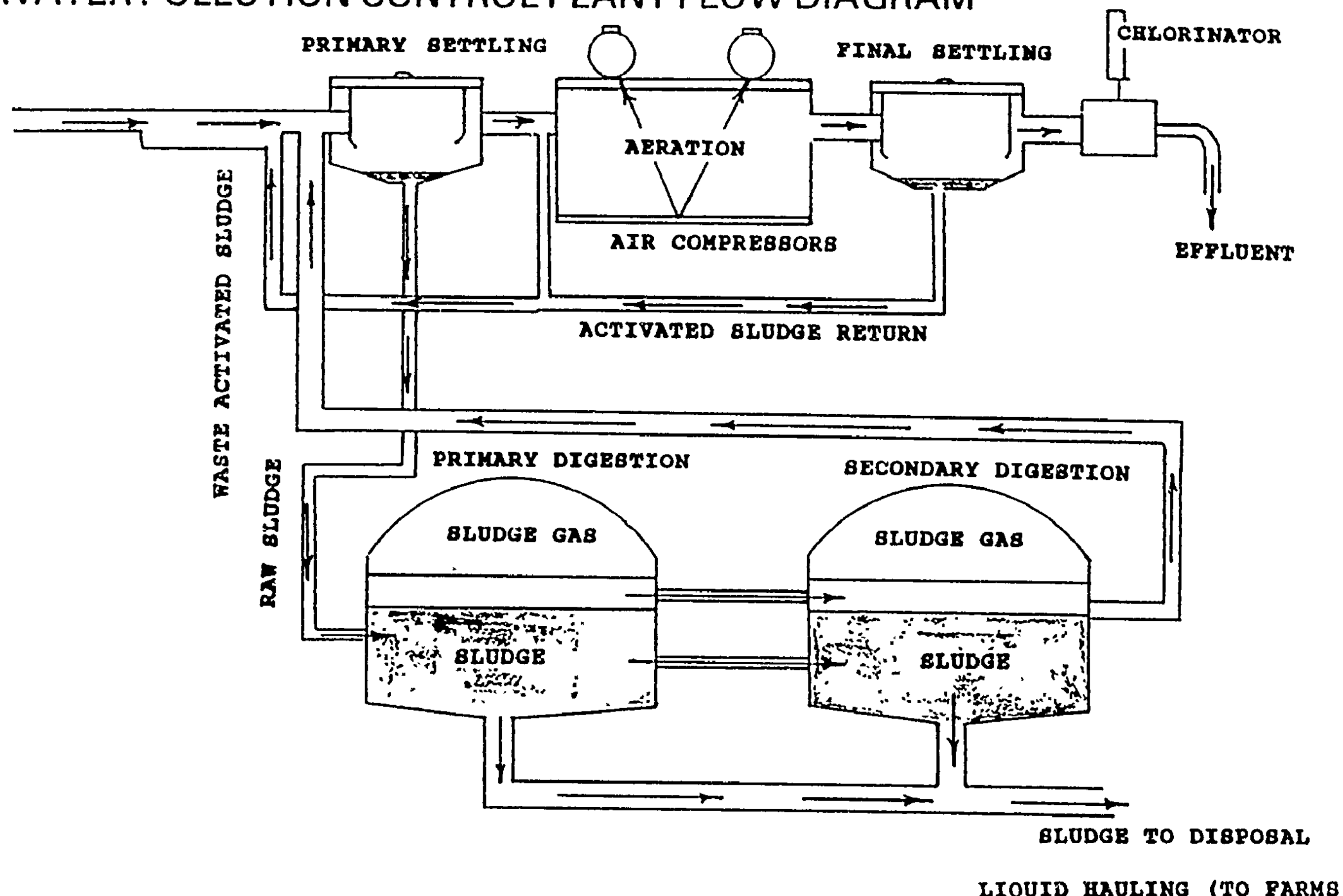
1.2 DEFINITION OF SLUDGE

Sludge results from sewage processed in municipal sewage treatment plants whereby waste is separated from the effluent water. In the activated sewage process, solids and heavy metals are permitted to settle, the resultant precipitate is a black fluid termed sludge (M.O.E., 1982). Eckenfelder et al. (1981) define sludge from a municipal sewage treatment plant as a solid-liquid mixture containing total solid concentrations from 2000 parts per million (ppm) to hundreds of thousands of ppm. Sludge settles in the primary settling tank of the sewage treatment plant after which it is pumped into digester tanks in which the sludge is stabilized, i.e. rendered fit for disposal/recycling, e.g. for use in agriculture (Figure 1.1). The digestion/stabilization phase is a form of pasteurization where sludge is heated to 32 degrees celsius for approximately thirty days. This process serves to sterilize the sludge and diminish its often foul odor.

1.3 SLUDGE TYPES

There are several types of sludges, their composition being characteristic of the type of industry in the locality. The composition of sludge is not consistent and changes from day to day because of varied industrial activity, e.g. industrial processes and varying operation capacities (M.O.E., 1982). The major differentiating factors for the categorization of sludges are the types of treatment processes they undergo, and their

WATER POLLUTION CONTROL PLANT FLOW DIAGRAM



Modified from (M.O.E., n.d.)

Figure 1.1

origin. Some common sludge types are chemical, limed, iron, and aluminum. The latter three are so named for their phosphorus (P) removal methods, the former is predominantly from chemical and car plants, and oil refineries. Aluminum, iron salts, or lime are used as coagulants, and cause P to precipitate, which is then removed (Seto and DeAngelis, 1978). In Ontario, in excess of 85% of sludges produced are treated for some form of phosphorus removal (Soon et al., 1980).Sludges can also be classified as either aerobic or anaerobic. The fundamental difference is that the former undergoes digestion with the presence of air as opposed to the latter which involves digestion under anaerobic conditions, i.e. without air. Another important factor to consider is that aerobic sludge tends to contain less nitrogen and nitrogen compounds.

1.4 SLUDGE COMPOSITION

The major constituents that make up sludge are phosphorus (P), nitrogen (N), and various compounds of each, other chemical compounds, micropollutants such as heavy metals and organics, and approximately 90-99.5% water (Davis, 1984). Tables 1.1 and 1.2 show the range of contaminants found in sludge, and examples of micropollutants. Many of the effects of P and N in the environment are understood, particularily those associated with eutrophication, e.g. a nutrient rich aquatic environment promotes excessive plant growth which in turn can reduce dissolved oxygen vital to other aquatic organisms (Elkin. 1986; GRIC, 1982). However, heavy metals and micropollutants are the least understood, and because a number of these are toxic, with potential carcinogenic and mutagenic effects, they are the constituents of primary concern (Waite, 1984). The most common heavy metals found in sludge are copper (Cu), chromium (Cr), bromium (Br), boron (Bo), nickel (Ni), lead (Pb), zinc (Zn), and cadmium (Cd) (Davis, 1984; Singh, 1979). The latter is of utmost concern, primarily because of its phytoxicity, peoples's low tolerance of it, and its long residence time allowing it to accumulate in both biomass and in soil (Waite, 1984).

(Table 1.1) THE RANGE OF CONCENTRATIONS OF HEAVY METALS IN DIGESTED SEWAGE SLUDGES

Element	Range (ppm)	Typical Median (ppm)	M.O.E. limit
Cd	1- 3,410	15	34
Cu	84-17,000	800	1,700
Cr	10-99,000	500	2,800
Hg	.6- 56	6	11
Ni	2- 5,300	80	420
Pb	13-26,000	500	1,100
Zn	101-49,000	1,700	4,200

Source: Bitton et al., 1980; M.O.E., 1986.

(Table 1.2) MICROPOLLUTANTS FOUND IN SLUDGE

Pollutant	Half-life (years)
Aldrin	1-4
DDT	3-10
Dieldrin	1-7
Chlordane	2-4
Endrin	4-8
Heptachlor	7-12
PBB's	+4
Taxophene	10

Source: Dacre, 1980.

The current thrust in waste treatment research is the search for seeking out new and innovative ways of reducing the heavy metal content in sludges so as to reduce their concentrations to levels which are considered less toxic. Santhanam et al. (1981) point out that the technology to reduce the level of contaminants in sludge exists, but current economics preclude any profitable recovery. In general, one percent of the volume of sewage is produced as sludge which contains between 50-80% of the total mass of heavy metal concentrations entering treatment plants (Lester, 1987). This ultimately means that the remaining metals which do not precipitate into the sludge are discharged into the streams and rivers as sewage treatment plant effluent. Treatment plants are employing increasingly sophisticated technology for treating waste water, and thus, are able to extract more of the heavy metals (Eckenfelder et. al., 1981). As a result, the sludge produced contains more heavy metals thereby increasing its toxicity, and making it more difficult to handle (Eckenfelder et. al., 1981). One can view this as a dilemma whereby water treatment plants seek to remove as much of the toxic substances from the sewage effluent as possible prior to discharging it into watercourses. Conversely, less toxic sludges are sought to render them fit for agricultural use. With the intention of reducing the discharge of contaminants into lakes and rivers, programmes such as those involving Municipal Industrial Strategy for Abatement (MISA) attempt to reduce pollution at its source. This entails in part monitoring the effluents of both sewage treatment facilities and various industries, and ensuring that permitted levels of pollutants/contaminants discharged into surface waters are not exceeded. By forcing industry to reduce the toxicity of waste effluents, sludge can effectively become "cleaner". This is especially beneficial for urban centers in which industrial waste is discharged into the municipal sewage system.

CHAPTER 2: LITERATURE REVIEW

2.1 SLUDGE MANAGEMENT

Sludge management plans can be very diverse and also vary from region to region. The availability of resources and facilities are the primary constraints of any management plan. Lack of storage facilities, treatment plants, manpower, and capital along with a means of disposal/recycling that is economic and environmentally sound are identified as constraints when designing effective management plans. A large agricultural sector in the vicinity of a large urban center offers a potentially good means of recycling sludge on land. However, among other constraints, the quality of the sludge will also dictate the choice of disposal/recycling alternatives. A poor grade of sludge, i.e. one that is high in toxic substances and pathogens is not suitable for agricultural purposes and must either be treated further, or disposed of in a landfill. A body of water near a city's sewage treatment plant may be an attractive receptacle for sludge. Coastal cities such as New York and Vancouver along with cities located near rivers such as Montreal in Quebec on the St. Lawrence River take advantage of these bodies of water to discharge sewage and sludge. Other municipalities may be forced to incinerate or dewater sludge. These methods serve to reduce the volume of sludge to be disposed.

Political, social and economic factors are integral to any management scheme. The sludge manager cannot simply implement a management plan without consideration for the social implications. For example, sludge spreading on land may be more widely accepted by a predominantly agricultural dominated area and less popular among people in residential areas. The often foul odor, the noise of trucks and potential health concerns necessary must be considered. Informing the public of the benefits of sludge and avoiding disruption of the peace of the area can win over the support of the community (Younos, 1987). The economic considerations involve initial cost of setting-up the operation and long-term operating costs. The spreading of sludge onto agricultural land is one of the most cost efficient ways of recycling sludge for municipalities located near a farming community.

When scheduling sludge spreading, an examination of local weather patterns is crucial (Curnoe, 1974). The variables that influence the level of risk of potential water contamination are heavily influenced by several meteorological parameters: the amount, intensity and duration of rainfall. Because water is the most dominant medium by which contaminants are diffused, and rain being the prime source of water, an examination of rainfall data is feasible. By examining rainfall data, it can be determined which months within the sludge spreading period experienced excessive rain. The excessively wet periods, i.e. those in which recorded levels of rain was higher than the average, can be regarded as periods in which the probability of contaminants diffusing, i.e. migrating from the sludge sites, is high. Sludge spreading during such periods can be labelled as high risk. When sludge spreading takes place during an unusually wet month, timing of spreading is essential because of the potential for freshly applied sludge to be flushed off the sites. Curnoe (1974) indicated that it is important to consider the weather forecast prior to sludge spreading because rainwater in significant amounts has a profound impact on the level of risk of water contamination. Moreover, ground conditions with respect to weather conditions must also be considered. For example, if the water table is high, and it is raining, less water would infiltrate into the ground. Conversely, a lower water table would be able to accomodate more water percolating from infiltrating rain water at the surface, and thus reduce the chance of surface runoff. Therefore, it is equally important to examine ground conditions to determine what impacts the weather will have on the sludge site and the immediate area.

During prolonged dry periods, sufficient time is available for farmers to till their fields shortly after sludge application. Dry periods can be considered as low risk for sludge application owing to the lack of water which is the medium by which contaminants are diffused. This ultimately reduces the risk of raw sludge being flushed into watercourses or adjacent properties. By tilling shortly after application farmers also avoid the loss of up to 50% of N through volatilization (M.O.E., 1985). Once such factors such as the socio-economic and ecological implications have been addressed, they are then incorporated into a common management plan. Such a plan may vary, although goals remain the same, e.g. disposing of waste the cheapest and most environmentally sound manner; difference may lie in the strategies adopted to reach initial objectives.

A common management strategy is that of a diversified disposal plan. An example of a comprehensive diversified sludge management scheme is that of the City of Los Angeles' Hyperion Treatment Plant. In November of 1987, ocean discharge of sludge into Santa Monica Bay was banned. This forced the city to restructure its existing waste disposal plan. The object of the plan was to maintain diversification: land recycling, landfill and energy recovery (Harrison et al., 1990). The emphasis remained on reuse of sludge. This meant reducing toxic substances, and ultimately reduce the amount of waste destined for landfills. The plan took into consideration economic and social costs where existing facilities were upgraded, and capacities increased and designating truck routes to avoid residential areas. The plan is to remain dynamic acknowledging changes in technology, legislation and acceptability of practices as time passes. Moreover, the degree of reliability of the facilities and contingency plans in the event of equipment failure also plays an important role. Diversity is integral whereby, waste could be treated uninterrupted despite the failure of one system and as a result, not compromising protection of both the environment and the public. What makes this plan effective is that it is flexible and changes with the times so that in the long-run, a complete costly restructuring could be avoided (Harrison et al., 1990).

In the United States, there is an increased trend towards beneficial use of sludge. A survey distributed to sludge management agencies in 21 states reveals that 15 are slowly phasing out landfilling (Goldstein, 1991). This is due to high costs of maintaining landfills, ecological constraints, and increased regulatory pressures (Goldstein, 1991, p. 46). Goldstein (1991) reports that New Jersey has banned landfilling of sludge.

Sludge is being regarded as a resource. The agricultural benefits have been reviewed; however, sludge is also being viewed as a source of fuel. During the digestion phase, methane gas is produced which is collected and used to operate various facilities in the treatment plant, e.g. methane gas is used to heat the sludge in its digestion phase. Other methods involve producing dried cakes of sludge for use as a fuel for boilers and heaters.

Another beneficial use of sludge is by way of composting. This is becoming increasingly popular in Canada and the United States. Composting has been practiced for a long time, however, the method and scale have changed. "Cocomposting" is the term commonly used and involves burying alternating layers of domestic organic waste (kitchen scraps and garden waste, e.g. leaves and twigs) and sludge beneath the soil. Municipalities are determined to recycle as much organic waste as possible.

Not all communities regard sludge as beneficial to agriculture. With increased concerns over the toxic substances in sludge, citizens of Gothenburg, Sweden protested the use of sludge on agricultural land (Balmer and Frost, 1990). Farmers were said to have refused all sludge as of January 1, 1990. A new alternative was sought to the disposal problem. A committee reviewed several alternatives to sludge disposal, and the final agreement was that sludge was to be pumped into underground caverns. These caverns were formerly used to store strategic oil reserves. The capacity of these caverns is 2.8 million cubic metres, sufficient storage space to pump in liquid sludge for 21 years; 35 years if sludge is partially dewatered (Balmer and Frost, 1990). The sludge in the cavern would produce methane providing a significant amount of energy.

The Bureau of Land Management (BLM) part of the U.S. Department of the Interior considers sludge to be too toxic for use on agricultural land used to grow food consumed by the public. It is recommended that sludge be used solely for park beautification, reclaiming mine land, growing of sod, forest regeneration, and enrichment of damaged construction sites (Goldstein, 1990). The Environmental Protection Agency (EPA) considered the BLM stand unfounded, since much of the land owned by the BLM was previously treated with sludge and proved beneficial in that vegetation growth was promoted by the nutrient value of sludge (Golstein, 1990).

In Canada, sludge use for agricultural purposes varies from province to province. Ontario, Alberta and British Columbia (B.C.) have a significantly higher proportion of municipalities utilizing sludge than the remaining provinces. In 1983, 65 municipalities in Ontario applied sludge onto land, 20 in Alberta, and 44 in B.C. (Environment Canada, 1984). It is interesting to note that B.C. with an overall smaller proportion of farmland compared to the prairie provinces has more sludge sites. Quebec, with a large agricultural base prohibited sludge spreading after 1984.

In 1989, the EPA released the proposed technical sludge utilization regulation -- 40 CFR Part 503 -- considered to be the most stringent regulation of its kind. Comments by individuals who reviewed the proposed regulation found it to be overly stringent, used unrealistic conservative assumptions and would discourage beneficial use of sludge, e.g. on agricultural land (Walker, 1989). This can also be construed as the EPA establishing safety margins because of the potential environmental implications of utilizing sludge on agricultural land. This should serve as an indicator to other agencies of various regions in North America of the seriousness of this practice.

Where sludge spreading takes place, the methods of application are determined by the nature of the site characteristics and the availability of equipment to spread the sludge. There are three main methods of sludge spreading on land of which there are variations: 1) irrigation injection; 2) surface application using tankers and flotation vehicles; 3) use of an irrigation wheel. Subsurface irrigation injection is when the sludge is injected directly into the ground into previously dug furrows. This method is best suited for sloping sites as it hinders direct runoff of sludge. Surface application using a conventional tanker is less popular today because of soil compaction problems. The flotation vehicle is preferred because it is specifically designed to minimize soil compaction. An irrigation wheel, is a sophisticated piece of equipment used to pull a hose along the lengths of the site. Because the wheel is connected to a "nurse" tank located on the site, no soil compaction occurs, and spreading can take place when crops become emergent. The "nurse" tank is filled by tankers which make several trips daily from the site to the treatment plant.

2.2 ASSESSMENT OF BENEFITS VERSUS RISKS

The potential for environmental degradation along with the severe repercussions that may result must not overshadow the benefits of utilization of sludge on agricultural lands. Despite the hazards, numerous advantages have been reviewed. The advantages are such as to have rendered utilization on agricultural land desirable, otherwise, this would not be such a widespread practice.

The advantage of sludge utilization on agricultural land is that it is recycling as opposed to disposal, and is a more effective and environmentally acceptable means of disposal. In disposing of sludge in landfills or into the ocean for example, some of the constituents such as the nutrients which are beneficial to agriculture are lost. In essence, it is a waste of a precious commodity; mainly fertilizer. With the price of fertilizer on the rise, nutrients such as nitrogen, phosphorus, and micronutrients such as zinc forgone to disposal is becoming more costly. The cost of energy expended in the various stages of production, packaging and distribution of fertilizers, wasting sludge, i.e. disposal of it becomes a questionable practice. Sludge is the waste generated by the various sectors of the municipality.

Sludge applied to agricultural land poses numerous hazards. However, the domain of the diffusion of contaminants is a manageable size, i.e. the area in which to contain the migration of contaminants is reasonably small. The risks can be minimized by proper management and the ability to contain the migration of contaminants. In essence, the parameters can be controlled to reduce the degradation of the environment. For example, runoff can be diverted, or minimized, by a properly functioning drainage system.

2.3 DISADVANTAGES OF ALTERNATIVE DISPOSAL METHODS ON A GLOBAL SCALE

Disposal of sludge into a large body of water such as the Great Lakes, or the sea, once the contaminants have diffused, their recovery is futile and no longer within a manageable area. The action of waves, underwater currents, marine life and different water chemical properties diffuse contaminants throughout the ocean. Contaminants eventually settle to the bottom where bottom dwelling organisms, e.g. crustaceans, are exposed to them. The intent is for the ocean to dilute sludge-borne contaminants. The bays and estuaries of numerous coastal cities have been polluted because of the tremendous volumes of waste including sludge that have been discharged into the ocean. In Barbados for example, 50% of the fringing reefs are dead as a result of the discharging of sewage sludge and other forms of waste into the ocean (Archer, 1986). In Canada, a similar scenario exists where large volumes of sludge and sludge-borne contaminants enter the Great Lakes. This has resulted in environmental stress which has affected the quality of the aquatic ecosystem. Clean-up operations of lake bottoms, bays and estuaries is both costly, difficult and time consuming. One of the greatest problems is the diffusion of contaminants which have settled to the lake bottom or ocean floor during dredging operations. Incinerating sludge releases contaminants, and toxic gases into the atmosphere. The destiny of these contaminants is left up to the prevailing winds. There is no way to contain the movement and dispersal of contaminants. The prime solution is preventative whereby filters, or "scrubbers" are used to minimize the release of contaminants into the atmosphere.

2.4 THE EFFECTS OF SLUDGE CONTAMINATION ON THE ENVIRONMENT

The risks attributed to sludge being applied onto agricultural land can be categorized into long-term and short-term. Long-term risks are generally associated with the effects of heavy metals and organics, whereas short-term risks are associated with the effects resulting from, for example, nitrates and pathogens. The short-term risks are short relative to the long-term risks associated with the effects of heavy metals for example. Long-term effects are more difficult to study because it is not known how long it will take for some form of change to occur or begin to become detectable. One of the greatest hindrances to advances in understanding long-term impacts is the lack of data, and as the M.O.E. (1981) indicated, there is no information on sludge application and its impacts prior to 1978. It is imperative, therefore, to maintain current monitoring programmes.

The effects of sludge contamination are such that the environment may be subject to degradation and public health may be at risk. The most pronounced consequences after application on farmer's fields are the formation of sludge blankets, which are thick layers of sludge on the soil surface due to irregularities resulting from small depressions; 0_2 depletion in watercourses from oxygen-demanding organic and chemical waste; increased eutrophication, turbidity, dissolved solids; and the introduction of contaminants into the food chain (W.P.C.F., 1972; Haghiri, 1973; Turner, 1973; L'Hermite and Ott, 1984). The contaminant of concern in regard to food chain implications is Cd because of its long residence time and the susceptibility for plant uptake (Davis, 1984; Bitton et al., 1980; M.O.E., 1980).

2.5 SOIL CONTAMINATION

Soil contamination from sludge is important to consider because soil contains both nutrients and contaminants which plants assimilate. The extent and degree of soil contamination is a function of the sludge application rate, concentration of elements, and nutrients in both soil and sludge. The degree to which toxic elements to migrate in the soil matrix is influenced by their solubility which is strongly dependent on soil pH and how they react with the soil. Moreover, the chemistry of the water and the soil, the chemical nature of the contaminant, the temperature of the infiltrating substance, and the hydraulic characteristics of the soil are also factors which contribute to how a contaminant migrates in the soil. Clay minerals, hydrous oxides, and organic matter have a surface charge and potential to become more negative, thereby increasing the adsorption of metal ions (Soon, 1981). This occurs due to the positively charged metal ions being attracted to the predominantly negatively charged clay particles. Cation exchange may also occur in which there is an exchange of ions adsorbed by the clay particle. Cottenie and Van

Landschoot (1984) stressed the complexity of the interaction of contaminants in the soil due to the multitude of reactions possible, e.g. adsorption - desorption and dissolution and precipitation to name a few.

Movement of heavy metals in soil may occur down to varying depths in the soil profile depending on soil type, climate, the contaminant and its chemical properties, and the time factor. Most activity takes place at depths of between 5 to 15 cm in the soil profile (Davis et al.. 1987; Sposito et al., 1980). Davis et al. (1987) found that Cd concentrations increased in soil upon sludge application. Cd was detected at depths of 10 - 15 cm in a calcareous loam, and of the total increase, 89% occurred in the 5 - 7.5 cm range. Sposito et al. (1980) found Cd concentrations to be restricted to 5 cm in the soil profile, and that Pb was detected at 10 cm. Larsen (1983) found Cd concentrations as far down as 25 cm in the profile of a sandy loam. Leaching of toxic elements can be attributed to a lowering in pH and varying soil types. However, movement may have occurred through physical infiltration of sludge particles following rainfall, or by the action of the soil fauna, especially earthworms (Davis et al., 1987, p. 111). Movement is also influenced by natural surface cracks in the ground and rapid infiltration to tillage depth.

2.6 INFILTRATION

A brief review of the basics will serve to illustrate what parameters affect water movement in soil and the migration of sludge-borne contaminants. Infiltration is the movement of water through a soil and rock matrix in which three interdependent processes are involved: entry through the soil surface, storage and transmission through the so'l (Dunn and Leopold, 1978, p. 165). Branson et al. (1981) use the term percolation once water has breached the soil surface. Hydraulic properties such as permeability and porosity are important to consider. Soil porosity is the percentage of volume of voids in a given volume of soil, and this in part determines how much water can be retained by the soil. Large pore spaces permit water to percolate and drain more readily than small pores because in the latter case, capillary and hygroscopic forces are stronger and hold water tighter. Velocity of percolating water is also dependent on pore size, interconnectedness and antecedent soil moisture in the vadose zone (Mazor, 1991, p. 10). During a rainstorm, assuming a constant rate of rain, the infiltration rate declines rapidly during the early part of a storm and reaches an approximate constant value after 1-2 hours of rain (Dunn and Leopold, 1978, p. 166).

2.7 GROUNDWATER CONTAMINATION

Sludge improperly applied to agricultural land may pose a risk of nitrate contamination to groundwater (Berg et al., 1987). This hazard tends to be a threat in a hydrogeologic setting where hydraulic conductivity of the geologic structure is high, e.g. sandy soil and gravel (Berg et al., 1987). It is important that the site not be chemically overloaded, and that application rates be tailored to the characteristics of the site in question. Excessive sludge loading may result in the leaching of nitrates into the water table (Eckenfelder et al., 1987). Higgins (1984) stressed the need to carefully calculate sludge loading rates, and confirmed its importance via test results which suggest that nitrates at any given depth tended to increase with increasing sludge application rates. Nitrate levels returned to normal values after sludge application ceased. However, as Hill

(1982) pointed out, it is often difficult to segregate sources of nitrates due to the diversity of soils and agricultural practices in a given area.

The problem with nitrates is that they are not readily adsorbed by soil materials (Berg et al., 1987). There is a risk that nitrates may be flushed through the soil. Nitrates are not filtered as they pass through the soil; this is true particularly in soils low in clay content where the cation exchange capacity (CEC) is low (Berg et al., 1987). Doty (1980) found clay subsoil of a sandy soil to be a potentially good barrier to nitrate movement. Furthermore, crop types can play an important role in the amount of nitrates that reach the water table, because certain crops require more nitrogen than others. This reduces the availability of nitrogen compounds to leaching, e.g. the N requirement for corn is greater than soybeans which means that there would be more N available for leaching in a soybean crop if equal amounts are applied (Berg et al., 1987).

There are numerous pathogens in sludge which can survive the stabilization process during anaerobic digestion (Edmonds, 1976; Demynck et al. 1985). Pathogens include bacteria, viruses, helminths, fungi, or protozoa. Fecal coliform bacteria are commonly found in sludge, and their presence in the environment, e.g. watercourses, is an indication of recent contamination. However, the source of fecal bacteria it is not easily determined because there are numerous sources from which it can originate. Runoff from manure piles, barnyards, slurry and sludge treated fields are common sources (GRIC, 1982).

Groundwater contamination from sludge-borne heavy metals is minimal to non-existent (Berg et al., 1987; Higgins, 1984 and Hill 1982). However, if the water table was to rise to the 5 cm range from the soil surface, the potential for chronic groundwater contamination is inherent. Reduced groundwater contamination is the result of the presence of a form of chemical buffer. The soil contains numerous binding agents which immobilize the heavy metals thereby preventing their leaching into groundwater (Sposito et al., 1976; Williams et al., 1980).

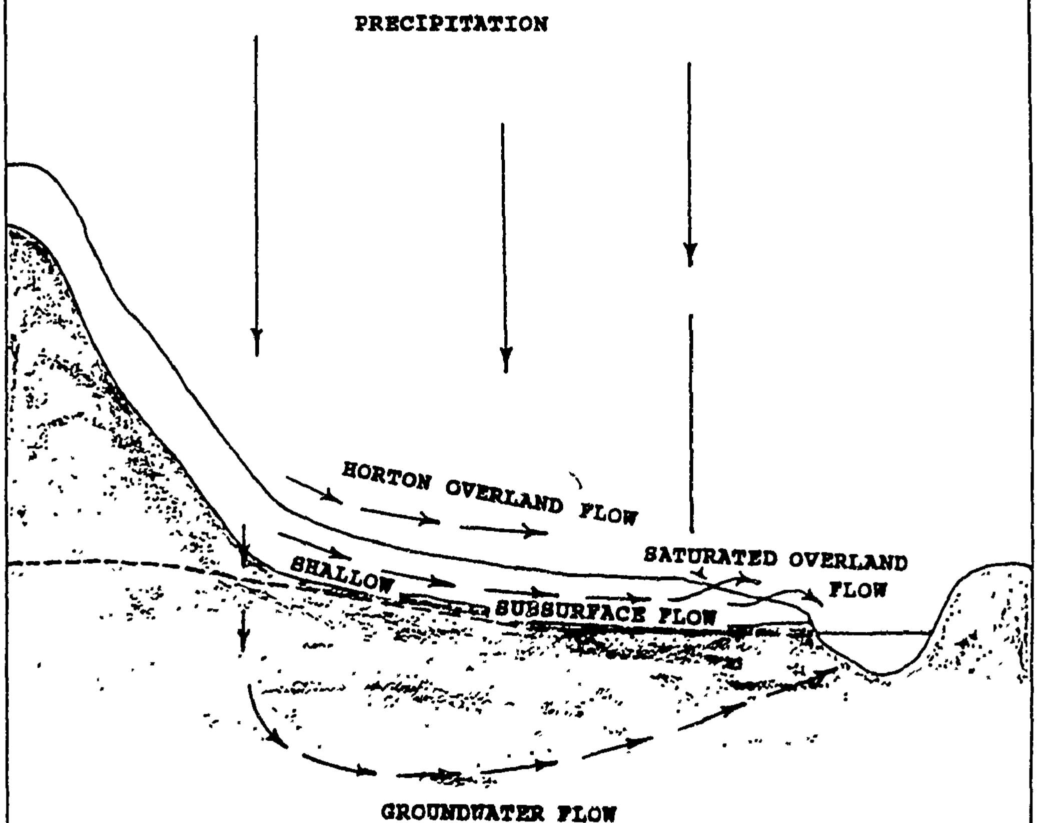
2.8 RUNOFF

Runoff will occur when the rainfall intensity exceeds the infiltration rate of the soil. If rainfall intensity is less than capacity, the infiltration rate will be equal to the rainfall rate, whereas, if rainfall intensity exceeds the ability of the soil to absorb moisture, infiltration occurs at the capacity rain; excess of rainfall over infiltration collects on the soil surface and runs over the ground to streams (Dunn and Leopold, 1978, p. 163). There are numerous factors which can affect the level of runoff; they include a blocking of small pores due to compaction and splashing of fine particles which can hinder infiltration, and antecedent moisture conditions which could reduce the time it takes for soil to become saturated in a subsequent storm.

Water migrates in numerous fashions which could be potential paths of contaminant movement. Dunn and Leopold (1978) classified them as Horton overland flow, groundwater flow, saturated overland flow, and shallow subsurface flow (Figure 2.1). Overland flow was discussed in the previous section. Groundwater flows mainly along the maximum hydraulic gradient, the hydraulic gradient equalling the slope of the water table projected along a given horizontal distance (Mazor, 1991). Saturated overland flow is a combination of infiltrated water and precipitation on a saturated area flowing to the ground (Dunn and Leopold, 1978). Shallow subsurface flow (throughflow) occurs when

SURFACE AND SUBSURFACE WATER MOVEMENT

Figure 2. 1



Modified from (Dunn and Leopold, 1978)

water flows underneath the soil in a predominantly horizontal path parallel to a sloping surface (Bowen, 1982).

2.9 SURFACE WATER CONTAMINATION

Water contamination from sludge-contaminated agricultural runoff contribute to: eutrophication, oxygen depletion, turbidity, dissolved solids and the introduction of toxic substances into the aquatic ecosystem. These water contamination problems cause stress on the aquatic ecosystem (W.P.C.F., 1972).The combined effects of the organic waste demands and the diurnal cycling of dissolved oxygen, along with the physical choking of some reaches by dense aquatic plant growths, render some sections of the Grand River in Ontario unsuitable habitats for fish and other desirable aquatic organisms (GRIC, 1982, p. 4.5) Eutrophication tends to drive out the less tolerant aquatic organisms and the introduction of more tolerant and less desirable species, e.g. brown algae is slowly replaced by blue-green algae (GRIC, 1982). Eventually, a restructuring of the aquatic ecosystem will take place. Turbidity indicates the presence of suspended particles of silt and clay. Suspended solids tamper with the respiratory organs of fish which can often result in suffocation (GRIC, 1982).

Surface water contamination may occur during periods in which appreciable volumes of surface runoff are generated while inadequate safeguards against potential contamination prevail. Contaminated runoff from freshly applied sludge yields the greatest concentration of contaminants. Once surface runoff has been generated, the safeguards implemented to minimize soil erosion will, in part, determine the risk of surface water contamination. Safeguards entail leaving vegetation stubble standing during the winter months, planting vegetation buffer zones, controlling drainage via a tiled drainage system and ploughing fields with new equipment designed to reduce soil erosion, and discourage surface runoff. By minimizing soil erosion, runoff waters will contain fewer soil particles and contaminants adsorbed to the clay faction and in solution. Other safeguards involve the timing of application and method of spreading, both issues to be discussed in subsequent sections.

The issue of surface water quality has been noted to be of utmost concern when dealing with land application of sludge (Dowdy et al., 1980). Numerous field studies have attempted to quantify the extent to which sludge-borne contaminants affect surface water quality. The parameters that govern the degree of potential water contamination vary predominantly with the physical characteristics of the site, type of sludge used, and the prevailing weather conditions. Contaminant concentrations in runoff waters vary with the time of the runoff event after sludge application and antecedent groundwater conditions. Curnoe (1974) and Dowdy et al. (1980) found the presence of heavy metals in surface water limited with the exception of when newly spread sludge is flushed off the field. Dowdy et al. (1980) noted that Cu was the first and most pronounced metal detected in runoff water; however, this would vary with the type of metals found in the sludge. Webber et al. (1977) found the contaminant concentrations from runoff from a site in the Halton region of southern Ontario to be within acceptable limits, and that there was no risk of contamination of adjacent watercourses.

2.10 PLANT UPTAKE

Cadmium and certain other heavy metals are found predominantly in the immobile form at the time of application (Williams et al., 1980). Materials present in the soil may cause the heavy metals to react to maintain their state of immobility. Such substances include clays, organic matter, and carbonates (Williams et al., 1980). Each one of these substances may act as a binding agent. The concern, in regard to how the soil and its constituents react with contaminants, is, in how much is made available to plants for uptake. Of Pb, Hg, and Cd, the latter is the most available in sludge amended soil for crop uptake (L'Hermite and Ott, 1984, p. 120; Bitton et al., 1980; M.O.E., 1980). Zinc, another heavy metal and also a micronutrient is found in significant concentrations in sludge is considered to be phytotoxic in high concentrations (MAFF, 1982). The Ministry of Agriculture Fisheries and Food (MAFF, 1982) state that Zn is an element of concern since it affects plant growth whereas other elements accumulate in the plant tissue with a minor effect on growth. However, M.O.E. (1972) found that Cd at 2ppm can reduce plant tissue growth.

The availability of toxic elements for crop uptake directly influences the level of contaminants entering the food chain. Every plant species absorbs certain contaminants in different ways and in varying concentrations. Every manner in which a plant absorbes toxic elements produces different resulting effects. Hydrogen ion concentration expressed as pH, organic matter and $Fe_2 0_3$ content are the major factors influencing the retention of Cd by the soil (Adams and Saunders, 1984; Soon, 1981; Neal and Sposito, 1986). This seems to suggest that the more strongly the element is retained by the soil, the less is available for plant uptake.

Soil pH is a controlling factor on how much of a contaminant in the soil can be uptaken by plants. The threshold pH for arable soil is 6.5, acidic soil may cause certain elements such as the heavy metals, e.g. Cd to desorb from soil colloids (Soon, 1981; Adam and Sanders, 1984). A pH of 6.0 is the M.O.E. limit for arable soil. Prior to sludge spreading, a soil with a pH of below 6.0 must be limed or treated otherwise to raise its pH. However, this varies from soil to soil and crop. Crops which are susceptible to Cd uptake are leafy vegetables such as cabbage, lettuce and spinach; tobacco is also an effective assimilator of Cd (Davis, 1984). Haghiri (1973) and Turner (1973) provide more in depth studies on Cd uptake by vegetable crops.

Heavy metals such as Pb, Hg, Zn, Cr and Ni can also severely reduce crop yields, (M.O.E., 1972). However, Chaney (1980) considered Hg, Pb, and Cr+3 to be insoluble, and plants do not normally translocate high amounts of Pb to their shoots. Webber et al. (1977) pointed out that Hg does not pose a problem in agricultural production; although Hg was detected in the soil, it remained within acceptable limits. Cottenie et al. (1984) found large concentrations of Ni were translocated by plants. Chang et al. (1987) stated that Cd and Zn availability for plant uptake to be highest during the first year of sludge application, and that uptake should not increase with time following termination of application, with the exception of a lowering of soil pH. However, Larsen (1983) found the uptake of heavy metals by plants to remain constant seven years after a single application of sludge. This supports the notion that in regard to persistent contaminants, the effects remain long after sludge application has ceased.

Experiments have been conducted over the last two decades in laboratories and in small test plots in the field (Chaney, 1982). The results from actual farm monitoring programmes provide the most representative results of the actual complex dynamics involved in contaminant behavior; such results can be used to draw feasible conclusions on where contaminants accumulate in the environment (Sommers et al., 1987). It is crucial to know how the variables interact under different environmental conditions, e.g. wet and dry conditions, or different soil pH ranges, so that applying sludge onto agricultural land can be rendered a safer more comprehensively understood practice.

2.11 FOOD CHAIN IMPLICATIONS

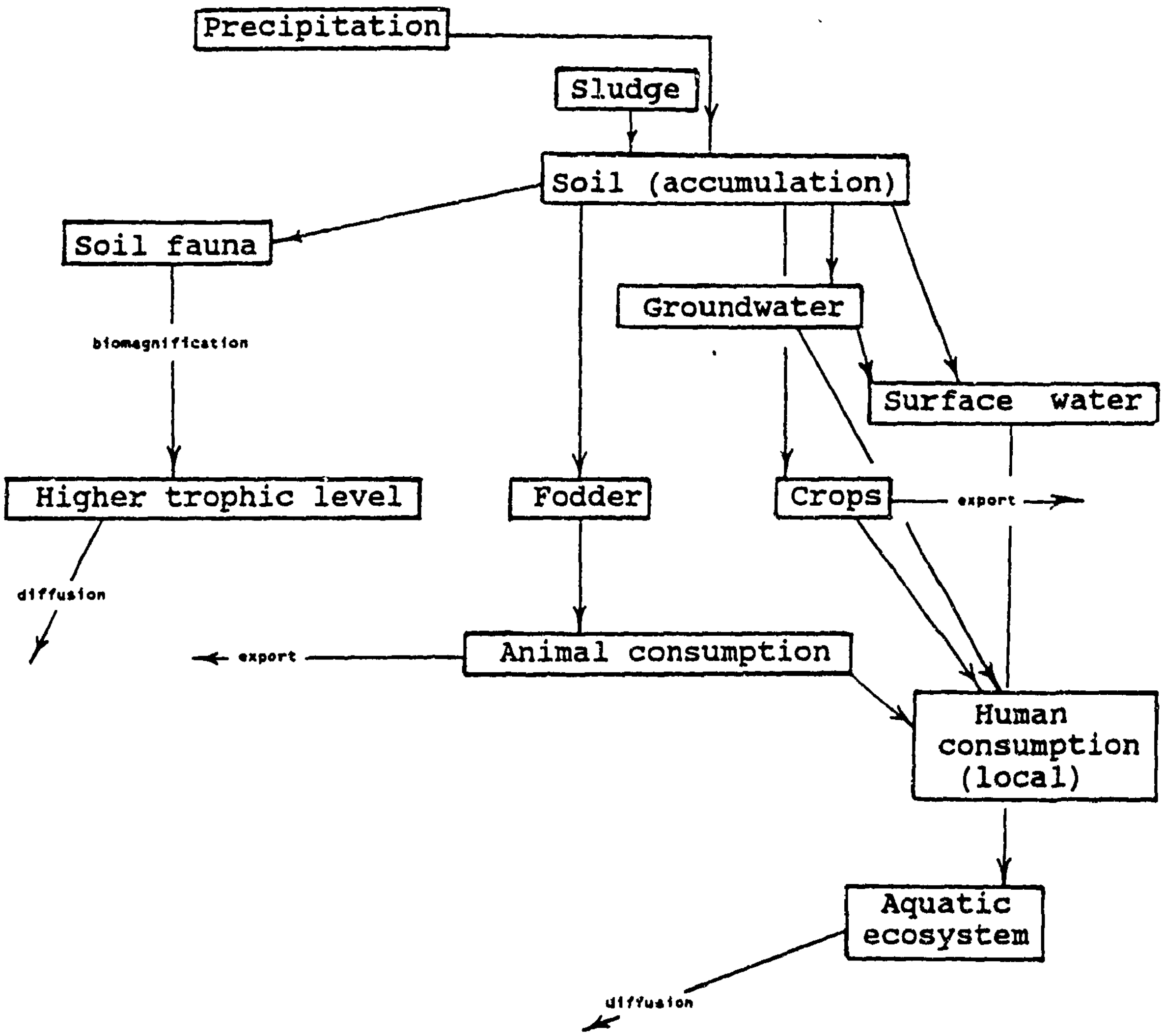
Cadmium enters the food chain from the consumption of contaminated meats and vegetables. Figure 2.2 shows the possible pathways that contaminants may enter the food chain on a local and national scale. The uptake by plants has been discussed, but the issue of meat contamination has not been addressed. Meat contamination can result from livestock feeding on contaminated fodder and/or contaminated grazing fields. Livestock may ingest sludge on herbage or contaminated soil because grazing animals consume small quantities of soil as part of their regular diet (Chaney, 1983). Chaney (1983) also noted that when liquid sludges are sprayed on pastures or forage crops, a thin film of sludge coats the plant foliage adhering to it strongly when dried. Bioaccumulation may also occur at the detrivore trophic level where earthworms may be contaminated. Birds which feed on earthworms would also be subject to contamination.

2.12 SLUDGE-BORNE PATHOGENS

The prevalence of any particular pathogen reflects the current incidence of disease in the community (WHO, 1981). Certain pathogens are capable of surviving the sludge stabilization process. For example, eggs of Ascaris, a species of parasitic roundworm

POSSIBLE SLUDGE-BORNE CONTAMINANT MOVEMENT
IN THE ENVIRONMENT

Figure 2.2



with human, cat and dog, hosts, are very resistant to harsh environmental conditions (WHO, 1981; Pawlowski and Schlutzberg, 1986). Ascaris eggs have been known to survive in soil for up to seven years (Pawlowski and Schlutzberg, 1986). Another concern is the reproductive capacity of female Ascaris which can produce 240,000 eggs a day, i.e. potentially up to 65 million in her life time (Lehman et al., 1983). To kill all pathogens in sludge, it has been suggested that it be heated to 55 degrees celsius for one day as opposed to the standard 32 degrees celsius for thirty days. Pathogens other than roundworms potentially found in sludge include bacteria, viruses, helminths (flatworms), fungi, or protozoa (Demynck et al., 1985).

The survival rate of pathogens in soil is a prime concern because of the hazard to both humans and animals that may come in contact with soil or other sources of sludge contamination. Survival rates are variable primarily because of the different thresholds of tolerance of the pathogens to stress induced by unfavorable environmental conditions. The most dominant environmental conditions that govern stress for pathogens are soil moisture, soil temperature, pH, availability of nutrients, humidity, sunlight, organic matter content, and the presence of competitive organisms (Edmonds, 1976; Gerba et al., 1975; Bell, 1976). Gerba et al. (1975) indicated that the survival rate of bacterial pathogens in soil would be restricted to less than 2-3 months in cold temperate climates on the premise that excessive cold temperatures would kill most pathogens. However, Edmonds (1976) found that fecal bacteria in forested soil remain viable for many months, and that regrowth occurs in spring. The results of this experiment tend to support those of Bell (1976) in which it was found that periods of bright sunlight coupled with low humidity reduced fecal coliform bacteria significantly. The experiment by Edmonds (1976) was conducted on forest soil which would tend to be shaded and devoid of substantial amounts of sunlight resulting in fecal bacteria being subjected to little sunlight and minimal heat. Table 2.1 lists several micro-organisms and their survival rates in soil, vegetables, and in water.

(Table 2.1) SURVIVAL TIMES OF VARIOUS MICRO-ORGANISMS IN SOIL, PLANTS, AND ON WATER

Organism	Surface	Survival Time
Coliform bacteria	Soil	38 days
	Vegetables	35 days
	Tomatoes	35 days
Salmonella typhi (bacterium)	Soil	1-120 days
	Vegetables	1-68 days
	Water	7-30 days
	Water with humus	87-104 days
Streptococcus spp. (bacteria)	Soil	26-77 days
Ascaris (roundworm eggs)	Soil	2-5 years
	Plants, fruit	1 month
Entamoeba histolytica cysts (protozoan)	Soil	8 days
	Tomatoes	8-42 hours
	Lettuce	8 hours
Necator sp. (hookworm)	Soil	6 weeks

Source: Lehmann et al. (1983), Sepp (1971), Bryan (1974) and Dunlop (1968).

The effects of pathogens on both humans and animals can be serious. Humans coming in contact with soil, water and plants contaminated by sludge-borne pathogens risk contracting infectious diseases, parasites and experiencing other discomforts associated with pathogens. Several cases of pathogen (bacteria) contamination related to sludge reaching epidemic proportions have been reported in Europe in the past (WHO, 1981). Although such cases linked to sludge are uncommon, they do, however, exist. Salmonella poisoning is the most pronounced. In Switzerland for example, between 1969-1978, cases of Salmonella poisoning from cattle was related to the times of year sludge was applied to fields during which animals grazed on contaminated fields (WHO, 1981). This is in part due to the complex cycles of transmission involving animals infected from the environment, from feedstuffs, meats, effluent from sewage water works, and water: the same conclusion drawn from research in similar problems in the Netherlands (WHO, 1981). Shortly after World War II between 1945-1948, 19 deaths from intestinal obstruction from Ascaris were reported in Darmstadt Germany (Pawlowski and Schlutzberg, 1980). To this day, such outbreaks are rare. A survey of sewage treatment workers' health was conducted in England to determine the effects of constant exposure to sludge and sewage effluent. the term "sewage worker syndrome" was coined and involved workers experiencing health complications such as nausea, diarrhea, headaches, fever and also several cases of jaundice were reported (Block, 1986). The source of contamination was found to be from airborne pathogens from sewage aerosols (Block, 1986). These findings would raise concern over aerosols, produced when spraying sludge on fields. Despite the various documented cases of health problems related to exposure to sludge, WHO (1981) concluded that there is insufficient evidence to make such a correlation.

2.13 VICTIMS OF SLUDGE INDUCED CONTAMINATION

Victims of sludge-borne contamination are those who consume contaminated produce. Fruits, meat and vegetables for example, contaminated from the use of sludge are consumed; similarly, organisms which feed on a contaminated source of food are also contaminated. Waite (1984) pointed out that it is not known exactly what sublethal doses of micropollutants do in the human body or animals. What is known is that some persistent contaminants tend to bioaccumulate. This would ultimately put the younger generation of all living organisms at risk because of the long period of time contaminants have to accumulate in certain parts of living tissue. In both the aquatic and terrestrial ecosystem, the organisms at risk are the less tolerant and those high in the trophic level. However, given the gaps in knowledge in regard to what contaminants actually do to living organisms, we are all at risk.

CHAPTER 3: THE CASE STUDY

3.1 METHODOLOGY

The assessment of the potential for environmental degradation is in essence qualitative in nature due to the minimal use of data gathered in the field. Assessment of potential environmental degradation involves identifying the potential for contamination resulting from both natural causes, e.g. site physical characteristics, and anthropogenic causes, e.g. managment issues of sludge utilization on agricultural land.

To identify the spatial distribution of sludge in the Region of Waterloo, sites with valid Certificates of Approval (C.A.'s) in 1990 were mapped. A list of the sites identified by concession and lot numbers was provided by the Ontario Ministry of the Environment (M.O.E.). The majority of high risk sites were selected because of their proximity to watercourses, and others further from watercourses were also selected based on risks resulting from soil type and slope.

Identification of the high risk sites was followed by field investigation. The selected sites were subject to investigation whereby site characteristics which could contribute to potential environmental degradation were examined. Seventeen sites in all were examined. These were the sites to which access was granted. Site physical characteristics examined included: soil type in terms of its texture, slope, and micro relief characteristics, e.g. undulating. Site characteristics anthropogenic in nature examined include: type of crop grown on sludge site, and how far the outer edge of the sludge site is from water wells, dwellings, and watercourses, and whether or not the site drainage system is tiled. Field investigations were simply used to confirm the accuracy of these files. M.O.E. files were useful in obtaining historical data such as the types of crops grown in 1990 from the selected sludge sites. The crops documented on the M.O.E. files do not necessarily correspond to crops grown during the time of field investigation. It must be noted that M.O.E. files were used as the main source of data, and that field investigations served to confirm the accuracy of these files.

The slope of the sites was first examined using topographic maps and large scale maps of the Region of Waterloo where change in elevation over distance was calculated for a preliminary assessment of the slope. Sites have many changes in slope, only the most dominant steep slopes were examined. None of the sites required actual physical measuring of the slope because it remained within the 3-6% range according to map calculations and M.O.E. files.

Soil type was determined using a very detailed soil report which contained soil maps of scales of 1:20,000 of the Region of Waterloo (Presant and Wicklund, 1972). The site on which sludge application took place was first identified on airphotos. Secondly, it was identified on a soil map; the soil zones which the site intersected determined the predominant soil type.

Distances to watercourses were measured in two ways: physically measuring distances using a tape measure, and calculating distances using airphotos and the appropriate scales. The sites from which actual separation distances to watercourses is measured involves measuring the distance from the outer periphery of the site adjacent to the watercourse to the stream banks. Several indicators such as water stained tree trunks and sorted stones and along the stream banks serve to reveal recent maximum water levels. Distance measured using airphotos is in essence an approximation. The scale of the photos used is 1:5000. This method of measuring was used for sites to which access was too difficult without treading on young emergent crop shoots.

To quantify to some extent whether in fact there is a detectable loading of sludge-borne contaminants into the Grand River, data published by the M.O.E. and the Regional Municipality of Waterloo was examined. This data was used because ministry monitoring stations are located throughout the Region of Waterloo, and a number of these are located near the sites which received sludge in 1990. The Grand River based on information gathered from topographic maps and maps of the watershed, receives runoff waters from numerous farms via a large number of their tributaries. Water quality data from the Breslau and Blair Bridge collection points along the Grand River was graphed. M.O.E. water quality data from the last ten years was analyzed to determine whether there are any observable trends which could be correlated to the application of sludge on agricultural lands.

Subsequent chapters deal with how management procedures are assessed to determine whether protection of the environment could be optimized. Observing the manner in which the sludge coordinator performed the required duties brought forth areas in which improvement is deemed necessary. Reviewing M.O.E. Guidelines governing sludge utilization on agricultural land, and communicating with the sludge coordinator, helped to identify what he/she is responsible for. However, the Guidelines proved ambiguous, i.e. sections were not explicit in the criteria for the separation distances between points of sludge application and watercourses.

To determine how stringent regulations are and how sludge acceptability criteria differ, those of Ontario are compared with those of other countries. Sludge management in the European Economic Community (EEC), various regions of the United States, and Canada were selected for this comparison in which selected aspects of each are discussed.

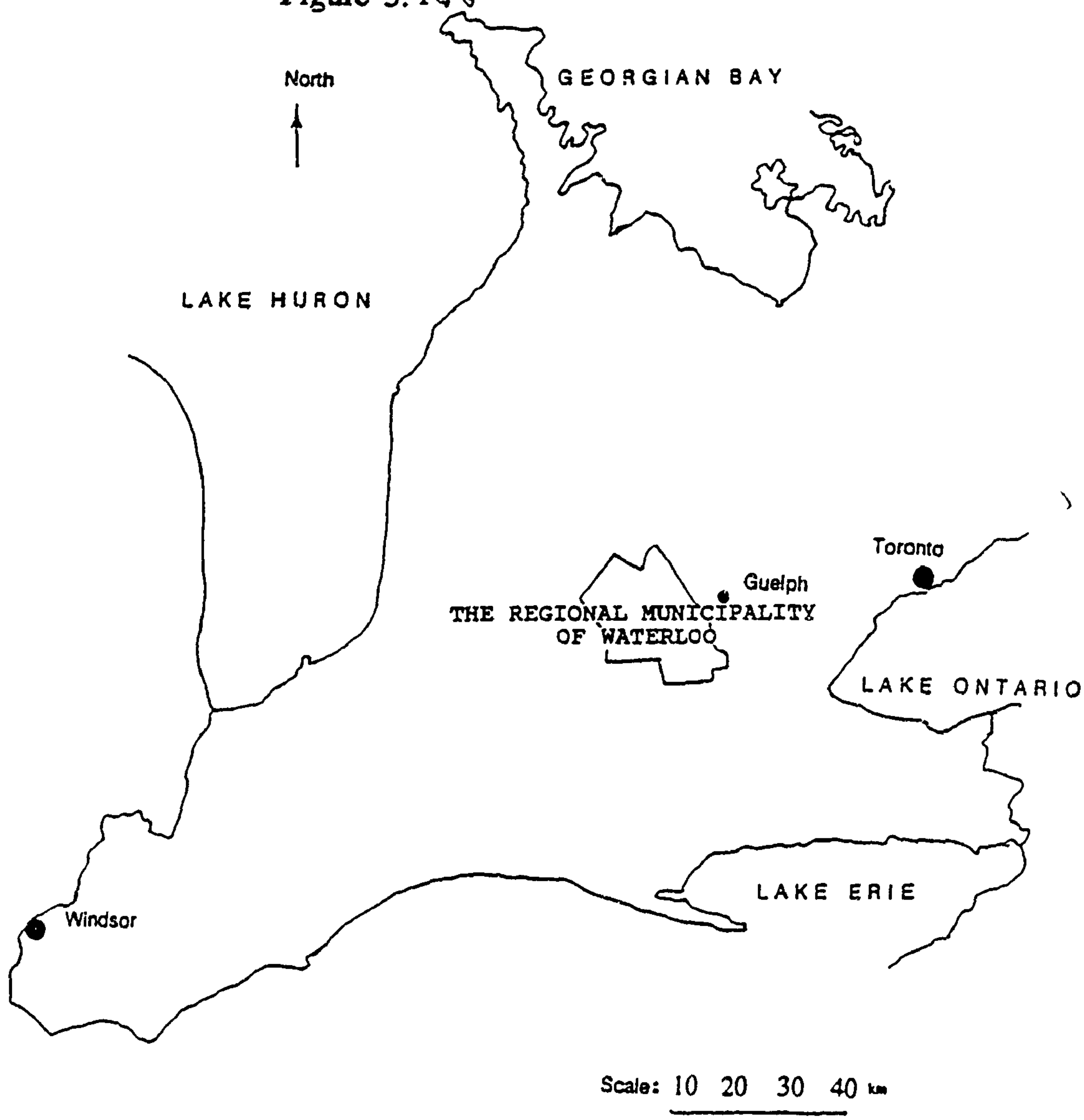
Assessment of the level of compliance was done primarily through monitoring of the actual sludge application and through reviewing historical Certificates of Approval (C.A.) application forms. Sludge haulers must comply with sections of the M.O.E. Guidelines and Regulations which pertain to them.

3.2 THE REGIONAL MUNICIPALITY OF WATERLOO

For the purpose of delineating an area of study of a reasonable dimension, and to obtain and utilize existing data, the boundaries of this study are those of the Region of Waterloo. The Regional Municipality of Waterloo is situated in westcentral Ontario, approximately 90 km southwest of Toronto (Figure 3.1). The Region harbours the Tri-Cities: Kitchener, Waterloo and Cambridge, all of which have recorded from 1972 to 1985 population growth of 25% (Elkin, 1986). With such growth, more waste is generated. Table 3.1 shows the increase in sludge hauled between 1987 and 1991, particularly from the larger treatment plants such as those in Kitchener, Waterloo and Cambridge. All of the sludge produced is destined for agricultural land which encompasses the major urban centres in the Region of Waterloo.

LOCATION OF THE REGIONAL MUNICIPALITY OF WATERLOO IN SOUTHERN ONTARIO

Figure 3.1



Source: modified from Elkin (1986).

(Table 3.1) SLUDGE GENERATED IN THE REGION OF WATERLOO

m^3

Treatment Plant	'87	'88	'89	'90	'91 year
Ayr	1,049.0	1,471.0	2,034.5	1,967.9	1,733.2
Baden	2,542.5	2,467.3	1,857.5	1,937.7	1,785.5
Galt	54,825.5	58,317.0	59,702.3	65,754.3	57,349.2
Hespeler	17,094.7	21,279.2	21,758.6	24,977.6	18,949.1
Kitchener	177,178.9	191,993.0	168,781.0	276,658.8	211,641.0
Preston	28,003.5	27,810.0	32,107.5	38,332.1	23,337.0
Waterloo	70,903.5	71,550.8	85,357.2	82,915.6	50,423.9
Wellesley	696.0	698.2	787.2	727.6	476.6

Source: M.O.E., 1991.

Once stabilized sludge that has been generated at the treatment plants in the Region of Waterloo, it is hauled to sites possessing valid Certificates of Approval (C.A.'s). During the winter, when hauling temporarily ceases, sludge is hauled to the Kitchener M.O.E. Transfer Station. At this point, the sludge is pumped into a day holding tank with a capacity of 1,800 cubic metres. A pipeline 2.7 km long connects the holding tank with two lagoons of a combined capacity of 180,000 cubic metres. Sludge is pumped into the lagoons where it remains for the duration of the winter. This is where sludge blending occurs. When a lower, unacceptable grade of sludge, e.g. one that does not meet the sludge quality criteria, is mixed with a higher grade, it is then considered fit for agriculture. When the spreading season resumes (April), the sludge is pumped back into the holding tank at the Transfer Station from which it is pumped into tankers.

In the Region of Waterloo, sludge spreading methods include surface spreading by flotation vehicles, irrigation wheel, and subsurface injection with a drag hose irrigation injection system. Tankers, the most commonly recognized vehicle have been phased out, but are still used on occasion. Tankers often cause excessive field damage especially under wet conditions when they are prone to get stuck. The vehicles currently used are modified tandem trucks and "terragators". The former have a holding capacity of 18 cubic metres of sludge, the latter, 11 cubic metres. The "terragator" is preferred because it is lighter and a much more sophisticated vehicle in that sludge can be spread as demanded by site characteristics; however, such a vehicle is very expensive.

The irrigation wheel employs a computer regulated system. A hose is unwound along the length of the site, after which the irrigation wheel winds the hose up at a predetermined rate, while spraying sludge at various set angles. Once the hose is wound up, the wheel is moved over to spread another length of the site. It is not uncommon to have several irrigation wheels in operation at one time. The irrigation wheel can spra up to 136 cubic metres of sludge per hour.

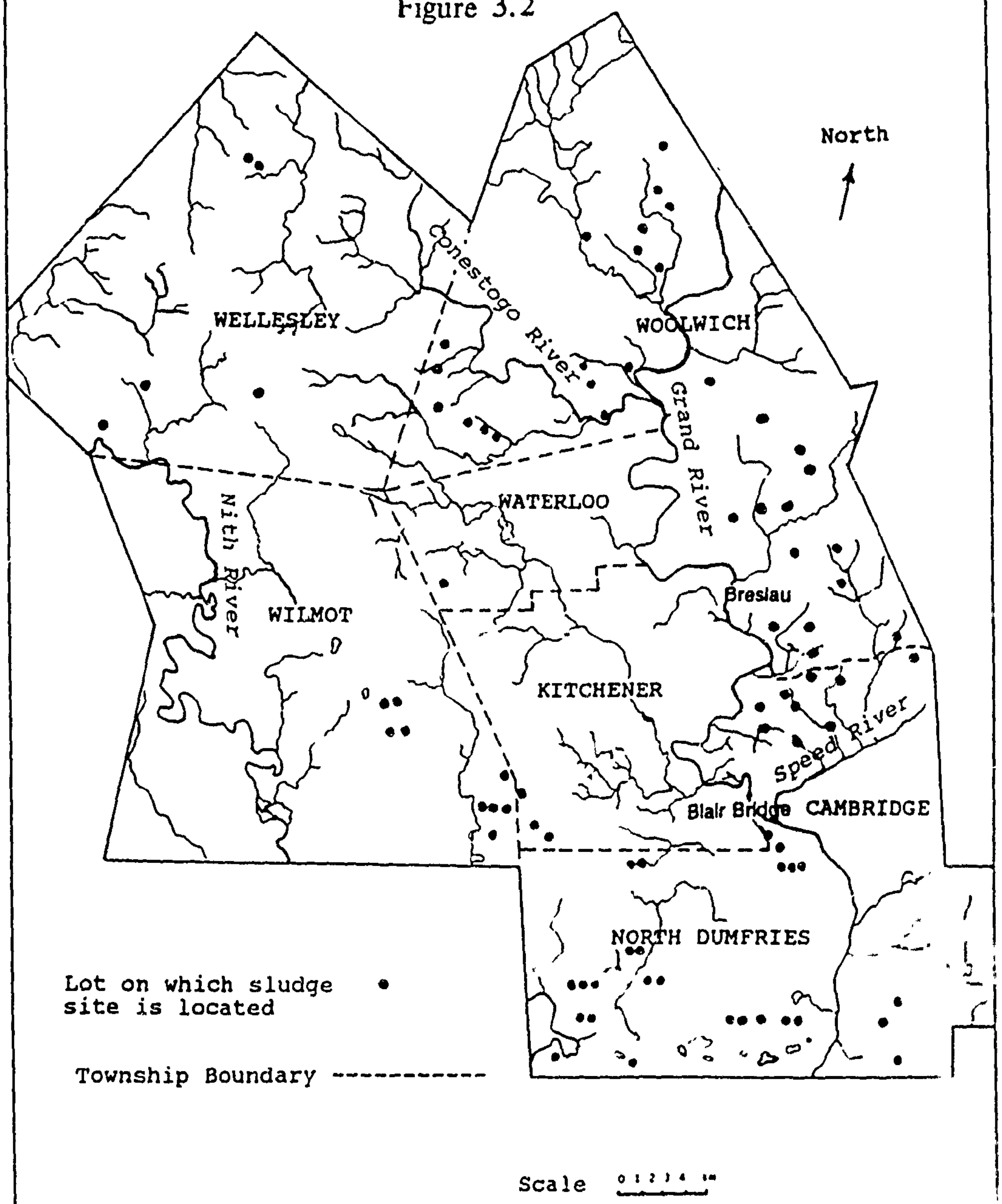
The drag-hose irrigation injection system entails using a tractor to drag nozzle injectors set below the soil surface in preploughed furrows up and down the length of the site. The injectors are, like the irrigation wheel, connected to a "nurse" tank.

3.3 SPATIAL DISTRIBUTION OF SLUDGE SITES

There is no apparant consistent pattern in the areal distribution of valid C.A.'s. However, certain townships appear to have a higher proportion of farms with valid C.A.'s than other townships (Figure 3.2). Woolwich and North Dumfries possess a large number

LOCATION OF SITES WITHIN THE REGION OF WATERLOO WITH VALID CERTIFICATES OF APPROVAL IN 1990

Figure 3.2



Source: M.O.E., 1990

of valid C.A.'s compared to Wellesley, and the city of Kitchener - Waterloo. This is further supported by the discrepancies in the amount of sludge hauled to each township (Table 3.2). Kitchener - Waterloo (K-W) and Cambridge have significantly fewer farms than Woolwich and North Dumfries; hence, the fewer valid C.A.'s.

It is assumed that the potential surface/groundwater contamination risk increases with increasing number of sludge application sites in any given township. The hazards are potential contamination of rivers streams, creeks, drainage systems, ponds, lakes, reservoirs, and groundwater. Numerous creeks and streams are tributaries that lead to any one of the four rivers: the Nith, Conestogo, Grand and Speed Rivers. It is important to note that the points identified on the map are the lots on which a sludge site is located. Employing the one map to ascertain the proximity of watercourses to sludge application sites poses a major problem: there is a false sense of the true proximity lots are to watercourses. This means that a lot is either closer to, or further away from a watercourse evident from the map. Moreover, small drainage channels not delineated on maps often flow directly into watercourses. This stresses the importance of site assessment by field investigations. The fact that a site is located near a watercourse could raise the potential for contamination, making it a high risk site. Lots further away from watercourses, pose another type of immediate risk; one which is associated with soil and groundwater contamination. Such sites should not be ignored.

Because it is cost efficient to apply sludge on sites relatively close to one another due to lower hauling costs, small isolated sub-regions possess a significant concentration of sludge amended farmfields.

(Table 3.2) TOWNSHIP AND CITY LOCATIONS, AND VOLUMES OF PROCESSED MUNICIPAL SLUDGE RECEIVED ORIGINATING FROM WATER POLLUTION CONTROLPLANTS LOCATED WITHIN THE REGION OF WATERLOO (JANUARY 1/89 - AUGUST 31/90)

Township within Region		
Location	volume rec'd (M^3)	% of total hauled
City of Cambridge	40,352.1	6.3
City of Kitchener	22,729.2	3.5
City of Waterloo	2,136.2	0.3
Twp. of North Dumfries	137,557.7	21.6
Twp. of Wellesley	12,964.5	2.0
Twp. of Wilmot	96,682.5	15.2
Twp. of Woolwich	135,371.0	21.3
Subtotals	447,813.2	70.2
Volume of sludge hauled outside Waterloo Region		
	189,035.2	29.8
Total hauled:	636,848.4	100.0

Source: M.O.E. (1990).

3.3 SOIL AND SITE PHYSICAL CHARACTERISTICS

The distribution of soil types throughout the Region of Waterloo is the result of a complex interaction of glacier movement, meltwaters, and pedogenesis (Presant and Wicklund, 1972). A general simplified overview suggests that the west portion of the

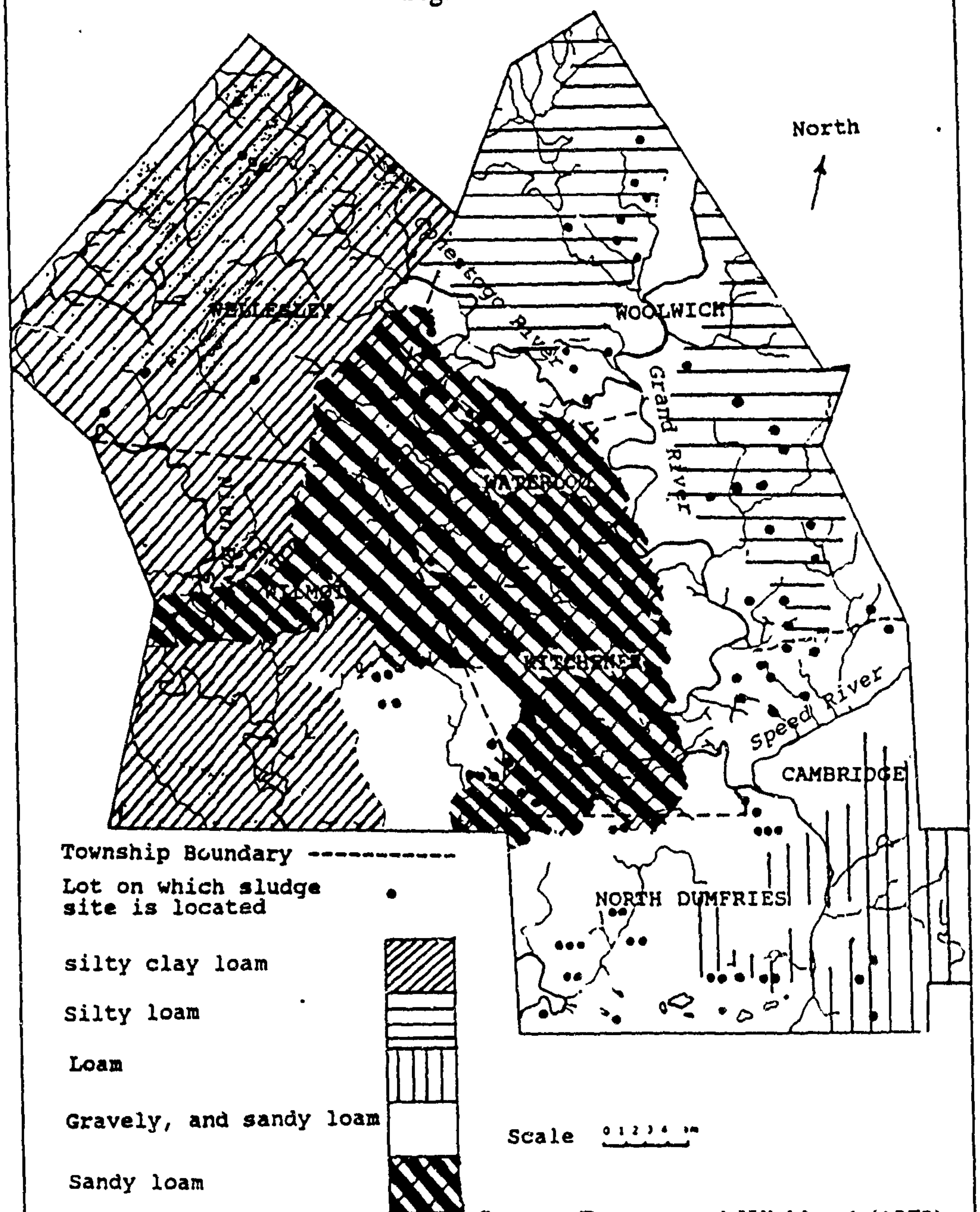
Region consists of predominantly silty clays, whereas in the central and east portion sand and sandy loams predominate (Figure 3.3). The latter includes the townships of Woolwich and North Dumfries, and the City of Cambridge. The soils are generally underlain by glacial till. Other common glacial landforms include moraines, kames, drumlins and eskers. These features are in part responsible for the rolling and hummocky relief of the region which in a number of instances is responsible for the numerous changes in slope of farm fields of the region.

Utilizing sludge on agricultural land of varying soil types poses different levels and types of risks depending on respective soil properties. Physical soil properties associated with the movement of water in the unsaturated and saturated parts of the groundwater regime such as porosity, permeability, and infiltration capacity are important to consider. A general view of the soils of the Region of Waterloo reveals that the western portion due to their higher clay content tend to infiltrate less efficiently than the coarser textured soils of the eastern portion. The former would promote overland runoff more readily than the latter because of the lower infiltration capacity. Furthermore, the higher clay content of soils found in the township of Wellesley for example, would possess a higher Cation Exchange Capacity (CEC) than the sandy soils of Woolwich. Any surface runoff from such soils may carry with it the clay with adsorbed contaminants.

The predominant soil types in the Region of Waterloo are sandy to silty loams. For sludge recycling purposes, a soil with a moderate permeability is preferred. If water does not infiltrate fast enough, surface runoff may occur. Too rapid infiltration could raise the risk of groundwater contamination because the percolating water may not have sufficient

GENERALIZED SOIL MAP OF THE REGION OF WATERLOO

Figure 3.3



Source: Presant and Wicklund (1972)

time for it to be purified by the substratum through which it flows. Environment Canada (1984) publishes tables which are a generalized collection of soil properties and textural classes from which a quick assessment of soil can be made; however, each soil possesses different characteristics. Therefore, a detailed soil analysis must be carried out prior to drawing any credible conclusions regarding soil feasibility for sludge utilization.

CHAPTER 4: RESULTS

4.1 RISKS IN THE REGION OF WATERLOO

The Ontario Ministry of the Environment (M.O.E.) is actively involved in attempting to minimize the risk of degradation of the environment. This is accomplished by way of publishing guidelines, factsheets and other pieces of literature in conjunction with having consultants available for farmers and the inquiring public from both the M.O.E. and the Ontario Ministry of Agriculture and Food (OMAF). The overall purpose of the Guidelines for sludge utilization on agricultural lands is to facilitate the sludge recycling programme while protecting the quality of the environment (M.O.E., 1986). The specific objective as stated in the Guidelines is to ensure that organic matter and micronutrients will benefit crops without degrading the environment or risking the health and productivity of the crops, animals, and people of Ontario (M.O.E., 1986). The M.O.E. sludge coordinator is responsible for ensuring that these Guidelines are adhered to in the assigned region, and sometimes, townships within other regions.

The application of sludge on agricultural land is governed by a series of specifications and recommendations as outlined by the M.O.E. Guidelines. The application of sludge must remain within specified distances from watercourses, wells and inhabited dwellings (Table 4.1). A site with a slope in excess of 9% cannot receive sludge due to the high risk of runoff during a rain storm. Other specifications are chemical in nature which outline required soil pH, and limits for nitrogen and heavy metal content in both sludge and soil. Failing to adhere to these guidelines can raise the risk of potential contamination of the environment.

(Table 4.1)MINIMUM DISTANCES TO WATERCOURSES

MAXIMUM SLOPE	SOIL PERMEABILITY	DISTANCE (METRES)
0 to 3%	Rapid to Moderately Rapid	60
	Moderate to Slow	120
3 to 6%	Rapid to Moderately Rapid	120
	Moderate to Slow	240
6 to 9%	Rapid to Moderately Rapid	180
	Moderate to Slow	Not Permitted
Greater than 9%	All permeabilities	Not Permitted

Notes: a) spreading should be suspended when runoff is expected.

b) separation distances should be increased when soils are frozen.

Source: Modified from M.O.E. (1986).

The pollution problem in the Region of Waterloo has been described by the Grand River Implementation Committee (GRIC) (1982) as localized and site specific. Farms can contribute to the pollution of water resources in numerous ways, including runoff from feedlots, barnyards, manure piles, fields receiving sludge, and malfunctioning private sewage facilities (GRIC, 1982). This is also exacerbated by inadequate safeguards against runoff and soil erosion. In essence, poor farm management is the prime cause of agriculture-based pollution (GRIC, 1982). The contaminants from this source of pollution are predominantly nitrates, phosphorus, and bacteria. These contaminants pose predominantly short-term risks to the environment and account for the localized and site specific nature of the pollution problem. Phosphorus concentrations often exceed provincial guidelines in the stem and major tributaries of the Grand River (GRIC, 1982, p. 6.20). It is worth mentioning that continuous loading of these contaminants results in long-term problems associated with eutrophication such as the killing of certain species of aquatic organisms due to the harsher environmental conditions, e.g. low oxygen levels, loss of a food source, and lowering of pH.

Common localized and site-specific problems in the Region of Waterloo include: contamination of wells, water reservoirs, lakes, and ponds, streams and rivers adjacent to the source of contamination which is most often farms on which some form of commercial fertilizer, manure, or sludge is being used (GRIC, 1982). Coliform and nitrate contamination of wells has been a recurring problem in the Region of Waterloo, especially where summer and early fall stream-flow dilution of bacteria is minimal (GRIC, 1982, p. 6.21). The results of a well sampling survey conducted by the Waterloo

Regional Health Unit in the summer of 1990 indicate a high proportion of wells are bacteriologically unacceptable (B.U.), and possess nitrate concentrations in excess of the 10 mg/l drinking water standard for Ontario (M.O.E., 1989). A total of 566 well samples were tested for a series of parameters, nitrates, total and fecal coliform bacteria. The location of the wells is identified by postal code sub regions. The survey served as a preliminary study of the quality of wells in the Region of Waterloo. It was noted that 207 out of the 566 wells were bacteriologically unacceptable (B.U.), of 210 wells in Woolwich, Cambridge, Wilmot, and Wellesley, 88 were B.U., four were unfit for drinking, 33 exceeded by far the 10 mg/l standard for nitrate levels, and 48 were slightly above.

The presence of fecal coliform bacteria is generally an indicator of recent and ongoing contamination. Farms that received sludge in the summer of 1990 may have been a source of contamination. A review of the results from the survey of areas that received sludge recently compared with those which did not receive sludge, showed no variation in contaminant concentrations. There appears to be no correlation between contaminated wells and sites receiving sludge (Brent Zehr, M.O.E. Transfer Station, Personal Communication, 1991). Based on what information is available on sludge induced contamination of small river tributaries, it appears that the high concentrations of nitrates, P, and coliform bacteria in the four main rivers in the Region of Waterloo is substantial. Maclean (1989) found N concentrations in tile outfalls flowing into a Grand River tributary during the winter months to be quite high. Cumulative loading of contaminants discharged into these rivers via small tributaries and non-point sources is the source of the elevated contaminant levels. During the months of January, February and December of 1990, sludge spreading did take place despite M.O.E. Guidelines and management procedures which dictate otherwise. The concern is that applying sludge onto frozen ground is known to pose a high risk of water contamination from contaminated runoff because of the reduced ability of sludge to infiltrate into the ground at this time, or during thaw periods in the winter.

A feasible approximation of the degree to which the ground is frozen can be determined by the ambient air temperature. However, one must also consider the amount of water in the soil, i.e. is the soil saturated, and how much of a snow cover is there because snow insulates the ground from the cold air. For the purpose of this thesis, ambient air temperature is sufficient. Using meteorological data (mean daily temperature) for the winter months revealed that the mean daily temperatures were well below freezing (Figures 4.1 - 4.3). It can be assumed that the risk of potential runoff of applying sludge on frozen ground was high. However, snow present on the fields at the time of application could act as an insulator and reduce the degree of ground freeze-up, thereby reducing the risk of subsequent surface runoff. The winter months are not devoid of melt periods: such occurrences will result in contaminated runoff from sludge amended soil. No record of snow characteristics and type of ground frost of the sites is available, but the meteorological records indicate that snow prevailed throughout January and February of 1990.

The transfer of sludge from a tanker to a "nurse" tank often results in the spilling of sludge outside the spreading site. The transfer is often carried out from the side of the

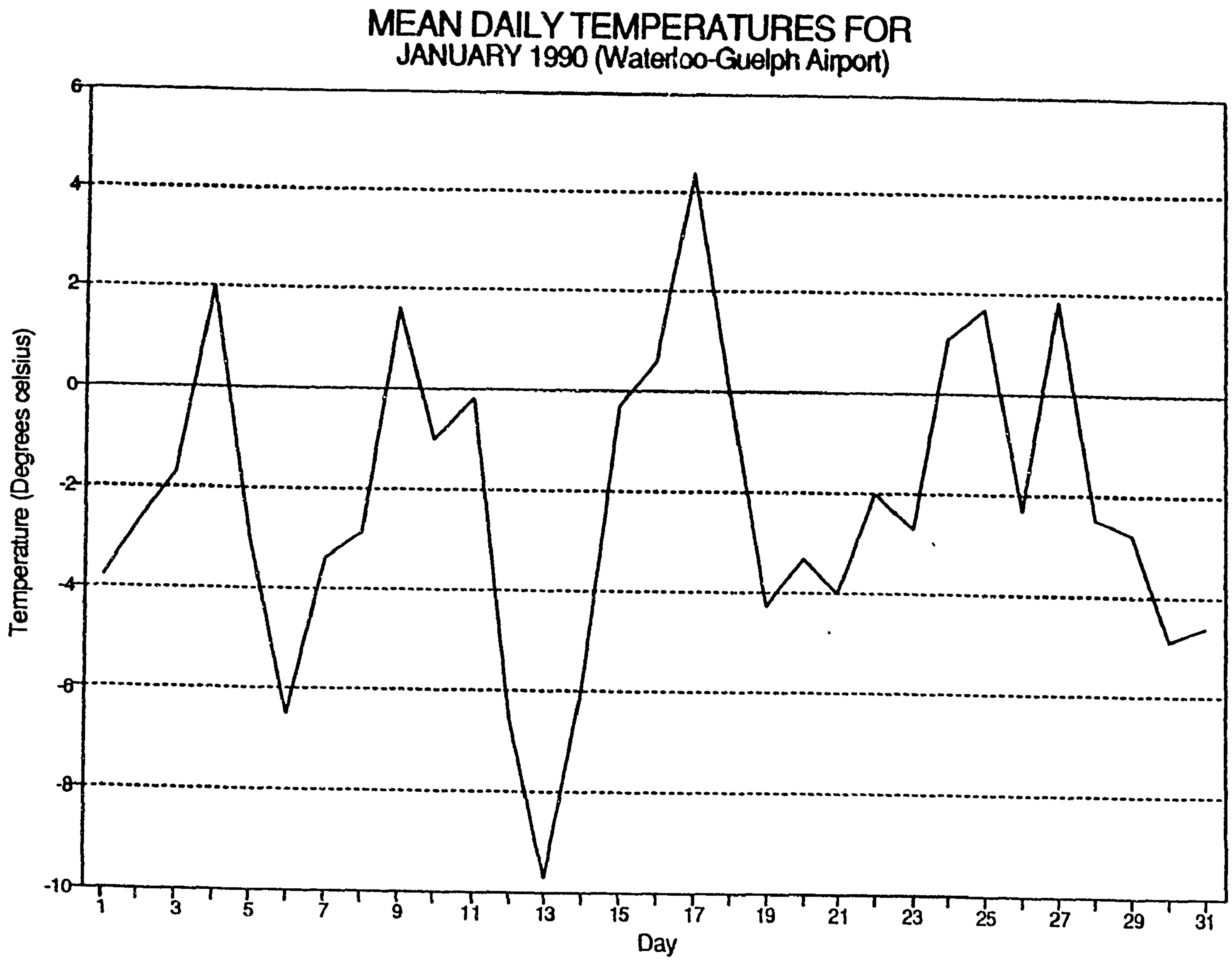


Figure 4.1

Source: Environment Canada, 1991

MEAN DAILY TEMPERATURES FOR FEBRUARY 1990 (Waterloo-Guelph Airport)

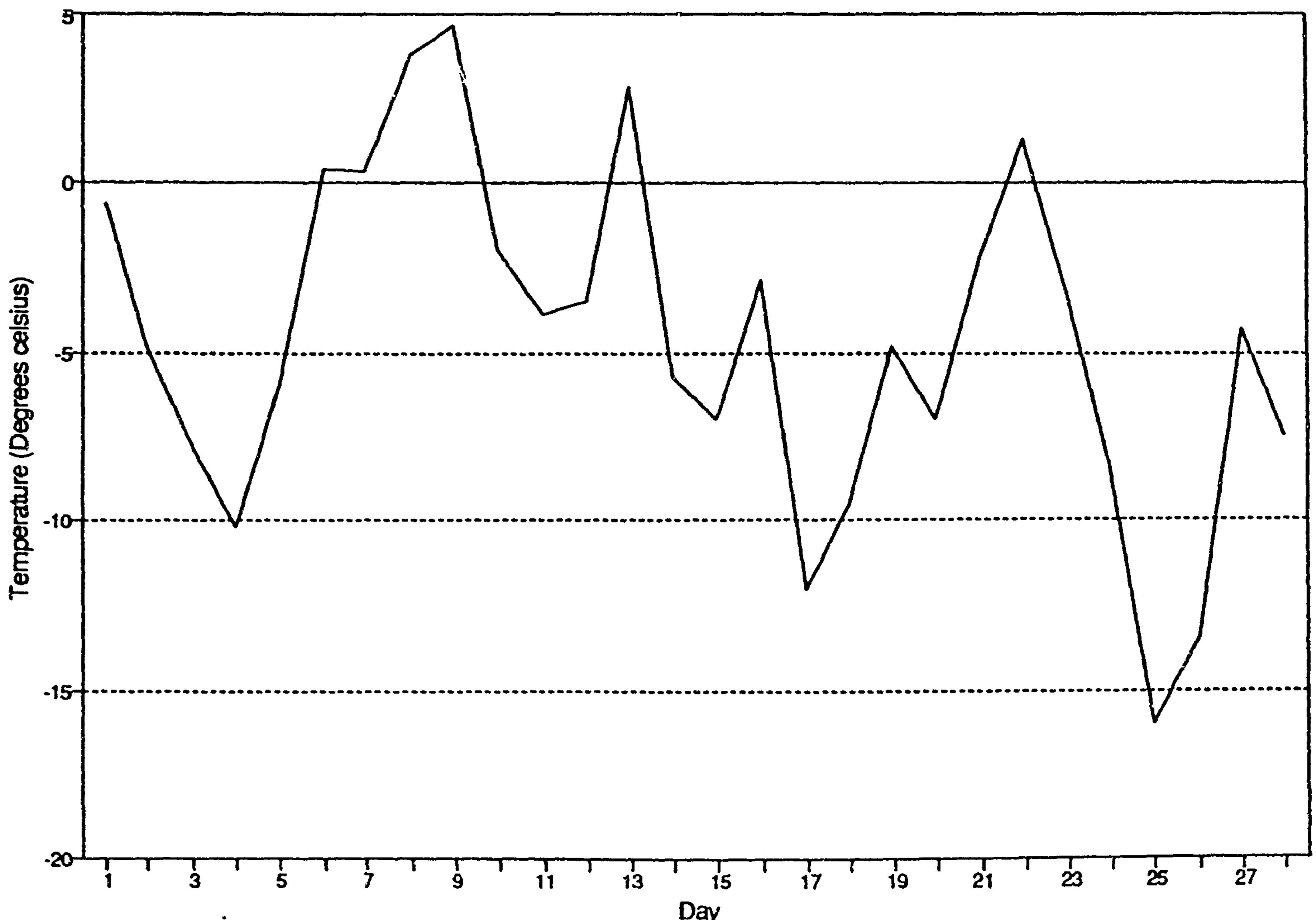


Figure 4.2

Source: Environment Canada, 1991

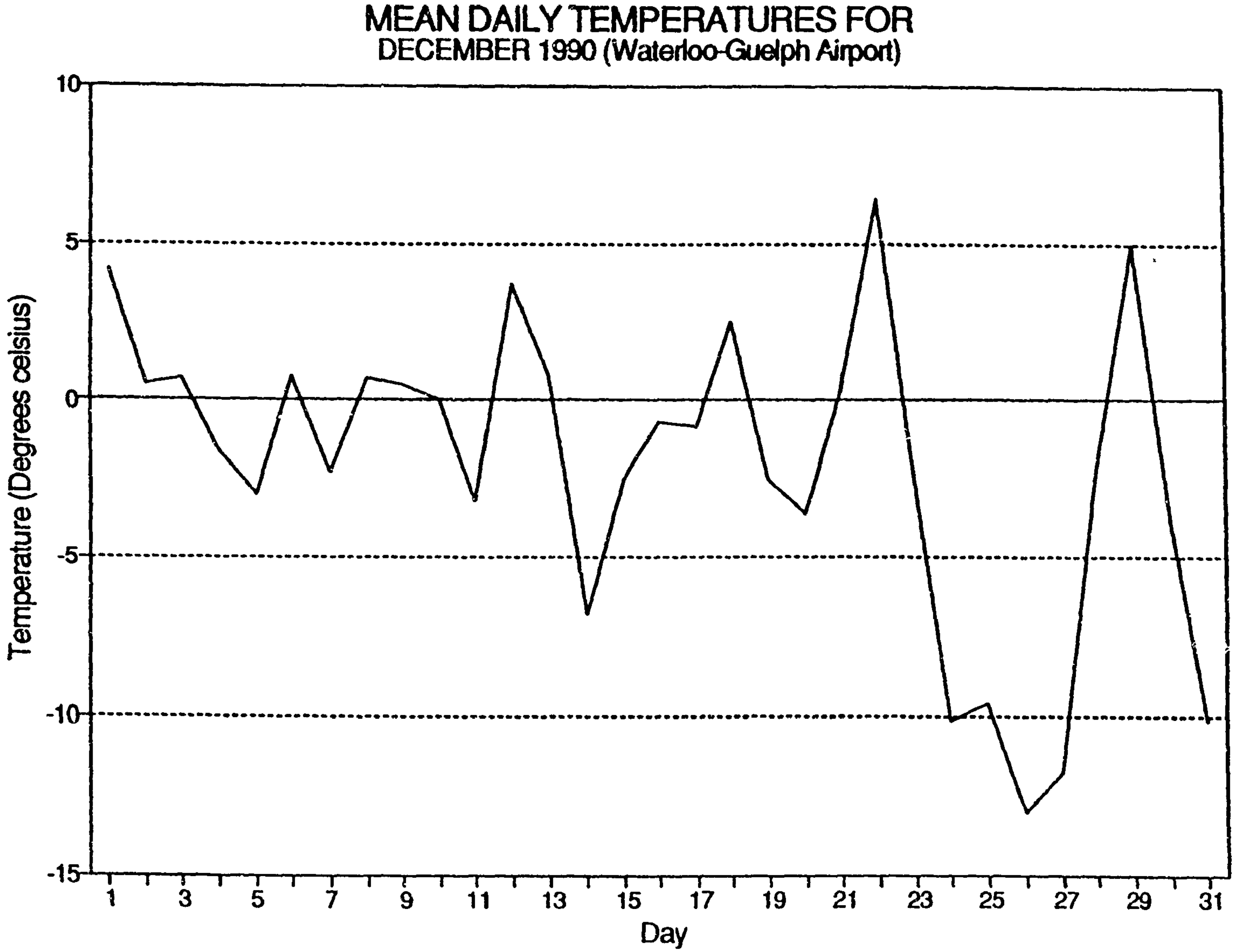


Figure 4.3

Source: Environment Canada, 1991

road where a hose connects the tanker to the "nurse" tank located on the site. These spills originate from sludge draining out of the piping system. The result is a patch of sludge not on the site, but on the side of a road, generally near a ditch. A number of them have been observed in the Bloomingdale area in the Region of Waterloo (see Figure 4.12). The spills are relatively small, however, the exposure of sludge outside a controlled designated area can have consequences since the sludge is not incorporated into the soil; it simply remains until flushed away by rainwater. This is in essence another characteristic of the localized and site specific nature of sludge induced contamination in the Region of Waterloo. When sludge remains on the ground with no warning signs, or fenced off areas, humans may come in contact with it, e.g. sludge can be brought into homes from residues off of shoes after people have stepped in a pool of sludge. There is no official documentation of people having been contaminated in this manner, but the risk is inherent.

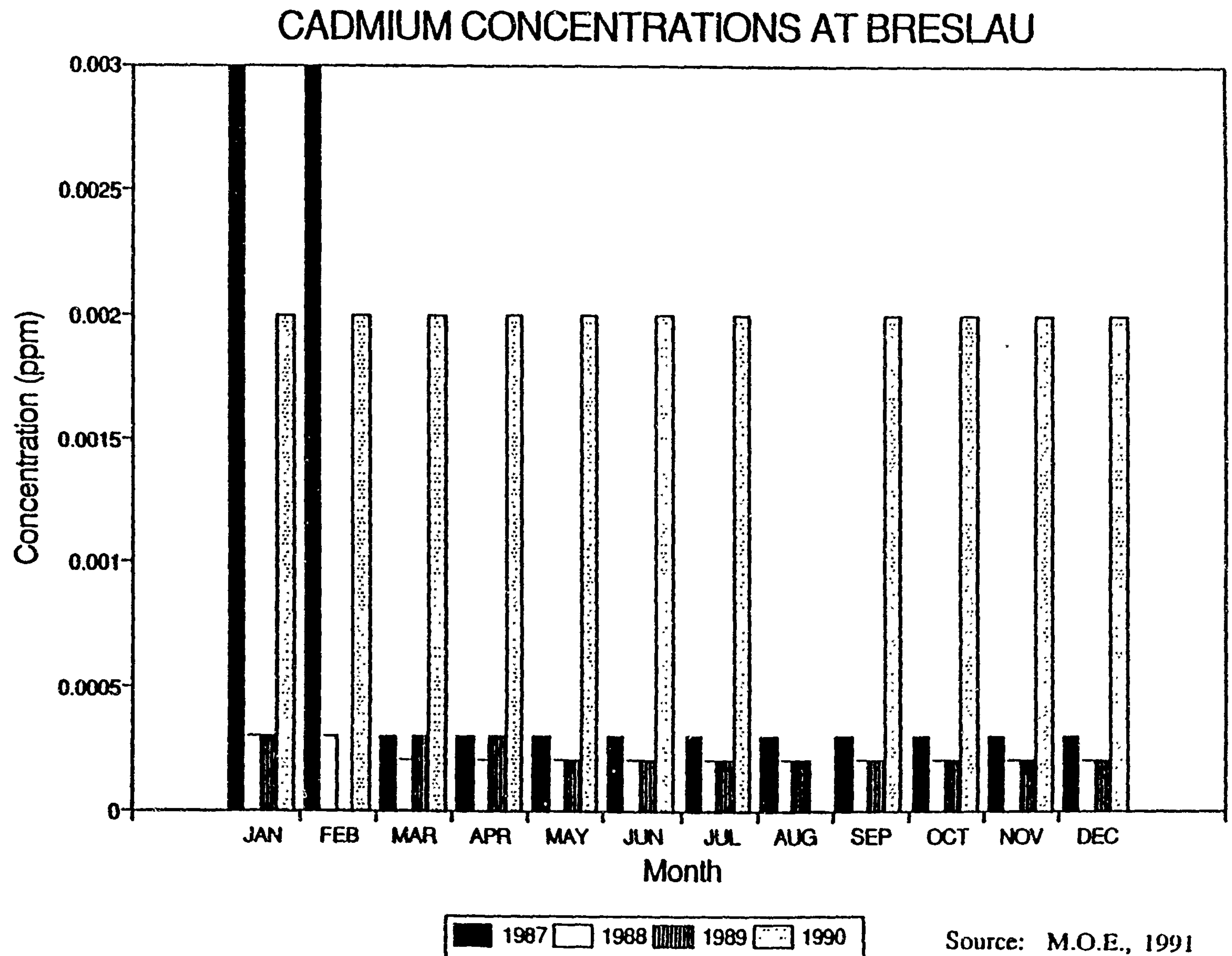
The pollution problem in the Region of Waterloo is not localized and site specific when dealing with contaminants such as Cd, organics, and other persistent substances found in sludge. In 1971, 24,264 kg of Cr, Cu and Zn were spread on farmland (Thompson, 1978). These contaminants are more appropriately attributed to long-term risks. Sludge amended soil releases small quantities of these contaminants into the environment. A portion of these contaminants are flushed into watercourses where they may be transported to the first order rivers that flow through the Region of Waterloo.

4.2 WATER QUALITY DATA

An examination of M.O.E. water quality data from the Breslau and Blair Bridge monitoring stations for the last ten years does not reveal a strong tendency for sludge-borne contaminants to be present in the Grand River. The sludge-borne contaminants were discussed in chapter 1. In The Region of Waterloo, heavy metals such as zinc, nickle, and copper are common because of the numerous metal finishing plants; phosphorus and nitrates are also common because of the large number of food processing and beverage companies in the area. The months from April to November inclusive are the primary months in which sludge spreading takes place. No significant increases in contaminants associated with sludge were observed during this period.

A significant proportion of the heavy metals in the Grand River come from urban generated sewage effluents. Copper, zinc, lead, cadmium, and silver concentrations are the result of corrosion of the pipes of the urban water supply and sewage systems (Forstner and Wittmann, 1981; Brown, 1988). Forstner and Wittmann (1981), and Beck and Lessard (1990) pointed out that during heavy rainstorms, sewage often bypasses the treatment system discharging raw sewage into watercourses, and within the first thirty minutes, the first flush carries exceptionally high loads of heavy metals.

Cadmium levels in the Grand River have risen over the last ten years and peaked in 1990 (Figures 4.4 - 4.5). GRIC (1982) indicated that as a result of sludge application, there had been an increase in Cd in surface water. Data from the M.O.E. suggests that Cd levels in the Grand River have risen with concentrations which are considerably higher than in previous years. However, in 1990, 0.002 ppm was found throughout the year.



Source: M.O.E., 1991

Figure 4.5

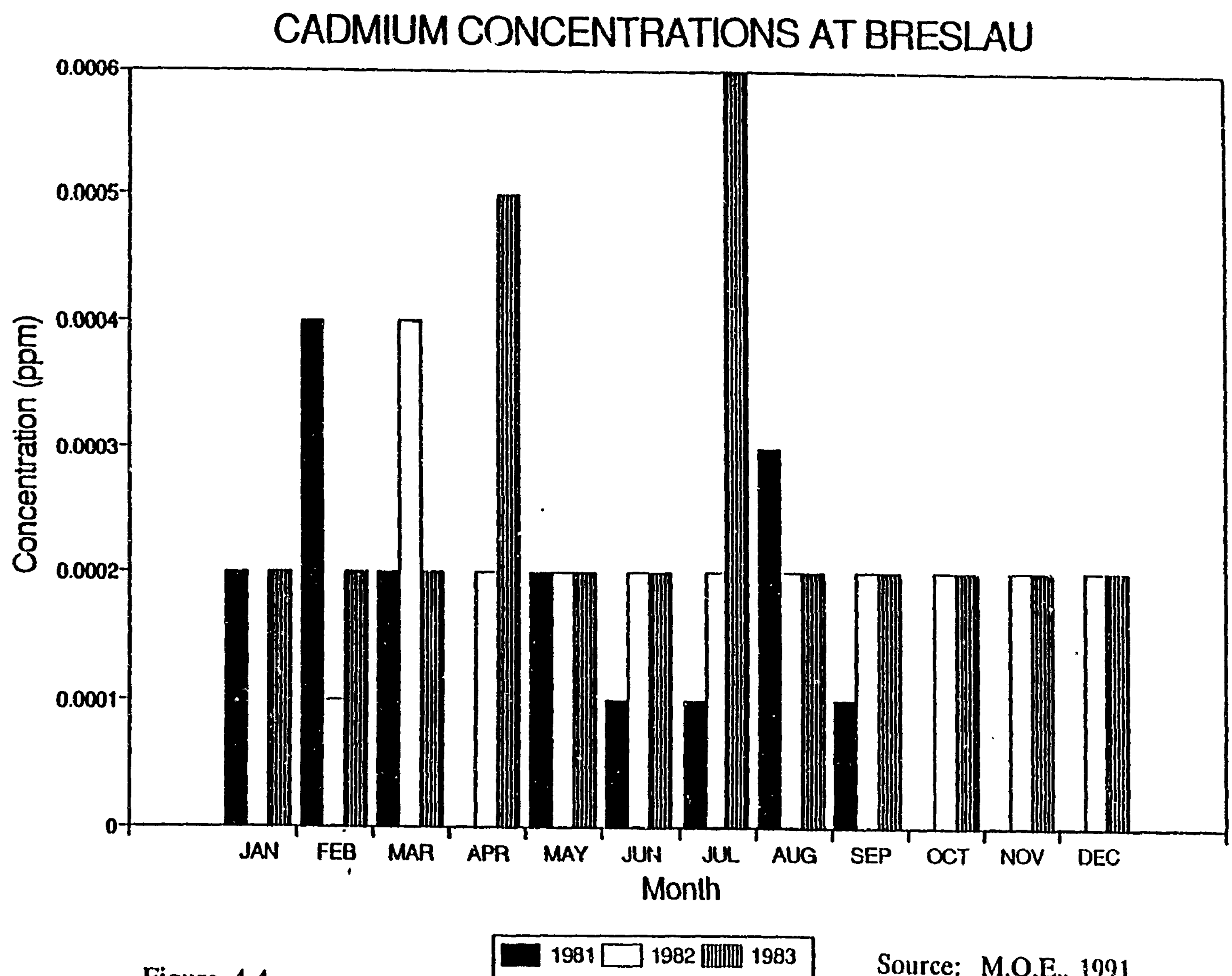


Figure 4.4

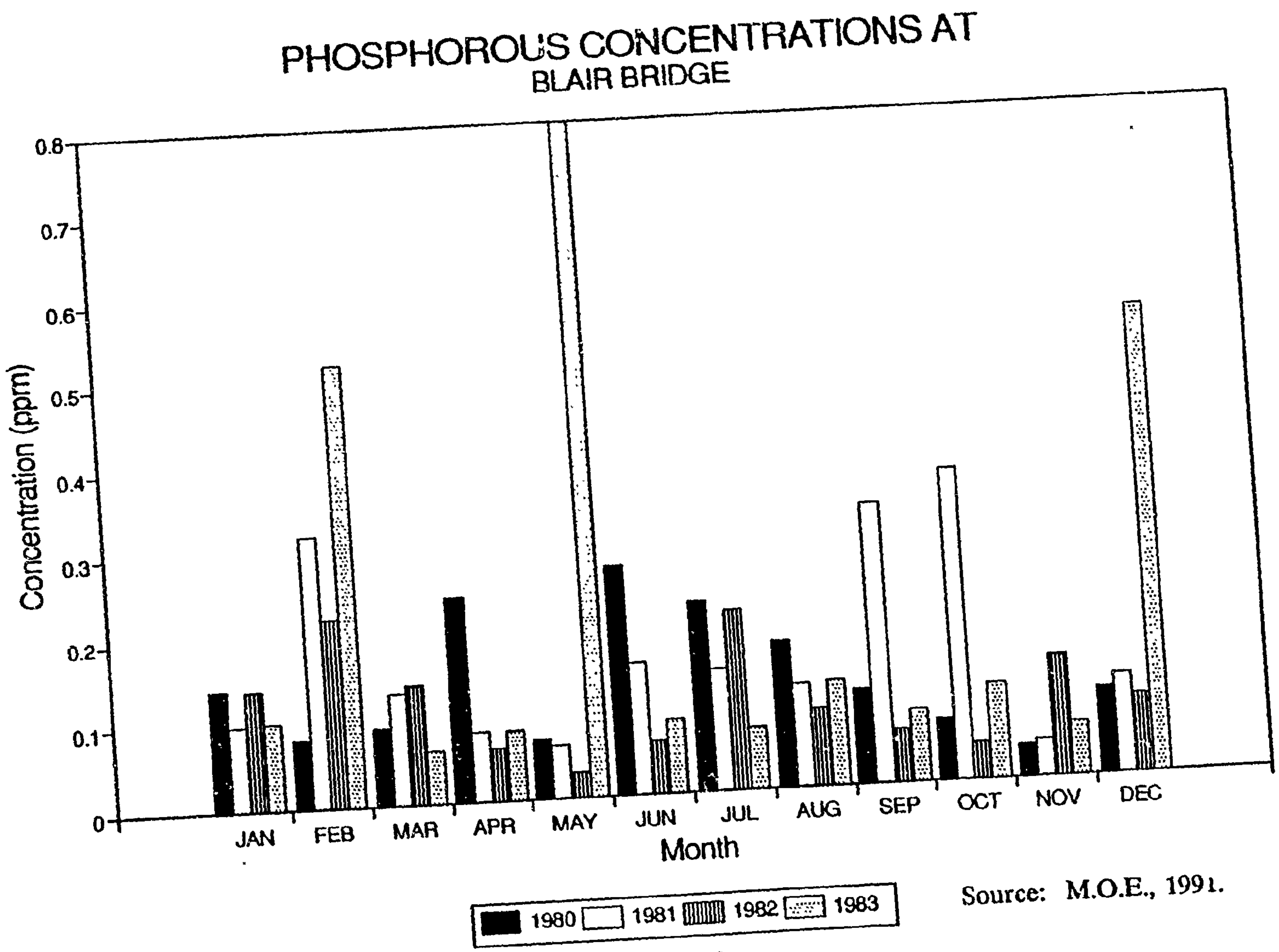
Source: M.O.E., 1991.

The plateaus in the graph indicate the limit of contaminant detected, e.g. < 0.002 ppm. It does not necessarily mean that exactly 0.002 ppm were detected. All data for 1990 was below this range of detectability.

The source of the Cd can be from a number of the steel finishing and plating companies in the Region of Waterloo. These companies include: American Standard Division of Wabco Standard, Crowe Foundry Ltd. and Birla Industries Inc. located in Cambridge, and Dunbar Aluminum in Kitchener (M.O.E., 1989). The rise in Cd may be consistent with increased use of sludge on agricultural land, particularly since artificial fertilizers are becoming increasingly expensive.

There appears to be no correlation between P in the Grand River and sludge application. In the last ten years, P concentrations have dropped (Figures 4.6 - 4.8). This reduction can be attributed to increased P removal from sludge at the sewage treatment plants, increased P consumption by plants and organisms.

There is no correlation between $N0_2$+$N0_3$ as N concentrations and sludge application (Figures 4.9 - 4.11). The highest concentrations appear to be late winter/early spring, and late fall/early winter. The lowest being June and late August. The lower N levels during the summer months correspond to the growing season and would, therefore, make N less available for runoff and leaching into watercourses and groundwater respectively. Moreover, when growth ceases, N uptake will stop making more available for leaching. Surface water will also carry with it N especially when saturated conditions exist. Elkin (1986) indicated that in late winter 80% of total N in the Grand River is from farm runoff, and 73% in early spring.



Source: M.O.E., 1991.

Figure 4.6

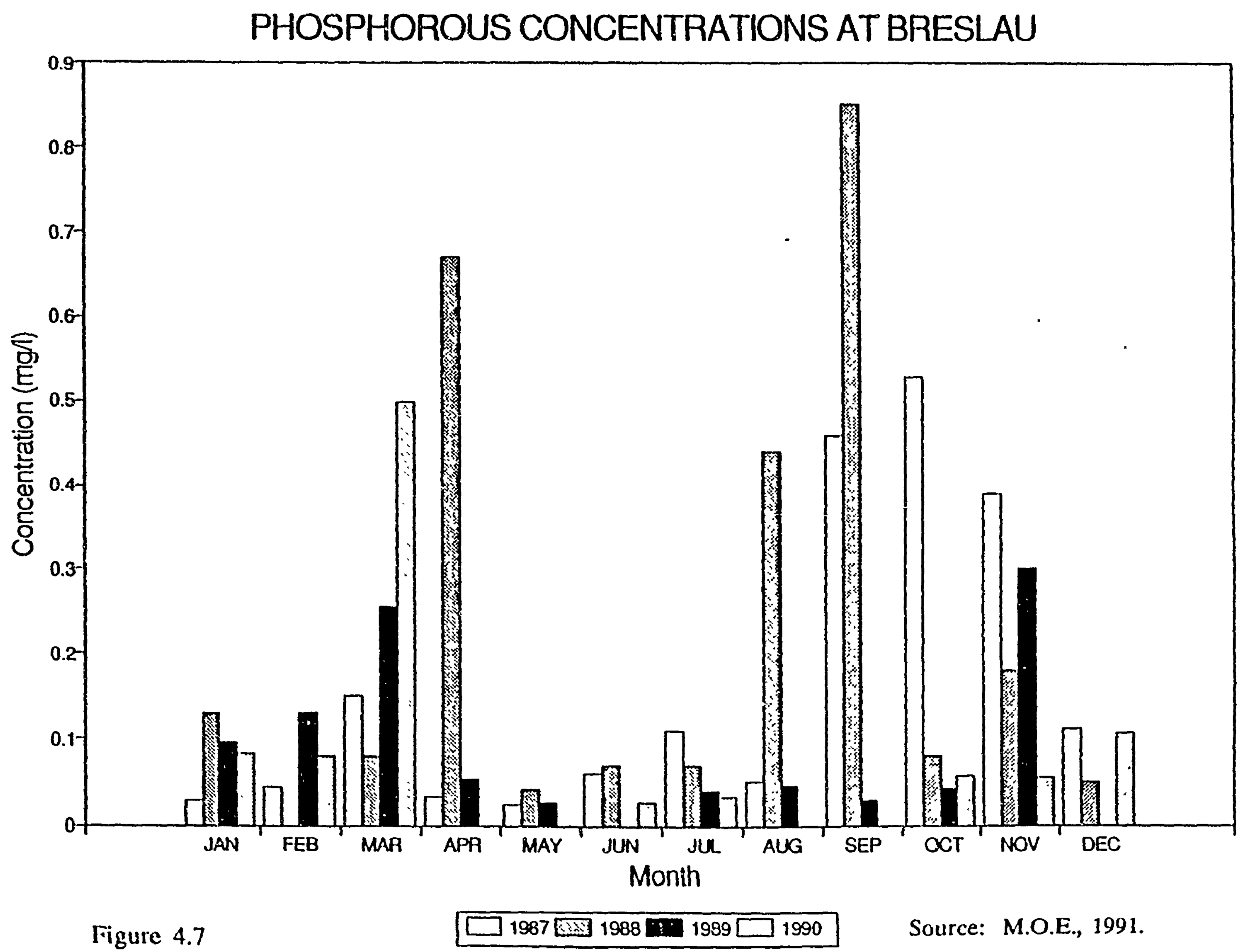


Figure 4.7

Source: M.O.E., 1991.

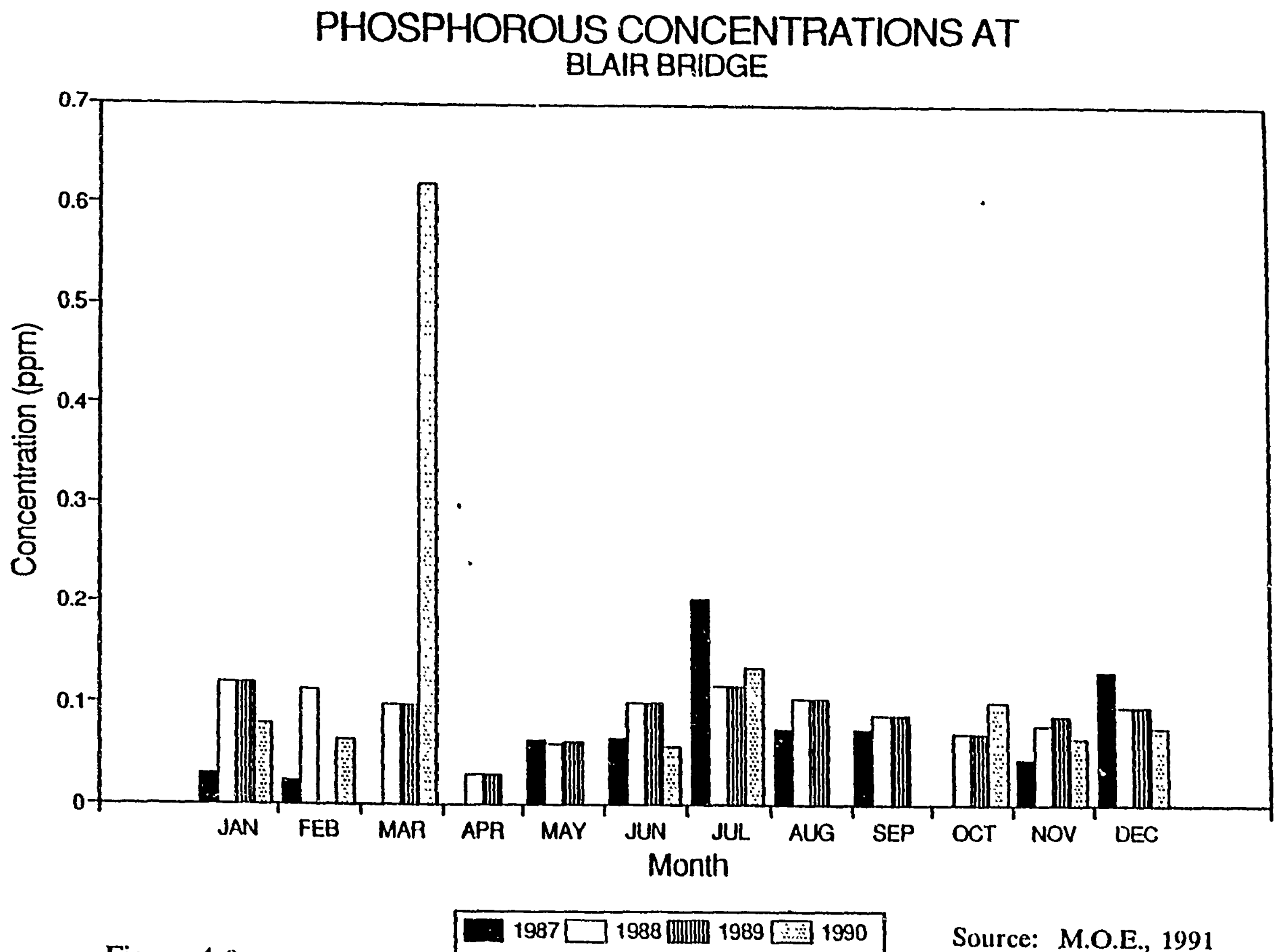
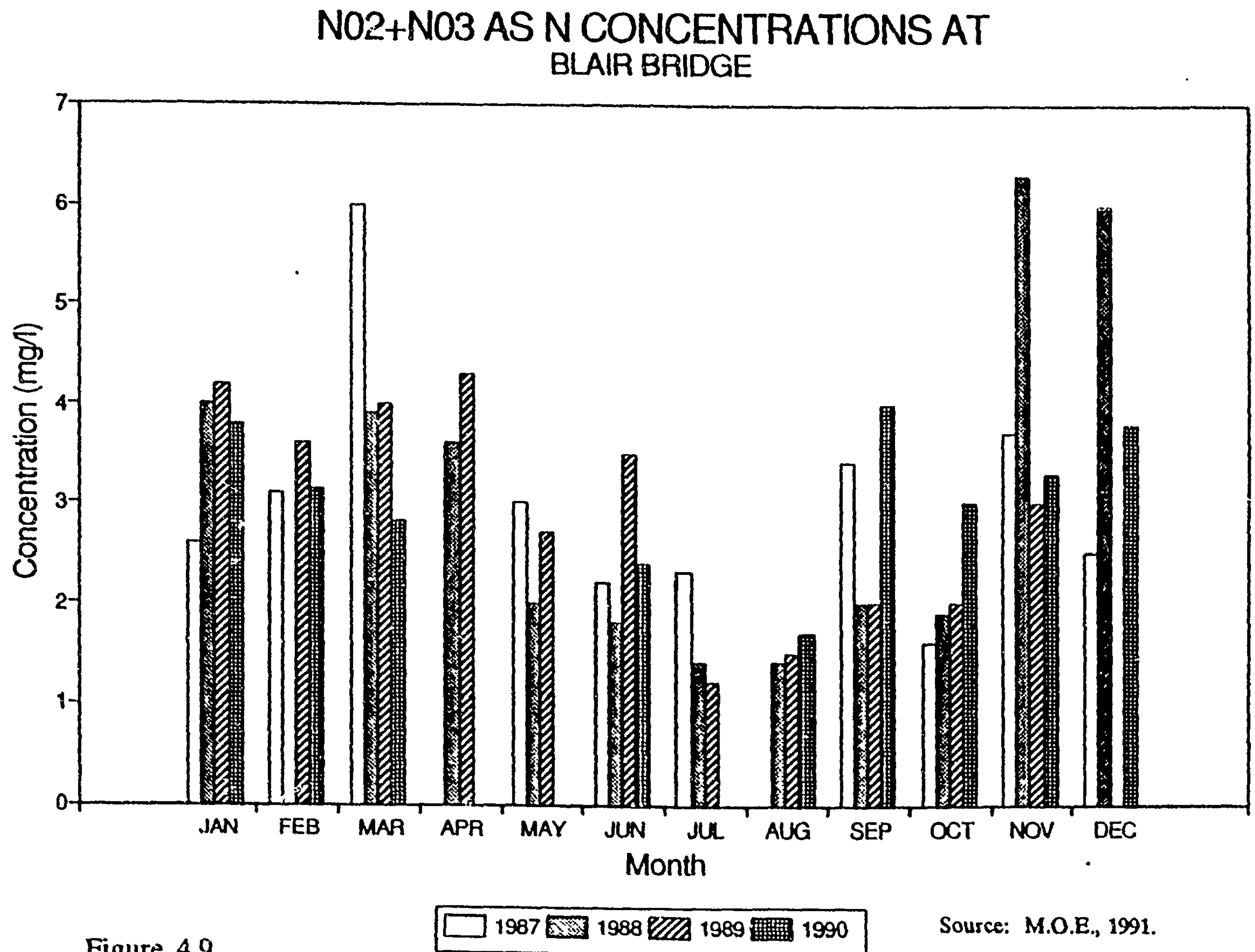


Figure 4.8

Source: M.O.E., 1991



Source: M.O.E., 1991.

Figure 4.9

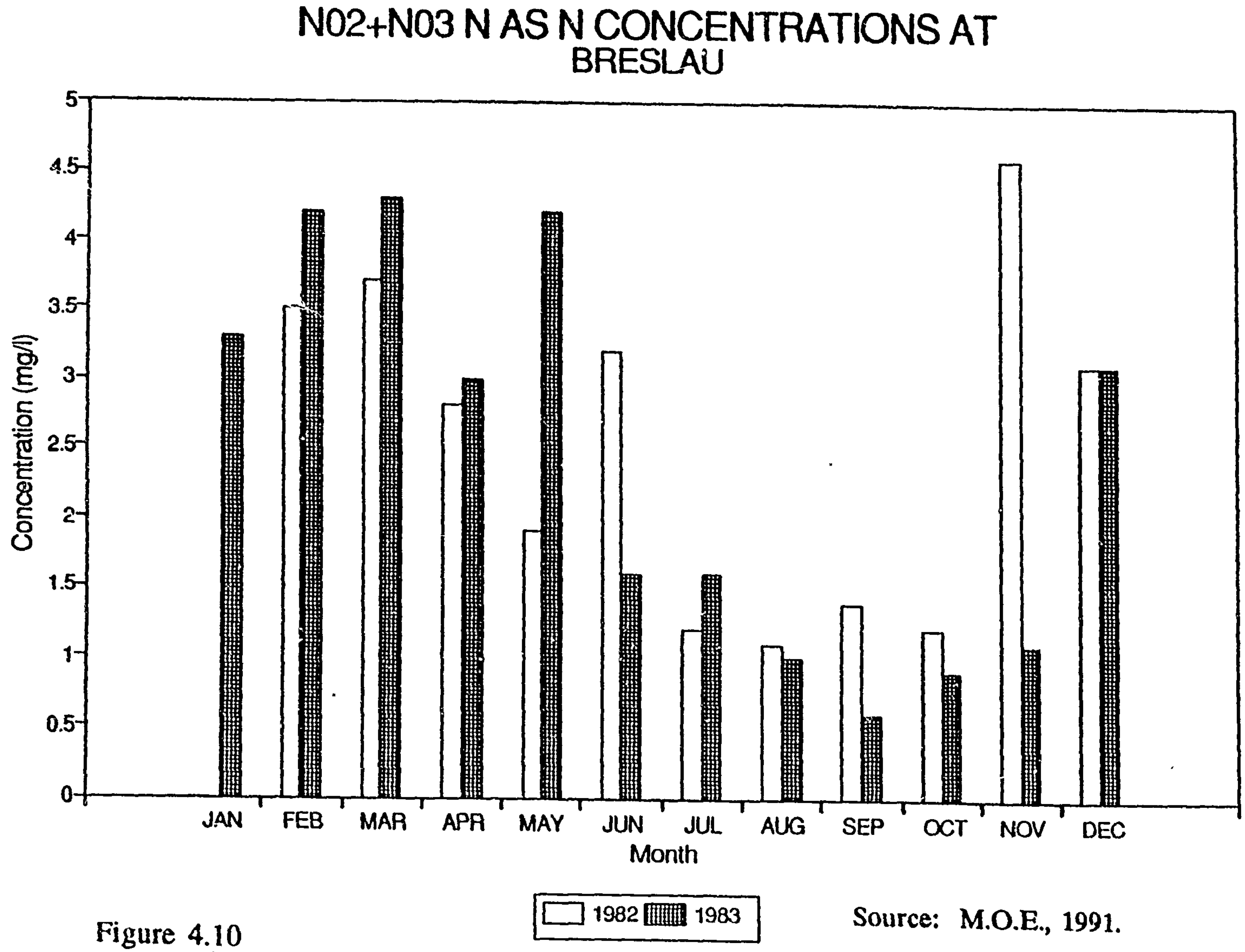


Figure 4.10

Source: M.O.E., 1991.

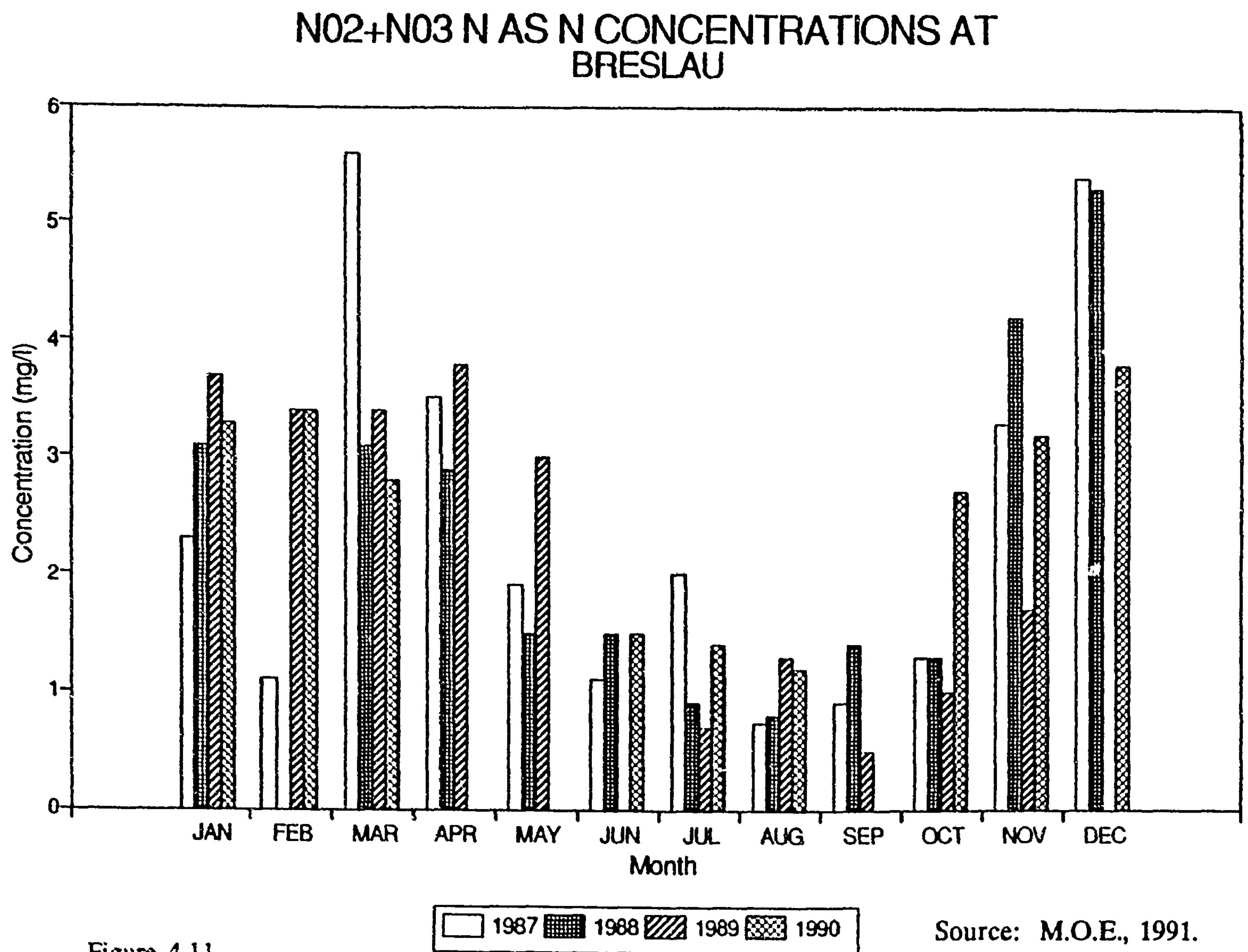


Figure 4.11

Source: M.O.E., 1991.

4.3 LIMITATIONS OF WATER QUALITY DATA

It is difficult to assess quantitatively the impact sludge amended soil has on surface water quality. The fundamental limitation is the absence of a water quality sampling programme tailored to sludge-borne contaminant monitoring. Data does exists for certain areas with test plots, but data representative of the Region of Waterloo is lacking. It is important to monitor the effects of applying sludge on agricultural land because all sludge generated in the Region of Waterloo is destined for agricultural use. However, monitoring on such a frequent basis is very costly. Data published by the M.O.E. is monthly, i.e. one day of the month is selected for sampling. Often data is missing for certain periods making the data inconsistent. Ultimately, because of the nature of this type of data, it cannot be readily used to determine short-term trends, however, long-term trends are observable.

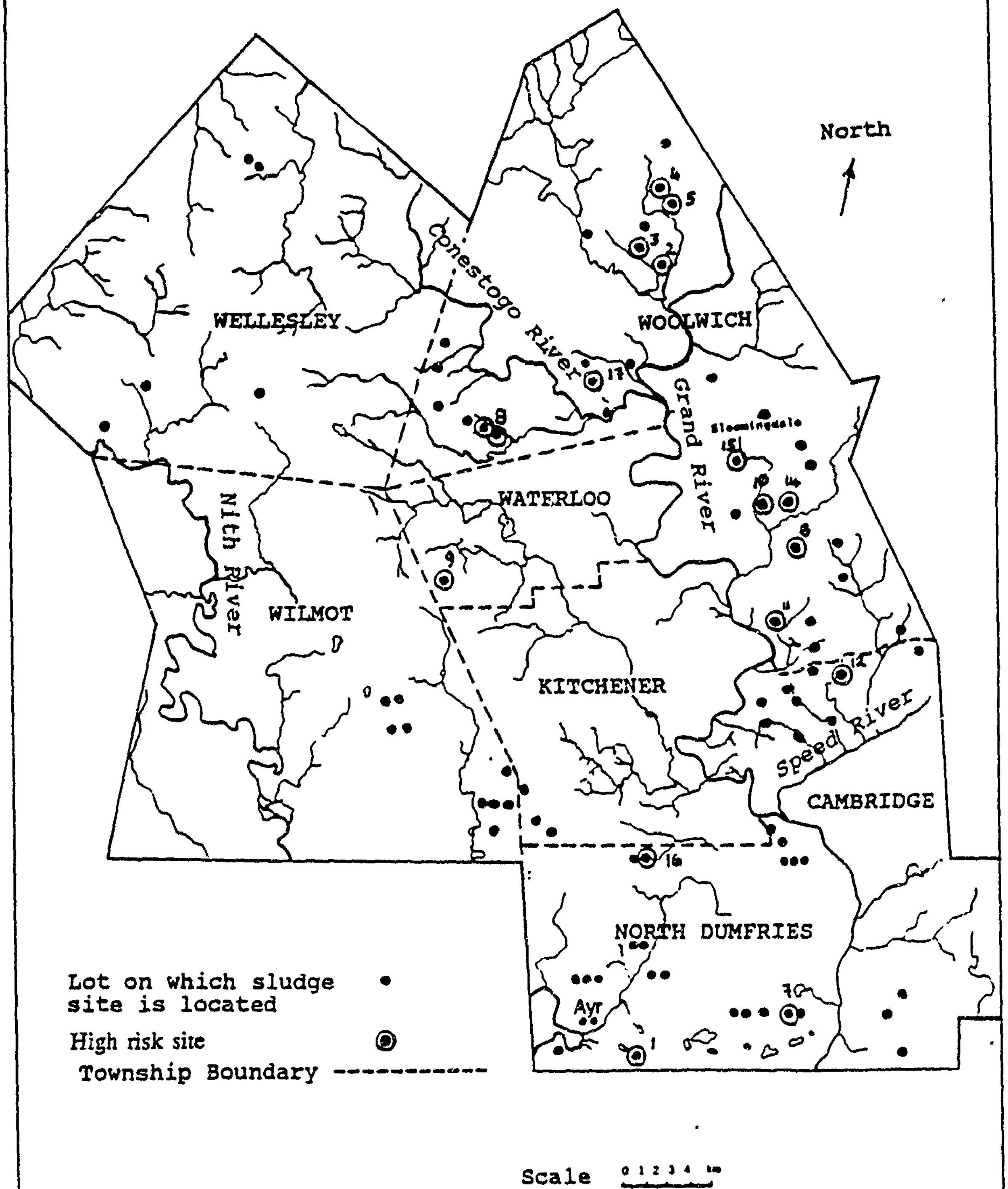
There is such a multitude of sources of contaminants that water quality data must be obtained from a water sampling survey tailored to the requirements of the initial objective. The end result would be data that in essence can reveal information on the timing and quantity of contaminants entering, e.g. a watercourse. In this manner one can limit background contaminants, and identify those emanating from the test site.

4.4 FIELD DESCRIPTION

In the Region of Waterloo, 17 sites were subject to investigation (Figure 4.12). In a number of instances, a high risk of surface water contamination was noted. The high risk sites require special attention during sludge application to prevent the undesired consequences of environmental degradation. Such precautions, i.e. maintaining minimum

SELECTED HIGH RISK SITES 1990

Figure 4.1 2



distances between sites and watercourses, not spreading on frozen ground and selecting days with a low probability of precipitation, are not always taken.

Each site possesses certain characteristics which may contribute to potential environmental degradation. These are listed in table 4.2. The purpose of this section is to describe and discuss the characteristics of a number of high risk sites in the Region of Waterloo.

The majority of crops grown in the Region of Waterloo on sludge amended soil are corn, barley, sod, soybeans, and hay, most of which are suited for this purpose because they do not assimilate contaminants as well as other crops such as leafy vegetables. Corn is the most common crop found in the Region and readily assimilates nitrogen. This makes nitrogen less available for leaching into groundwater. Soybeans, require less nitrogen, and a higher proportion is made available for leaching. Other crops such as fodder crops: hay, barley, and certain varieties of corn which are not directly consumed by humans are also well suited for sludge amended soil. The heavy metals which are translocated by these crops are ingested by animals leading to concern regarding the animals becoming contaminated. Other products grown on sludge treated land are sod and trees. Since they are not consumed, there is no concern regarding food chain implications. The Environmental Protection Agency (EPA) and Environment Canada have recommendations for crops well suited for the recycling of sludge, i.e. do not translocate heavy metals readily, and use the nutrients.

A large number of farms do not have tiled drainage systems in place. The majority used a system of drainage ditches and culverts to divert excess rain water from the

(Table 4.2) **SLUDGE SITE CHARACTERISTICS IN THE REGION OF WATERLOO**

Site No.	Size(acres)	Volume (m3) Sludge Hauled	Slope Max. %	Drainage Tiled Y/N	Soil Type	Crop
1	100	1255	9	No	Sandy	Barley, hay, corn
2	45	2512.4	3	-	Silt loam	-
3	60	2121.6	3	-	Loam	-
4	115	1812.6	3	Yes	Sandy loam	-
5	85	3336.3	3	-	Sandy loam	-
6	154	3945.3	6	No	Sandy gravely loam	
7	160	7002.4	6	No	Clay loam	Corn
8	79	2613.3	6	-	Loam	-
9	36	1989	-	Yes	Silty loam	Corn, hay
10	250	5151.8	-	-	Silty loam	-
11	110	3342.6	3	No	Sandy clay loam	Corn, grass
12	20	1297.8	3	No	Loam	Corn
13	100	3207.1	3	-	Silty loam, loam	Sod
14	73	4752.6	6	No	Loam	Sod
15	145	2687.3	6	-	Loam	Beans
16	88	2871.8	3	No	Sandy and clay loam	Corn
17	73	4752.6	6	No	Sandy loam	Sod

Site No.	Separation distance
1	75 to watercourse
2	Drainage channel/stream immediately adjacent to site
3	70 metres to well and house
4	80 metres to watercourse
5	Drainage channel/stream immediately adjacent to site
6	20 metres to watercourse
7	-
8	200 metres to watercourse, 70 metres to well and house
9	500+ metres to watercourse
10	-
11	-
12	400 metres to watercourse
13	-
14	150 metres to watercourse
15	150 metres to watercourse
16	Drainage channel/stream immediately adjacent to site
17	250 - 300 metres to watercourse

Note: most values are close approximations.

Source: M.O.E., 1991

sites.This tends to result in uncontrolled dispersal of contaminated runoff, and increased erosion, especially in areas where vegetation is sparse. Tiled drainage systems also divert contaminants into watercourses. This type of drainage system does not eliminate or reduce the level of contaminants, but simply controls their dispersal into a more narrowly defined area (point source).

Most of the investigated sites possess slopes between 3-6%, and are for the most part relatively flat. A steep slope will promote runoff and result in contaminated runoff waters exiting the site; however, a flat field with inefficient drainage may also result in undesired consequences, e.g. persistent saturated conditions after rainfall, infiltration of contaminated water into groundwater, and soil erosion from excess undrained water.

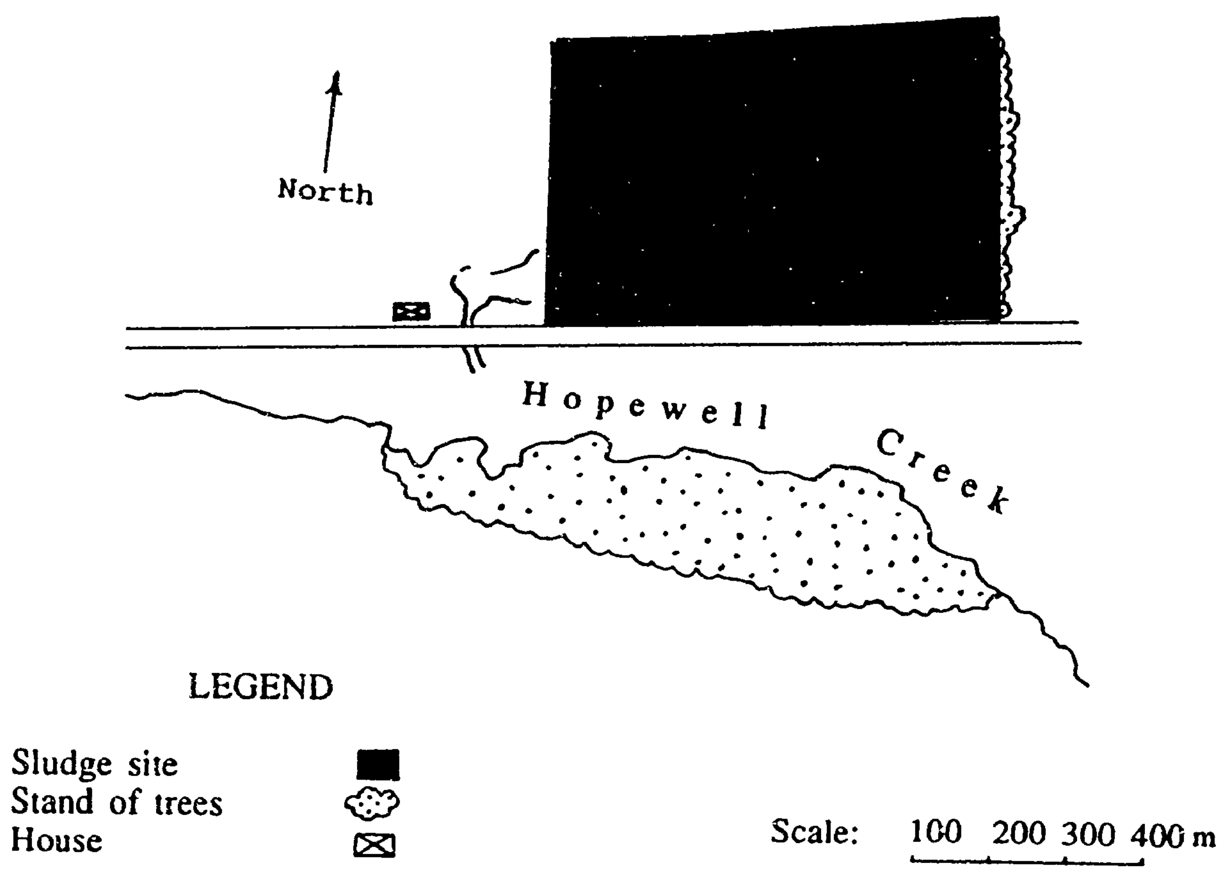
Separation distances to watercourses ranged from 20 metres to 400+ metres. Although most sites remained within specified distances from watercourses as outlined in M.O.E. Guidelines (Table 4.1), the risk of subsurface contaminant movement exits. This is particularly true in regards to throughflow on sites adjacent to sloping surfaces, e.g. site 14 (Figure 4.13).

Site 14 (Figures 4.12 and 4.13) is a high risk site because of its proximity to an inhabited dwelling at the slope of the drainage area adjacent to the site. Hopewell Creek flows 150 metres past this sod farm. What makes this site potentially hazardous is that a culvert diverts drainage water from the field directly into the creek. Furthermore, the runoff water flows past the eastern portion of the farmhouse ten metres away. Locals described this particular site as a "mess".

Site 17 is located in proximity to the Conestogo River near one of the flood plains

SITE 14 PLAN

Figure 4.13



(Figures 4.12 and 4.14). Steep embankments and a moderate slope (3-6%) which demarcate the flood plain concentrate runoff which collects in the immediate stream and flows directly into the Conestogo River. The site is among numerous sources that feed into an intermittent stream which flows through an adjacent cornfield. It is worth noting that sludge application took place in the winter of 1990-91.

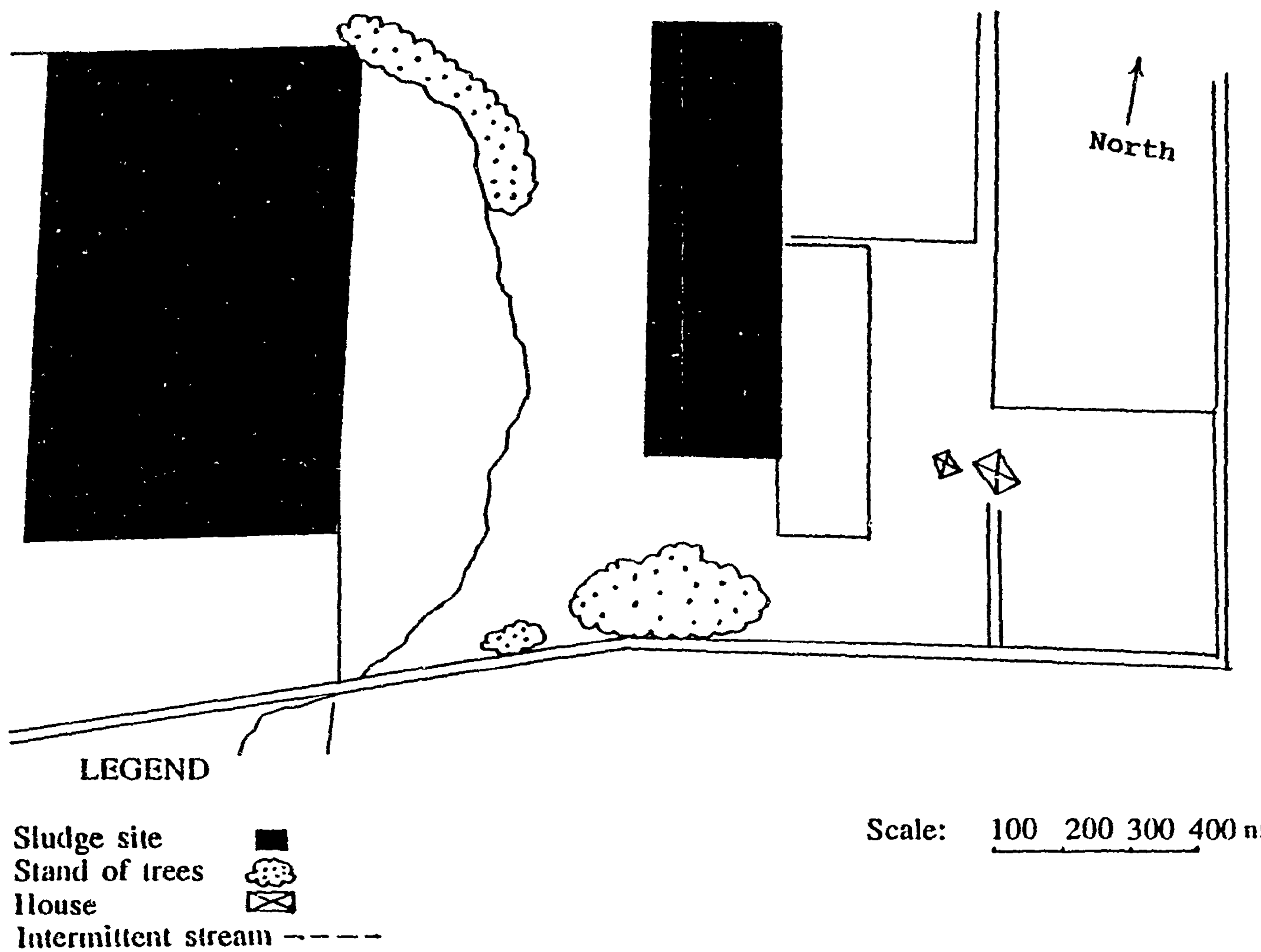
Along the banks of the Grand River, near Galt a number of sludge sites were located (Figure 4.12). This area makes up part of a flood plain and is a flood hazard area. Two days after heavy rainfall the area remained saturated, evident by observed pools of water, dark patches on the fields, and some portions of the fields even remained flooded. Sludge can be readily flushed off the fields and directly into the Grand River. Moreover, the subsurface and surface water interaction, e.g. the migration of contaminated surface and subsurface water into the watercourse, is inherent by how close the sites are to the river.

The immediate area surrounding Ayr (Figure 4.12), is moderately undulating, with occasional steep slopes along with numerous bodies of water which comprise small lakes and ponds. This area harbours significantly more lakes and reservoirs than in Woolwich and Cambridge. This creates a greater risk of contamination from runoff waters and airborne contaminants due to the large surface area exposed and susceptible to receiving airborne contaminants from sprays when the sludge is spread on the fields. Moreover, a number of sites are in proximity to the Nith River and several of its tributaries.

The size of the farm and the amount of sludge applied must be considered when determining the risk of water contamination. This is because the amount of sludge on the

SITE 17 PLAN

Figure 4.14



site governs the quantity of contaminants that could potentially be diffused into the environment. The size of sludge sites vary because of the different scales of the farming operations. The size of the sites vary from 18 to 560 acres. As can be expected, the volume of sludge spread on the sites is the most important factor determining the amount of sludge that can be applied. The chemical characteristics of the soil and sludge are secondary. The amount of sludge applied per acre on each site also varies, but must not exceed 52 cubic metres per acre. An average of 30 cubic metres/acre of sludge was applied on agricultural land in Woolwich Township. 35 in Wellesely, 48 in Kitchener. 32 in North Dumfries, and 38 in Cambridge.

CHAPTER 5: DISCUSSION

5.1 MANAGEMENT ISSUES

Efficient management of sludge utilization programmes is central to optimum protection of the environment. The hazards associated with sludge have been discussed; therefore, it is important to have competent individuals overseeing sludge utilization on agricultural land. It is equally important to have an efficient set of management procedures to deal with any situation that may arise. The combined effect of competent management and effective procedures to guide them, can make sludge utilization a feasible practice (Fekete and Pettit-Chase, 1987).

It is the responsibility of the sludge coordinator to see to it that M.O.E. Guidelines and sections 309 of the Water Resources Act are complied with. The sludge hauler must comply with these Guidelines and regulations which are enforced by the M.O.E. Farmers are also obliged to adhere to the Guidelines and regulations along with any information provided by the M.O.E. However, the activities of the farmer, having such a profound influence on the risk of potential environmental degradation should be more closely monitored. Once the sludge is applied onto the site, the farmer tends to his/her farm. Any omission of safeguards against runoff and reducing the potential for food contamination by not adhering to the proper waiting periods before certain crops can be planted, particularily those which are consumed raw, may result in degradation of the environment and compromise public safety.

The risk of environmental degradation is substantially increased where proper management procedures are not adhered to. This is exacerbated if a number of the procedures are deficient. The issue of management can be quite complex because problems may originate from three different sources: the sludge coordinator, the sludge hauler, and the farmer. For simplification purposes, management can be categorized into three levels, level one (sludge coordinator), level two (the sludge hauler), and level three (farmer). Precautions are taken by the M.O.E. to maximize protection of the environment, but any breach of the Guidelines by the hauler will cancel out those taken by the former. Similarly, if at level one and two all precautions are taken to ensure that sludge is applied in an environmentally sound manner, poor farm management (level three) can still render previous efforts useless. The problem is more serious if no precautions are taken at any level. In short, there must be mutual cooperation among the three levels of management whereby each one carries out their responsibilities and respects the efforts taken by others to minimize environmental degradation.

One of the most pronounced deficiencies is the absence of an integrated weather forecasting system in the M.O.E. management procedure. Weather forecasts are observed, however, a more efficient procedure should be devised whereby sludge haulage should cease beyond a certain probability of precipitation. A direct line to the local weather station could provide the sludge coordinator with the latest forecast. This type of system would not eliminate cases in which freshly applied sludge is flushed from the field because weather reports are never entirely accurate. A more up-to-date report, and a carefully devised contingency plan can reduce the risk of runoff related contamination. The reason for the concern over rain and sludge application is that contaminant concentrations in runoff water are highest when freshly applied sludge is flushed off the field. When the chance of rain is in the forecast, and sludge is hauled that day, farmers should also be prepared to till the soil as soon as possible to minimize the loss of fresh sludge.

Monitoring of both sludge haulers and the activities of the farmers is not well coordinated at present, and is in part due to the lack of resources allocated to such activities. The number of farms with valid C.A.'s in 1990 for example was on the order of about 250, covering a vast area that includes the Region of Waterloo, and parts of Blanford Blenheim, Oxford County, Flamborough and Hamilton-Wentworth. One person monitors the activities of this entire region. So numerous are the sites, that often a detailed site investigation is reserved until complaints arise. When a complaint is filed, in the majority of cases, they vary from odor to water quality problems. In the latter case, the combined resources of the Ontario Ministry of Agriculture and Food (OMAF) and the Waterloo Regional Health Unit are employed.

The sludge hauler is a private waste disposal company contracted by the M.O.E. to distribute sludge to farms with valid C.A.'s. The companies in the Region of Waterloo are predominantly Kon-Mag and Raydel. The instant the hauler leaves the sewage treatment plant or the transfer station, there is a form of transfer of responsibilities from the regulatory body, i.e. the M.O.E., to a private company. The M.O.E. relies on a truck driver to make sure the Guidelines are adhered to. At times, the hauler may not comply with all sections of the Guidelines that apply to him/her, and this could effectively diminish the margin of safety they were intended to maintain. The reason for the deviation from the Guidelines could be due to a time constraint, in which the hauler would hasten the spreading of sludge, or, inadvertently raise the risk of environmental degradation by spreading too close to dwellings, watercourses and wells because they may not be aware of the manner in which sludge-borne contaminants can migrate, via aerosols, leaching and/or plant uptake. The hauler is also paid by the volume of sludge hauled; therefore, the faster the application process is, the more can be hauled. On occasion the sludge coordinator will oversee the actual sludge application, but the haulers knowing they are being observed, will tend not to deviate from the Guidelines. With more monitoring, haulers would be more diligent in the manner in which they spread sludge.

The farmer upon receiving sludge has a number of responsibilities which are to till the soil shortly (within 24 hours, or prior to anticipated rain) after sludge has been applied, having proper drainage of storm water, and taking measures to minimize soil erosion, e.g. planting vegetation barriers. In addition to these, the farmer must adhere to specified waiting periods for selected crops; that is, after sludge has been applied, the farmer must wait a certain period of time before planting. This is especially critical when planting vegetables that are consumed raw. The concern is that certain pathogens may still be alive on the vegetables, and the absence of cooking them will increase the risk of consuming a number of the pathogens. Other waiting periods are also imposed to prevent livestock from feeding on contaminated fodder.

The combined effect of inefficient management and the site physical characteristics can be a hindrance to the safe and proper application of sludge. An undulating farmfield may have several changes in slope forming a series of depressions throughout the field. Slope may change in some portions of the site to values greater than 9% which is the maximum permissible slope according to the M.O.E. Guidelines. The hauler may not necessarily cease application of sludge because of the increased slope. If it rains within a short period after sludge application, the probability that sludge will be flushed into either neighboring land, watercourses, or back to another portion of the site is high. The latter could result in the creation of sludge blankets which could be potential breeding grounds for bacteria (W.P.C.F., 1972). If a farm is located near an embankment, the risk of runoff into watercourses is equally high.

An M.O.E. management plan includes monitoring of sludge and soil, and is vital in determining their quality in terms of the acceptability criteria outlined in the Guidelines. Table 5.1 shows the results from sludge analysis from the Waterloo treatment plant for one year; contaminants did not exceed M.O.E. limits. Sludge from every treatment plant is sampled monthly. This may appear insufficient, but is standard procedure in most Canadian and American municipalities since sludges remain in the digesters for approximately thirty days (M.O.E., 1986). Once sludge has been identified as unacceptable for agricultural purposes, it must be either mixed with a higher grade, or disposed of in landfills. The difference among municipalities with regard to sludge monitoring is the number of parameters sludge and soil are tested for.

Insufficient monitoring of soil previously amended with sludge, makes it difficult to determine the effect it has on soil quality. In Ontario, a fixed number of soil samples are analyzed annually. If 400 samples can be sent to the laboratories in one year, and 400 applications for C.A.'s are filed, there can be no further testing of soil beyond the initial test conducted upon application for the C.A. No monitoring of soil quality occurs

METAL CONTENT IN SLUDGES FROM THE WATERLOO (Table 5.1) TREATMENT PLANT

Month	Element (ppm)					
	Cu	Ni	Pb	Zn	Cd	Hg
Jan	24.00	0.93	3.80	23.00	0.084	0.100
Feb	31.00	1.60	4.50	28.00	0.010	0.160
Mar	28.00	1.20	4.50	24.00	0.260	0.110
Apr	23.00	0.75	3.30	15.00	0.140	0.110
May	29.00	0.64	3.60	21.00	0.210	0.110
Jun*	NSS	NSS	NSS	NSS	NSS	NSS
Jul	24.00	0.78	3.20	21.00	0.110	0.100
Aug	31.71	1.03	3.19	24.88	0.160	0.100
Sep	7.45	0.29	0.88	7.18	0.023	0.030
Oct	26.89	1.07	3.14	21.35	0.170	0.080
Nov	17.38	0.67	0.20	13.15	0.029	0.060
Dec	28.02	0.99	0.20	21.09	0.068	0.500

*NSS denotes no sample taken.

Ammonia/Metal Ratio

Jan	34	866	212	35	9583	8050
Feb	26	507	180	29	81100	5069
Mar	34	783	209	39	3612	8536
Apr	41	1260	286	63	6750	8591
May	30	1358	241	41	4138	7900
Jun	-	-	-	-	-	-
Jul	38	1167	284	43	8273	9100
Aug	27	838	271	35	5394	8630
Sep	90	2300	758	93	29254	22233
Oct	24	606	206	30	3812	8100
Nov	27	693	2320	35	15782	7733
Dec	19	549	2720	26	8024	5440
*(Min)	10	40	15	4	500	1500

*The ammonia to metal ratio must not exceed the minimum value for each metal. Where the metal content is excessively high, the ratio would be lower, and the sludge may not be fit for use in agriculture. Corrective measures would include blending the poor grade sludge with one of higher quality.

after sludge application. The only circumstance under which soil is sampled a second time is when a farmer reapplies for another C.A. which is generally every five years. Random sampling does take place on occasion, but it is not common practice. The few results on file reveal minute elevations of selected heavy metals (Brent Zehr, M.O.E. Transfer Station, personal communication, 1992).

5.2 SLUDGE MANAGEMENT IN NEW JERSEY

An assessment of how comprehensive guidelines are with regard to addressing all aspects of environmental protection and public safety of the sludge utilization programme in the Region of Waterloo, can be done so by comparing the guidelines and procedures of similar programmes in other regions of the world. Some of the most comprehensive and stringent programmes are in effect in New Jersey. The New Jersey sludge utilization programme entails an array of procedures specifically designed for sludge utilization along with the formation of a Task Force that deals with sludge use on land and related issues. The Task Force is made up of chemists from academia, industry, people from sewage treatment plants, members from the Environmental Protection Agency (EPA), and the New Jersey Department of Environmental Protection (NJDEP) (Fekete and Pettit-Chase, 1987, p. 331). In response to a need for different parameter testing methods for sludge, the Task Force developed a set of laboratory procedures tailored to sludge testing. Such methods include sample preservation, quality preservation and control requirements (Fekete and Pettit-Chase, 1987). O'Dette (1991) indicates that the quality of sampling and analysis is a serious problem, e.g. inconsistent sampling, methodology, and improper sample handling in sludge quality assessment. Site evaluations, parameter testing and monitoring are very strict and comprehensive. Site evaluations are conducted using criteria of (Table 5.2), and include an inventory of domestic and public water supplies, streams, drains, lagoons and groundwater flow direction. A map clearly identifying the sludge site relative to the items on the inventory list is also included and is attached to the permit (known as a Certificate of Approval in Ontario). In the Region of Waterloo, there is no inventory of the previously mentioned items, nor is groundwater flow direction indicated on the Certificate of Approval. In New Jersey, monitoring of the effects that sludge may have on local water quality involves the installation of four monitoring wells at each sludge site. One well is drilled hydraulically up gradient and three down gradient from the site. Wells may be located on adjacent property. In Ontario, no wells are drilled for the sole purpose of monitoring groundwater of each sludge site with the exception of the investigation of complaints of poor water quality, or monitoring of an experimental site. Another difference in regard to sludge spreading on farm land is that in New Jersey, farmers must till the soil 24 hours after sludge application, conditions permitting. In Ontario, it is "suggested" that soil be tilled shortly after sludge application.

On the whole, the number of parameters that sludges are tested for are significantly higher in New Jersey. A possible explanation for such strict guidelines may be that the sludge may be more toxic due to the degree and variety of industry in New Jersey.

There are a number of areas where the New Jersey sludge utilization guidelines are not necessarily superior to those of Ontario. The permissible sludge contaminant concentrations in New Jersey for a number of parameters is higher, e.g. Pb 2400 ppm for class A, and 4880 for class B (Table 5.3). In Ontario, the limit is 1100 ppm. Table 5.4

(Table 5.2) **SOIL AND SITE LIMITATIONS FOR LAND APPLICATION OF SLUDGE (New Jersey)**

Characteristics:	Degree of Limitation Slight	Moderate	Severe
Permeability of the more restricting layer within 5 feet of the surface.	0.6 - 6.0 inches/hour	6 - 20 and 0.2 - 0.6 inches/hr	>20 or <0.2 inches/hr
Soil drainage	Well to moderately well drained	Somewhat poorly drained	Excessively poorly and very poorly drained
Flooding	None	Flooded only during non-growing season	Flooded during growing season
Slope	<6%	6 - 12%	>12%
Depth of seasonal water table	>4 ft	2 - 4 ft	<12 ft
Depth to bedrock	>4 ft	2 - 4 ft	<2 ft

Source: Modified from Fekete and Pettit-Chase (1987).

outlines the permissible contaminant concentrations. Another deficiency in the New Jersey system is the lack of a weather forecasting system to set an application agenda.

Table 5.3 LAND APPLICATION SLUDGE QUALITY CRITERIA IN NEW JERSEY

Metals (ppm, dry weight basis)

	*Class A	**Class B
Cadmium	20	40
Copper	600	1200
Lead	2400	4800
Nickel	625	1250
Zinc	1200	2400
Chromium	1000	1000
Mercury	10	10
Arsenic	10	10

*Class A sludge can be applied for a period of 40 years until cumulative metal loadings have been reached
**Class B sludge can be applied for 20 years.

Source: Feket and Pettit-Chase (1987) p. 336.

(Table 5.4) GROUNDWATER MONITORING REQUIREMENTS PARAMETERS AND LIMITATIONS (NEW JERSEY)

Parameter	Limitation (ppm)	Affected sludge farms
Cadmium	0.01	All
Zinc	5.00	All
Copper	1.00	All
Lead and compounds	0.002	All
Zinc and compounds	5.00	All
Ammonia-N	0.50	All
Chloride	250.00	Some
Nitrate-N	10.00	All
Sodium	50.00	Some
Sulfate	250.00	Some
Total dissolved solids	500.00	All
Total organics	-	Rare
Fecal coliform	-	All

Source: Feket and Pettit-Chase (1987), p. 336.

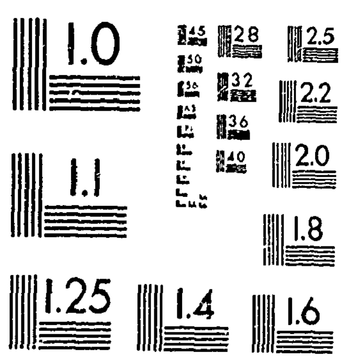
Manuals prepared by the Federal Governments of Canada and the United States provide the foundation for guidelines in Canadian provinces and American States respectively. It is absolutely essential for a project in any location to insure as one of the first activities that all regulatory requirements from all responsible authorities are included in the preliminary planning considerations (Younos, 1987). These manuals outline most of these regulations, and the various stages in the conception, planning and implementation of sludge management plans. A significant amount of detail is provided for the social, economic, technical and environmental components of the management scheme. The latter for the purpose of this study, is of concern and is governed by another set of regulations and guidelines. Aspects of the environmental component entail sludge quality acceptability criteria, i.e. contaminant levels in sludge, and in soil, site characteristics and evaluation, and crop selection. However, in designing guidelines regarding acceptable contaminant levels in sludge, soil and crops a problem exists. Chaney (1982) pointed out that it is difficult to set contaminant limits for crops because the data used are the results obtained from laboratory experiments where plant roots are confined to the contaminated soil. These results do not reflect the true behavior of contaminants in relation to plant uptake. To date, it is not known what levels of many of the toxic substances are tolerable to the human body (Waite, 1984). Therefore, a margin of safety is implemented, whereby contaminant limits in soil and sludge are set at higher standards. What often happens is that other levels of regulatory control reduce criteria values or add other constraints with little more apparent justification than the perception that more stringent numbers may mean greater safety rendering a safe and reliable project economically unfeasible (Younos, 1987). Guidelines governing the separation distances of sludge sites on specified slopes to watercourses differ from region to region. Ontario M.O.E. Guidelines indicate minimum separation distances to watercourses based on soil permeability and slope. American guidelines provide recommended type of application for the various soil types, slopes and separation distances, e.g. a surface with a slope of 6% or greater, must have sludge applied by subsurface injection; the same applies to sites within 50 -200 feet of an inhabited dwelling (Younos, 1987). Furthermore, any slope greater than 12% requires immediate incorporation of sludge and effective runoff control (Younos, 1987). In Ontario, no sludge is to be applied to a surface with a slope greater than 9%. The U.S. Federal regulations also require that public access to sludge sites be controlled for at least 12 months after application. In Ontario guidelines there is no mention of site accessibility restrictions.

Guideline objectives in the United Kingdom are similar to those of Ontario, but more specific about the health concerns. The objectives of sludge use on land are: to prevent unacceptable contamination of agricultural land, e.g. by heavy metals to prevent the dissemination of human, animal and plant diseases; to avoid public nuisance by avoiding the spraying of sludge upwind near residential properties (Davis 1986). Similar to Canada and the United States, the objectives promote beneficial use of sludge. It was estimated that 15 million English pounds of sludge - fertilizer equivalent are produced annually (Davis, 1986).

Guideline objectives from different countries may be similar, but sludge acceptability criteria differs. In Ontario, only digested sludge sludges are acceptable, and there is a six month waiting period after application for the planting of fruit, vegetables or grazing fields (M.O.E., 1986). In Alberta sludge is not to be used for growing tobacco, root crops, or food crops which are consumed raw. However, in Ontario, sludge can be applied to land on which vegetables which are consumed are grown. The United States (EPA), stress extensive treatment of sludges, i.e. the removal of toxic substances and sterilization, prior to application on agricultural land. In the U.K., raw sludge may be used for the production of animal feed and crops which are cooked prior to consumption. The use of raw sludge in the U.K. appears a questionable practice in light of the previously mentioned guideline objectives, where health concerns are highly regarded.

2 of/de 2

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT



PRECISION℠ RESOLUTION TARGETS

5.3 M.O.E. GUIDELINE AMBIGUITIES

The ambiguity of certain sections of M.O.E. Guidelines can effectively undermine the safeguards they were intended to maintain. Numerous sections provide significant leeway in terms of how they can be interpreted. This is also true regarding the various exemptions from certain sections. Some examples of such ambiguities as quoted from the M.O.E. Guidelines are:

> According to Ontario Regulation 309, the minimum separation distance from any water well shall be 300 feet. If the Regulation should, in the future, permit it and where there is little cause for concern, this distance *may* be reduced (p. 10-11).

> The minimum distance between the spreading site and a surface watercourse *should* normally be determined from Table 4, which takes into account land slope and soil permeability. If sludge is incorporated into the soil at the time of application, it *may* be applied closer to a watercourse than is indicated in the table. However, it *should* not be applied within ten metres of any watercourse or body of water (p. 9)

> Spreading *may* be allowed on frozen soil, provided that the risks of runoff have been determined to be minimal (p.12).

These examples, of which there are more, illustrate how vague a number of sections of the Guidelines are in outlining exactly what the separation distances must be. An explanation for such vagueness is that farms are commonly located near sources of water. Water and farming are inseparable, therefore, when concerned about surface water contamination from substances used on farmland, the potential is inherent. One must not lose sight of the fact that too stringent guidelines would result in much less sludge being applied onto agricultural land. Under such circumstances, other, more costly means of disposing of sludge would have to be devised. Cost efficiency being the dominant factor in utilizing sludge for agricultural purposes makes it favorable to other disposal methods.

There are no guidelines defining the criteria for the exemptions, and ultimately, judgement is at the discretion of the sludge coordinator, the hauler, and the farmer. The section that outlines winter application of sludge can be interpreted in a variety of ways. This section summarizes the circumstances under which sludge may be spread on frozen ground. Despite a site's being deemed to pose a risk of runoff, runoff may occur because the field must be drained in some manner. Applying sludge on frozen ground in winter, would reveal no apparent risk, and this could be somewhat deceiving because a lag is created between application of sludge and thawing of the ground when warmer temperatures set in. Applying sludge within ten metres of a watercourse is extremely close. Should runoff occur, the probability that soil particles and sludge will be flushed into the watercourse is high.

The definition of a watercourse may cause confusion resulting in potential inadvertent deviation from the Guidelines. A surface watercourse is defined as a natural or established surface watercourse or an open municipal drain along which water flows on a regular basis; points of direct access such as catch-basins to drainage tiles or municipal drains should be treated as watercourses for separation distance purposes (M.O.E., 1986). It is often difficult to determine where such drainage systems are located because of vegetation covers. Often one immediately looks for a natural watercourse, e.g. stream or creek, however, according to the definition, the drainage system is also a watercourse.

5.4 COMPLIANCE WITH M.O.E. GUIDELINES

To determine whether M.O.E. Guidelines have been and are being complied with can be somewhat difficult. Historical data identifies the sites, but documentation is not consistent or necessarily accurate. Farmers can identify the sites that received sludge, but as time passes, their recollection diminishes in accuracy. Sludge haulers draw very crude often undecipherable maps of sludge site locations on the respective lots. From this scanty information, assessment of compliance with the Guidelines is problematic.

Each site C.A. application is accompanied by a sheet identifying site characteristics such as soil type, slope, and proximity to watercourses. However, often the sheets are inadequately filled out, with vital information omitted. The information is filled out to give an approximation of site characteristics, but no formal instrumentation is used to measure slope, or distances from watercourses, dwellings and wells. This is generally estimated through guess-work. This method fosters the potential for errors and inaccuracies.

A section on the site characteristics sheet is devoted to indicating the height of the water table. The form simply specifies whether the water levels are above or below one metre. Water table levels fluctuate with the seasons and the quantity of rainfall; in short, the water table is dynamic in most systems, and changes in response to changes in rain events, snowmelt, recharge and pumping (Mazor, 1991, p. 34). Such fluctuations can be quite significant. Haulers should take into consideration the time of year, and the amount of rain that has fallen in the weeks prior to sludge application. Spring and late fall would be periods where water levels tend to be higher. Conversely, during the summer, especially during dry spells, water levels tend to drop. A water level reading could be taken in mid-summer and it would be below one metre; however, in the following autumn, the water level may rise above one metre depending on the amount of precipitation.

In light of the problems of determining the historical level of compliance with M.O.E. Guidelines, monitoring the actual spreading of sludge is the only way to be able to document the level of compliance. By monitoring the sludge spreading, any problems that begin to surface can be rectified before it is too late. Preventative measures are much more effective and cost efficient than attempting to implement a later both costly and futile clean-up operation.

CONCLUSION

The most pronounced environmental consequences resulting from the utilization of sewage sludge on agricultural lands have been reviewed. This indicates how serious this practice can be in terms of risks and hazards. It is, therefore, vital to consider how sludge utilization programmes are managed. Comparing the manner in which these programmes are managed in regions other than the Regional Municipality of Waterloo, illustrates to what extent these regions, or municipalities protect the environment.

The United States and selected European Economic Community (EEC) members are at the forefront of sludge disposal/recycling. However, guidelines, regulations and sludge management in Ontario can be considered at standards compatible with those at the forefront. In a number of instances, Ontario sludge criteria standards for selected contaminants are higher than EEC standards. Despite high standards the actual implementation of management plans can hinder the realization of initial management objectives. In short, one must not be mislead by high standards and stringent guidelines. How a plan is implemented, and its effectiveness will largely influence the final outcome.

A review of the management procedure and guidelines in the Region of Waterloo, brought forth shortcomings in which management efficiency should be improved: weather forecasting used to plan application agenda and contingency planning; site selection and monitoring of both sludge hauler and farmer; and both guidelines and regulations which are open to interpretation in a variety of ways. Another issue that must be addressed is that of implementing a consistent site monitoring programme after sludge has been spread.

Despite the hazards, applying sludge onto agricultural land has its benefits. One of the reasons why the EPA standards are so high is that the benefits to agriculture have been acknowledged. In Ontario, for example, sludge is delivered to the farmer at no cost. The fertilizer equivalent is substantial. By "cleaning-up" sludge, agricultural use of it can be rendered a much safer practice. The drive to clean-up industrial effluents and those of other sectors of society must be maintained. With sufficient information on the effects of sludge on the environment to establish a strong foundation from which to work, management issues become the underlying factors to the optimization of the protection of both the public and the environment. The toxicity of sludge along with its benefits have been the subject of numerous decades of research. Armed with what is known. the management of sludge utilization programmes, and farm management can effectively help in the minimization of risks. One cannot afford to take the risk of following a certain practice with no regard for future ramifications. The combined effect of efficient management and less toxic sludges can minimize the environmental impacts and maximize the benefits. It is in everybody's interest to reduce the risk because of the bioaccumulation of persistent contaminants which may not be felt in the short-term. but in the long-run will reveal their effect. a time when remedial measures may be ineffective. and/or very costly.

RECOMMENDATIONS

Based upon the conclusions reached in this thesis, the following recommedations are offered:

1) Integrate a formal weather forecasting system with sludge application agenda to reduce the chance of freshly applied sludge from being flushed off the site.

2) Contingency planning in the event of unexpected changes in weather conditions, e.g. emergency storage facilities.

3) Monitoring of sludge haulers and the activities of the farmer to ensure compliance with guidelines and regulations that ensure the safe and beneficial use of sludge.

4) Implement monitoring programmes for soil; surface and subsurface water quality during and after sludge application. Data should be compared with base conditions, and prepare a site evaluation matrix which identifies site characteristics and potential risks attributed with each, and a recommended plan of action.

This type of matrix mentioned in recommendation 5 should be designed to save time by being able to make a quick assessment of suitability of the site, and/or identify which sites should be examined more closely.

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