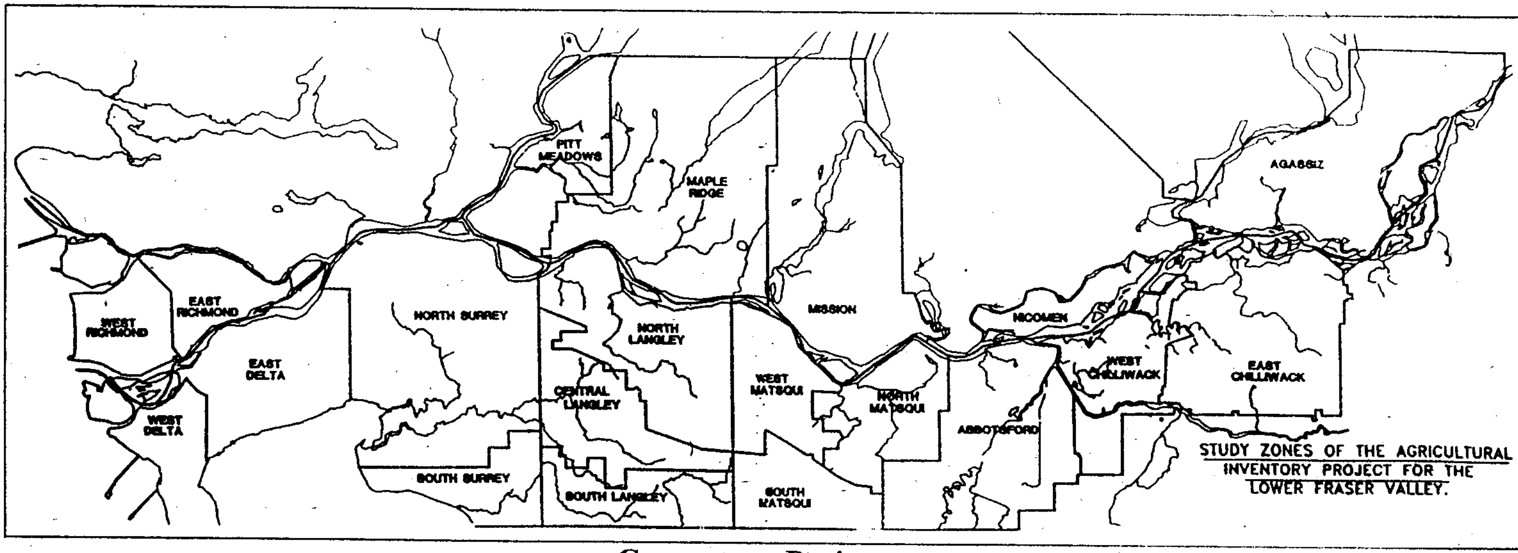
AGRICULTURAL NUTRIENT PATHWAYS



STUDY ZONES OF THE AGRICULTURAL INVENTORY PROJECT FOR THE LOWER FRASER VALLEY.

Component Project
of
Management of Livestock and Poultry Manures in the Lower Fraser Valley

REPORT 3

DOE FRAP 1995 - 28

Environment Canada
FRASER RIVER ACTION PLAN

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Ministry of Environment, Lands and Parks

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AGRICULTURAL NUTRIENT PATHWAYS

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1.0 INTRODUCTION

The objectives of the Management of Agricultural Wastes in the Fraser Valley program are to evaluate, within the Lower Fraser Valley, the production, treatment and disposal of agricultural wastes, and then to utilize this information in developing strategies for improving nutrient (manure and inorganic fertilizer) management.

The first project in this program was to develop an inventory, based on the 1991 Census of Agriculture, of the agricultural land base, livestock and poultry and commercial fertilizer use in the Lower Fraser (Brisbin,1994; Brisbin,1996).

The subject of this report is a general discussion of the environmental impacts of agricultural nutrients and the pathways along which these nutrients flow.

2.0 IMPACTS OF AGRICULTURAL NUTRIENT MANAGEMENT

The management of agricultural wastes (manures) impacts both specific agricultural operations and the surrounding environment; impacts which can be beneficial or harmful.

Manure has a value as a source of plant nutrients and as a soil amendment, however when mismanaged manure can have an adverse impact on soils, crops, water, animals and humans. Table 1 provides estimates of the primary (macro)nutrients excreted by various types of livestock and poultry.

The following is a brief discussion of the potential impacts of non-sustainable agricultural nutrient management.

2.1 WATER

Potential impacts to domestic water supplies and aquatic life have been the major environmental concerns with agricultural nutrient management. Water issues related to agriculture fall within the area of non-point source (NPS) and have been the focus of major initiatives elsewhere (EPA-USDA, 1993).

Agricultural activities have been implicated as the primary cause of high nitrate concentrations in several Lower Fraser Valley groundwater sources, most notably the Abbotsford Aquifer where nitrate concentrations well in excess of drinking water standards are common (Zebarth et al,1995; Wassenaar,1994, Liebscher et al,1992). Figure 1 shows trends in nitrate concentrations in the Abbotsford Aquifer.

Watercourses of the lower Fraser Valley provide an important habitat for salmonids, particularly Coho salmon. Approximately 60% of the Fraser River coho spawn and rear in streams downstream of Hope (Nener, per. com.) Before migrating to the ocean the young fish stay in fresh water for one year or more. During this time these fish are dependent on healthy, small stream ecosystems (Figure 2) in the Lower Fraser Valley, many of which have become less productive over time. Agricultural activities have played a significant role in the degradation of many of these streams (Hutton,1987).

Impacts to water fall into two general categories; introduction of toxic substances and oxygen depletion. In extreme (acute) situations manure contaminated runoff entering a stream can cause fish kills, impacting adult spawning fish and juvenile fish rearing in the stream. Within the Lower Fraser Valley the major chronic concern with the aquatic environment is often the low oxygen content of the water. Figure 3 shows dissolved oxygen content measured in the Clayburn Creek - Matsqui Slough system.

The ammonia, nitrite and nitrate forms of nitrogen can all be toxic to both humans and aquatic life. Heavy metals, although generally not present in high concentrations in agricultural wastes may be leached from the soil at accelerated rates when agricultural wastes are not managed properly.

Inorganic nutrients, primarily nitrogen and phosphorus, can promote the growth of algae in the receiving waters. While the algae is growing the amount of oxygen released through photosynthesis tends to be greater than that consumed through respiration, increasing the oxygen content of the water. However, when the algae die and decompose they represent an oxygen demand. Excessive growths of the algae can lead to serious oxygen depletions. Excessive algal growth can also physically damage habitat by covering the substrate and is aesthetically unpleasant.

In many Lower Fraser Valley watercourses the level of inorganic nutrients may be so high that the maximum accumulated growth is limited not by the availability of nutrients but by other physical constraints such as the turbidity of the water limiting light penetration. In these situations there would have to be significant and sustained reductions in inorganic nutrient loading before any improvements to water quality are seen.

Table 2 shows total inorganic nitrogen and dissolved phosphorus levels in two Lower Fraser Valley lowland streams. This data shows that inorganic nitrogen and dissolved phosphorus levels are high, except for upper Clayburn Creek where dissolved phosphorus levels are low. The relatively high nitrogen to phosphorus ratios (N:P>>10) suggest that phosphorus is the limiting nutrient rather than nitrogen (Sharpley et al, 1994).

Figure 4 presents nitrate levels which have been measured in the Clayburn Creek - Matsqui Slough system and show how the nitrate concentration in a stream can increase as it flows through an agricultural area.

The introduction of organic material with a high carbon and nitrogen content may promote the growth of fungi and bacteria in surface waters, and thereby lower oxygen levels (fungi and bacteria consume oxygen when growing and, like algae, consume oxygen when they decompose at the end of their life cycle). However the major impacts of organic loading may not be oxygen depletion but rather physical (covering natural sediments) and aesthetic impacts.

The severity of impact depends on the amount of the material introduced, the time of the year and the location. Impacts to the aquatic environment can be complex and difficult to predict, particularly in systems which have been modified or regulated for intensive agricultural purposes (e.g. dykes, floodgate controls).

The impacts of organic material tend to be more localized and immediate, in that microbial growth tend to occur quite close to the point where the material is introduced and soon after the material is introduced. The impacts of inorganic nutrient loading may not be noticed until some distance downstream and these impacts may not become evident until some time after the loading has occurred. Inorganic nutrients may also be generated within organically enriched sediments on the stream bottoms and be released over time, further complicating the understanding of nutrient dynamics in some streams.

Impacts to the aquatic environment can be most dramatic during the "first flush" of runoff in the fall. Stagnant water which has accumulated in drainage ditches and which, due to the introduction of organic matter and the process of eutrophication, has a high oxygen demand, flushes through the system. As well the first flush of runoff may introduce a high loading of toxic chemicals, and manure itself has a high oxygen demand and if it enters a stream it will deplete oxygen levels This first flush is important in that it is the time when andromonous fish (fish which move from salt water to spawn in fresh water, e.g. Coho) are moving into the tributaries of the Fraser River. Dissolved oxygen levels measured in one Lower Fraser Valley stream system flowing through agricultural areas have been presented in Figure 3.

Soil and crop characteristics also have a major influence on the impacts which nutrient management may have on water resources. Soil characteristics such as depth and texture and crop characteristics such as species and stage of growth can significantly influence the amount and quality of both runoff and infiltrated water.

2.1.1 Organic Matter

The introduction of organic matter to surface water courses can promote the growth of aquatic microorganisms (fungi and bacteria) which may physically impact the watercourse (the growth can smother the streambed) and deplete oxygen levels.

2.1.2 Nitrogen

High levels of nitrite and nitrate in drinking water represent a health concern. Drinking water standards call for a maximum nitrate plus nitrite level of 10 mg N/l and a maximum nitrite concentration of 1.0 mg N/l (BC Environment,1994a).

Water quality criteria for fresh water aquatic life are set a maximum nitrate concentration of 200 mg N/l and a 30 day average of 40 mg N/l (BC Environment,1994a). However there is some evidence that nitrate may be toxic to some salmonid eggs and fry at concentrations as low as 5 mg N/l (CCREM,1987).

More significantly, nitrate is an inorganic nutrient which may accelerate the eutrophication process and result in depleted oxygen levels. It may be that the nitrate criteria for fresh water may not be adequate to limit primary production (algae) sufficiently to maintain adequate oxygen levels in some situations. Unfortunately, information on the impacts of nitrate loading and its role in the eutrophication process specific to Lower Fraser Valley lowland streams is lacking.

The levels at which livestock production will suffer economic impacts are considerably higher than what is acceptable for domestic water. A maximum nitrate-N concentration of 100 mg N/l is the criteria for both livestock and wildlife (BC Environment,1994a).

Ammonia is toxic to several groups of aquatic organisms, including fish, at quite low concentrations. The toxicity of ammonia is a function of water temperature and pH; there are criteria for maximum and 30 day average ammonia-N concentrations, presented as a function of temperature and pH (BC Environment,1994a). As an example, the criteria for the average 30 day concentration of total ammonia, at pH 6.5 and 17 ^{o}C is 1.5 mg N/l.

The toxicity of nitrite in an aquatic environment is dependent on the concentration of chloride, increasing as the chloride concentration decreases. Nitrite criteria for the protection of aquatic life are more stringent than those for drinking water. At chloride concentrations less than 2 mg/l the criteria call for a maximum nitrite concentration of 0.06 mg N/l and a 30 day average of 0.02 mg N/l (BC Environment,1994a).

In addition to their toxic impacts both ammonia and nitrite represent an oxygen demand in that they will tend to oxidize to nitrate, consuming oxygen in the process.

2.1.3 Phosphorus

The primary impact of phosphorus on receiving waters is through eutrophication. Within the Fraser Valley many of the surface water bodies have extended low-flow periods of up to several months. During these periods there is very little flushing action and with limited riparian cover (shade trees) along many watercourses the water can become quite warm, a condition which enhances aquatic plant growth when nutrients are plentiful.

Phosphorus is often the nutrient which promotes accelerated eutrophication. In surface waters it is felt that essentially all of the dissolved inorganic phosphorus and a portion of the phosphorus associated with suspended sediments will be available to algae and aquatic plants (Sharpley et al,1994).

Information related to acceptable phosphorus concentrations in Lower Fraser Valley watercourses is not readily available and there are no water quality objectives or criteria proposed for phosphorus concentrations in Lower Fraser Valley streams.

Criteria for lakes are for total phosphorus concentrations and range between .005 and .015 mg/l for aquatic life and a maximum total phosphorus concentration of .010 mg/l for drinking water and recreation (BC Environment,1994a).

2.1.4 Potassium

Potassium is generally not a concern in either surface water or groundwater. It is unlikely that agricultural management of potassium will adversely impact Fraser Valley water resources.

2.1.5 Micronutrients

Even though manure generally contains low levels of micronutrients poor manure management practices can increase soil acidity and lead to an accelerated leaching of metals from the soil.

However, if sustainable agricultural nutrient management is practiced with respect to either nitrogen or phosphorus there should be no problems with the introduction of excess levels of micronutrients to either surface or groundwater.

2.1.6 Salinity

Salinity can affect the utility of the water for livestock watering and for irrigation and poor nutrient management can lead to conditions of high salinity. However, as with concerns about metals if agricultural nutrients are managed properly no salinity problems should develop.

2.1.7 Pathogens

Micro-organisms contained in manures can be pathogenic; there are more than 100 diseases which are transmissible between animals and humans (BCMAFF-BCFA,1993). The primary concerns with these pathogens reaching water courses are impacts to drinking water and shellfish contamination.

Since soils are effective in removing pathogenic micro-organisms from water, eliminating direct runoff of manure contaminated water from both cattle handling areas and fields will remove the most significant pathogen pathway.

2.2 SOIL

The soil provides the reservoir which will store applied nutrients for later use by crops and provides an effective filter which removes potential contaminants from water. The capacity of soils to perform these functions is, however, limited and if manure and inorganic nutrients are applied at excessive rates the soil will not be able to accommodate the applied materials. When manure and inorganic fertilizers are over-applied both water quality and soil quality will be jeopardized (Bertrand,1993).

2.2.1 Organic Matter

The application of manure will obviously add organic matter to the soil and increased soil organic matter is often desirable in that several soil characteristics, such as moisture and nutrient retention, soil structure and trafficability, will be improved. Soil organic matter provides a reservoir of nutrients which become available to plants over a period of time as the organic matter decomposes.

If very large amounts of manure are applied the soil may become excessively organic and suffer from poor drainage and slower warming in the spring.

2.2.2 Carbon:Nitrogen Ratio

Productive agricultural soils should have a carbon:nitrogen (C:N) ratio in the range of 10:1 to 25:1. If manure and inorganic fertilizers with a C:N ratio greater than that of the soil are applied the excess carbon will tie up free nitrogen (that which is available to plants). On the other hand if manure and fertilizers with a C:N ratio less than that of the soil are applied, there will be a tendency for soil organic matter to mineralize at a rate greater than it is being added.

To maintain or enhance the productivity of a particular soil manure and inorganic fertilizer applications must be managed to achieve the appropriate C:N ratio.

2.2.3 Nitrogen

The interactions of the nitrogen compounds within the soil are complex and of significant magnitude. The net result of the various interactions may be that nitrogen will be fixed as organic matter or that nitrogen will be released, primarily as nitrate or as nitrogen gas.

The organic matter in soil represents a large reservoir for nitrogen (it is not uncommon for an agricultural soil to contain more than 6000 kg N/ha in the top 30 cm) and the movement of nitrogen in and out of this reservoir can vary significantly between seasons and between years. Under conditions of constant nitrogen and organic matter application and constant cropping there will be a tendency toward an equilibrium where the amount of nitrogen in the soil organic matter will not fluctuate on an annual basis; the amount applied will equal that removed by the crop plus that lost to the environment.

However, since soil organic matter content is sensitive to changes in cropping and management, changes in crop selection or management practices can have a significant influence on soil organic matter content and hence on the amount of nitrogen which is either released from or fixed within a particular soil.

2.2.4 Phosphorus

Most soils have a high capacity to immobilize phosphorus. Phosphorus reacts with iron and aluminum in acid soils and with calcium in alkaline soils to form insoluble compounds.

Applications of phosphorus which exceed crop removal will therefore increase soil phosphorus levels. This enrichment with phosphorus occurs in the surface soils first and migrates down through the soil profile.

A phosphorus enriched soil increases the amount of phosphorus which can enter surface water through soil erosion and research indicates that the phosphorus immobilization capacity of a soil profile can become saturated and phosphorus will be leached out with drainage water.

2.2.5 Potassium

Excessive applications of potassium can lead to high levels of potassium in grass crops, since they will take up more potassium than is required for their growth (luxury consumption), and subsequently a high potassium content in dairy rations. High potassium levels in dairy rations reduce the utilization of calcium and magnesium by lactating cows and may lead to related herd health problems; the production of urine is increased, this requires more energy and places additional stress on kidneys, and cows are more prone to milk fever (Paul and Fisher,1994).

Excess potassium in dairy rations can be a costly problem and perhaps 75% of Lower Fraser Valley dairy farms suffer from potassium related problems. In some cases additional magnesium is being added to feed rations and fertilizer mixes in an effort correct the problem (Van Kleeck, per. com.), however this is a short term solution in that unless potassium is applied at a sustainable rate soil potassium levels will continue to increase.

2.2.6 Micronutrients

Manure may be of benefit in supplying necessary micro-nutrients which are not normally found in commercial fertilizers.

The micronutrient content of manures will depend in part on the composition of the animal feed and it is not expected that there will be micronutrient concerns unless a particular micronutrient is added as a feed supplement and if manure is applied at very high application rates.

Of particular concern in the Lower Fraser Valley are copper and other micronutrients which are added to hog rations. Soil sampling in fields with a history of hog manure applications indicate that manure must be applied at high rates before problems will develop and if nutrients are managed to achieve a reasonable nitrogen balance there will be no excess micronutrient problems (Van Kleeck, per. com.).

2.2.7 Acidity

Manure must be applied at high rates before there would be any appreciable impact on soil acidity. It is anticipated that several other factors would be much more significant in determining appropriate application rates for manure.

Some inorganic fertilizers will tend to have an acidifying effect on soils, however if nutrients are being applied at acceptable rates there should be no soil acidification problems.

2.2.8 Salinity

When manure is applied at high rates there can be plant growth problems due to high levels of salinity, however if manure is applied at rates which achieve an acceptable nutrient balance there should be no soil salinity concerns.

Soil salinity problems can occur if manure is stockpiled uncovered and on the ground.

2.2.9 Other Issues

Handling and application of manure has the potential to introduce other contaminants to soil. Potential contaminants which would flow along some of the same pathways as do nutrients include antibiotics, pesticides, synthetic hormones, manure additives, pathogens, weeds and plant diseases. These contaminants are not addressed in this series of projects.

2.3 AIR

The most significant air quality issue related to agricultural nutrient management may be related to the smaller fraction (less than 2.5 micrometres, PM2.5) of the fine particulate matter (less than 10 micrometres, PM10) found in the atmosphere (Thomson, per. com.).

These small particles (PM2.5) are small enough to penetrate deep within the lungs and lead to serious respiratory problems. They are also very efficient in scattering light thereby producing significant visibility concerns. Current levels of fine particulates may constitute a greater danger to health than other air quality concerns such as ground level ozone, sulphur dioxide and carbon monoxide (BC Environment,1994b).

Recent research on air quality suggests that ammonia may play a key role in the formation of fine particulates through the formation of ammonium nitrate and ammonium sulphate. An emphasis on this process has occurred only recently, after it was found that the air above the Lower Fraser Valley has surprisingly high levels of ammonia (Thomson, per. com.).

Agricultural activities are thought to generate most of the atmospheric ammonia in the region while the major contributors of NOx are felt to be automobile emissions and SOx industrial, primarily cement plants and Washington based petroleum refineries (Thomson, per. com.).

Ammonia based particulates tend to generate a white haze as opposed to the brown haze which results from industrial emissions. This white haze tends to be quite widespread in the eastern portions of the Lower Fraser Valley with no obvious areas of concentration.

At present the various processes are not understood well enough to say whether the formation of the ammonia based fine particulates is limited by the amount of ammonia or by the amount of NOx and SOx, and therefore the impact of reducing ammonia emissions is not known. However, if ammonia is limiting and ammonia emissions are reduced the result could be the formation of more acidic aerosols which may be of greater concern to health than the ammonia based fine particulates (Thomson, per. com.).

Also, the Lower Fraser Valley airshed dynamics are not understood well enough to consider the impacts of changes in the atmosphere which would result from changing the spatial distribution of manure production or application. For example, would increasing manure applications in the Richmond and Delta areas, which are closer the major sources of NOx and SOx, result in an overall increase in the generation of small particulates.

Ammonia can also be a significant contributor to acid rain. In the Netherlands it is estimated that agricultural emissions are the cause of almost 40% of the acid rain. It has also been estimated that atmospheric deposition of nitrogen averages 40 kg/ha/yr in the Netherlands, where animal densities are similar to those of the Lower Fraser Valley, and may be as high as 80 kg/ha/yr (Zebarth, per. com.). No information is available on nitrogen deposition rates in the Lower Fraser Valley.

The anaerobic decomposition of manure can produce several gases which, if allowed to accumulate in manure storage structures or in livestock housing facilities can create a human or livestock health problem. These issues have not been addressed in this study.

3.0 NUTRIENT PATHWAYS IN AGRICULTURE

The following is a brief discussion of the major nutrient pathways which exist in Lower Fraser Valley agricultural systems; a graphical presentation of these pathways is provided in Figure 5.

The pathways shown in Figure 5 provide a simplified and partial description of the complex nutrient cycles which exist in our agricultural systems. Each pathway is composed of several complex, highly variable and often interrelated steps.

3.1 ORGANIC MATTER

Most agricultural soils have a very high capacity to retain organic matter, therefore the pathway of most concern for organic matter will be direct runoff to surface water.

3.2 NITROGEN

Nitrogen is a very dynamic within agricultural systems. It is a major nutrient within these systems with significant and complex exchanges between agricultural materials, the soil, the atmosphere and surface and groundwater, and constant transformations between different forms of nitrogen.

The losses of nitrogen to the atmosphere, most significantly as ammonia, are moderately well understood however the dynamics of nitrogen within the Lower Fraser

Valley airshed and the deposition of nitrogen on the agricultural land base have received relatively little research and are very poorly understood. High losses to the atmosphere can occur from livestock housing and handling facilities, manure storage structures and agricultural soils (particularly shortly after manure applications).

Nitrogen losses (as surface water and infiltration) to water during livestock housing and handling and manure storage can also be significant; however the amounts lost are highly dependent on the adequacy of the structures and management. With proper structures and good management losses of nitrogen through these pathways should be insignificant.

Another major pathway for the loss of nitrogen to surface water is through runoff from the soil surface. The significance of this pathway is accentuated by the fact that the lost nitrogen is often in the form of ammonia (which is more toxic in an aquatic environment than an equivalent amount of nitrogen in the nitrate form). High surface runoff losses of ammonia can occur during or shortly after land application and can be minimized with proper timing of land applications.

The interactions of nitrogen compounds within the soil are large and complex. Under conditions of constant nitrogen application and cropping there will be a tendency toward an equilibrium under which the amount of nitrogen applied will equal the amount of nitrogen released. However the reservoir of nitrogen represented by soil organic matter can be very large and changes in management can dramatically effect the rate at which nitrogen is accumulating within or released from the soil.

Nitrogen which enters the soil as ammonia will generally be tightly held within the exchange complex of the soil and therefore not very susceptible to leaching. However, microbial action within the soil will transform the ammonia to nitrate, often very quickly.

Nitrate, held only very loosely in the soil, is very susceptible to movement through the soil profile and hence to drainage water or groundwater. Nitrate losses through the soil profile can be minimized if nitrogen applications are matched to crop needs. Since the rate at which a particular crop utilizes nitrogen is a function of the specie and the stage of growth, nutrient applications should be carefully planned with respect to both the amount and the time of the year.

Soil nitrates can be reduced through microbial action to nitrous oxide and nitrogen gas. The resultant volatilization losses can be significant, particularly with wet soils and poor aeration.

3.3 PHOSPHORUS

Surface runoff, particularly when it contains solids (manure or soil) is considered the major pathway by which phosphorus will reach surface water.

Since most soils have a high capacity to immobilize phosphorus (applied phosphorus readily reacts with other soil chemicals, particularly iron and aluminum, to form insoluble compounds) it is often assumed that leaching losses of phosphorus through the soil will be negligible. However, this immobilization capacity of a soil is finite.

As well, even though the losses of phosphorus in subsurface runoff may be small in comparison to the amounts which are applied and immobilized in the soil, the amounts lost may be significant in terms of phosphorus enrichment of receiving waters.

Phosphorus applications will lead to an enrichment of soil phosphorus levels. This enrichment will occur in the surface soils first and then migrate down through the soil profile as the immobilizing capacity of the soil is used. Since the efficiency with which plants take up applied phosphorus is relatively low the phosphorus enrichment may occur even if applications match crop needs; "excess" phosphorus is often required to ensure that crops will take up what they need. Enriched soils then represent a higher risk that phosphorus will be introduced to surface water through surface runoff and soil erosion.

Surface runoff from sites on which phosphorus has been surface applied tend to be higher in dissolved phosphorus than runoff from sites on which phosphorus has been incorporated. Incorporation of the phosphorus lessens the concentration of phosphorus in the surface layer of the soil and hence reduces the amount of phosphorus which may leave a site through soil erosion.

As the phosphorus immobilization capacity of the soil is taken up and the enrichment migrates downward the "phosphorus saturated" zone will eventually reach the water table and phosphorus loss may be accelerated.

As well, the immobilizing capacity (precipitation) of soil is more effective under aerobic conditions; it may be that under anaerobic conditions some previously immobilized phosphorus will be transformed to more soluble or mobile forms. This may be significant in many lower Fraser Valley situations where there is a relatively high water table for a portion of the year.

In situations where drainage has been accelerated by the installation of artificial drainage systems the drain water may contain phosphorus associated with soil colloids.

Phosphorus exchange between agricultural systems and the atmosphere are negligible.

3.4 POTASSIUM

Even though potassium can be lost both through surface runoff and leaching the most significant environmental concern will be with the accumulations of potassium in the soil.
Excess potassium in the soil can lead to high potassium levels in grass crops and hence in the rations fed to dairy cattle and resultant herd health problems.

The majority of applied potassium is in forms which are readily available to plants. These available forms are soluble and therefore subject to leaching, however they are also subject to immobilization by the soil through the processes of fixation and through the exchange complex. Within the soil these two forms of potassium are in equilibrium.

As with phosphorus the exchange of potassium between agricultural systems and the atmosphere are negligible.

4.0 AGRICULTURAL RUNOFF

Losses of agricultural nutrients to water from land will follow one of two pathways; water will runoff over the land surface or it will infiltrate through the soil before entering either groundwater or surface water.

Of these two pathways direct surface runoff may the most significant in that the quality will tend to poorer than that of water which has infiltrated through an agricultural soil. Surface runoff will tend to have a much higher content of solids and the associated problems with sedimentation and organic matter. Surface runoff can contain very high levels of ammonia nitrogen (particularly if runoff occurs during or shortly after an application of manure) and phosphorus concentrations in surface runoff (phosphorus will tend to be in the solids) are generally far in excess of those found in water which has moved through the soil.

Runoff occurs when rainfall (or irrigation) rates exceed the infiltration capacity of the soil. It is a complex process and the quantity and quality of runoff will be a function of several variables, including rainfall intensity and duration, slope, soil (texture, organic matter content, moisture content) and vegetative cover (type and stage of growth). Vegetative cover immediately adjacent surface water courses is of particular importance. A healthy vegetated buffer strip can significantly improve the quality of surface runoff and reduce streambank erosion.

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Figure 1: Nitrate Concentrations - Abbotsford Aquifer*

* After Liebscher et al., 1992. The plot of annual means shown on the figure suggests that the trend is to progressively higher nitrate concentrations over time.

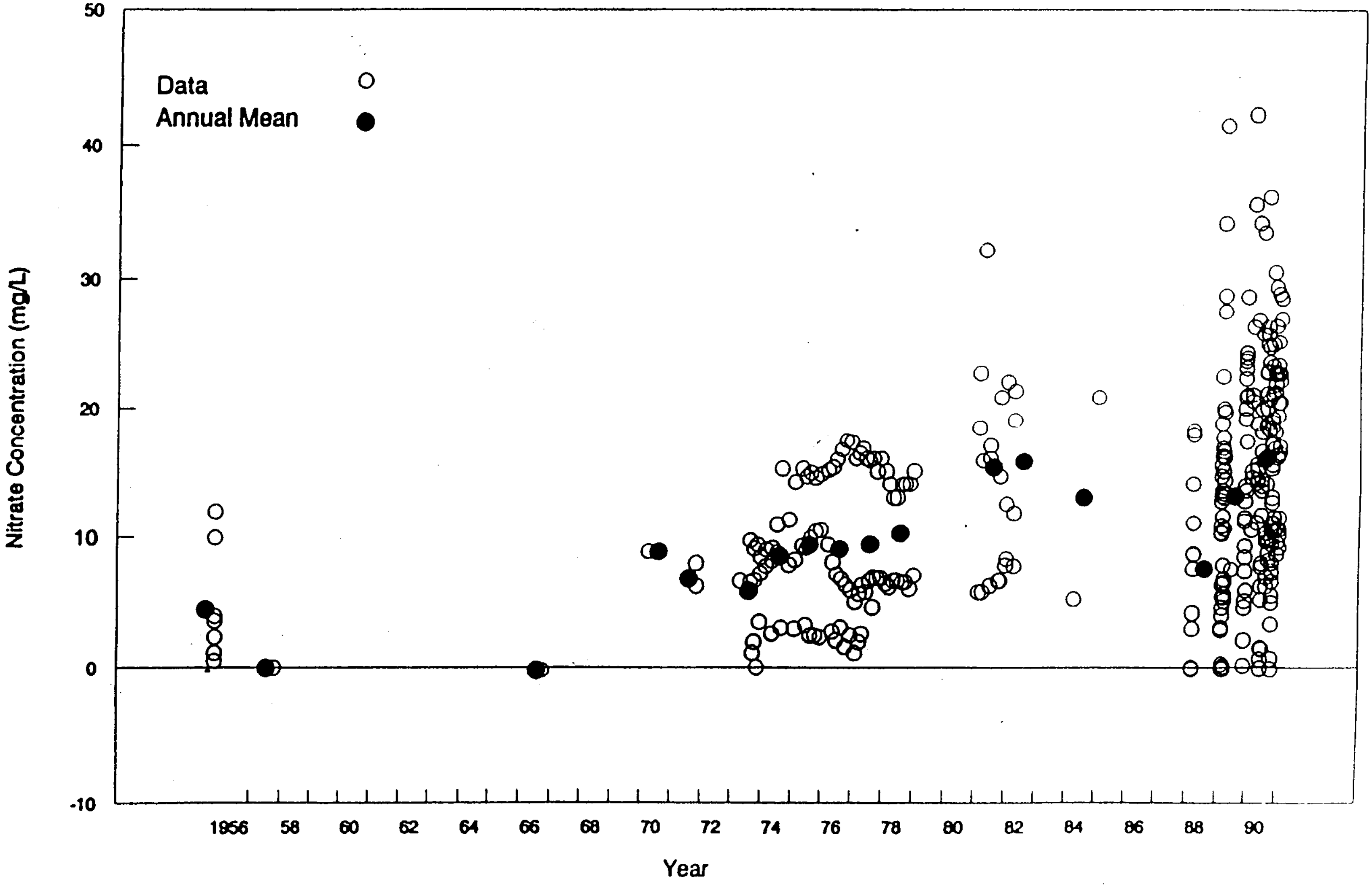
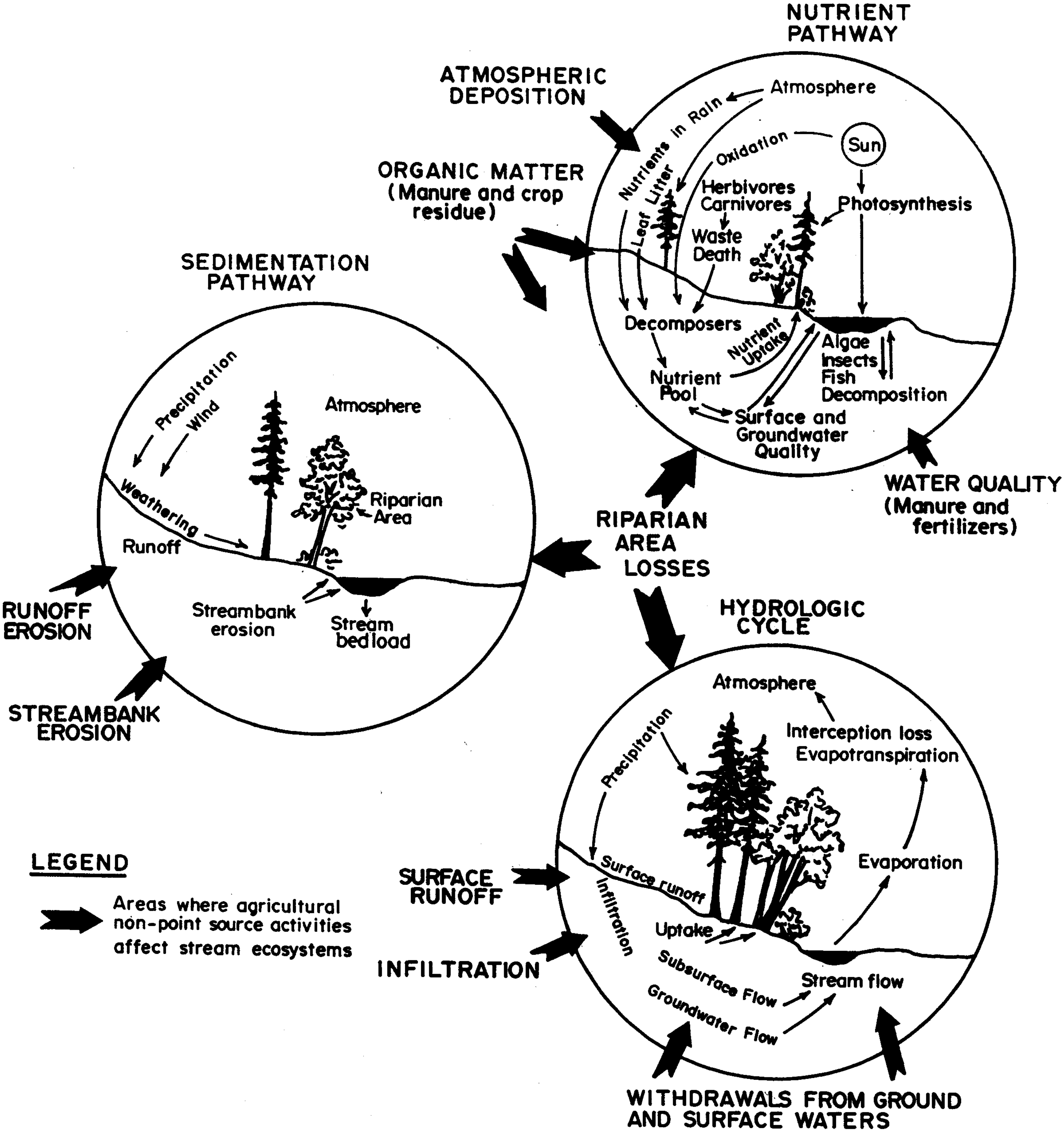
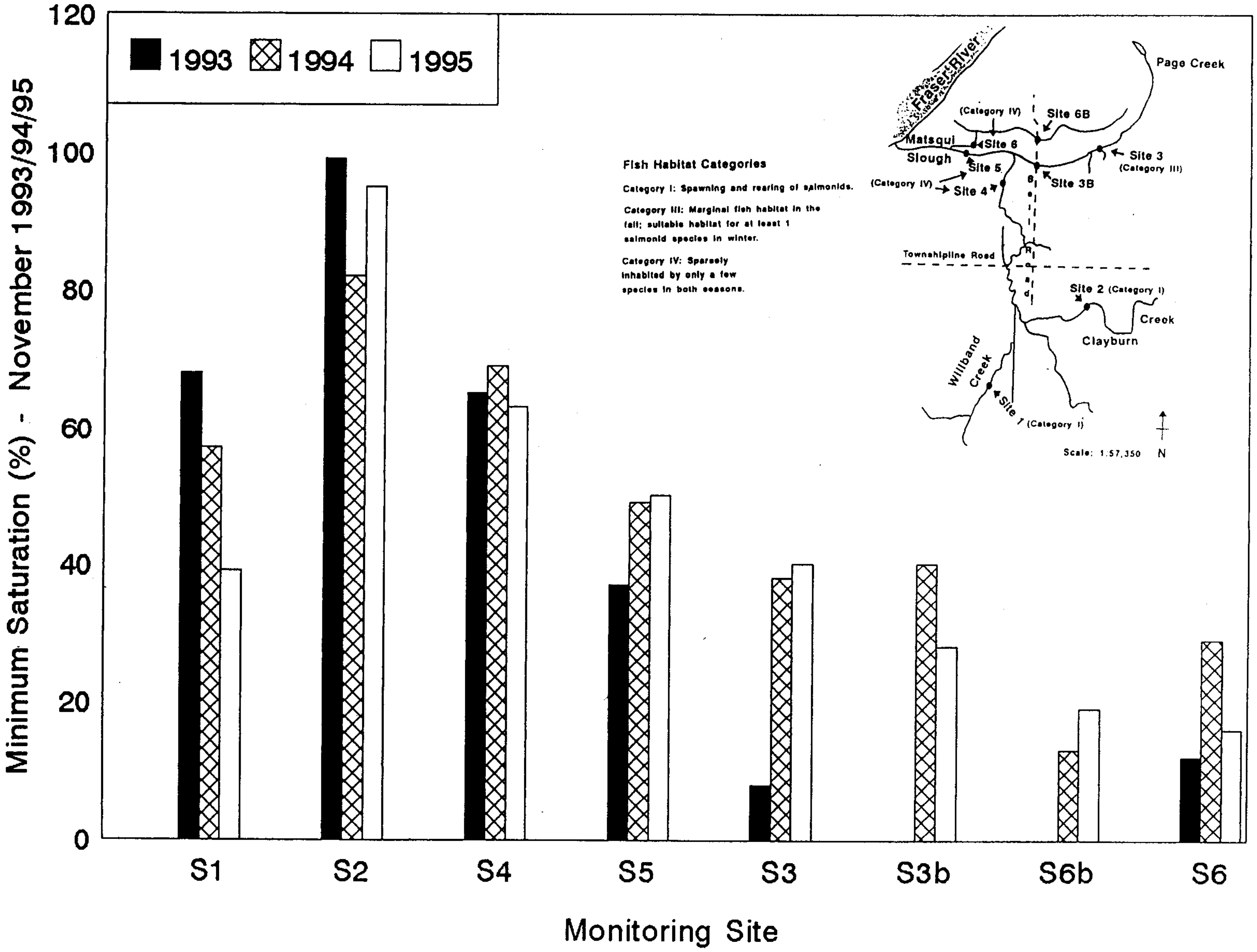


FIGURE 2: Processes of the Stream Ecosystem*



*After Toews and Brownlee, 1981

Figure 3: Dissolved Oxygen For Clayburn Creek - Matsqui Slough Watershed
Minimum Recorded November Levels



Source - Unpublished BCMELP/DFO Monitoring Data

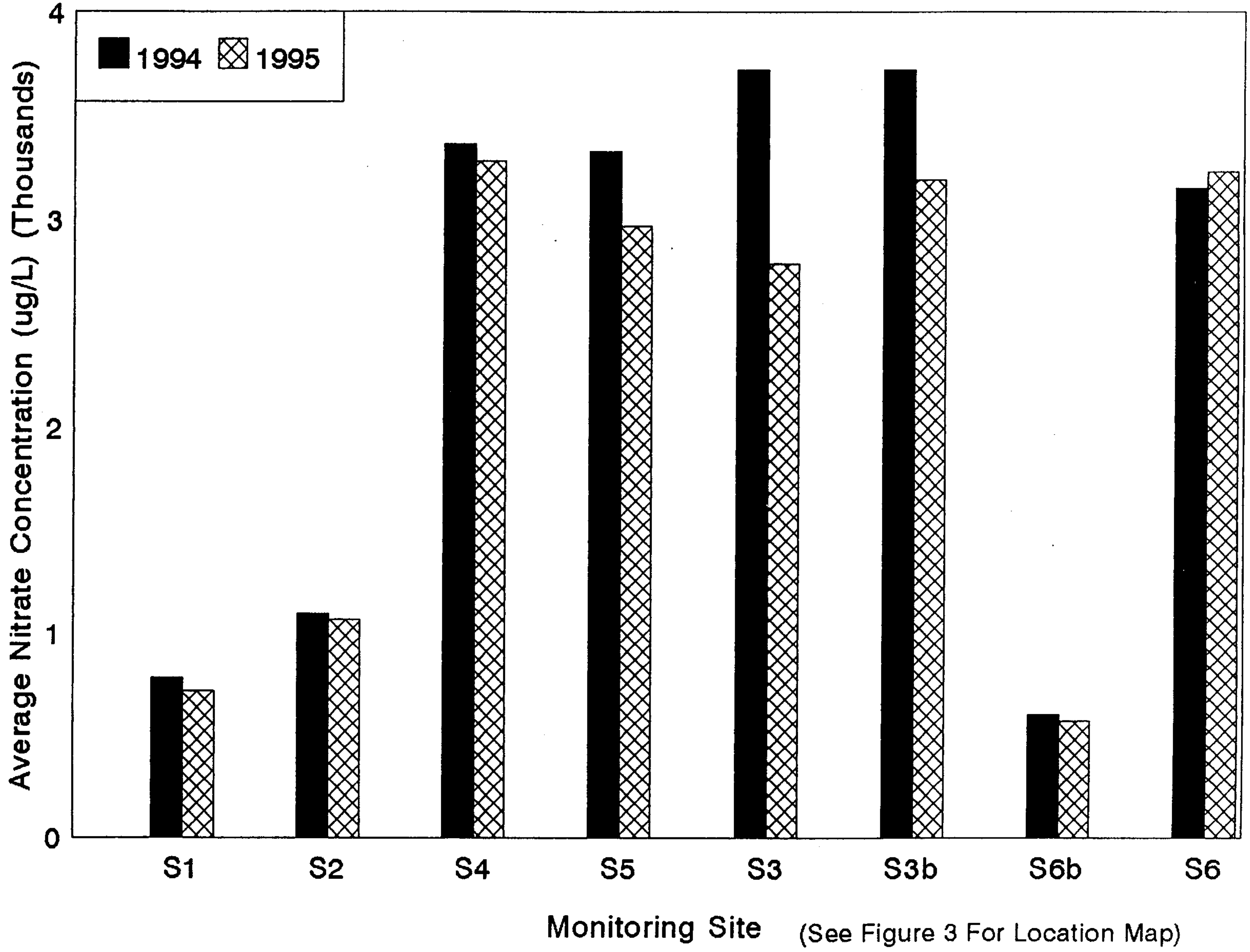
Fish Habitat Categories

Category I: Spawning and rearing of salmonids.

Category III: Marginal fish habitat in the fall; suitable habitat for at least 1 salmonid species in winter.

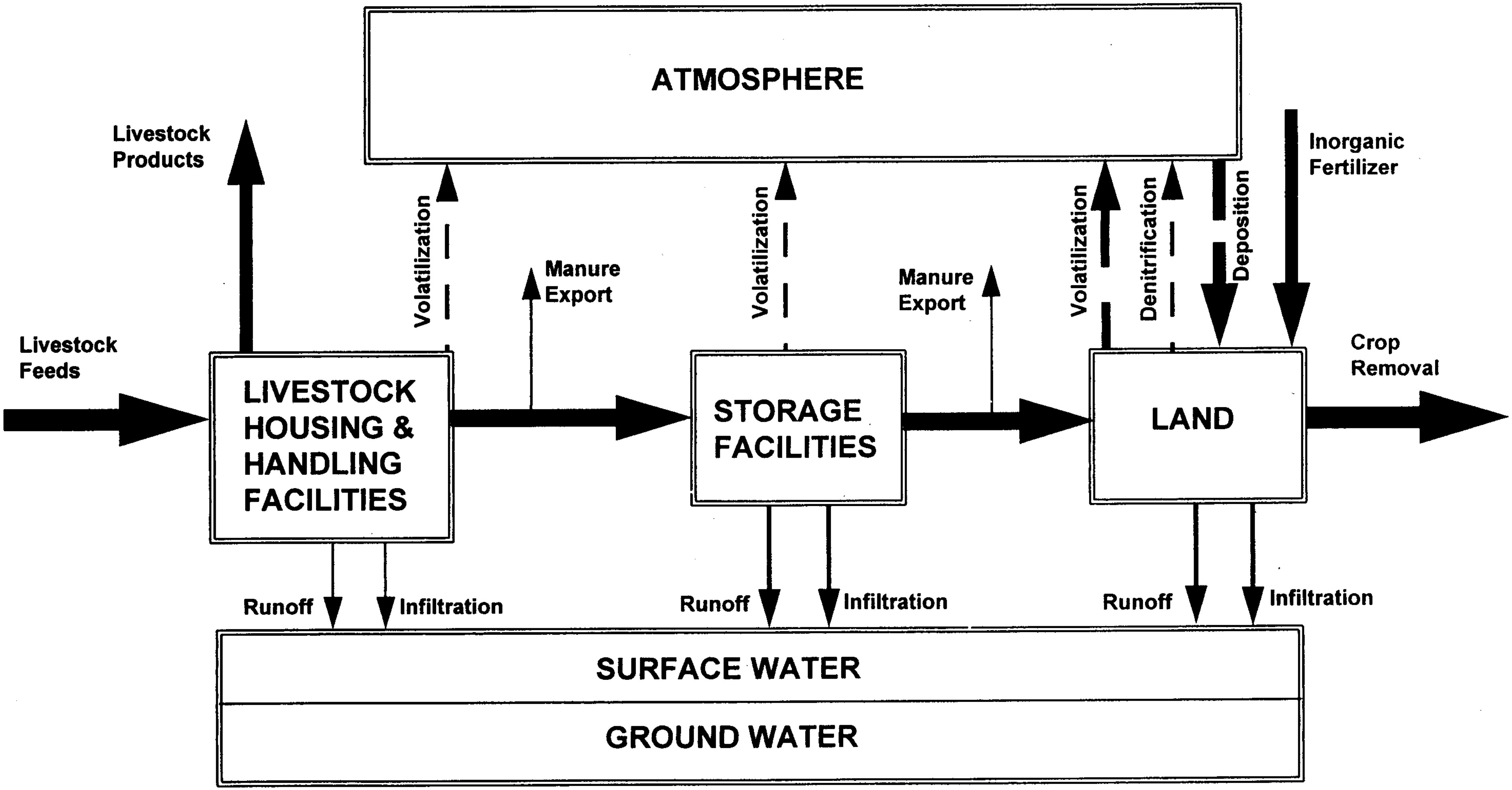
Category IV: Sparsely inhabited by only a few species in both seasons.

Figure 4: Nitrate For Clayburn Creek - Matsqui Slough Watershed
Autumn Levels



Source - Unpublished BCMELP/DFO Monitoring Data

Figure 5. Major Nutrient Pathways



(– – – – –) Denotes Nitrogen Pathway Only

Table 1

NUTRIENTS EXCRETED BY LIVESTOCK TYPE

livestock type			**nutrients excreted** (kg/animal/year)		
			N	**P**	**K**
Dairy	bulls		112	20.1	76.4
	cows		116	13.1	97.1
	heifers		42	47.2	37.4
	calves		20	21.9	14.9
	milking centre *		1.7	1	2.4
Poultry (meat)	chickens	(1000's)	0.6	0.23	0.28
	turkeys	(1000's)	0.86	0.27	0.43
	other	(1000's)	0.6	0.23	0.28
Poultry (layers)	pullets	(1000's)	0.34	0.1	0.12
	layers	(1000's)	0.8	0.23	0.28
Swine	boars		24.3	7.5	9.5
	sows		18.3	5.6	7.1
	other		7.2	2.4	4.6
Beef	bulls		112	20.1	76.4
	cows		78	13.5	39.8
	heifers		44	14.4	33.2
	steers		50	16.2	36.5
	calves		20	21.9	14.9
Horses			45.5	7.6	28.4
Sheep	rams		11	1.6	8
	ewes		11	1.6	8
	lambs		4.4	0.6	3.2
Goats			11	1.6	8

* per milking cow

Table 2

INORGANIC NITROGEN AND DISSOLVED PHOSPHORUS

Clayburn Creek Watershed March 1994
(summarized from IRC,1994a)

Location	Inorganic Nitrogen ammonia ug/l	nitrate ug/l	total ug/l	Dissolved Phosphorus ug/l	N:P
Upper Clayburn Creek		1930	1930	14	138
	7	1590	1597	7	228
	<5	1390	1395	6	233
Lower Willband Creek	159	942	1101	39	28
	330	1140	1470	22	67
	39	1520	1559	15	104
Lower Clayburn Creek	280	1910	2190	78	28
	108	1640	1748	51	34
	127	1950	2077	30	69

Sumas River Watershed March 1994
(summarized from IRC,1994b)

Location	Inorganic Nitrogen ammonia ug/l	nitrate ug/l	total ug/l	Dissolved Phosphorus ug/l	N:P
Upper Sumas River	192	4640	4832	142	34
	487	3360	3847	106	36
	153	3330	3483	35	100
Mid Sumas River	190	4580	4770	153	31
	270	3060	3330	40	83
	195	3190	3385	41	83
Lower Sumas River	210	4640	4850	145	33
	540	2690	3230	120	27
	302	3030	3332	40	83