Uncertainty in

Sustainable Water Quality Management

by

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ABSTRACT

The decision to upgrade the Annacis and Lulu Island sewage treatment plants in the Greater Vancouver Regional District (GVRD) was analysed in light of uncertainty regarding future population growth and inputs from industrial and urban runoff sources. Sustainability is often cited as a reason for maintaining pristine water quality. However, there are several sustainability world views and they do not all necessarily advocate the maintenance of pristine water quality. Approaches to sustainability are reviewed and discussed in the context of water quality management. Methodology was developed to link discharges from industrial sources, urban runoff and sewage treatment plants to user defined inputs of economic activity, development and land-use patterns and population growth. The pollutant loading was then used to determine the water quality at various locations in the Fraser River Estuary. Inputs from industrial sources, urban runoff and sewage treatment plants upstream of the GVRD were assumed to be completely mixed at the sewage treatment plant outfalls and to affect ambient water quality. Local impacts from urban runoff, industrial discharges and upstream sewage treatment plants were not considered. The primary reason for considering these sources was to determine whether future levels of discharge are likely to have an effect on management decisions regarding municipal sewage treatment plants. Diffusion factors and dispersion coefficients have been determined for various locations in the Fraser River. These were adapted to determine the local impacts on water quality from future increases in sewage treatment plant discharge. The changes in ambient and local water quality were added to determine the overall water quality for each future scenario. The decision to upgrade the two treatment plants was discussed in the context of water quality criteria and sustainability world views.

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INTRODUCTION

The Lower Fraser Basin in Southwest British Columbia has seen rapid population and economic growth in the last two decades resulting in increased pressure on water and air resources. In 1995 the provincial government ordered the addition of secondary treatment at Annacis Island and Lulu Island sewage treatment plants in response to concerns about deteriorating water quality in the Fraser River. The estimated cost of the two projects exceeds $600 million. The projects were undertaken despite studies which showed that treatment is likely unnecessary for the protection of aesthetics, fish and human health. These issues are addressed by the three facets of sustainability: environment, social well being and economy. This thesis is an attempt to determine whether the upgrade of the treatment plants and the resulting water quality is congruent with the goals of sustainability.

Sustainability and sustainable development are two terms which have come into vogue since the publication of the Brundtland Commission Report in 1987. *Sustainable development* was defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their needs' (WCED 1987). Many people had difficulties with the connotation of the word development in sustainable development. *Sustainability* is a concept which conveys many of the same messages as sustainable development without using the term 'development'. Sustainability has been adopted as a concept by many disciplines. Ecologists use it to express their concern for the state of entire ecosystems. Economists have emphasised the maintenance and improvements of human living standards in which natural resources and environment may be important. Other disciplines, (notably geography and anthropology) are concerned with the functioning of the social and cultural systems (Toman, 1992).

There are three relatively well defined sustainability paradigms which reflect different levels of trade-offs between economic growth and environmental preservation. These are:

1. Weak sustainability
2. Strong sustainability
3. Deep ecology or thermodynamic sustainability

Sustainability is a concept that is difficult to be ethically opposed to. Sacrificing the welfare of future generations for our own benefit does not seem just. Water quality management decisions must balance the interests of environment (habitat destruction/preservation), economy (fisheries productivity/cost of construction) and society (aesthetics/taxes/morals).

Water quality management decisions are made in light of predictions in trends in water quality. Studies have been undertaken to predict future water quality in the Lower Fraser River. However, the only pollutant source that was considered was municipal sewage treatment plants (STPs) and uncertainty regarding the population growth and impacts from urban development and increased industrial discharges were not considered. The decision to upgrade the Annacis Island and Lulu Island STPs is affected by changes in ambient water quality as a result of municipal discharges, industrial discharges and urban runoff upstream of the STP outfalls. Methodology was developed to determine the pollutant loading which would result from several future scenarios. The scenarios were developed to reflect a range of uncertainty regarding growth rates in population and ecenomic activity and changing land uses.

The BC Water Quality Objectives for municipal-type wastes allow for an Initial Dilution Zone (IDZ). The BC Water Quality Ojectives must be met at the edges of this IDZ. Near-field water quality was determined by estimating the future loading levels from Annacis Island and Lulu Island STPs and modelling the resulting effect on pollutant dispersion. Overall water quality was determined by adding the changes in ambient water quality, (due to industrial discharges, urban runoff and upstream STPs), and the change in near-field water quality, (from Annacis Island and Lulu Island STP discharges), to the current background pollutant concentrations. In this study uncertainty was addressed by determining water under a variety of future scenarios addressing a wide range of population and economic growth and sewage treatment options. The overall water quality in each scenario was assessed to determine whether upgrading the sewage treatment plants achieved the goals of sustainability.

1. SUSTAINABILITY WORLD VIEWS

Sustainability is value laden and individuals may have differing views of what it entails. The different sustainability paradigms have different implications for water quality management in the LFB. The relative strengths and weaknesses of each is crucial to our decision making. Each of the sustainability paradigms is discussed in detail in this section. Sustainability implications for water quality management are discussed in Chapter 2.

1.1 Weak Sustainability

Weak Sustainability argues that any consumption of natural capital must be offset by the creation of an equal or greater amount of manufactured or intellectual capital. In the words of Solow (1993), “There is no reason for our society to feel guilty about using up aluminum as long as we leave behind a capacity to perform the same or analogous functions using other kinds of materials-plastics or other natural or artificial materials”. Weak sustainability emphasises the substitutability of technology and man-made capital for natural capital. Some scholars even question whether sustainability is a significant issue, pointing out that humankind has managed to avoid the spectre of Malthusian scarcity through resource substitution and technical ingenuity.

1.1.1 Weak Sustainability: Theory and Economics

Neo-classical economics focuses on the relationship between scarcity and price which has lain the foundation for weak sustainability. Alan Kneese, an economist in the sixties, was interested in environmental degradation and the depletion of resources. Kneese, together with colleagues at Resources for the Future, developed most of the agenda for contemporary resource economics. The umbrella under which this theory developed was neo-classical economics (Victor, Kay and Ruitenbeek, 1991). The neo-classical approach to resource economics is summarised in a book by Kneese and Hernfindahl entitled ‘Economic Theory of Natural Resources’. Capital is central to their discussion, and is defined as "anything which yields a flow of productive services over time and which is subject to control in production processes." They add that "this definition does not restrict capital to 'man-made durable instruments of production'.

This definition of capital, as all controllable sources of services, emphasises the commonality of natural resources and man-made capital. The high degree of substitution between various types of manufactured capital and between manufactured capital and natural resources is central to their argument. The implication is that manufactured capital may be substituted for depleted resources or a degraded environment. The easier it is to substitute manufactured capital for natural resources, the less we should be concerned about diminishing resources. Some examples of this are the reduced use of copper through reduction in the number of intercontinental submarine cables and increased reliance on satellite telecommunication; the increased use of polymers and reduced use of steel in the automobile industry and the increased fuel efficiency of modern cars which reduces the amount of gasoline consumed per kilometre driven. An example of the use of technology to increase the production of capital is aquaculture. Aquaculture accounted for 37 percent of the production of salmon in BC in 1995 (Ministry of Agriculture, Fisheries and Food, 1996). This percentage is expected to rise in the future as larger net cage operations come on-line and a higher percentage of space suitable for net cage operations is utilised. This illustrates the potential for man-made capital to substitute or augment natural capital.

Dasgupta and Heal, 1979 have focused more directly on the substitutability between manufactured and natural capital. Dasgupta and Heal define a resource as exhaustible if "it is possible to find a pattern of use which makes its supply dwindle to zero." This definition includes mineral resources, biotic resources such as fish and forests, fertile land and fresh water. Dasgupta and Heal assume that there will be no technological progress to overcome the diminishing resource stock. In their model, some natural resources are required, but as supplies dwindle, output may be maintained through substitution by manufactured capital. It is concluded "even in the absence of technological progress, exhaustible resources do not pose a fundamental problem" if reproducible capital is sufficiently substitutable for natural resources.

Dasgupta and Heal's model assumes a constant degree of substitutability, (or marginal rate of substitution), between natural and manufactured capital, regardless of their relative proportions. In economic jargon, this means the elasticity of the substitution between resources and capital is unity. That is, the percentage change in the relative amounts of capital and resources used in production brought about by a percentage change in their prices is constant. Thus, no matter how far an economy degrades its resources, and substitutes capital for resources, the potential for additional substitution never diminishes.

Weak sustainability may be criticised because it does not recognise that capital is made from resources, whereas resources are a gift from nature. The problem is that increased substitution of capital for resources will ultimately result in increased pressure on resources to manufacture and operate this capital. Therefore it is difficult, if not impossible, to maintain output in the face of limited resources through the substitution of capital for natural resources.

1.2 Strong Sustainability

Strong Sustainability would be more closely associated with the definition put forward by UNESCO: "...every generation should leave water, air and soil resources as pure and unpolluted as when it came on earth." Strong sustainability argues that manufactured capital may not be substituted for all natural capital because natural capital performs many functions which can not be performed by manufactured capital. Therefore, a minimum level of natural capital must be preserved to perform basic life support functions on the planet.

1.2.1 Strong Sustainability: Theory and Economics

Pearce and Turner are generally regarded as the strongest proponents of strong sustainability. They concentrate on the meaning and desirability of maintaining the natural stock as a condition for sustainability in *Economics of Natural Resources and the Environment*, 1990. Natural stock is not defined although they suggest it is synonymous with natural resources. Pearce and Turner offer two reasons for differentiating between natural and manufactured capital:

1. Manufactured capital is not independent of natural capital; the latter is often required to make the former.
2. Natural capital fulfils other economic functions, including basic life support; it is multifunctional to an extent not shared by manufactured capital.

Following from the above, it is not always possible to substitute manufactured capital for natural capital. Natural capital is often required for the production of manufactured capital. Natural capital is a source of raw materials and a sink for the waste products of the production and operation of manufactured capital.

The concept of natural capital may be illustrated again using aquaculture as an example. The Suzuki Foundation (1996) recently published a review of net cage operations in British Columbia. It was shown that 1.5 Kg of fish feed, (derived from less valuable fish from South America), are required to produce 1 Kg of farmed salmon. Therefore, although the value of the farmed salmon is greater than that of the feed fish, the net production is only 67 percent of the natural production. The report also focused on external costs that the net cage industry puts on the environment including wastes and disturbing wildlife. This demonstrates that although the apparent productivity of the net cage industry is high it can not perform some of the functions of the natural system.

The concept of natural capital can also be demonstrated by water. Water is a source of raw material for industry and agriculture in addition to being inhabited by fish. The assimilative capacity of water is used as a sink for the pollutants in the effluent from industry, STPs and urban runoff. The assimilative processes of water include dilution, sedimentation and degradation of pollutants. The loss of natural capital may result when the assimilative capacity is breached. The loss of natural capital may be irreversible to a degree not matched by increases in manufactured capital. For example, capital, such as a river dam, may be constructed and later demolished, thus regaining the natural capital. However, if a river is polluted to the point that a fishery is damaged or eliminated, it is effectively impossible to recreate these components of the natural environment. Moreover, natural capital has intrinsic value not often matched by manufactured capital. People generally would not find a leisure centre an adequate substitute for the natural countryside or public access to a watershed. Natural systems are complex. We do not have a complete understanding of how natural systems function; therefore, they can not be replaced by manufactured capital.

Further justification for the maintenance of natural capital is provided by Pearce and Turner (1990):

1. In some circumstances, such as a rural setting in a developing country, more natural capital can mean more resilience to shocks, and hence, a more sustainable society.
2. Considerations of intergenerational equity demand that the resource stock be maintained so as to ensure broadly equal access to it by different generations.
3. Preservation of natural capital is consistent with a world view that recognises the rights of other species to coexist with humans.

Uncertainty and irreversibility are central in any discussion of sustainability. There is uncertainty regarding the supporting role the environment plays in the economy and the effect of economic activity on the environment.

There is real uncertainty in the sense that probabilities can not be assigned to alternative outcomes. The complete set of outcomes is often unknown and therefore a probabilistic approach is untenable.

Having put forth numerous reasons for maintaining the stock of natural capital, Pearce and Turner devoted their attention to the measurement of natural capital. They are quoted at length as they attempt to explain what the requirement that natural stock be held constant might mean:

> "There are several interpretations. First, we could say that the capital stock is constant if its *physical quantity* does not change. But we have no way of adding up the different physical quantities (tonnes of coal, cubic metres of wood, litres of water, etc.). The standard economic approach would be to value each type of resource on money terms and compute the overall aggregate money value. If this could be done, in the same way as we make estimates of the 'national wealth' - i.e., the stock of man-made capital - then we could rephrase the natural capital requirement in terms of a constant real value of natural assets.
>
> "Second, we could think in terms of the unit value of the *services* of natural capital. That is, we could look at the *prices* of natural resources and aim to keep these constant in real terms. Provided we are satisfied that prices reflect absolute scarcity. . . constant real prices will imply a constant natural capital stock in this modified sense. One obvious problem here is that many resources do not have observable prices. We need to find implicit or 'shadow' prices in some way."
>
> "Third, we could think of a *constant value* of resource flows from the natural stock. This is different from constant prices because we would allow quantity to decline but the price to rise, keeping value constant."

The three points made by Pearce and Turner offer four interpretations of the requirement to hold constant the stock of natural capital:

1. The *physical quantity* of natural resources should remain unchanged.
2. The *total value* of the natural resource stocks should remain constant in real terms.

3. The *unit value of the services* of the natural resources, as measured by the prices of natural resources, should remain constant in real terms
4. The *value of the resource flows* from the natural resource stock should remain constant in real terms (where resource flow is the product of price and quantity used).

Under the strong sustainability paradigm, the economic activity of society may be limited or modified such that natural capital is maintained for future generations. The Commission on Resources and the Environment, CORE essentially limited economic activity when it set aside 12% of the land area of British Columbia in each management district as part of its sustainability strategy. They are working toward 13% which is the number suggested by the Brundtland Commission as the minimum necessary to preserve biodiversity (WCED 1987).

1.2.1.1 Physical Quantity of Natural Resources

Maintaining a constant natural stock requires that the total amount of resources remains the same, not that the quantity of individual resources remains constant. Measuring the natural stock strictly in physical terms is difficult because it involves adding up different physical quantities in different physical units. e.g. barrels of oil plus number of trees or volume of wood. The measurement of natural stock in this discussion is limited to the evaluation of water quality. However, the comparison of incompatible units is still a factor e.g. kg of Cd vs. tonnes BOD vs. kg phenol. When considering the construction of municipal waste water treatment plants, how does one evaluate the increased land area required required for higher levels of sewage treatment with improvements in water quality?

There is also a quantity vs. quality problem. Even though there is still the same quantity of a resource, it may not be of equal value to the original resource. An example of this is the issue of old growth versus second growth forests. Old growth forests have qualities that planted and second generation forests do not have and vice versa.

Some levels of human activity may exert a measurable change in the level of a contaminant in the environment, however, this may not lower the value or productivity of the affected area. How do we determine the threshold level, or the assimilative capacity above which the concentration of the contaminant has a noticeable detrimental effect on the ecosystem? The threshold level may not be the same for all ecosystems and increased concentrations may have varying effects in different ecosystems. The CCREM guidelines publish water quality criteria for different water uses. The criteria used in this study were those listed for the primary water use in the area under consideration.

1.2.1.2 Total Value of Natural Resources

Calculating the total value of natural resources involves evaluating the quantity of natural resources in monetary terms. This approach has several problems. There is no market price for many resources such as water, air and wilderness. Damages to these resources has been overlooked in traditional accounts which has led to extensive research on non-market valuation. Attempts have been made to 'green' the GDP by giving consideration to the issues of loss and degradation of the environment (Bartelmus, 1994). The economic losses from deteriorated water quality are difficult to assess and may be very subjective. An economic evaluation of the impacts of pollution on the value of natural resources is beyond the scope of study and is not considered

1.2.1.3 Unit Value of Natural Resources

Market prices may also not reflect the true value of resources due to market imperfections such as tariffs, subsidies or taxes. These prices with their inherent inaccuracies reflect conditions at the margin. Using these prices to value entire stocks may result in over-exploitation of a resource. For example, it is possible to envisage a situation where the price of a resource rises faster than the rate of decrease in physical stock. This would lead to the counterintuitive result that maintaining a constant value of the resource would result in consumption of the resource until there is none left. Market prices reflect the value that the present generation puts on resources; therefore, future generations may not be adequately represented in an environmental account that utilises market prices.

1.2.1.4 Value of Resource Flows

Maintaining a constant value of the resource flows assumes that the optimum level of consumption may be determined. If the level of consumption is set too high, sustainability will not be achieved and natural stocks will gradually disappear. If the level is set too low, then human well-being will not be maximised. The valuation of resource flows has the advantage of being relatively easy to monitor, however, there are problems determining what the maximum sustainable rate of consumption is. In water quality terms, this may be interpreted as the assimilative capacity of the receiving water. If the assimilative capacity of the receiving water is exceeded, this will result in an economic loss, however, the assimilative capacity should be used to its maximum potential to derive the greatest human benefit. The assimilative capacity of the receiving waters is determined by the precautionary principle. This outlines the maximum concentration of pollutants which maintains acceptable water quality. These concentrations may differ between world views.

1.3 Thermodynamic School

Thermodynamic sustainability considers the effect of the economy on the environment in the very long term. It is more restrictive than the strong sustainability paradigm and some advocates of thermodynamic sustainability could be considered ecocentrists rather than anthropocentrists. The laws of thermodynamics are the guiding principles for this school of sustainability (Jacobs, 1991).

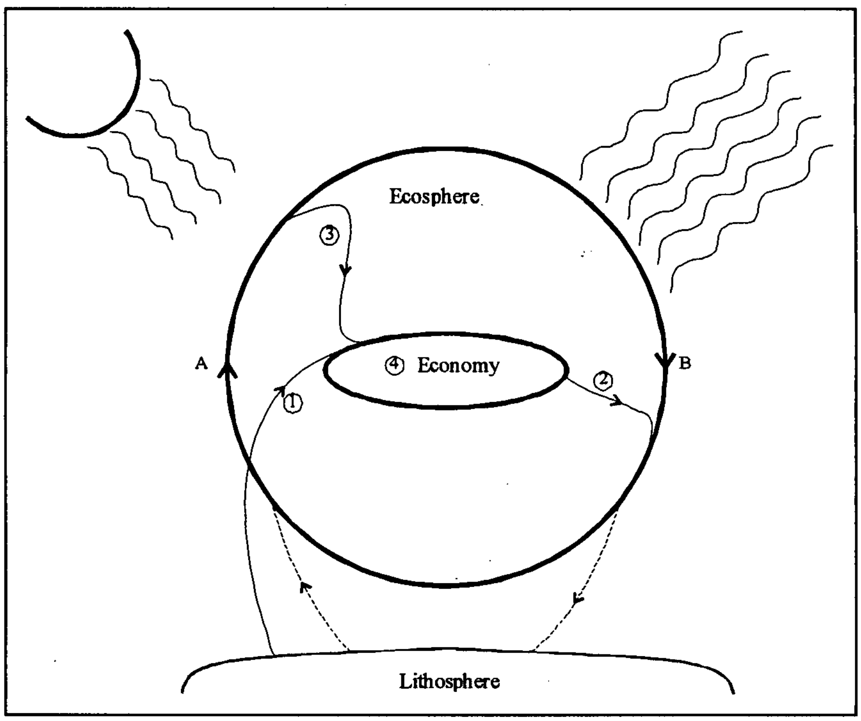
- Matter-energy can neither be created nor destroyed
- Entropy in a closed system will increase with time

This has interesting consequences when one considers the effect on the economy. The first law states that all matter and energy consumed by the economy must be returned to the environment. The second law shows that the economy takes low entropy inputs and converts it to high entropy matter-energy. The entropic nature of economic activity explains the reason why 100% recycling within a closed system is impossible.

1.3.1 Thermodynamic Sustainability: Theory and Economics

Thermodynamic sustainability is much more ecocentric compared to the anthropocentric viewpoints of weak and strong sustainability. Ecosystem health has value in its own right in addition to economic value under this paradigm. The thermodynamic approach attempts to demonstrate how the fundamental laws of physics impact on the economy. Economic activity can not create or destroy matter-energy; it can only rearrange it into different forms which may be more marketable. Consequently, all materials input to the economy must eventually be disposed of in the environment. Nature has a limited resource creating capacity for the substances that society extracts as well as a limited attenuation for the wastes or emissions society returns to nature. This illustrates the interconnectedness of economic activity and the ecosphere which runs contrary to traditional economic models which consider environment and economy separately. Figure 1.1 and Figure 1.2 illustrate two models of economic interaction with the environment.

Figure 1.1: Economic Interactions with the Environment: Thermodynamic Model

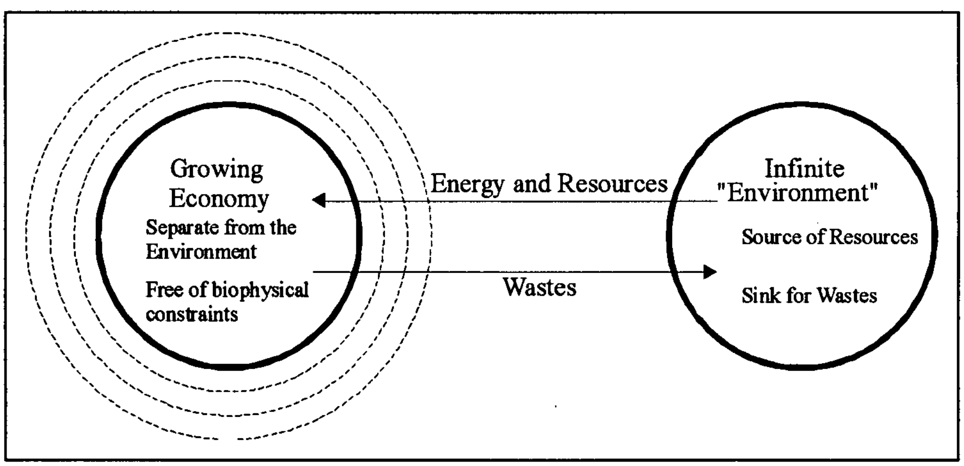


1.	Extraction of substances from the lithosphere
2.	Emissions of artificial substances
3.	Manipulation of the ecosphere
4.	Economic transformations of natural resources into services

Source: Holmberg, 1995

Note: the original illustration had *Society* in the centre ellipse instead of *Economy.*

Figure 1.2: Economic Interactions with the Environment: Expansionist Model



Source: Rees, 1995

The Institute of Physical Resource Theory in Göteborg, Sweden has been analysing material flows in industrial society (Holmberg, 1995). The metabolism of society is characterised by the *exchange* of energy and materials with nature and by *manipulation* of natural systems.

Exchange takes place through the extraction of resources from nature, e.g. minerals, and the return of emissions to nature, e.g. CO_2 emissions and wastewater. Resources may be extracted from *deposits* (minerals), *funds* (forests) and *natural flows* (sunlight, river water etc.). Deposits are gradually depleted, funds regenerate slowly and natural flows are continuous. The first law of thermodynamics demonstrates that at some point in the future all of the resources extracted from nature will eventually return to nature.

Manipulation can decrease the assimilative capacity of the environment. Societal manipulation of nature includes: (i) displacement of nature (societal activities force away ecological systems or geophysical functions, e.g. construction of highways), (ii) reshaping the structures of nature (e.g. damming of rivers, ditching) and (iii) guiding of processes and flows (e.g. agricultural practices or gene manipulation).

Holmberg asserts that the earth can not tolerate a systematic shift in environmental parameters (i.e. systematically increasing the concentration of some substances in the ecosphere) and suggests that this is the path that society is taking. If we are to create a truly sustainable society, we must reverse the trends described above. From this assertion, four socio-ecological principles for a sustainable society were developed. These are outlined below.

1. Substances extracted from the lithosphere must not systematically accumulate in the ecosphere.
2. Society produced substances must not accumulate in the ecosphere.
3. Physical conditions for production and diversity within the ecosphere should not be systematically deteriorated. i.e. we must not take more from the ecosphere than can be regenerated and we must not reduce natural productivity.
4. The use of resources must be efficient and just with respect to meeting human needs. This means an increase in technology and organisation in global society and more equitable resource distribution.

The thermodynamic school recognises the importance society plays in material flows in nature. This differs from the view that nature can deliver an unlimited amount of goods and assimilate an unlimited amount of waste. The basis of the thermodynamic school is that the economy should be limited in size or modified according to the natural flows of energy and materials (Karlsson, 1994).

2. Sustainability Implications for Environmental Management

The benefits of the modern economic system can not be delivered with zero environmental risk. Some method of determining acceptable levels of trade-offs between environmental risk and pollution abatement costs must be developed. Pollution externalities are the costs borne by society and the environment above the costs borne by the polluter and may be internalised though full-cost accounting. The three sustainability paradigms are reflected in two broad policy approaches utilised to internalise pollution externalities - the *precautionary approach* and the *cost benefit approach*. These two approaches are discussed in more detail below.

2.1 Precautionary approach

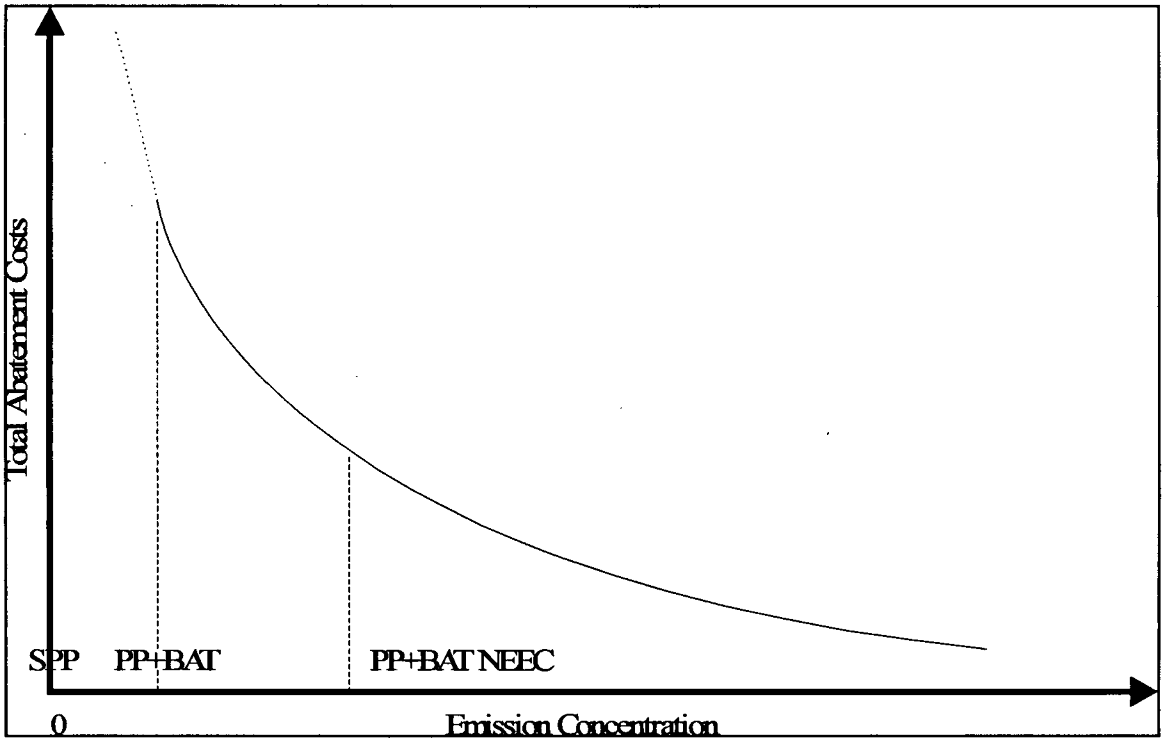
The precautionary principle says that because of the uncertainties in environmental sensitivity, caution should be taken when setting emission standards. This approach to balancing risks and benefits differs from the cost-benefit approach in that it considers the risks associated with persistent pollutants accumulating and damaging the waste assimilation capacity of the environment. The precautionary approach is based on the concept of safe minimum standards (SMS). SMS can be accompanied by specific policy instruments such as pollution taxes or permits which will be discussed in Section 2.3. The precautionary principle may be applied in two general forms: legislated treatment levels and critical loading.

2.1.1 Legislated Treatment

Legislated treatment requires polluters to treat effluent to a prescribed level set by the regulatory agency. The range of levels which could be legislated is illustrated in Figure 2.1. These levels reflect different views on sensitivity and represent different levels of trade-offs between environmental quality and cost.

Legislated treatment levels is a 'command-and-control' approach to setting environmental standards without the aid of market-based incentives. Traditionally environmental control has been based on command and control regulations. In the UK, the regulations state that pollution prevention and the best available treatment technology not entailing excessive cost **(PP+BAT NEEC)** be employed, (Weak sustainability). The US EPA requires polluters to exercise pollution prevention and treat their effluent to a uniform standard achieved by the best available pollution control technology **(PP+BAT)**, (Strong sustainability). Under conditions of extreme environmental sensitivity, it is possible to imagine a regulatory agency enforcing the strict precautionary principle **(SPP)**, (Thermodynamic sustainability) which may entail restricting industrial activity in areas or requiring very high levels of pollution prevention and wastewater treatment.

Figure 2.1: Levels of Treatment and the Precautionary Principle



Source: Ramchandani and Pearce (1992)

Many economists have argued that the direct control of environmental discharges is economically inefficient. Two broad sources of inefficiency in the command and control approach are identified by Turner, Pearce and Bateman, 1993:

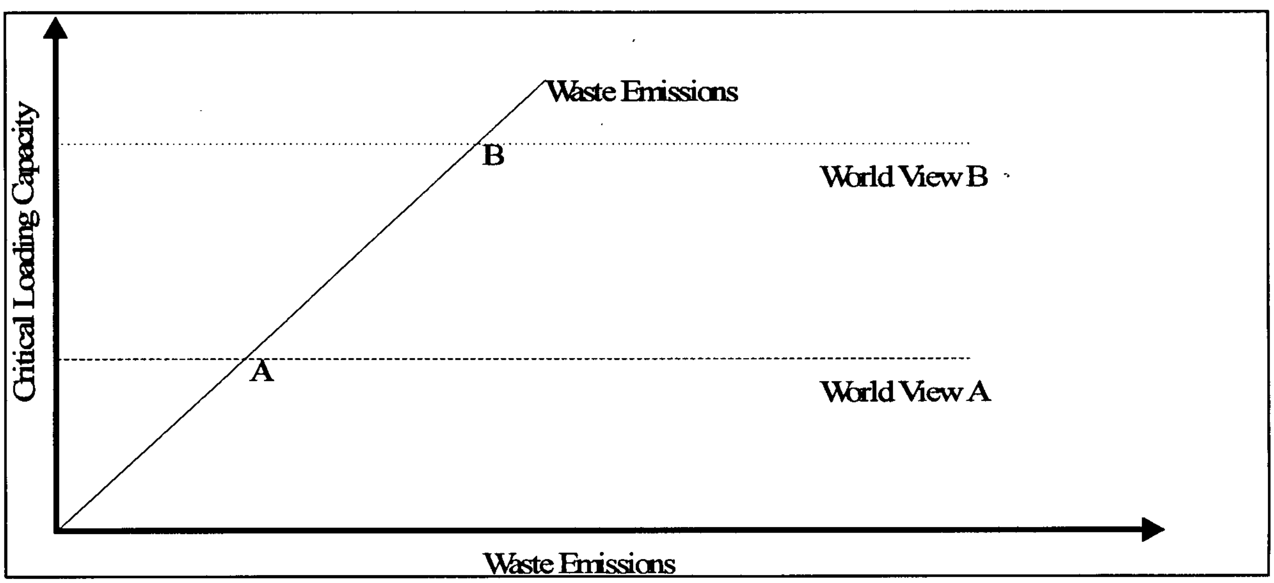
1. Regulators expend a lot of resources to acquire information that the polluter already possesses. For example, a polluter knows how much it will cost to clean a given discharge, however, under the command and control approach, the regulatory agency must acquire this information.
2. Polluters vary in the cost with which they can abate pollution. If the control processes were concentrated in the industries or firms which had the lowest pollution abatement costs, this would be a more economically efficient system to achieve the same level of pollutant discharge. However, the command and control approach of assigning uniform emission standards across the board does not allow for this efficiency.

The sustainability world view most appropriately linked with each level of legislated discharge is given in brackets above, however, legislated treatment levels may not be directly related to water quality. In areas where there is a high population density or intense industrial activity, high levels of wastewater treatment do not guarantee acceptable water quality. In addition, in areas of low population density or low industrial activity, imposition of strict effluent standards may entail excessive treatment costs for marginal improvements in water quality. Therefore, legislated requirements can not be directly linked to individual sustainability world views, however, the different levels of treatment illustrate the thinking of the world views in terms of trade-offs between economy and the environment.

2.1.2 Critical Loads

Critical load factors are ambient water quality standards and may vary depending on water use. The 'biological' critical load must be distinguished from 'economic' critical load. The economic critical load is based on an 'acceptable' level of damage to human welfare and the perception and valuation of environmental changes whereas the biological critical load is based on the assimilative capacity of the environment. The weak sustainability world view is typically represented by the economic critical load and the strong sustainability paradigm is typically represented by the biological critical load. Figure 2.2 illustrates how critical load may be affected by world view.

Figure 2.2: Critical Loads for Different World Views



Weak sustainability is typically associated with World view B. The higher level of critical loading reflects the substitutability of manufactured capital for natural capital. Loss of environmental productivity in some areas could be compensated for by increases in manufacturing capacity. For example, point B could be associated with the point where the natural salmon run is eliminated. Losses to the productivity of natural salmon streams would not be considered a catastrophe under this paradigm if it were accompanied by concomitant increases in fish farming productivity.

Strong sustainability is typically reflected by World view A. This critical load reflects the level of pollution which can be tolerated without damaging the natural productivity of the stream. Under this world view, ambient water concentrations would be set to limit industrial emissions. Point A is the maximum level of discharge without exceeding the assimilation capacity of the environment. The biological critical load may vary according to the water use. Water used for rearing by fish would have a different biological critical load than water used to irrigate farmland

One would usually expect the economic critical load to be greater than the biological critical load. This would be the case if there were any economic costs associated with achieving World View A. However, it is also possible to imagine a case where the biological critical load is greater than the economic critical load. A river used by industry that requires very clean water, but that supports very few, hardy species illustrates this possibility.

Thermodynamic sustainability would emphasise the long term impacts of pollution. The critical load would be the same or lower than that for strong sustainability.

2.2 Cost-benefit approach

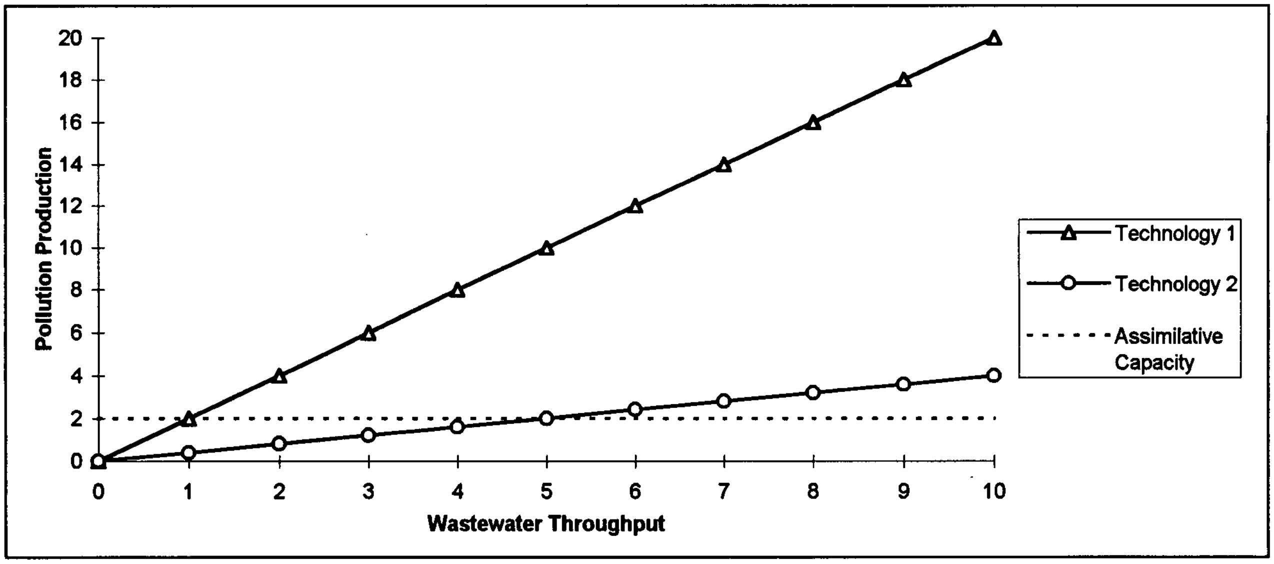
The cost-benefit approach to pollution management would result in the reduction of pollution to the level where the marginal cost of pollution reduction is equal to the marginal cost of the damage caused by such pollution. In simple terms a project or policy is considered worthwhile if its non-environmental benefits (B) minus its non-environmental costs (C) plus or minus the value of the environmental change (E), all discounted to a present value is positive. Equation 2.1 summarises the condition for an acceptable project.

Equation 2.1: Cost-Benefit Condition

$$\sum_t (B_t - C_t \pm E_t)(1+r)^{-t} > 0$$

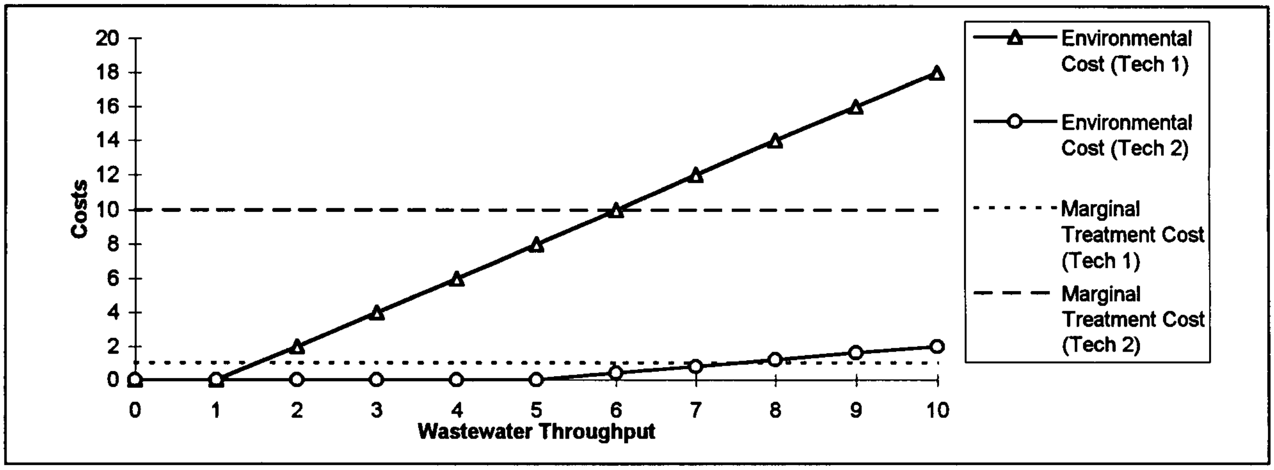
A simple example of a cost-benefit analysis is described below. A wastewater treatment technology must be chosen to mitigate against potential damage to a river. There is a choice of two hypothetical treatment technologies, Technology 1 and Technology 2. Technology 2 is five times more efficient at removing pollutants than Technology 1 and ten times more expensive to implement. Figure 2.3 illustrates that the assimilative capacity of the environment is exceeded at a much higher wastewater flow using Technology 2 than Technology 1. For this example, all treatment and environmental costs may be assumed to be discounted to their present value. A more detailed discussion of the merits of discounting in environmental economics is given in Daly and Cobb, 1994 and Pearce et al., 1989.

Figure 2.3: Pollution Production as a Function of Wastewater Throughput



Damage costs to the environment are illustrated in Figure 2.4 and are not incurred until the assimilative capacity is breached. The sustainability world view could have a significant impact on the point where Technology 2 is implemented over Technology 1.

Figure 2.4 Marginal Costs for Two Treatment Technologies



Source: Adapted from Kneese, 1964

Weak Sustainability: would result in the implementation of Technology 2 at the point where the environmental cost using Technology 1 is greater than the marginal treatment cost of technology 2. In this example, Technology 2 would be implemented when the wastewater throughput reached 6.

Strong Sustainability: This world view would result in the implementation of Technology 2 when the assimilative capacity is exceeded, regardless of cost. This would preserve natural capital, but would result in greater expenditures for environmental protection. In this example, Technology 2 would be implemented when the wastewater throughput reached 1 (see Figure 2.3: the point where the assimilative capacity of the environment is exceeded when using technology 1).

Thermodynamic Sustainability: This world view might have assume a lower assimilative capacity than the strong sustainability world view. The emphasis would be on limiting the growth of society and implementation of the best available technology (Technology 2) at all levels of wastewater throughput in an effort to preserve environmental quality.

The point at which Technology 2 is implemented determined by the assimilative capacity and the cost-benefit approach. Under the strong sustainability world view, Technology 2 must be implemented at the point where the *assimilative* capacity of the environment is breached. However, the assimilative capacity is determined by the precautionary principle and may not represent the strong sustainability world view. I.E. it may assume a much higher assimilative capacity than would be associated with the strong sustainability world view. Therefore, although Technology 2 was implemented under the precautionary principle, it may represent the weak sustainability world view. Therefore, the sustainability world views as they apply to the cost benefit approach are intended as a guide and do not represent definitive boundaries.

2.3 Sustainability Implications for Water Quality Management

Sustainability world views may affect which water quality management strategy is chosen. Various combinations of policies may reflect different world views. Table 2.1 summarises how the sustainability world views can be represented by different policy combinations.

Weak sustainability water quality management practices would focus on the infinite substitutability that this world view assumes. Weak sustainability allows for actual compensation for environmental damage through shadow projects, direct payment or taxes. Thus, a polluter may decide it is cheaper to compensate parties affected by the pollution than to incur treatment costs. For example, consider the case of fish farms vs. natural salmon runs. Due to the infinite substitutability under this world view, farmed salmon would be valued the same as wild salmon. Therefore, under the weak sustainability approach, it may be cheaper to offset damage to the natural salmon run through the construction of hatcheries rather than by treating effluent or developing better management practices.

Strong sustainability would involve the implementation of the precautionary principle. Constant capital would be maintained through ambient water quality standards which could be enforced through permit trading, permits or technology-based effluent standards. The safe minimum standard would be affected by primary and secondary valuation of the environment. Conservation zoning may be undertaken to protect areas of higher sensitivity. This 'layering' methodology would apply water quality criteria at a more local level and consider impacts in the initial dilution zone and impacts from non-point sources.

Thermodynamic sustainability reflects a biocentric viewpoint. Cost-benefit analysis would be abandoned and the highest level of treatment would be adopted. If the highest level of treatment is not affordable, population and economic growth would be restricted and very strong effluent and operational standards would be enforced. Emphasis would be placed on the long-term accumulation of contaminants when developing ambient water quality standards and effluent permits. Water quality standards would not need to be developed for individual locations.

The highest level of treatment would be required at all locations. The emphasis for water quality management would shift from an end of the pipe approach toward a more holistic approach.

The management policies outlined in Table 2.1 are those typical to each sustainability world view. It must be emphasised that these policies represent typical management policies and are not specific to individual world views. For example, pollution taxes could be used to achieve either weak or strong sustainability objectives depending on the degree of taxation and the threshold level of implementation.

Table 2.1: Summary Table of Sustainability Practice

Sustainability Mode (overlapping categories)	**Management strategy (as applied to projects, policy or course of action)**	**Policy instruments (most favoured)**
Very Weak Sustainability	conventional Cost-Benefit Approach: Correction of market and intervention failures via efficiency pricing; potential Pareto criterion (hypothetical compensation); infinite substitution.	e.g. pollution taxes, elimination of subsidies, imposition of property rights
Weak Sustainability	Modified Cost-Benefit Approach: Extended application of monetary valuation methods; actual compensation, shadow projects, etc.; systems approach, 'weak' version of safe minimum standard	e.g. pollution taxes, permits, deposit-refunds, ambient targets
Strong Sustainability	Fixed Standards Approach: Precautionary principle, primary and secondary value of natural capital; constant natural capital rule, social preference value; 'strong' version of safe minimum standard	e.g. ambient standards; conservation zoning; process technology-based effluent standards; permits; severance taxes; assurance bonds
Thermodynamic Sustainability	Abandonment of Cost-Benefit Analysis: severely constrained cost-effective analysis; bioethics	standards and regulation; birth licences

Adapted from: R.K. Turner (1993)

2.4 Water Quality Management Strategies in British Columbia

Several water quality management strategies are in use in British Columbia. These operate with different objectives and within different paradigms. The water pollution legislation and associated policy instruments are discussed and compared to the sustainability policies outlined in Table 2.1.

2.4.1 Fisheries Act

The Fisheries Act sets standards for effluent discharges to rivers and oceans in the absence of local legislation. The primary Section of the Fisheries Act which applies to the discharge of municipal wastes to receiving waters is Section 50 (Fisheries Act, 1996) which states:

> (1) Subject to subsection (2), no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish …
>
> (2) No person contravenes subsection (1) by depositing or permitting the deposit in any water or place of
>
> > a) any waste or pollutant of a type, in a quantity and under conditions authorised by regulations applicable to the waters or place made by the Governor in Council under any Act other than this Act…

The wording of this Act as it is presented here suggests a Strong Sustainability world view. A deleterious substance is defined as:

> … any water that contains a substance in such quantity or concentration…that it would if added to any other water, degrade, alter or form part of a process of degradation or alteration of the quality of that other water so that the other water is rendered or is likely to be rendered deleterious to fish or fish habitat…

However, substances. which may be described as deleterious, are allowed to be discharged if they are permitted. Therefore, the Fisheries Act does not solely represent a strong sustainability approach to water quality management.

The Act does not overtly allow for a mixing zone, however it does suggest that the dilution and assimilative capacity of the receiving water should be used. Therefore, it does not represent the Thermodynamic Sustainability world view. The Act is designed to maintain water quality at the point where it does not impact on fish. The regulations do not allow for the deterioration of fish habitat to the point where the loss of productivity of the fishery is greater than the cost of mitigation. Therefore, the Fisheries Act represents a Strong Sustainability world view. The Act also stipulates that a deleterious substance may be released in accordance with local regulations. The BC regulations governing the release of effluent are discussed below.

2.4.2 Ambient Water Quality Guidelines

Table 2.1 illustrates that ambient water quality objectives may be used in both strong and weak sustainability world views. The CCREM has developed ambient water quality guidelines for 5 different water uses:

1. drinking, public water supply and food processing,
2. aquatic life and wildlife,
3. agriculture,
4. recreation and aesthetics, and
5. industrial.

The guidelines are not specific to individual water bodies, but represent typical values for the preservation of each water use. Guidelines differ from Regulations in that guidelines can not be legally enforced. The guidelines represent several world views. The criteria are anthropocentric in their objectives. Aquatic life and wildlife are primarily protected for their economic value, otherwise all water bodies would have at least that level of water quality. They are also not sensitive to local variation in ambient water quality. Therefore, in areas with pristine water quality, they may represent a weak sustainability world view. Conversely, in locations with *naturally* high concentrations of 'pollutants' the guidelines may represent a strong sustainability world view.

2.4.3 Water Quality Objectives

Ambient water quality objectives have been developed for the Fraser River Basin by the BCMOE and are outlined in Swain and Walton, 1985. Ambient water quality objectives are similar to ambient water quality guidelines, however, they are specific to individual water bodies. Ambient water quality objectives vary depending on the water body, the species considered and the life stage of the species in question. The guidelines may vary throughout the year to accommodate changes in the water quality due to flow. This approach suggests a stronger sustainability world view than the CCREM guidelines because the standards are based on local knowledge of the water body.

2.4.4 Pollution Control Objectives

In 1970, the British Columbia Pollution Control Board initiated a process to establish pollution control guidelines under the Pollution Control Act for the major industries in the province (Dorcey et al, 1991). The Pollution Control Board established a range of guidelines for five types of industrial activity:

1. Forest Products Industry (1971, updated 1977)

2. Chemical and Petroleum Industries (1973, replaced 1979)
3. Mining Smelting and Related Industries (1973, replaced 1979)
4. Food Processing, Agriculturally Oriented and Other Miscellaneous Industries (1975)
5. Municipal Type Discharges (1975)

The Pollution Control Objectives for Municipal Type Waste Discharges (Department of Lands, Forest and Water Resources, 1975) state that 'the assimilative capacity of the environment may be used within limits without causing unacceptable conditions'. The Objectives state 'the capacity of receiving waters to assimilate wastes is a renewable resource…' The Municipal Objectives also stipulate the allowance of an 'Initial Dilution Zone' (IDZ) -

> It is recognised that the RECEIVING WATER quality objectives listed herein will not likely be satisfied in the immediate vicinity of the point of an effluent discharge. An INITIAL DILUTION ZONE is therefore defined in terms of a distance from the point of discharge…in the case of streams and rivers, in terms of both a distance downstream from a diffuser and a fraction of the cross-sectional area of the stream or river at the diffuser. This definition precludes extension of a diffusion system completely across a river or stream bed, thereby providing for relatively safe passage of aquatic life past the point of discharge.

The IDZ is an area lost to productivity, but is deemed an acceptable cost by the Objectives suggesting Weak Sustainability. There are also requirements for 'Effluent Quality', 'Parameters That May be of Concern' and 'Receiving Water Quality' suggesting a stronger version of sustainability than is represented by just the allowance of an IDZ.

The 'Effluent Quality Objectives', relating effluent quality to dilution capacity, (Appendix A), are risk-based Objectives and vary according to the type of system (rivers, lakes, marine). The Effluent Quality Objectives reflect a variety of world views. There is an allowance for an IDZ which is the acceptable area of lost productivity suggesting Weak Sustainability. However, the regulations do not go as far as to stipulate that the loss in environmental productivity must not exceed the cost of mitigation. This suggests the policy lies somewhere between Weak and Strong Sustainability

The 'Limits for Effluent Parameters That may be of Concern', (Appendix B), are not scaled according to either the type or the dilution capacity of the receiving water. These regulations are technology-based. They may represent differing world views depending on the dilution capacity of the receiving water. Strong sustainability would be represented in systems with a high dilution capacity (resulting in lower ambient concentrations) and Weak sustainability would be represented in systems with a low dilution capacity (resulting in higher ambient concentrations). This demonstrates that several world views may be represented by a single policy instrument.

The 'Receiving Water Quality Maintenance Objectives', (Appendix C), are based on the critical load concept. The pollutant loading must be kept below the level which exhibits the effect outlined in the Objectives. This may represent both Strong and Weak Sustainability world views depending on the sensitivity of the system and the severity of the Objectives. The allowance of an IDZ suggests the Objectives lean toward a Weak Sustainability world view. However, the Objectives limit the loss in productivity to the IDZ and economic trade-offs between mitigation and productivity are not discussed. Therefore, this policy also represents a combination of Weak and Strong Sustainability world views.

There is a stipulation that a site specific environmental assessment must be carried out for municipal discharges over 1,000,000 GPD. This is a risk-based approach. The Objectives infer that an environmental assessment would result in more stringent pollution control measures being required in cases of large discharges. However, the wording of the Objectives do not eliminate the possibility of less stringent discharge control measures being enforced.

2.4.5 Permit Pricing

Effluent discharge licences are permitted and the permit fees go into the Sustainable Environment Fund. This fund is used to run 'shadow projects' such as managing the disposal of lead-acid batteries. Shadow projects are designed to indirectly offset the damage created by an activity by improving management or disposal in another activity. Discharge licenses do not account for a large proportion of the operating costs of firms in British Columbia and consequently there is not much incentive to reduce discharges. Low licensing fees, combined with shadow projects suggest a weak sustainability approach to effluent permits.

There are also permit fees for water withdrawal. The fee levels for the withdrawal permits are relatively cheap and Pearce and Tate, 1991, argue that water fees are a very small proportion of total industry production costs. The fees go into the governments general operating fund and not into an environmental fund. Moreover, low permit fees are not designed to alter behaviour, but to raise revenue. Therefore, this policy is represents a weak sustainability world view.

2.5 Summary of Regulatory Approaches

The regulations governing the disposal of effluent in British Columbia appear to reflect both Weak and Strong Sustainability world views. None of the regulations appeared to represent a Thermodynamic approach to sustainability. The regulatory approaches also reflect a variety of approaches to risk management. Lave and Malès, 1989, summarised the regulatory approaches which could be taken to achieve different levels of sustainability and risk. Their findings, along with the regulatory approaches in British Columbia are summarised in Table 2.2. Policies in British Columbia are not exclusive to individual world views and levels of risk-reduction. The Pollution Control Objectives outline ambient water quality objectives which are based on a perceived level of acceptable risk, however, the Pollution Control Objectives also outline effluent quality standards suggesting technology based requirements.

Table 2.2: Summary of Regulatory Approaches

<table>
<tr><th>Regulatory Approach</th><th>BC Regulation</th><th>Sustainability World View</th><th>Economic Efficiency</th><th>Equity</th><th>Administrative Simplicity</th><th>Risk Reduction</th></tr>
<tr><td>No-Risk</td><td></td><td>Thermodynamic</td><td>very low</td><td>very high</td><td>high</td><td>very high</td></tr>
<tr><td rowspan="4">Risk-based (regulations)</td><td>Pollution Control Objectives</td><td rowspan="4">Strong/Weak</td><td rowspan="4">low</td><td rowspan="4">high</td><td rowspan="4">high</td><td rowspan="4">high</td></tr>
<tr><td>Water Quality Objectives</td></tr>
<tr><td>Ambient Water Quality Guidelines</td></tr>
<tr><td>Fisheries Act</td></tr>
<tr><td>Technology-based (regulations)</td><td>Pollution Control Objectives</td><td>Strong/Weak</td><td>very low</td><td>low</td><td>very high</td><td>high</td></tr>
<tr><td>Cost-Benefit Analysis</td><td></td><td>Weak</td><td>very high</td><td>low</td><td>low</td><td>low</td></tr>
<tr><td>Economic Incentives</td><td>Discharge Permits</td><td>Weak/ Very Weak</td><td>very high</td><td>low</td><td>low</td><td>high</td></tr>
</table>

Source: Adapted from Lave and Malès (1989)

The regulations governing effluent discharges in British Columbia appear to provide high levels of risk reduction with a high level of equity. However, economic efficiency appears to have been sacrificed to maintain this high level of risk-reduction. A very high level of economic efficiency would be achieved by using a cost benefit approach to justify the construction of environmental mitigation projects. Extensive research is required in environmental impact assessments to demonstrate that proposed development projects will be environmentally acceptable. A similar approach could be taken for environmental mitigation projects, such as sewage treatment plants. It would have to be demonstrated that mitigation projects would result in enough environmental improvement to justify the cost. This Weak approach to Sustainability appears to makes sense economically, however, individuals probably would not like to see a degraded environment solely in the name of economic efficiency.

In terms of economic efficiency, risk-based regulations lie between the cost-benefit approach and technology-based regulations. Secondary sewage treatment is not universally required throughout the province suggesting a risk-based approach. However, the Annacis Island and Lulu Island STPs are being upgraded despite preliminary studies which suggested that water quality impacts may be acceptable at the current level of treatment (GVRD 1988). The decision to upgrade the STPs appears to be based on the Pollution Control Objectives governing effluent quality which is a technology based regulation. Interpolating from Table 2.2 it is found that this approach results in a low to very low economic efficiency. Higher economic efficiency could be achieved if the province had conducted an environmental risk assessment of the Annacis and Lulu Island STP discharges to determine whether environmental risks were high enough to warrant the upgrade of the STPs.

Was the $600 million spent on the project warranted or could it have been more effectively spent somewhere else? Environmental risk assessments may be a more effective way for the government to minimise risk and economic cost. This shift toward risk-based regulation need not be universal, however, it does seem warranted for large environmental mitigation projects given their high cost. Chapter 3 outlines an approach to determine the water quality of different futures in the lower Fraser Basin. The outcomes of the water quality model could be used to determine whether the improvement in water quality is worth the cost of the upgrade. Management strategies based on environmental risk rather than technology could be more effective at maintaining acceptable environmental quality at reduced cost.

3. Scenario Development

Future water quality may be evaluated to determine whether the STP upgrades are required. The GVRD LWMP (1988) estimated that current levels of treatment would be sufficient to maintain acceptable water quality through 2030. However, the LWMP only evaluated a single population growth scenario and ignored future water quality impacts from industry and urban runoff. There is uncertainty regarding future population growth and impacts from other sources. The GVRD LWMP anticipated a 'most probable' population scenario of 992,000 in 2036 for the Fraser Sewerage Area. This may be compared to the current GVRD population forecast for the Fraser Sewerage Area of 1.5 million in 2021. The future population of the GVRD can not be accurately determined. However, sensitivity checks may be performed to assess whether higher levels of population growth will result in unacceptable water quality. Other sources of water pollution may also be evaluated to determine whether future loading will affect water quality enough to necessitate the upgrade. There are five sources of pollutants which may be evaluated:

1. Industrial discharges
2. Municipal wastewater (**STP's**)
3. Urban runoff
4. Combined Sewer overflows (**CSO's**)
5. Agricultural waste

It is assumed that pollutant loading from CSO's will not increase dramatically because combined sewers are no longer constructed in the lower mainland. Agriculture runoff is not considered in this investigation because the fate of many agricultural pollutants is seepage to ground water.

Industrial discharges are related to economic activity in the LFB. Each industry has a characteristic level of discharge per unit of output. Using this data it is possible to predict what the total discharge will be for a hypothetical economy in the future. Loading to STP's is dependent on population growth in the basin. Each person has a characteristic unit loading factor for each type of contaminant. Land use affects urban runoff. Each urban land use has a characteristic runoff coefficient which affects hydraulic and pollutant loading. Sensitivity checks can be run with different levels of population growth, economic development and land use changes to determine if different futures are likely to affect decisions regarding water quality.

Decisions must often be made many years before a problem is evident to ensure that there is enough time for construction and political approval before the water quality deteriorates to an unacceptable level. Scenario development gives an idea of the water quality outcomes of different development paths. The development of possible future scenarios is discussed in detail in the following sections.

3.1 Industrial Discharges

Evaluating future scenarios requires that we know current levels of pollutant loading from industry. It is possible to determine pollutant loading through monitoring, however, due to the expense, very little monitoring has been performed and actual pollutant loading for specific industries is not known (Dorcey, 1991). Alternatively, pollutant loading from industry may be estimated from the maximum concentrations given in the discharge permits. It is likely that this would lead to an inflated estimate of some pollutants because firms are generally below their discharge limits (Westwater Research Centre, 1994). On the other hand, discharge permits do not give limits for all pollutants that are in the waste stream, therefore, there would be an underestimation of these pollutants. Pollutant loading calculated from direct discharge permits may not differentiate between manufacturing, service industry and domestic discharges. Direct discharges are often referred to as industrial discharges. In fact, many of these discharges are domestic discharges. This may lead to an inflated estimate of the level of industrial discharges.

Alternatively, satellite discharges accounts may be used to determine the effect of future levels of economic activity. Satellite discharge accounts describe discharges per dollar of output for each industry. This may be used to predict discharges due to future levels of economic activity. Two approaches to attaching satellite emissions accounts to economic activity are described below.

Lave et al. (1994) used Input/ Output analysis to determine economy wide increases in air emissions as a result of activity increases in different drinking container industries. Lave et al. assigned a characteristic level of emissions per dollar by dividing the emissions listed in the Toxic Registries Index (TRI) by the GDP for each industry. Both the TRI and the GDP list industries by SIC making comparisons possible. The National Pollutant Registries Index (NPRI) is the Canadian equivalent to the American TRI. Both databases only include operations that emitted more than 10,000 kg of any listed substance. This eliminates the vast majority of small plants operating in the LFB. Both databases also rely on plant managers to estimate the level of emissions for each industry. The level at which substances must be reported does not vary depending on the toxicity of the substance. Hypothetically, a plant emitting 10,000 kg of methanol would have to report the discharge, however, a plant emitting 9,999 kg of highly toxic 2,3,7,8 tetra chloro dibenzo dioxin would not report the discharge to the NPRI database. The NPRI and TRI databases are also limited in that many pollutants of concern are unreported. The two databases focus on highly toxic pollutants and do not consider pollutants such as phosphorus, BOD and suspended solids. These pollutants are of great concern when developing a regional water quality management plan, therefore these data sources are of limited value. The NPRI data is useful to a certain extent when attempting to determine national economy wide trends in discharges as a result of increases in the activity of specific industries.

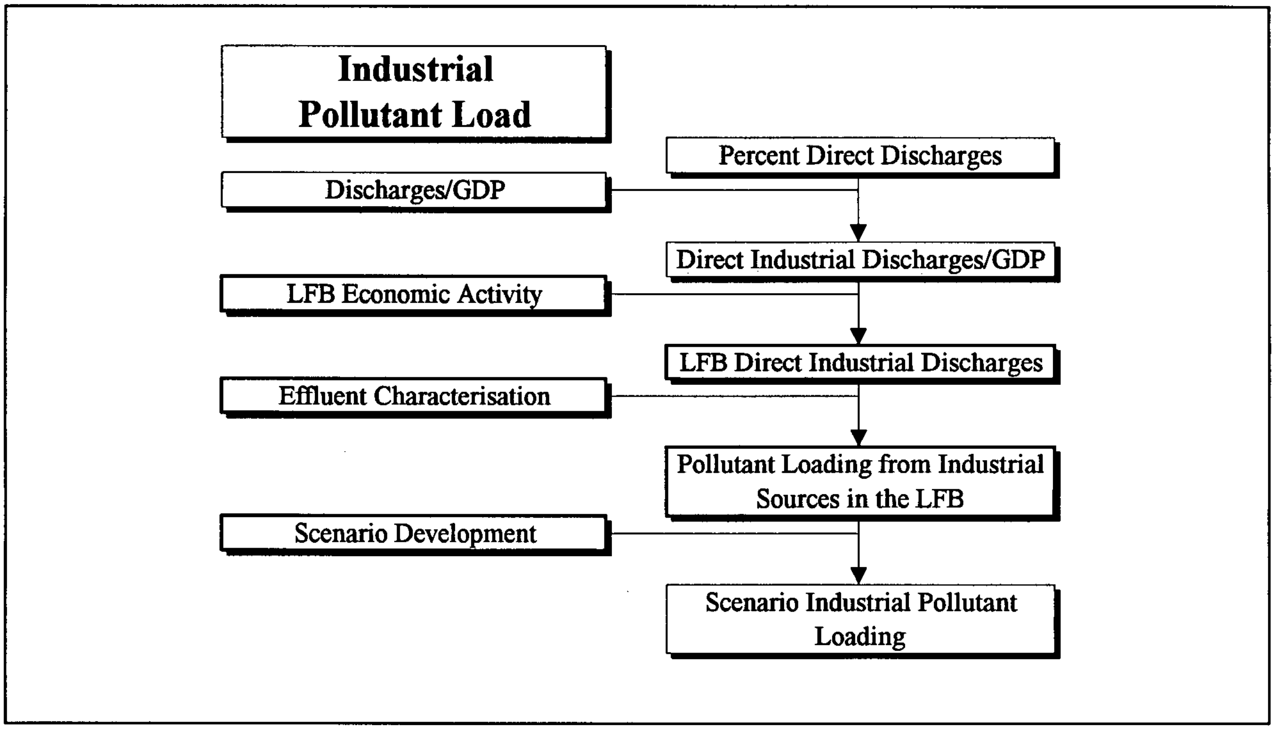
Lonergan et al, 1995 used satellite accounts and deterministic modelling to determine future levels of emissions as a result of changes in economic activity in British Columbia. Lonergan, 1995 assigned satellite air emissions based on the data provided by the Air Quality Branch of BCMOE. The data is contained in the PERFICT database. Economic futures for the Fraser Basin were created using an input/ output table. The increases in pollutant discharges as a result of increased economic activity were determined using the satellite emissions accounts. The approach is similar to that being taken here, however, water discharges are being considered and the study area is only the Lower Fraser Basin. Input/ output analysis was not used for several reasons. The technical coefficients between industries do not change in Input/ Output analysis, thus limiting the ability of the table to adapt to technology changes. The table was also designed for the entire province although Lonergan used it at the Fraser Basin level.

Both methods described above were developed to determine air emissions. The satellite account methodology had to be developed to evaluate wastewater discharges. Satellite accounts easily adjust for relative changes in the economic activity of different sectors, however, they are complicated by several factors.

1. The existence of direct and indirect discharges
2. Changes in technology and changes within individual Standard Industrial Codes (SICs)
3. Effluent characterisation
4. Spatial distribution of the discharges

The process to determine scenario industrial pollutant load is outlined in Figure 3.1.

Figure 3.1: Determination of Industrial Pollutant Load



3.1.1 Direct vs. Indirect Industrial Discharges:

Industries may discharge directly to receiving water bodies or indirectly via municipal STPs. Direct discharges from each industry are determined by multiplying the total discharges by the percent direct discharges. Total industrial discharges are determined by multiplying the industrial activity by the discharge/GDP published by Statistics Canada.

Permitted discharges were used to determine the proportion of direct and indirect discharges for each industrial sector. Information on direct discharging permits is available through the Fraser River Point Source Inventory (FRPSI) (1994). No monitoring data is provided, but maximum flow and maximum pollutant concentrations are given. The GVRD licences discharges to sewer (indirect discharges to the Fraser River) as part of its source control program. The permits are assigned by sewerage district and contain information on the level of flow and the type of industry. The permitted flows for each industry for the direct and indirect discharges are outlined in Table 3.1 (Greater Vancouver Sewerage and Drainage District, 1995). Some sectors discharge a higher percentage of their waste to sewer than others. Therefore, increases in these sectors would have less impact on direct discharges than increases in industrial sectors with a higher percentage of direct emissions.

This exercise illustrates how industrial discharges to the Fraser River may be underestimated. Data on industrial discharges to the Fraser River in the past have not taken indirect discharges into consideration (Hall, 1991). Table 3.2 shows the significance of adjusting sewage discharges to account for the industrial contribution. The discharges are adjusted by subtracting indirect industrial discharges from the municipal sewage treatment plant column and adding it to the industrial discharges column. Industrial discharges calculated in this method are significantly larger than often quoted by conventional estimates of industrial discharges.

Table 3.1:Permitted Direct and Indirect Discharges

Industry	SIC	Indirect Discharges (m^3/day)	Direct Discharges (m^3/day)	% Indirect	% Direct
Fish processing and Food	10	46788	52095	47.3%	52.7%
Beverage	11	22635	0	100%	0.0%
Plastics	16	350	0	100%	0.0%
Textiles and clothing	19,24	1170	0	100%	0.0%
Wood and wood products	25	1200	5812	17.1%	82.9%
Paper and allied products	27	25050	21828	53.4%	46.6%
Metal and metal products	29,30	5820	53150	9.9%	90.1%
Electronics	33	860	0	100%	0.0%
Non-metallic mineral	35	235	25132	0.9%	99.1%
Refined Petroleum and coal	36	9500	1810	84.0%	16.0%
Chemical products industries	37	694	45620	1.5%	98.5%
Other Manufacturing	39	415	2	99.5%	0.5%
***Municipal Discharges**		8655	871379	1.0%	99.0%
Total Permitted Manufacturing Discharges		114717	205449	35.8%	64.2%
Total Permitted Municipal Discharges		8655	871379	1.0%	99.0%
Total Permitted Discharges		123372	1076828	10.3%	89.7%

Note the Indirect discharge data also includes 30,000 m^3/day of discharges from Iona Island STP which does not discharge into the Fraser River.

*Direct municipal discharges are provincially permitted discharges to the Fraser River. Indirect municipal discharges are permitted municipal discharges to sewer including landfill leachate.

Table 3.2: Discharges, Corrected for Direct and Indirect Discharges

	Municipal Sewage Discharges (m^3/day)	Industrial Discharges (m^3/day)	STPs (% of total)	Industrial (% of total)
***Unadjusted**	871,379	205,449	80.1%	19.8%
****Adjusted**	756,662	320,166	70.3%	29.7%

*Unadjusted sewage discharges = Direct permitted sewage discharges
*Unadjusted industrial discharges = Direct permitted industrial discharges
**Adjusted sewage discharges = Direct permitted sewage discharge - indirect permitted industrial discharges
**Adjusted industrial discharges = Direct plus indirect permitted industrial discharges

Resource extraction, wood and wood products, metal and metal products, non-metallic mineral, chemical industries and non-manufacturing industries have much more significant direct than indirect discharges. Therefore, increases in the activity of these industries will have a more significant impact on direct discharges than increases in other industries. Industries such as fish processing and food, wood and paper and service industries are almost evenly split between direct and indirect discharges. Beverage industries and refined petroleum and coal were found to have much higher indirect than direct discharges. Future discharges in all sectors will be split by the current percentages of direct and indirect discharges. The direct discharges are considered here and the indirect discharges are captured by the characteristic unit loading values discussed in section 3.2.2.

3.1.2 Economic activity in the LFB

Economic activity for the LFB must be assessed to determine local discharges to the Fraser River. Economic activity of individual industries in the LFB is not directly available, however total economic activity in the LFB is known. A possible method of determining the economic activity of each industry in the LFB is to multiply the provincial level of activity for each industry by ratio of total economic activities of the LFB/BC. However, this is unacceptable because some industries are represented to a greater or lesser degree in the LFB than for the entire province.

The ratio of employment for the LFB/B.C for each industry multiplied by the provincial GDP was used to calculate the basin's economic activity. This is illustrated in Equation 3.1.

Equation 3.1: Basin GDP_{sector}

$$(\text{Basin GDP})_{\text{sector}} = \left(\frac{\text{LFB Sectoral Employment}}{\text{Provincial Sectoral Employment}}\right) \times (\text{Provincial GDP})_{\text{sector}}$$

It was assumed that GDP/employee is constant for each industry throughout the province. Table 3.3 shows the change in economic activity, (GDP at Factor Cost), for manufacturing industries in British Columbia from 1984 through 1993, (CANSIM, 1996). This shift has occurred in only 9 years. Future industrial scenarios must be sensitive to growth in specific industrial sectors. This is why the satellite accounts methodology was chosen to assess future industrial discharges.

This method of determining sectoral activity in the LFB allows a better estimation of the activity level of each industry in the basin. One can see that relatively few people work in paper and allied products industries in the LFB relative to the province, but that employment in electronic industries is nearly 100% of the provincial total. Table 3.4 shows the calculated value for GDP in the LFB by manufacturing sector. Sectoral employment data was obtained from BCSTATS at the provincial and basin level. LFB employment data for chemical and chemical products industries and refined petroleum and coal industries had to be derived from the FIRM's database developed by Contacts Target Marketing. The data is probably somewhat less reliable than the BCSTATS data as it was carried under a different survey methodology.

Table 3.3: Changes in activity in major manufacturing sectors in British Columbia 1984 vs. 1993

Sector	SIC	1984 ($\$10^6$)	1993 ($\$10^6$)	Percent Change
Food	10	751	741	-1.5
Beverage	11	196	161	-18.2
Plastics	16	80	131	63.4
Primary textile	19	35	48	34.3
Clothing	24	69	97	41.3
Wood industries	25	1772	2431	37.1
Furniture	26	48	64	34.4
Paper	27	1282	1368	6.7
Printing & publishing	28	339	375	10.6
Primary metal	29	397	468	17.7
Fabricated metal	30	363	520	43.2
Machinery	31	197	200	1.4
Transportation equipment	32	317	272	-14.2
Electrical	33	123	262	114.1
Non-metallic mineral	35	228	282	24.0
Petroleum and coal	36	211	215	2.2
Chemical	37	237	230	-2.8
TOTAL		6761	7986	18.0

Note: All Activity levels are given in 1991 constant dollars

Statistics Canada has compiled characteristic water discharge data for industrial sectors (Statscan, 1995). The Statscan data for industrial discharge was used instead of permitted discharges. This should give a more accurate representation of the level of direct industrial discharges than is provided by the discharge permits. Statistics Canada discusses some of the limitations on data accuracy and state that the data is generally 'adequate', but that it may be significantly out of date for fabricated metal, machinery, transportation equipment, electrical and 'other' industries. This estimate of water use is not exact, but it should give a more accurate representation of actual industrial discharges than simply using permitted levels. Table 3.5 shows the direct discharges of aggregated economic sectors in the LFB.

Table 3.4: LFB Manufacturing GDP

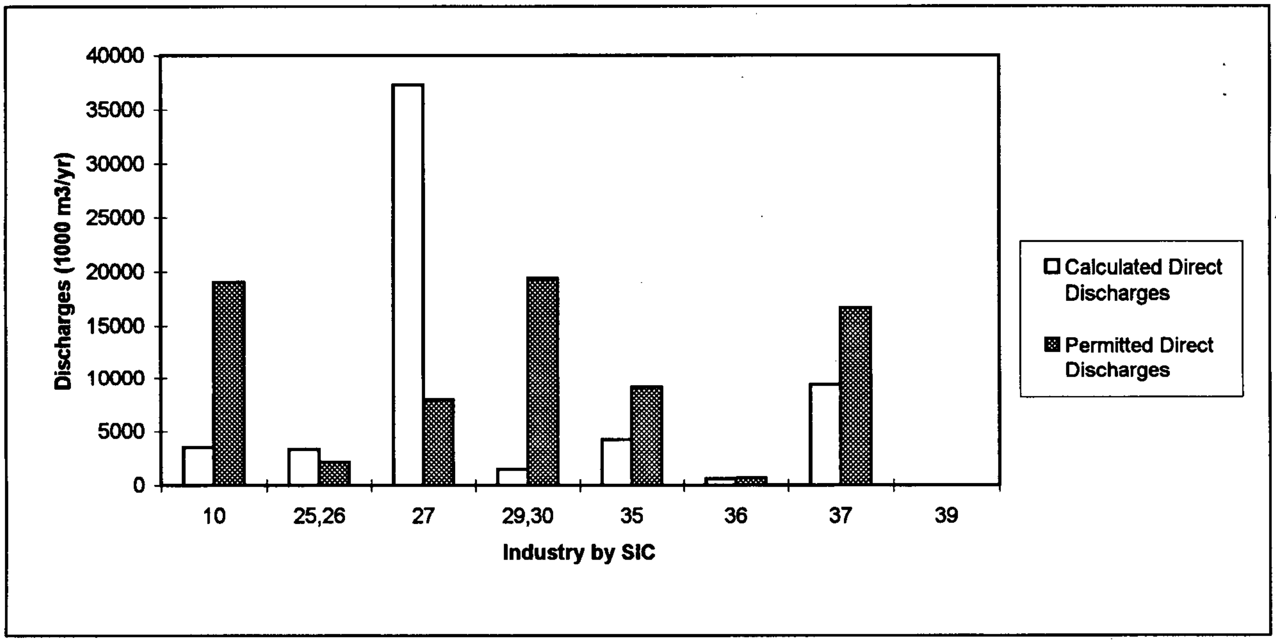
Sector	SIC	1986 Employment LFB	1986 Employment BC	1986 Employment LFB (% of BC)	1991 GDP Provincial ($\$10^6$)	1991 GDP LFB ($\$10^6$)
Food	10	10,977	12,225	89.8%	893.1	802
Beverage	11	1652	2,119	78.0%	201.2	157
Plastics	16	1,769	2,107	84.0%	142.9	120
Primary textile	19	807	886	91.1%	52.7	48
Clothing	24	3,041	3,041	100.0%	121	121
Wood industries	25	12,104	34,498	35.1%	2,592.6	910
Furniture	26	1,770	1,918	92.3%	78.0	72
Paper and Allied Products	27	3,167	8,408	37.7%	1,676.4	632
Printing & publishing	28	6,576	8,618	76.3%	487.5	372
Fabricated metal	30	6,285	7,714	81.5%	581.7	474
Machinery	31	3,583	3,738	95.9%	242.1	232
Transportation equipment	32	3,550	5,849	60.7%	383.2	233
Electrical	33	3,991	4,055	98.4%	263.5	260
Non-metallic mineral	35	2,005	2,632	76.2%	367.6	280
Refined Petroleum and Coal	36	834	1,827	45.6%	344.6	157
Chemical Products	37	1,810	3,041	59.5%	299.2	178
Other	39	5,291	24,076	22.0%	671.6	148
Total		69,212	126,752	54.6%	9,397.6	5,197

Table 3.5: Direct Industrial Discharges

Industry	SIC	1991 LFB GDP ($\$10^6$)	Discharge/GDP (Statscan 1995) ($m^3/\$10^3$)	Total Discharge (1,000 m^3/year)	Percent Direct Discharge	Direct Discharges (1,000 m^3/ year)
Fish processing and Food	10	802	8.3	6,656	52.7%	3,507
Beverage	11	157	10.6	1,660	0.0%	0
Plastics	16	120	9.3	1,118	0.0%	0
Textiles and clothing	19,24	169	13.0	2,187	0.0%	0
Wood and wood products	25,26	982	4.1	4,014	82.9%	3,327
Paper and allied products	27	632	126.6	80,039	46.6%	37,269
Metal and metal products	29,30	474	3.5	1,660	90.1%	1,496
Electronics	33	260	1.2	312	0.0%	0
Non-metallic mineral	35	280	15.1	4,232	99.1%	4,192
Refined Petroleum and coal	36	157	23.1	3,636	16.0%	582
Chemical products industries	37	178	53.6	9,557	98.5%	9,414
Other Manufacturing	28,31 32,39	985	1.5	1,525	0.5%	7

Figure 3.2 illustrates that the calculated level of discharge was lower than the permitted level for most industries, however there is one anomaly which must be explained. SIC code 27 has higher calculated direct discharges than permitted. This is most likely due to the wide range of industries in the SIC code. SIC code 27 is for paper and allied products which includes pulp mills. Pulp mills are highly water intensive and there are not any in the LFB. The assumption regarding employment being directly related to discharges may also be incorrect. Many industries have head offices in the Lower Mainland. Therefore, a lot of this employment is not directly related to production and therefore would lead to inflated estimates of discharges. Therefore, direct discharges/GDP for SIC code 27 were assumed to be the permitted level of discharge rather than the calculated level. SIC code 39 has higher calculated discharges than permitted discharges. The level of discharge is relatively small and the discrepancy is likely due to large numbers of small indirect discharges which are not permitted. Flows under 5 m^3/day are not required to have permits (Alistair Moore, GVS&DD, 1995).

Figure 3.2: Calculated and Permitted Discharges by SIC



Direct discharges/GDP were calculated based on the calculated level of discharge rather than on the permitted level of discharge for all sectors except paper and allied industries, (SIC 27). Direct discharges/GDP are shown in Table 3.6. These values can be used to determine the future level of discharge resulting from an increase in economic activity for a specific sector assuming a constant split between direct and indirect discharges.

Table 3.6: Manufacturing Industries Direct Discharges/GDP

Industry	Fish processing and Food	Textiles and clothing	Wood and wood products	Paper and allied products	Metal and metal products	Non-metallic mineral	Refined Petroleum and coal	Chemical products industries	Other
SIC	10	19,24	25,26	27	29,30	35	36	37	28,31 32,39
Direct Discharge/ GDP (m^3/ 1,000$)	4.4	0.0	3.4	13.0	3.2	15.0	3.7	52.8	0.01

This method of allotting direct discharges can be used to predict trends in water quality as a result of changes in the industrial composition of the LFB. The industries represented and the ratio of direct/indirect discharges are specific to the LFB. Direct discharges/GDP would have to be calculated for each study area of interest. It is impossible to predict exact future levels of wastewater discharges due to several factors:

- The direct/indirect split may not remain the same
- The industries in the LFB may not be representative of the entire SIC code
- There is very little spatial resolution
- Characteristic water use/GDP may change

However, this method may be used to give a more accurate idea of industrial discharges to the Fraser River than simply calculating pollutant loading from direct permitted discharges. The characteristic discharges, discussed in Section 3.1.3, may also be varied to allow for technological innovation or a shift in the composition of industries in specific SIC codes.

3.1.3 Effluent Characterisation.

The direct discharges per unit of economic activity were discussed in section 3.1.2. The discharges per unit of economic activity must be multiplied by the characteristic pollutant concentration for each industry. Characteristic pollutant concentrations were determined for each SIC code from a limited number of published detailed effluent characteristics, DOE FRAP (1994-09), DOE FRAP (1994-13), DOE FRAP (1993-05), DOE FRAP (1993-06), DOE FRAP (1993-08). The published data varied in parameters measured and the proportion of the SIC code represented by detailed study. Pollutant concentrations varied dramatically within individual SIC codes. This reflects the variety of industries and processes used within a specific SIC code. For example, SIC code 25 represents wood and wood products industries which encompasses sawmills and chemical wood treatment facilities. There are significant differences in the pollutant characteristics of these effluents. The characteristic contaminant concentrations were calculated using literature values for pollutant concentrations of a cross-section of the industries present in the LFB. The effluent characterisations are outlined in Appendix D. Effluent Characterisations were only performed for large direct discharging industries. Direct discharges from both Refined Petroleum Products and Coal (SIC 36) and Other Manufacturing Industries (SIC 39) are small compared with other industries and therefore were not characterised. The pollutant loading for each scenario may be calculated by Equation 3.2

The pollutant loading data was limited by several factors. Not all of the pollutants of interest were analysed or detection limits were too high making loading estimates impossible. Many of the studies only considered parameters which were included in the discharge permits or pollutants which are specific to the individual plant. The pollutant concentrations for each SIC are an average of representative firms. Calculated pollutant loadings are intended as an estimate to illustrate trends and may give levels of discharge higher or lower than actual discharges.

Equation 3.2: Pollutant Loading $_{sector}$

$$(\text{Pollutant Loading})_{sector} = (\text{Water Use / GDP})_{sector} \times (\text{Characteristic pollutant concentration})_{sector} \times \text{GDP}_{sector}$$

3.1.4 Future Economic Activity in the LFB

Future economic activity may be estimated in a number of ways. Industrial growth may be assumed to be uniform across sectors. Sectoral growth may also be based on historic trends or economic forecasts. Alternatively, other 'intuitive' scenarios may be evaluated. Scenarios I_1 and I_2 were based on trends in economic growth. Scenario I_3 was designed to simulate an economic boom. This would simulate a possible 'worst case' scenario for water quality due to manufacturing economic growth. This provides a margin of safety by evaluating scenarios with more serious consequences than the most probable scenarios. The scenarios are described in greater detail below.

***Scenario I_1*:**	Manufacturing economic activity is assumed to grow at the same rate that it did between 1984 and 1994 in each sector.

***Scenario I_2*:**	Manufacturing economic activity in each sector is assumed to grow at the economy-wide average growth rate from 1986 to 1994 which was 1.59%.

***Scenario I_3*:**	Growth in high technology and value added industries seems most likely to stimulate high economic growth. The industries which best fall under this category are plastics, textiles, metal finishing, electrical and non-metallic mineral industries and are assumed to grow 5% per year. The growth in non-metallic mineral industries is to accompany construction activity during economic growth. All other industries will be assumed to grow at the overall average for the economy from 1984 to 1994.

A summary of the level of economic activity for direct discharging industries for each scenario in the year 2021 is given in Table 3.7. The discharges were calculated assuming no change in water intensity for individual SICs. 2021 was chosen because it coincides with the GVRD population forecasts in the Liveable Region Strategic Plan. The increase in direct loading from increased industrial activity can be estimated by multiplying the level of activity by the characteristic water usage by the characteristic contaminant concentration for each industry.

Once the level of economic activity has been determined for each scenario, the future level of loading may be calculated using Equation 3.2. The total manufacturing pollutant loading may then be determined and used to evaluate trends in ambient water quality.

Table 3.7: Industrial Activity Scenarios

Sector	Fish Processing and Food	Wood and Wood products	Paper and Allied Products	Metal and Metal Products	Non-metallic mineral	Chemical Products
SIC	**10**	**25,26**	**27**	**29,30**	**35**	**37**
1994 level ($\$10^6$ 1991)	831	1146	674	505	279	184
I_1 Average Annual % Increase	0.28%	1.90%	-0.92%	3.47%	4.22%	0.84%
2021 I_1 ($\$10^6$ 1991)	896	1906	525	1269	849	231
I_2 Average Annual % Increase	1.59%	1.59%	1.59%	1.59%	1.59%	1.59%
2021 I_2 ($\$10^6$ 1991)	1272	1754	1032	773	426	282
I_3 Average Annual % Increase	1.59%	1.59%	1.59%	5.0%	5.0%	1.59%
2021 I_3 ($\$10^6$ 1991)	1272	1754	1032	1884	1040	282

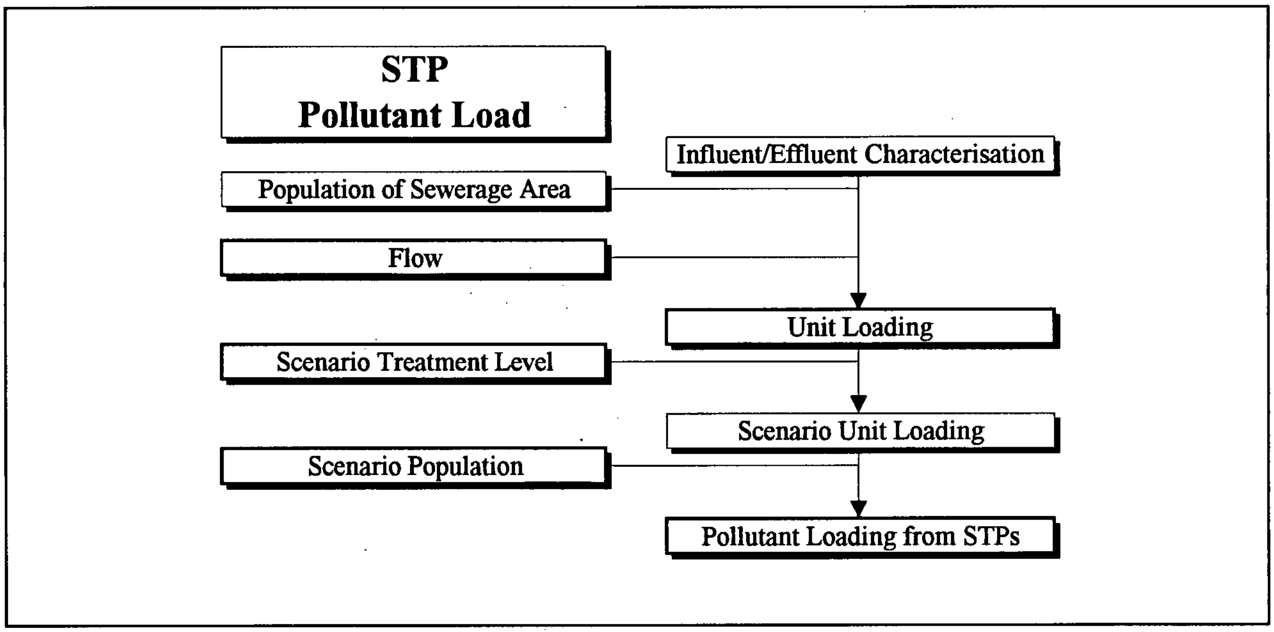
3.2 Sewage Treatment Plants

Pollutant loading from sewage treatment plants is primarily affected by population growth, but it is also influenced by other factors such as:

- land use,
- industrial activity
- Drinking water treatment
- infiltration rate

The GVRD consists primarily of separated sewers, however, some areas have combined sewers. Combined sewers allow urban runoff to enter sewage treatment plants; therefore, changing land use can change pollutant loading. Industrial discharges also affect municipal sewage quality. Even drinking water can affect sewage quality. The low alkalinity and pH of GVRD drinking water dissolves metal pipes and ultimately increases metals loading to the Fraser River. The GVRD is currently in the process of designing drinking water treatment plants. The potential decrease in metals loading should be considered when evaluating potential future impacts on water quality due to sewage treatment plant discharge. Fluctuations in flow, caused by infiltration of rain water during storm events, can affect the performance of secondary treatment plants. Increased flow rates can also inhibit settling of suspended particulates and reduce effluent quality in primary treatment STPs. Although land use, industrial activity, drinking water treatment and infiltration rate all affect sewage treatment plant loading, the primary factor affecting pollutant loading is population. Therefore, future loading levels were evaluated on the basis of population growth. The process used to determine STP pollutant load is outlined in Figure 3.3.

Figure 3.3: Determination of STP Pollutant Load



3.2.1 Population Effects on STP loading

Population is directly correlated to pollutant loading to municipal sewage treatment plants. Contaminant loading from each sewage treatment plant is determined by Equation 3.3.

Equation 3.3: Contaminant Loading

$$\text{Contaminant Loading} = \text{Unit Loading} \times \text{Population} \times \text{Removal Efficiency}$$

This allows decisions, regarding the implementation of waste water treatment technologies, to be made in the context of potential future levels of population in the river basin.

3.2.2 Unit Loading

Unit loading is the characteristic loading of individual pollutants per capita per day to the sewage treatment plants and is calculated by Equation 3.4. Most unit loadings have been relatively constant, however, some unit loadings have decreased and some have increased over the period 1985-1994. This may be attributed to changes in the industrial loading or changes in behaviour. Influent concentrations and unit loads for Annacis Island STP and Lulu Island STP are summarised in Appendix E.

Equation 3.4: Calculation of Unit Loads

$$\text{Unit Load} = \frac{(\text{Flow} \times \text{Pollutant Concentration})}{\text{Population}}$$

Historical industrial activity was reviewed to determined whether changes in unit loading could be attributed to changes in the proportion of industrial wastewater in domestic sewage. It was assumed that the percent indirect discharge remained the same over the period 1986/1994. This is impossible to verify because the GVRD did not start issuing sewer discharge permits until 1991 (Moore, Alistair, 1996). Table 3.9 shows that total industrial activity in the LFB rose approximately 10 percent between 1986 and 1994. However, discharges to sewer decreased four percent. Over the period 1986 to 1994, population grew 25 percent (CANSIM, 1996). Therefore the decline in unit loading of some pollutants may be partially attributable to more rapid population growth than industrial growth.

The total loading of parameters with significant changes in unit loading was also checked to determine if there are significant correlations with increases in specific industries. This may allow some prediction of changes in unit loading for future scenarios. Table 3.8 shows the percent changes in total loading for selected pollutants.

Table 3.8: Change in Unit and Total Loading for Selected Pollutants from 1985 to 1994

Year	Increase in Influent Unit Loading to Annacis Island	Increase in Influent Unit Loading to Lulu Island	Increase in Total Loading to Annacis Island STP	Increase in Total Loading to Lulu Island STP
TKN	8%	-5%	47%	22%
NH_3-N	31%	86%	79%	17%
MBAS	107%	61%	182%	107%
SO_4	-5%	-17%	29%	7%
P_{Total}	-7%	-12%	26%	13%
$P_{Diss.}$	-12%	-13%	20%	12%
O&G	-12%	-2%	19%	25%
Phenol	-19%	46%	10%	87%
Al_{Total}	-49%	-72%	-31%	-64%
Cu_{Total}	-15%	40%	15%	80%
$Cu_{Diss.}$	42%	134%	93%	201%
Fe_{Total}	11%	-28%	52%	-8%
$Fe_{Diss.}$	63%	-18%	121%	6%
Pb_{Total}	-84%	-84%	-78%	-80%
Zn_{Total}	-27%	-56%	-1%	-43%
$Zn_{Diss.}$	-21%	-48%	7%	-33%

Some interesting observations may be made from the two data sets. The most dramatic increases in unit and total loading arose from ammonia, MBAS, and copper. Conversely, the unit and total loading of Al_{Total}, Pb_{Total}, Zn_{Total} and $Zn_{Diss.}$ decreased over the period 1986 to 1994 in both sewerage areas. One might have expected an increase in metals loading to reflect the 31% increase in activity in fabricated metal industries. The department of Source Control at the GVRD has a mandate to evaluate, regulate and control discharges to the District's sewerage and drainage system at source (GVRD, 1995b). Source Control programs may be partially responsible for the decrease in loading of some parameters (Alistair Moore, 1996). It has been suggested that decreases in Pb_{Total} concentrations in storm water in the LFB are attributable to the switch to unleaded gasoline in the last decade (Hall, 1991). Municipal sewage consists of domestic sewage and urban run off. The decrease in Pb_{Total} concentration in urban run off portion may be partially responsible for the decrease in Pb_{Total} loading from municipal STPs.

Increases in loading of $Fe_{Diss.}$, Fe_{Total} and NH_3-N from Annacis Island may partially attributable to leachate from Burns Bog landfill. Burns Bog landfill was connected to the GVRD sewerage system in 1980. Pollutant loading from Burns Bog is summarised in Appendix F. Burns Bog accounts for 8.6 percent of NH_3-N loading to Annacis Island and 6.7 percent of the Fe_{Total} loading.

Table 3.9: Manufacturing GDP for Permitted Industries in BC (Constant 1991 Dollars)

Sector	SIC	1986 LFB Industrial GDP ($1,000,000) ($ 1991)	1994 LFB Industrial GDP ($1,000,000) ($ 1991)	Water Discharges per GDP (m^3/$1000)	Percent Discharge to Sewer	1986 Indirect Discharge (10^3 m^3/year)	1994 Indirect Discharge (10^3 m^3/year)	Percent Increase Indirect Discharges
Fish Processing and Food	10	812.1	830.6	8.3	47%	3188	3261	2%
Beverage	11	189.3	170.8	10.6	100%	2007	1810	-10%
Plastics	16	94	147.3	9.3	100%	874	1370	57%
Textiles and Clothing	19	153.1	189.1	13	100%	1990	2458	24%
Wood and wood products	25	985.1	1145.7	4.1	17%	691	803	16%
Paper and Allied Products	27	725.3	673.8	126.6	53%	49033	45552	-7%
Fabricated Metal	30	384.1	504.8	3.5	10%	133	175	31%
Electrical	33	201.5	366	1.2	100%	242	439	82%
Non-metallic Mineral	35	200.1	278.5	15.1	1%	27	38	39%
Refined Petroleum and Coal	36	120.9	110	23.1	84%	2346	2134	-9%
Chemical Products	37	172.2	184.2	53.6	2%	138	148	7%
Other Manufacturing	28,31 32,39	1012.6	1031.9	1.5	100%	1511	1540	2%
Total		5051.1	5633.1			62181	59729	-4%

Cu_{Total} loading has not increased significantly over the last decade, however there has been a significant increase in loading of $Cu_{Diss.}$ The pH of Annacis Island sewage has decreased .2 since 1985. This may account for part of the increase in $Cu_{Diss.}$ and $Fe_{Diss.}$

3.2.2.1 Summary of Unit Loading

The unit loading of pollutants in the wastewater streams of GVRD sewage treatment plants was discussed. The changes in unit and total loading were discussed in an attempt to predict future unit loading values. Many factors contribute to the variability of unit and total loading. Among the primary factors are:

- Connection of new large sources to the system (New subdivisions, landfills)
- pH shift in effluent
- Changing character of urban runoff
- Source control efforts to reduce loading to the system
- Increases in activity of specific industries

The unit loading of Cu increased 66% between 1986 and 1994. Copper corrosion decreases with time (Macquarrie, 1993). The large increase in soluble copper loading may be the result of an increase in new housing developments. Drinking water treatment may increase or decrease the rate of copper solubilisation. An increase in the pH from 4 to 7 reduces copper corrosivity by an order of magnitude. However, chlorination may increase copper corrosivity due to the formation of HOCL and pH reduction. The reactions are illustrated in Equation 3.5.

Equation 3.5: Corrosion of Copper with Chlorine

$$2Cu^{o} + HOCL + H^{+} = 2Cu^{+} + Cl^{-} + H_{2}0 \qquad E = +0.969\ V$$

$$2Cu^{o} + OCL^{-} + H_{2}0 = 2Cu^{+}\ Cl^{-} + 2OH^{-} \qquad E = +0.379\ V$$

Therefore, assuming a constant unit loading for Cu may lead to serious underestimation of the actual loading. Higher unit loading values for Cu will be explored to determine if elevated Cu unit loading leads to serious environmental consequences. Unit loading of Fe_{Total} and $Fe_{Diss.}$ appears to be increasing, however, Fe is not of great concern. The unit loading for other metals of concern is either constant or decreasing; therefore, the pollutant loading estimates are likely to be conservative. The unit loading of surfactants is increasing rapidly, however, the impact of these chemicals is not of great concern at this time. The unit loading of NH_3-N has increased over the last decade, however, this is most likely attributable to large discharges from Burns Bog landfill.

Given the number of factors affecting unit loading to municipal STPs, it is impossible to predict what the wastewater quality will be in the future. Therefore, the average pollutant concentration in each sewerage area in 1994 was used to determine loading in future scenarios. Higher concentrations of Cu will be considered in future scenarios since this is a pollutant of primary concern

3.2.3 Characteristic Removal Efficiencies

Characteristic removal efficiencies are the average pollutant removal from each sewage treatment technology. This allows the determination of future levels of loading by Equation 3.2. Current influent pollutant concentrations, primary effluent pollutant concentrations, pollutant removal efficiencies for secondary treatment and secondary effluent pollutant concentrations are listed in Table 3.10. The effluent concentrations will be used to determine the impact on water quality. The estimated effluent unit loading as a result of implementation of secondary treatment in the three sewerage areas of interest, Fraser Sewerage Area (FSA), Lulu Island Sewerage Area (LISA) and the Fraser Valley Sewerage Area (FVSA), illustrated in Figure 3.4, are listed in Table 3.11. These values will be used to calculate the pollutant loading as a result of the scenarios described in section 3.2.4. The values used for the unit loading from the FSA and the LISA are the 1994 values. The influent unit loading for the FVSA was assumed to be the average of the LISA and the FSA. The Vancouver Sewerage Area (VSA), which discharges to the Iona Island STP, is not under consideration because the discharge does not impact water quality at the Annacis Island and Lulu Island STP outfalls.

Table 3.10: Characteristic Removal Efficiencies and Resulting Effluent Concentrations

	Treatment Level				Annacis Island			Lulu Island		
	Primary[1]	Enhanced Primary[2]	Secondary[3]	Tertiary[2]	Influent	Primary Effluent	Secondary Effluent[4]	Influent	Primary Effluent	Secondary Effluent[4]
	% Removal	% Removal	% Removal	% Removal	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
SS	59%	85%	85%	92%	164	60	25	234	56	35
Chloride	n.q.	n.q.	n.q.	n.q.	50	52	50	68	73	68
COD	37%	n.q.	82%	n.q.	404	266	73	509	290	92
BOD	35%	60%	90%	92%	205	137	20.5	226	150	22.6
Faecal Coliforms	99.99%	99.99%	99.9999%	99.999999%	80	8E-03	8E-05	170	0.017	0.00017
TKN	12%	27%	20%	90%	32	27	26	31	29	25
NO_3/NO_2-N	n.q.	n.q.	n.q.	n.q.	0.05	0.068	0.05	<0.1	n.q.	n.q.
NH_3-N	2%	5%	12%	90%	19	18	17	18	19	16
Fluoride	n.q.	n.q.	n.q.	n.q.	0.08	0.08	0.08	0.25	0.25	0.25
MBAS	13%	50%	85%	90%	3.5	3.2	0.5	3.1	3.2	0.5
SO_4	1%	1%	1%	1%	35	35	35	28	25	25
Alk.	6%	6%	6%	6%	139	124	124	106	92	92
P_{total}	17%	85%	20%	80%	5	4.1	4.0	4.9	4.5	3.9
$P_{diss.}$	3%	3%	3%	3%	2.7	2.7	2.6	2.6	3.1	2.5
O&G	25%	25%	25%	25%	38	27	27	46	30	30
Phenol	9%	9%	9%	n.q.	0.06	0.05	0.05	0.07	0.05	0.06
CN_{Total}	n.q.	n.q.	n.q.	n.q.	0.02	0.02	0.02	<0.02	n.q.	n.q.
$Sulphide_{Diss.}$	90%	90%	90%	90%	0.05	0.1	0.005	0.8	n.q.	0.08
Al_{Total}	37%	75%	75%	75%	0.7	0.4	0.2	0.9	0.6	0.2
$Al_{Diss.}$	n.q.	n.q.	n.q.	n.q.	0.1	0.1	0.1	<0.1	n.q.	n.q.
As_{Total}	n.q.	n.q.	n.q.	n.q.	0.001	0.001	0.001	<0.001	n.q.	n.q.
Ba_{Total}	30%	30%	30%	30%	0.044	0.029	0.029	0.049	0.036	0.036
$Ba_{Diss.}$	n.q.	n.q.	n.q.	n.q.	0.01	0.01	0.01	0.01	0.01	0.01
B_{Total}	1%	1%	1%	1%	0.16	0.16	0.16	0.16	0.14	0.14
$B_{Diss.}$	5%	5%	5%	5%	0.14	0.14	0.13	0.13	0.13	0.12
Cd_{Total}	15%	75%	85%	85%	0.0005	0.0005	0.000075	0.0009	n.q.	0.00014
$Cd_{Diss.}$	n.q.	n.q.	n.q.	n.q.	0.0005	n.q.	n.q.	<0.0005	n.q.	n.q.

Notes: [1]Determined by averaging the removal efficiencies of Annacis Island and Lulu Island STPs in 1994; [2]GVRD, 1988; [3] Metcalf and Eddy, 1991; GVRD Liquid Waste Management Plan, 1988; Wetter and Slezak, 1975, Oliver and Cosgrove, 1974; [4]Determined by multiplying the 1994 Influent concentration by the removal efficiency. n.q. = Not Quantified

Table 3.10: Continued

	Treatment Level				Annacis Island STP			Lulu Island STP		
	Primary	Enhanced Primary	Secondary	Tertiary	Influent	Primary Effluent	Secondary Effluent*	Influent	Primary Effluent	Secondary Effluent*
	% Removal	% Removal	% Removal	% Removal	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Cr_{Total}	26%	n.q.	80%	85%	0.011	0.008	0.0022	0.031	0.021	0.0062
$Cr_{Diss.}$	8%	n.q.	50%	50%	0.004	0.003	0.002	0.011	0.009	0.0055
Co_{Total}	n.q.	n.q.	n.q.	n.q.	0.02	0.02	0.02	<0.02	n.q.	n.q.
$Co_{Diss.}$	n.q.	n.q.	n.q.	n.q.	0.02	0.02	0.02	<0.02	n.q.	n.q.
Cu_{Total}	17%	75%	75%	85%	0.17	0.14	0.04	0.27	0.17	0.07
$Cu_{Diss.}$	-5%	n.q.	60%	n.q.	0.06	0.07	0.024	0.09	0.08	0.036
Fe_{Total}	21%	75%	75%	85%	2.8	2.38	0.7	2.2	1.8	0.6
$Fe_{Diss.}$	8%	8%	50%	0%	1.34	1.24	0.67	0.92	0.92	0.46
Pb_{Total}	31%	75%	65%	85%	0.012	0.008	0.004	0.015	0.009	0.005
$Pb_{Diss.}$	n.q.	n.q.	50%	n.q.	0.004	n.q.	n.q.	<0.005	n.q.	n.q.
Mn_{Total}	12%	75%	33%	85%	0.11	0.1	0.074	0.090	0.080	0.060
$Mn_{Diss.}$	6%	n.q.	10%	10%	0.08	0.07	0.072	0.050	0.060	0.045
Hg_{Total}	n.q.	n.q.	n.q.	n.q.	0.0005	n.q.	n.q.	<0.0005	n.q.	n.q.
Mo_{Total}	n.q.	n.q.	n.q.	n.q.	0.03	0.03	0.03	<0.03	n.q.	n.q.
$Mo_{Diss.}$	n.q.	n.q.	n.q.	n.q.	0.03	0.03	0.03	<0.03	n.q.	n.q.
Ni_{Total}	29%	85%	30%	85%	0.013	0.009	0.009	0.055	0.028	0.039
$Ni_{Diss.}$	10%	10%	10%	10%	0.009	0.008	0.008	0.038	0.022	0.034
Se_{Total}	n.q.	n.q.	n.q.	n.q.	0.001	n.q.	n.q.	<0.001	n.q.	n.q.
$Se_{Diss.}$	n.q.	n.q.	n.q.	n.q.	0.001	n.q.	n.q.	<0.001	n.q.	n.q.
Ag_{Total}	19%	19%	19%	19%	0.005	0.003	0.003	0.022	0.016	0.016
$Ag_{Diss.}$	n.q.	n.q.	n.q.	n.q.	0.002	0.002	0.002	0.008	0.008	0.008
Sn_{Total}	n.q.	n.q.	n.q.	n.q.	0.3	0.3	0.3	<0.3	n.q.	n.q.
$Sn_{Diss.}$	n.q.	n.q.	n.q.	n.q.	0.3	0.3	0.3	<0.3	n.q.	n.q.
Zn_{Total}	20%	85%	80%	n.q.	0.1	0.08	0.02	0.2	0.1	0.04
$Zn_{Diss.}$	3%	n.q.	30%	n.q.	0.05	0.05	0.02	0.08	0.05	0.04
$Hydrocarbons_{Total}$	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.		n.q.	n.q.
PAH	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.		n.q.	n.q.

Notes: [1]Determined by averaging the removal efficiencies of Annacis Island and Lulu Island STPs in 1994; [2]GVRD, 1988; [3] Metcalf and Eddy, 1991; GVRD Liquid Waste Management Plan, 1988; Wetter and Slezak, 1975, Oliver and Cosgrove, 1974; [4]Determined by multiplying the 1994 Influent concentration by the removal efficiency.. n.q. = Not Quantified

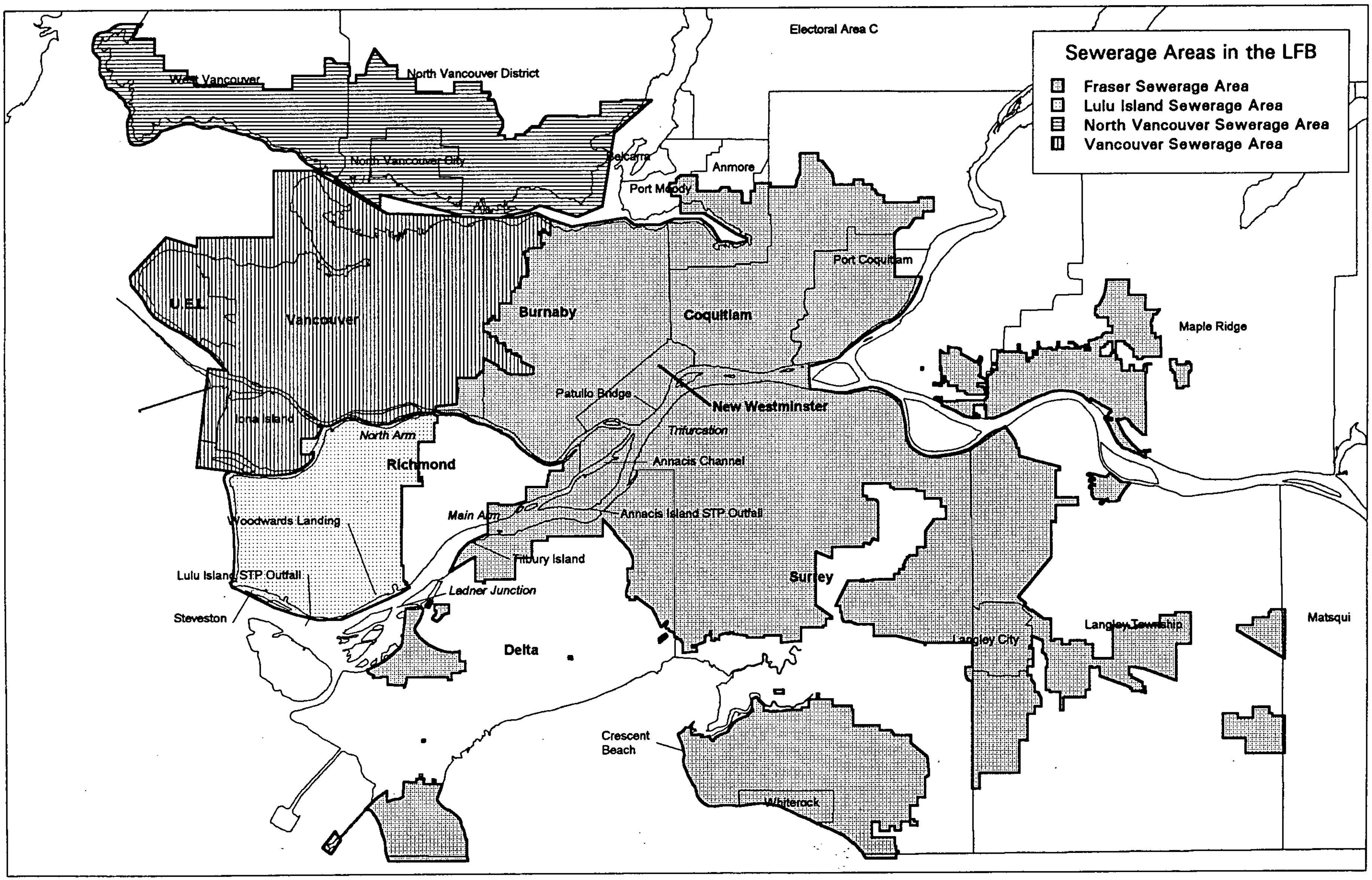
Table 3.11: Unit Loading from STPs after Secondary Treatment

Parameter	Units	Influent Unit Loading			Secondary Treatment Effluent Unit Loading		
		FSA	LISA	FVSA	FSA	LISA	FVSA
SS	(g/day/capita)	68	93	80	10	14	12
Chloride	(g/day/capita)	21	27	24	21	27	24
COD	(g/day/capita)	167	202	185	30	36	33
BOD	(g/day/capita)	85	90	87	8.5	9.0	8.7
TKN	(g/day/capita)	13.2	12.3	12.8	10.6	9.8	10.2
NO_3/NO_2-N	(g/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
NH_3-N	(g/day/capita)	7.9	0.1	4.0	6.9	0.1	3.5
Fluoride	(g/day/capita)	0.03	0.10	0.07	0.03	0.1	0.1
MBAS	(g/day/capita)	1.4	1.2	1.3	0.2	0.2	0.2
SO_4	(g/day/capita)	14	11	13	14	11	13
Alkalinity	(g/day/capita)	58	42	50	58	42	50
P_{Total}	(g/day/capita)	2.1	1.9	2.0	1.7	1.6	1.6
$P_{Diss.}$	(g/day/capita)	1.1	1.0	1.1	1.1	1.0	1.1
O&G	(g/day/capita)	16	18	17	16	18	17
Phenol	(mg/day/capita)	25	28	26	25	28	26
CN_{Total}	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Sulphide_{Diss.}$	(mg/day/capita)	n.q.	317	317	n.q.	317	317
Al_{Total}	(mg/day/capita)	290	357	323	290	357	323
$Al_{Diss.}$	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
As_{Total}	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Ba_{Total}	(mg/day/capita)	18	19	19	18	19	19
$Ba_{Diss.}$	(mg/day/capita)	4.1	4.0	4.1	4.1	4.0	4.1
$Boron_{Total}$	(mg/day/capita)	66	63	65	66	63	65
$Boron_{Diss.}$	(mg/day/capita)	58	52	55	58	52	55
Cd_{Total}	(mg/day/capita)	n.q.	0.36	0.36	n.q.	0.05	0.05
$Cd_{Diss.}$	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Table 3.11: Continued

Parameter	Units	Influent Unit Loading			Secondary Treatment Effluent Unit Loading		
		FSA	LISA	FVSA	FSA	LISA	FVSA
Cr_{Total}	(mg/day/capita)	4.6	12.3	8.4	0.91	2.5	1.7
$Cr_{Diss.}$	(mg/day/capita)	1.66	4.36	3.01	0.83	2.2	1.5
Co_{Total}	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Co_{Diss.}$	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Cu_{Total}	(mg/day/capita)	70	107	89	17.6	26.8	22.2
$Cu_{Diss.}$	(mg/day/capita)	25	36	30	9.9	14.3	12.1
Fe_{Total}	(mg/day/capita)	1159	884	1022	290	221	255
$Fe_{Diss.}$	(mg/day/capita)	555	365	460	277	182	230
Pb_{Total}	(mg/day/capita)	5.0	5.9	5.5	1.7	2.1	1.9
$Pb_{Diss.}$	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Mn_{Total}	(mg/day/capita)	46	36	41	30.5	23.9	27.2
$Mn_{Diss.}$	(mg/day/capita)	33	20	26	29.8	17.8	23.8
Hg_{Total}	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Mo_{Total}	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Mo_{Diss.}$	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Ni_{Total}	(mg/day/capita)	5.4	22	14	3.8	15.3	9.5
$Ni_{Diss.}$	(mg/day/capita)	3.7	15	9.4	3.4	13.6	8.5
Se_{Total}	(mg/day/capita)	0.41	n.q.	0.41	0.41	n.q.	0.41
$Se_{Diss.}$	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Ag_{Total}	(mg/day/capita)	2.1	8.7	5.4	2.1	8.7	5.4
$Ag_{Diss.}$	(mg/day/capita)	n.q.	3.2	3.2	n.q.	3.2	3.2
Sn_{Total}	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Sn_{Diss.}$	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Zn_{Total}	(mg/day/capita)	41	79	60	8	16	12
$Zn_{Diss.}$	(mg/day/capita)	21	32	26	14	22	18
$Hydrocarbons_{Total}$	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
PAH	(mg/day/capita)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Figure 3.4: Municipalities and Sewerage Districts in the GVRD



3.2.4 Sewerage Area Population Scenarios

Scenarios were developed to determine the effect of future growth in the LFB on the decision to upgrade the STPs at Annacis Island and Lulu Island to secondary. Water quality in the Fraser River is known at present; therefore, consideration must only be given to the changes in water quality attributable to future growth. Scenarios describing loading to the Fraser River from municipal STP's require a population distribution and information on the level of treatment. Population growth is separated by sewerage area. The sewerage areas are roughly defined by municipal boundaries. A small portion of Burnaby lies within the Vancouver Sewerage Area, however, a small portion of Vancouver lies within the Fraser Sewerage Area. The municipal boundaries and sewerage areas are illustrated in Figure 3.4. For the coarse estimate in this study, it was assumed that these areas cancel one another out. The FVSA contains several municipalities. Each municipality discharges to its own sewage treatment plant. The municipalities and their sewage treatment plants are outlined in Table 3.12. The population served by each plant in the FVSA was determined by a telephone survey of plant operators

Table 3.12: Sewerage Areas in the LFB

TREATMENT PLANT	MUNICIPALITIES SERVED	POPULATION SERVED (1994)
Kent Plant	Agassiz,	3000
Chilliwack Plant	Chilliwack	35000
Harrison Hot Springs Plant .	Harrison Hot Springs	800
Hope Plant	Hope	5000
James Plant	Matsqui, Mission, Abbotsford	52000
Langley Plant	Township of Langley	16000

The GVRD Liquid Waste Management (LWMP), (1988)only took into account one future level of population when determining the effect on water quality. This method has obvious limitations. For example, the level of population evaluated for the FSA by the GVRD LWMP was 992,000 in 2030. More recent population forecasts predict a population of 1,500,000 for the FSA by the year 2021. Therefore multiple population growth scenarios will be used here to determine the sensitivity of water quality to different levels of population.

Three population growth scenarios will be evaluated. Scenario P_1 considers the population growth targets set by the GVRD Strategic Planning Department (GVRD, 1995c). Scenarios P_2 and P_3 consider population levels 110% and 125% of scenario P_1 respectively. The GVRD growth management targets resolve population growth at the municipality level. These were amalgamated to the two main sewerage districts in the GVRD, the FSA and the LISA. Population forecasts are not available for the FVSA, so estimates for the future number of sewerage hook-ups were made. The base estimate is double the population currently served in each municipality. Table 3.13 shows the current population in each of the sewerage areas and the GVRD growth management targets for the year 2021. Population forecasts for scenarios P_2 and P_3 are also shown.

Two treatment scenarios, (primary and secondary treatment), were evaluated for each population scenario for the FSA and the LISA. It was assumed that all future discharges from the FVSA will receive secondary treatment. This allows the improvement in water quality to be quantified as a result of increased levels of treatment.

Table 3.13 Population Growth Scenarios for Three Sewerage Districts

Sewerage District	Municipality	1994	P_1, 2021 (GVRD 1995c)	$P_2=1.10\times P_1$	$P_3=1.25\times P_1$
FSA	Burnaby	173197	291930	321123	353235
	Coquitlam	97356	219520	241472	265619
	Delta	95576	107734	118507	130358
	Langley City	21435	34639	38103	41913
	Maple Ridge	55051	100253	110278	121306
	New Westminster	47736	78783	86661	95327
	Pitt Meadows	13526	13275	14603	16063
	Port Coquitlam	43117	80915	89007	97907
	Port Moody	20000	45380	49918	54910
	Surrey	281058	549338	604272	664699
	White Rock	17427	17197	18917	20808
	Total FSA	**865479**	**1538964**	**1692860**	**1862146**
LISA	Richmond	**139435**	**184558**	**203014**	**223315**
		Population Served*			
FVSA	Agassiz	3000	6000	6600	7500
	Chilliwack	35000	70000	77000	87500
	Harrison Hot Springs	800	1600	1760	2000
	Hope	5000	10000	11000	12500
	Matsqui, Mission, Abbotsford	52000	104000	114400	130000
	Township of Langley	16000	32000	35200	40000
	Total FVSA	**111800**	**223600**	**245960**	**279500**

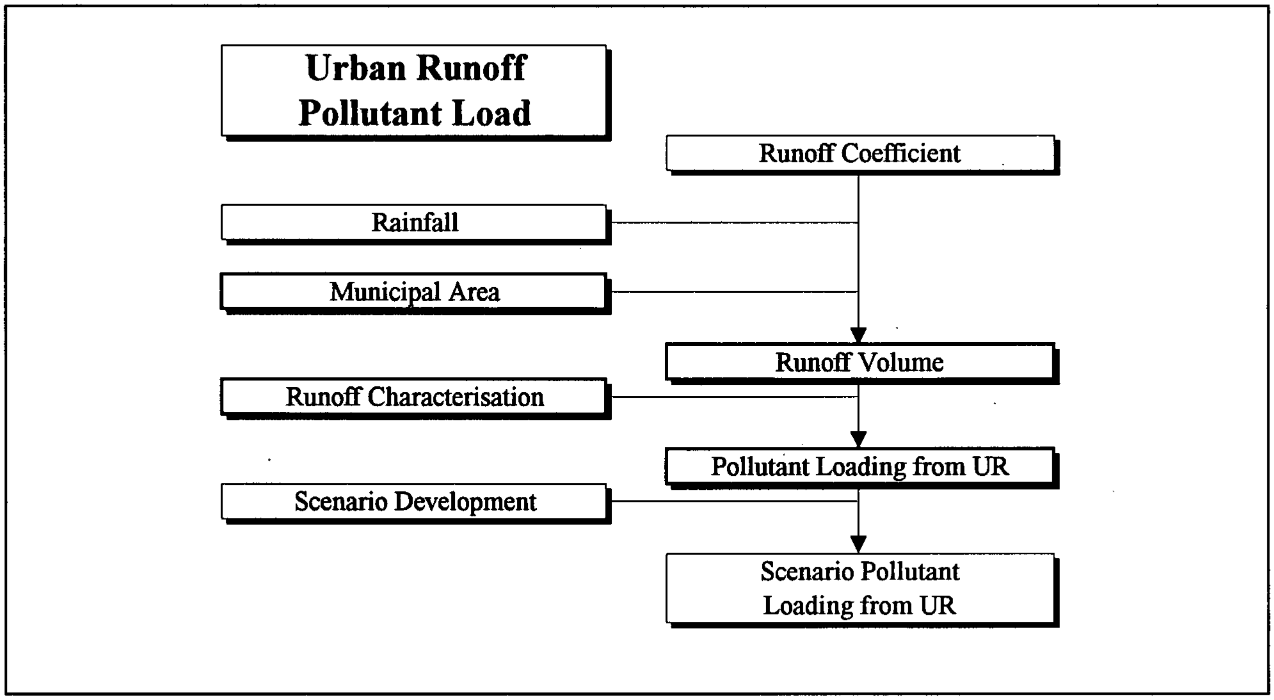
Notes: *Population Served represents the population served by domestic sewers, not the total population

3.3 Urban Runoff

Urban runoff is often overlooked as a major contributor to pollutant loading. Priority has been given to treating large point sources of pollution, such as sewage treatment plants or industrial point sources, rather than diffuse sources. Air pollution management evolved in a similar fashion. Attention has shifted from large point sources to recognising the contributions from diffuse sources. The California tailpipe emissions requirements and the new emission requirements for British Columbia, recently announced by Minister Moe Sihota, are indicators of the new direction being taken in air emissions. Similarly, interest in managing the diffuse sources of water pollution, such as urban runoff, has increased.

The decreased permeability of surfaces in urban neighbourhoods, due to paving, buildings and levelling, results in a larger fraction of the rainfall ending up in catchment streams. This results in increased pollutant loading and scouring of stream channels due to increased hydraulic loads which contributes to increased levels of suspended solids in the water column. The process used to determine urban runoff pollutant load is outlined in Figure 3.5.

Figure 3.5: Urban Runoff Pollutant Load



3.3.1 Urban Runoff Volume

The runoff volume is dependent on the level of precipitation and runoff coefficients. Runoff coefficients describe the percentage of the precipitation which is not absorbed into the ground. Runoff coefficients vary according to land use and level of precipitation. High rainfall in the winter often saturates the ground resulting in a higher runoff coefficient. Topography also affects runoff coefficients. Stanley and associates have developed summer and winter runoff coefficient for all municipalities in the LFB. Winter coefficients apply from October 1 through April 30 and summer coefficients apply from May 1 through Sept. 30.

Pollutant concentration variation across land uses is assumed not to vary for the purpose of this study. This is discussed further in Section 3.3.2. However, the quantity of urban runoff does vary across land uses due to variability in runoff coefficients. There are three primary land uses in the LFB; residential, industrial and commercial, each with its own runoff coefficient. These typical runoff coefficients are affected by average rainfall and topography. Table 3.14 summarises runoff from individual municipalities determined by Stanley and Associates, (DOE FRAP 1993-19). Average annual rainfall data is found in Appendix G.

Table 3.14: Runoff Coefficients for Municipalities in the LFB

Sewerage District	Municipality	Industrial Winter Runoff Coefficient	Commercial Winter Runoff Coefficient	Residential Winter Runoff Coefficient	Industrial Summer Runoff Coefficient	Commercial Summer Runoff Coefficient	Residential Summer Runoff Coefficient
FSA	Burnaby	0.72	0.77	0.50	0.57	0.72	0.25
	Coquitlam	0.72	0.77	0.50	0.57	0.72	0.25
	Delta	0.59	0.63	0.41	0.47	0.59	0.21
	Langley City	0.72	0.77	0.50	0.57	0.72	0.25
	Maple Ridge	0.72	0.77	0.50	0.57	0.72	0.25
	New Westminster	0.62	0.67	0.43	0.49	0.62	0.22
	Pitt Meadows	0.72	0.77	0.50	0.57	0.72	0.25
	Port Coquitlam	0.72	0.77	0.50	0.57	0.72	0.25
	Surrey	0.62	0.67	0.43	0.49	0.62	0.22
LISA	Richmond	0.62	0.67	0.43	0.49	0.62	0.22
FVSA	District of Abbotsford	0.68	0.74	0.47	0.55	0.68	0.24
	District of Chilliwack	0.62	0.67	0.43	0.49	0.62	0.22
	Township of Langley	0.72	0.77	0.50	0.57	0.72	0.25
	District of Matsqui	0.68	0.74	0.47	0.55	0.68	0.24
	District of Mission	0.72	0.77	0.50	0.57	0.72	0.25

Source: Stanley and Associates, (DOE FRAP 1993-19)

Many of the municipalities in the LFB drain to more than one watershed. Table 3.15 shows the area of each municipality which drains to the Fraser River.

Table 3.15: Urban Areas in the LFB Draining to the Fraser River

Municipality	Municipal Area (ha)	Urban Area (ha)	Industrial (ha)	Commercial & Institutional (ha)	Residential (ha)
City of Burnaby	10,674	9,788	924	643	7210
City of Coquitlam	15,275	3,976	732	244	2,554
Corporation of Delta	36,433	5,900	2,950	450	2,500
City of Langley	1,018	714	105	216	393
District of Maple Ridge	27,710	3,274	353	101	2,820
City of New Westminster	2,200	2,200	108	62	845
District of Pitt Meadows	5,006	651	139	30	482
City of Port Coquitlam	2,509	1,920	193	74	1,653
District of Surrey	37,140	5,264	1,263	52	3,949
City of Richmond	16,819	11,060	4,240	280	6,540
District of Abbotsford	13,930	2,440	375	70	1,995
District of Chilliwack	26,533	1,972	303	56	1,613
Township of Langley	31,765	4,112	1,029	178	2,905
District of Matsqui	21,921	2,280	165	145	1,972
District of Mission	25,300	2,315	246	79	1,990

Source: Stanley and Associates, (DOE FRAP 1993-19)

The runoff volumes can be calculated by multiplying the area of each type of land use by the corresponding runoff coefficient by the precipitation (See Equation 3.6). Some parts of Burnaby and New Westminster are connected to combined sewers. The total area of each municipality connected to combined sewers is 106 ha for Burnaby and 1015 ha for New Westminster (McCallum, 1996). That area is relatively small for Burnaby, but accounts for approximately half the runoff from New Westminster. Table 3.15 has been corrected for the area that drains directly to a sewage treatment plant.

Equation 3.6: Runoff Volume

$$\text{Runoff Volume}_{\text{Municipality}} = \sum\nolimits_{\text{Month}} \text{Average Rainfall}_{\text{Moth}} \times \text{Runoff Coefficient}_{\text{Month}} \times \text{Land Area}$$

3.3.2 Urban Runoff Quality

Land use is regarded as a major influence on the quality of storm water. Several studies have been performed to determine the relationship between land use and storm water quality.(Ferguson and Hall, 1979; Hall, 1991). Ferguson and Hall, 1979, found that runoff from residential neighbourhoods had a different character than that from commercial and industrial areas. Table 3.16 illustrates the change in storm water quality with land use patterns.

Table 3.16 Storm Runoff Quality in the Lower Mainland for different Land Uses[1]

Quality Indicators	Residential Site	Industrial Site
Biochemical Oxygen Demand	<10	14
Chemical Oxygen	33.2	77.6
Suspended Solids	19.8	84.7
Conductivity	52	121.6
Faecal Coliforms	2400+	2860
Total Nitrogen	1.6	1.3
Total Phosphorus	0.09	0.42
Total Copper	0.04	0.04
Total Lead	0.07	0.22
Total Zinc	0.12	0.24
Oil and Grease	3.0	7.8

Notes:1 Adapted from Hall et al (1991) All data in mg/l except conductivity which is µS/cm and faecal coliforms which are MPN/100 ml, mean values for wet weather flow

Other researchers have found that urban runoff quality is very site specific and that data can not be extrapolated from one location to another with any degree of confidence (B.C. Research, 1991). It was also found that "Where site - specific data are not available, there is little justification for differentiating among general land use categories. Typical values for "general urban land use" were identified as estimates for planning purposes (DOE FRAP 1993-19). The concentrations represent upper and lower concentration boundaries in addition to a 'most likely' loading. Typical values are outlined in Table 3.17.

Studies have shown the nature of urban run off changes as new technologies are introduced (Hall, 1991). The level of lead contamination in the Brunette River sediment has decreased, but levels of manganese have increased. This was attributed to the conversion to unleaded gasoline. Unleaded gasoline is low in lead, but may contain elevated levels of manganese. The characteristic values from the BC Research study were derived from National Urban Runoff Program in the United States in the 1970's. Hall et al. (1996b) analysed the concentration of pollutants in storm runoff from mixed use watersheds in Burnaby. The data was collected in 1994-95 and more accurately reflects the current pollutant concentrations in runoff from mixed use watersheds in the GVRD. These values were used to calculate pollutant loading from urban runoff.

Table 3.17: Typical Concentrations of Pollutants in Urban Runoff

Contaminant	Units	Stanley Pollutant Concentration[1]	Pollutant Concentration Range[1]	Pollutant Concentrations from Brunette Watershed[2]
SS	(mg/l)	125	100 - 150	62
Chloride	(mg/l)	n.q.	n.q.	18.2
COD	(mg/l)	70	60 - 80	40
BOD	(mg/l)	9	5 - 14	6
Faecal Coliforms	(MPN/100mL)	12,000	20 - 24,000	12,000
TKN	(mg/l)	1.75	1.5 - 2.0	0.33
NO_3/NO_2-N	(mg/l)	0.7	0.17 - 1.19	0.22
NH_3-N	(mg/l)	0.15	0 - 0.80	5
Alkalinity	(mg/l)	n.q.	n.q.	19.2
P_{Total}	(mg/l)	0.35	0.3 - 0.4	0.22
O&G	(mg/l)	5	3 - 31.0	5
Phenol	(μg/l)	13	1 - 115	13
As_{Total}	(μg/l)	13	10 - 15	13
Cd_{Total}	(μg/l)	8	5 - 10	0.4
$Cd_{Diss.}$	(μg/l)	n.q.	n.q.	0.17
Cr_{Total}	(μg/l)	10	5 -15	7.3
$Cr_{Diss.}$	(μg/l)	n.q.	n.q.	1.5
Cu_{Total}	(μg/l)	35	20 - 50	34
$Cu_{Diss.}$	(μg/l)	n.q.	n.q.	29
Fe_{Total}	(μg/l)	n.q.	n.q.	255
Pb_{Total}	(μg/l)	150	100 - 200	12
$Pb_{Diss.}$	(μg/l)	n.q.	n.q.	4.5
Mn_{Total}	(μg/l)	n.q.	n.q.	129
$Mn_{Diss.}$	(μg/l)	n.q.	n.q.	35
Ni_{Total}	(μg/l)	25	20 - 30	3.3
$Ni_{Diss.}$	(μg/l)	n.q.	n.q.	1.4
Zn_{Total}	(μg/l)	150	100-200	102
$Zn_{Diss.}$	(μg/l)	n.q.	n.q.	56
Tot. Hydrocarbons	(μg/l)	4	1.8 - 9.2	4
PAH	(μg/l)	1	0.3 - 12	1

Source: [1]Stanley and Associates, 1992 (DOE FRAP 1993-19),
[2]Hall et al, 1996, .

Storm water quality is also dependent on such factors as rainfall intensity, climate, build-up time and traffic intensity. The 'first flush effect' is also an important phenomenon when evaluating stormwater discharges. The first flush occurs after pollutants have had time to accumulate during a dry spell and are then rapidly transported down sewers in the 'first flush' of a storm event. Pollutant loading from 'first flush' runoff may be approximated by using values toward the upper end of the concentration range for contaminants outlined in Table 3.17. It has been estimated that the pollutant loading to the Fraser River, during the first hour of a storm event, exceeds the combined loading from Annacis Island, Lulu Island and Iona STPs (Hall, 1991).

3.3.3 Urban Runoff Best Management Practices

Urban runoff Best Management Practices (BMPs) have been developed to mitigate against the hydraulic and pollutant loading problems associated with urban runoff. Urban runoff guidelines were developed for the province of British Columbia, BC Research, 1991. Several BMPs and their pollutant removal efficiencies are summarised in Table 3.18. New developments in the LFB must incorporate these BMPs. Each BMP has its own characteristic pollutant removal efficiency and it is not known which BMPs will be implemented in future scenarios; therefore, an average pollutant removal for all BMPs was estimated to determine what effect implementation would have on pollutant loading. It was assumed that the pollutant removal for lead and zinc was reflective of the removal efficiency for all metals. The estimated collective pollutant removal efficiency of BMPs and the resulting pollutant concentrations are outlined in Table 3.19.

Table 3.18: Summary of Urban Runoff BMPs

BMP	Source	Range of Reported Contaminant Removal					
		Suspended Solids	COD	Pb_{Total}	Zn_{Total}	P_{Total}	TKN
Extended Detention Dry Basins	Design Manuals	50-100	0-60	75-90	30-60	0-60	0-40
	Field Studies	3-74	16-41	24-84	40-65	10-56	24-60
Wet Ponds	Design Manuals	60-100	20-60	20-80	10-80	40-80	20-80
	Field Studies	5-91	2-69	9-95	0-79	3-79	0-60
Wetlands	Design Manuals	80-100	60-80	60-80	60-80	40-60	40-60
	Field Studies	64-99	54-89	88-97	33-96	0-97	0-95
Grassed Swales	Design Manuals	0-40	0-40	0-20	0-20	0-40	0-40
	Field Studies	80	25	50-80	50-60	0	0
Vegetated Filter Strips	Design Manuals	20-100	0-80	20-100	20-100	0-60	0-60
	Field Studies						
Infiltration Basins	Design Manuals	75-99	70-90	75-99	75-99	50-75	45-75
	Field Studies						
Porous Pavement	Design Manuals						
	Field Studies	82-95	82	98	99	65	80-85

Source BC Research, 1991

Table 3.19: BMP Characteristic Pollutant Removal

Contaminant	Units	Pollutant Removal from BMPs	Treated Runoff Pollutant Concentration
SS	(mg/l)	75	15.5
Chloride	(mg/l)	50	9.1
COD	(mg/l)	50	20
BOD	(mg/l)	50	3
Faecal Coliforms	(MPN/100mL)	90	1200
TKN	(mg/l)	50	0.17
NO3/NO2-N	(mg/l)	50	0.11
NH3-N	(mg/l)	50	2.5
Alkalinity	(mg/l)	50	9.6
P_{Total}	(mg/l)	50	0.11
O&G	(mg/l)	50	2.5
Phenol	(mg/l)	50	6.5
As_{Total}	(mg/l)	50	6.5
Cd_{Total}	(mg/l)	50	0.2
$Cd_{Diss.}$	(mg/l)	50	0.085
Cr_{Total}	(mg/l)	50	3.65
$Cr_{Diss.}$	(mg/l)	50	0.75
Cu_{Total}	(mg/l)	50	17
$Cu_{Diss.}$	(mg/l)	50	14.5
Fe_{Total}	(mg/l)	50	128
Pb_{Total}	(mg/l)	50	6
$Pb_{Diss.}$	(mg/l)	50	2.25
Mn_{Total}	(mg/l)	50	65
$Mn_{Diss.}$	(mg/l)	50	17
Ni_{Total}	(mg/l)	50	1.65
$Ni_{Diss.}$	(mg/l)	50	0.7
Zn_{Total}	(mg/l)	50	51
$Zn_{Diss.}$	(mg/l)	50	28
Tot. Hydrocarbons	(mg/l)	50	2
PAH	(mg/l)	50	0.5

Source: BC Research, 1991

3.3.4 Future Scenarios

Three future land use scenarios were developed for each level of population. Scenario A assumes that the land area per capita in the future is the same as it was in 1991. This scenario must be evaluated at the basin level. Maintaining the same land use/capita for some municipalities would require an increase in the area of the municipality. Scenario B assumes that the population density increases 5% and that the land use/capita decreases 5% for each land use. The outcome of scenario B is a 5% percent reduction in pollutant loading from Scenario A. Per capita land use areas for scenarios A and B are found in Appendix H.

Scenario C is a 'best case' scenario. This scenario assumes that the residential land use/capita remains the same for all municipalities except Burnaby, Port Coquitlam and New Westminster. These municipalities must increase in density if they are to reach the population forecast by the GVRD. Higher runoff coefficients are expected when the housing stock shifts from single family units toward multiple units and apartments (ASCE, 1992). McCallum, 1995, showed that although population in Burnaby rose 30 percent between 1973 to 1993, the increase in impermeable area was only 20 percent. It was assumed that this relationship between density increase and impermeable area would hold between 1993 and 2021. This leads to approximately a 66 percent increase in the runoff coefficient for the average population growth in these three municipalities. The modified runoff coefficients are listed in Appendix I. It was assumed for Scenario C that all new developments would have urban runoff BMPs in place that were discussed in Section 3.3.3. This may have a dramatic effect on pollutant loading from urban runoff. Urban runoff scenarios A, B and C are outlined below.

Scenario A:	Land Use	= 1991 per capita levels for all municipalities.
	Runoff Coefficients	= 1991 levels for all urban areas.
	Pollutant Concentrations	= 1991 levels.
	Scale	= Basin Wide.
	Justification	= Shows the resulting pollutant load of current trends.

Scenario B:	Land Use	= 95 % of 1991 per capita levels for all municipalities.
	Runoff Coefficients	= 1991 levels for all urban areas.
	Pollutant Concentrations	= 1991 levels.
	Scale	= Basin Wide.
	Justification	= Shows the pollutant load resulting from a moderate lifestyle change.

Scenario C:	**For all municipalities except Burnaby, Port Coquitlam and New Westminster:**	
	Land Use	= 1991 per capita levels.
	Runoff Coefficients	= 1991 levels for all urban areas.
	Pollutant Concentrations	= BMP levels for all new development.
	Scale	= May be evaluated at a municipality level.
	For Burnaby, Port Coquitlam and New Westminster:	
	Land Use	= 1991 total level for each land use.
	Runoff Coefficients	= Increase 66 % of the increase in population density over 1991 levels for each population scenario for residential areas. Assumed to remain at 1991 levels for industrial and commercial areas
	Pollutant Concentrations	= 1991 levels.
	Scale	= May be evaluated at a municipality level.
	Justification	= Shows the likely 'Best Case' Scenario for pollutant loading.

3.4 Summary

The development of scenarios to determine the effect of different future on pollutant loading to the Fraser River was discussed. Scenarios are a useful way of exploring uncertainty in the future. This Chapter outlined methodology to determine future pollutant loading from industries, urban runoff and STPs. This analysis is limited to three levels of industrial activity, three population scenarios, two levels of sewage treatment and three land uses. Other scenarios may be evaluated rapidly if pollutant loading is sensitive to increases in loading from specific sources. This provides a measure of sensitivity to uncertain futures which is not characteristic of other estimates of future pollutant loading to the Fraser River. It was assumed that population growth and economic activity are not directly linked. Many combinations of urbanisation and industrial activity may be evaluated to determine whether pollutant loading is more sensitive to industrial growth or changes in land use.

Future pollutant loading from STPs is dependent on population growth and the level of treatment. Three population growth scenarios were developed. The population increase was assigned to the three sewerage areas.

Discharging tot the Fraser River. This allows the determination of local effects from discharge. Two levels of treatment were assessed to determine the implications on water quality from different levels of treatment.

A new approach to determining total discharges as a result of industrial activity was developed. The characteristic water use per unit of GDP for each industry was multiplied by the GDP of each industry to determine the total water discharge. The characteristic pollutant concentrations for each industry were multiplied by the level of discharge to determine pollutant loading. Three industrial activity scenarios were discussed to determine the sensitivity of the approach to changes in the relative proportions of each industry.

This tool is simple yet powerful. This analysis is limited to three levels of industrial activity, three population scenarios, two levels of sewage treatment, and three possible land uses. Many more scenarios may be evaluated rapidly if pollutant loading is very sensitive to increases in loading from specific sources. This provides a measure of sensitivity to uncertain futures which is not a characteristic of other estimates of future pollutant loading.

Pollutant loading from urban runoff was assumed to be directly correlated with runoff volume. Urban runoff volume is dependent on land use, topography and rainfall. The area for each land use is dependent on population growth. Scenario A represents the worst case scenario and Scenario C represents a potential 'best case' scenario. The land use scenarios were designed to reflect a range of potential changes in residential, commercial and industrial density and runoff treatment.

4. Changes in Water Quality in Future Scenarios

Once the pollutant loading has been determined, the change in water quality must be determined. The effect of pollutant loading on water quality may be determined by:

- simple dilution calculations
- modelling using dispersion coefficients
- spatial determination of dilution ratios
- modelling using combined hydraulic and dispersion models.

Studies have been identified which used each of these approaches and the relative strengths and weaknesses are discussed. The methodology used to determine water quality at various positions in the Fraser River is a combination of the reviewed approaches. Pollutant loading and the impact on water quality in the Fraser River are discussed in Chapter 5.

4.1 Simple Dilution

The change in water quality using simple dilution is determined by pollutant loading divided by the river flow rate. This increase in concentration would be added to the background pollutant concentration to determine the overall water quality. This method is appropriate for determining the effect of urban runoff, industrial discharges and upriver STPs on the water quality at the Annacis Island and Lulu Island outfalls. This gives a 'worst case' water quality as a result of these discharges by assuming that these discharges are uniformly distributed across the Fraser River. It is likely that pollutants discharged from these sources are more concentrated near the banks of the Fraser River. If the effect on ambient water quality is significant, a more refined estimate of water quality at the outfall can be made to determine whether future discharges from these sources will affect the decision to upgrade the STPs at Annacis and Lulu Island.

Goldie, 1967, pointed out the limitations of this methodology to determine the water quality impacts from STPs. Both river and effluent flow rates are heavily influenced by the season. Therefore an average flow rate would not reflect possible 'worst case' conditions which occur under dry weather flow. The location of the outfall is also influenced by the tide. This results in pooling of the effluent and transport of pollutants upriver of the outfall. This results in higher effluent concentrations at some locations than are predicted by simple dilution estimates. Therefore, this methodology was not used to determine the impacts on water quality from STPs.

4.2 Modelling using Dispersion Coefficients

Simple dispersion modelling may be used to predict water under conditions of constant flow, however, the river flow rate at the Annacis Island outfall is influenced by the tide. This may result in pooling of effluent under some conditions. Therefore, the dispersion coefficients must be combined with a hydraulic river model to determine water quality impacts from the Annacis Island outfall. Hydraulic models of the Fraser River Estuary have been constructed by other investigators (Hodgins, 1977, Seaconsult, 1995a).

4.3 Spatial Determination of Dilution Ratios

BC research undertook a dye tracer study in 1975 to determine whether ambient water quality objectives were met outside the initial zone of dilution of the Annacis Island outfall. Rhodamine dye was continuously discharged through a single riser over a complete tidal cycle. Pooling and dispersion of the slack water cloud were measured as it drifted with the flood and ebb tides. This allowed the accurate determination of the dilution factors associated with near-field mixing at several locations in the river at different tidal levels. This empirical method of determining dilution factors is the most accurate method of determining pollutant concentrations in the near field. Therefore, this method was chosen to determine pollutant concentrations around the IDZ

There were several limitations to the study. Similarly to Ward, there was no accurate method of locating sampling points relative to the riser. The dye was discharged through a single riser at the end of the diffuser array. This riser was not equipped with the same diffuser head as the rest of the risers in the array. Therefore dilution values obtained may be slightly lower than are actually present. Since there was only one riser, the dye tracer was only released into a small section of the river. This section may not have had mixing levels characteristic of the entire river.

4.4 Models Combining Hydraulic and Dispersion Modules

Seaconsult combined an hydraulic model with a pollutant dispersion model to determine the effect on water quality spatially and temporally as a result of discharge from the Annacis Island STP outfall. The hydraulic model has a grid spacing of 470 metres and was run in 30 s time steps for the period of February 13 to March 1, 1993. The water level and area averaged velocity at every grid point at every time step was calculated and input into the water quality module. The transverse and longitudinal diffusion coefficients were adapted from the study by Ward. 1976. The model accounts for the discharge and fate of five pollutants. Cu dissociation and sedimentation, BOD consumption, ammonia degradation, Faecal Coliform survival and PAHs were also incorporated in the model. The mean and maximum pollutant concentrations for all grid points in the Fraser River Estuary were determined.

Modelling the impacts on water quality has several advantages over dilution and tracer studies. Once calibrated, models have predictive capabilities. The model constructed by Seaconsult, 1995, predicts some pollutant dispersion which has not been verified empirically; specifically, the flood tide transporting pollutants upriver to the trifurcation at New Westminster and subsequently transporting pollutants down Annacis channel and the North Arm of the Fraser River on the ebb tide. The model also allows the determination of average pollutant concentrations at many locations.

Dispersion coefficients for the Fraser River estuary were determined shortly after the Annacis Island STP began operations (Ward, 1976). The study involved a plug discharge of rhodamine dye directly over the location of the outfall under low and medium river flows. Both analyses were carried out under periods of ebb tide. There is some uncertainty as to the validity of the coefficients. The study was carried out without the benefit of GPS systems which would accurately position sampling locations relative to the outfall. Preliminary investigations by Seaconsult under high river flow conditions found that the transverse diffusion coefficient is probably lower than that found by Ward (Seaconsult, 1995b).

Dye tracer studies are limited by the number of sampling locations and cost, however, dye tracer studies must be undertaken to calibrate the dispersion model. The Seaconsult model is also limited in its ability to determine near-field impacts on water quality. This is due to the relatively large grid spacing (470 m), and the importance of local river geometry. The Seaconsult model is able to determine the distal effect water quality, but must be supported by dye tracer studies to determine local effects and for calibration.

4.5 Urban Runoff, Industrial Discharges and Upstream STPs: Impact on Water Quality

Urban runoff, industrial discharges and effluent from upstream STPs were assumed to be completely mixed at the Annacis Island outfall. Therefore, the simple dilution method was used to determine the pollutant concentration. The change in ambient water quality from these three discharges was evaluated at low river flow to determine the maximum impact on ambient water quality. The change in faecal coliform concentration was determined by the mean winter runoff divided by the river flow rate, times the characteristic concentration in urban runoff. See Equation 4.1.

Equation 4.1: Determination of River Faecal Coliform Concentration

$$\Delta[\text{Feacal Coliform}]_{\text{River}} = \{(\text{Mean Winter Runoff}) / (\text{River Flow Rate})\} \times [\text{Feacal coliform}]_{\text{Urban Runoff}}$$

It was assumed that the 1994 discharges from urban runoff, industry and FVSA STPs were all reflected in the ambient water quality in 1994. It was also assumed that all of the pollutants are conservative, that is they do not degrade, settle out, volatilise, or otherwise decrease in mass in the water column. The pollutants from urban runoff are probably more concentrated near the banks and not uniformly distributed across the river. Therefore, the concentration at the Annacis Island and Lulu Island STP outfalls is likely less than that determined by assuming complete mixing.

4.6 Annacis Island and Lulu Island STPs: Impact on Water Quality

A combination of the approaches discussed in section 4 was used to determine dilution factors at various locations in the Fraser River. The near-field effects were determined by adjusting values determined in dye-tracer studies (BCRI, 1977). The far-field dilution values were determined by adapting the dilution values from a hydraulic/dispersion model of the Fraser River Estuary model to the individual flow scenarios, (Seaconsult, 1995b). The methodology of determining the dilution values is outlined in Sections 4.6.1 and 4.6.2.

4.6.1 Near-Field Dilution Factors

Near-field changes in water quality were determined by modifying the dilution factors measured in dye tracer studies. The initial dilution zone for the Annacis Island outfall is illustrated in Figure 4.1 as described by the Pollution Control Objectives (1975). Dilution factors were measured by BCRI in 1977 for several locations around the IDZ. The dilution factors were measured under discharge from a single riser with a flow of .11 m^3/s. Discharge from the Annacis Island diffuser array is from three parallel sets of six risers for a total of 18 risers. To simplify the diffusion equations, each set of three parallel risers was evaluated as a single riser, giving six risers. Therefore, dilution factors for flow rates other than .11 m^3/s may be determined for the Annacis Island outfall for each scenario by Equation 4.2. A constant per capita flow rate was assumed. The corresponding flow rate ratios for each population scenario is outlined in Table 4.1: Flow and Flow Rate Ratios for Annacis Island STP.

Equation 4.2:Dilution Factors for Future Discharges

$$\text{Dilution Factor}_{\text{Scenario}} = \text{Dilution Factor}_{\text{BCRI}} \times \text{Flow Rate Ratio}$$
$$\text{Flow Rate Ratio} = \left\{ \frac{.11\text{m}^3/\text{s}}{\text{Scenario Flow Rate}/6} \right\}$$

Table 4.1: Flow and Flow Rate Ratios for Annacis Island STP

Scenario	Flow (m^3/s)	Flow Rate Ratio
1994	4.15	0.159
Scenario 1	7.3	0.090
Scenario 2	8.1	0.081
Scenario 3	8.9	0.074

The IDZ for the Lulu Island outfall is slightly larger than for the Annacis Island outfall (see Figure 4.1 and Figure 4.2) because the river is wider at this location and the outfall is located further from shore. The dilution factors around the IDZ of the Lulu Island STP outfall have not been determined by dye tracer studies. Therefore, it was assumed that the dispersion coefficients at the Lulu Island outfall were similar to those at Annacis Island. These dilution factors must also be corrected for the relative flow rate of the BCRI study and the scenario flow rates for the Lulu Island STP. The Lulu Island STP diffuser array contains four vertical risers compared to the six at Annacis Island. Therefore the flow rate ratios and dilution factors for future discharges from Lulu Island must be determined by Equation 4.3.

Equation 4.3: Dilution Factors for Lulu Island STP Scenarios

$$\text{Dilution Factor}_{\text{Scenario}} = \text{Dilution Factor}_{\text{BCRI}} \times \text{Flow Rate Ratio}$$
$$\text{Flow Rate Ratio} = \left\{ \frac{.11\text{m}^3/\text{s}}{\text{Scenario Flow Rate}/4} \right\}$$

Figure 4.1: Annacis Island STP IDZ

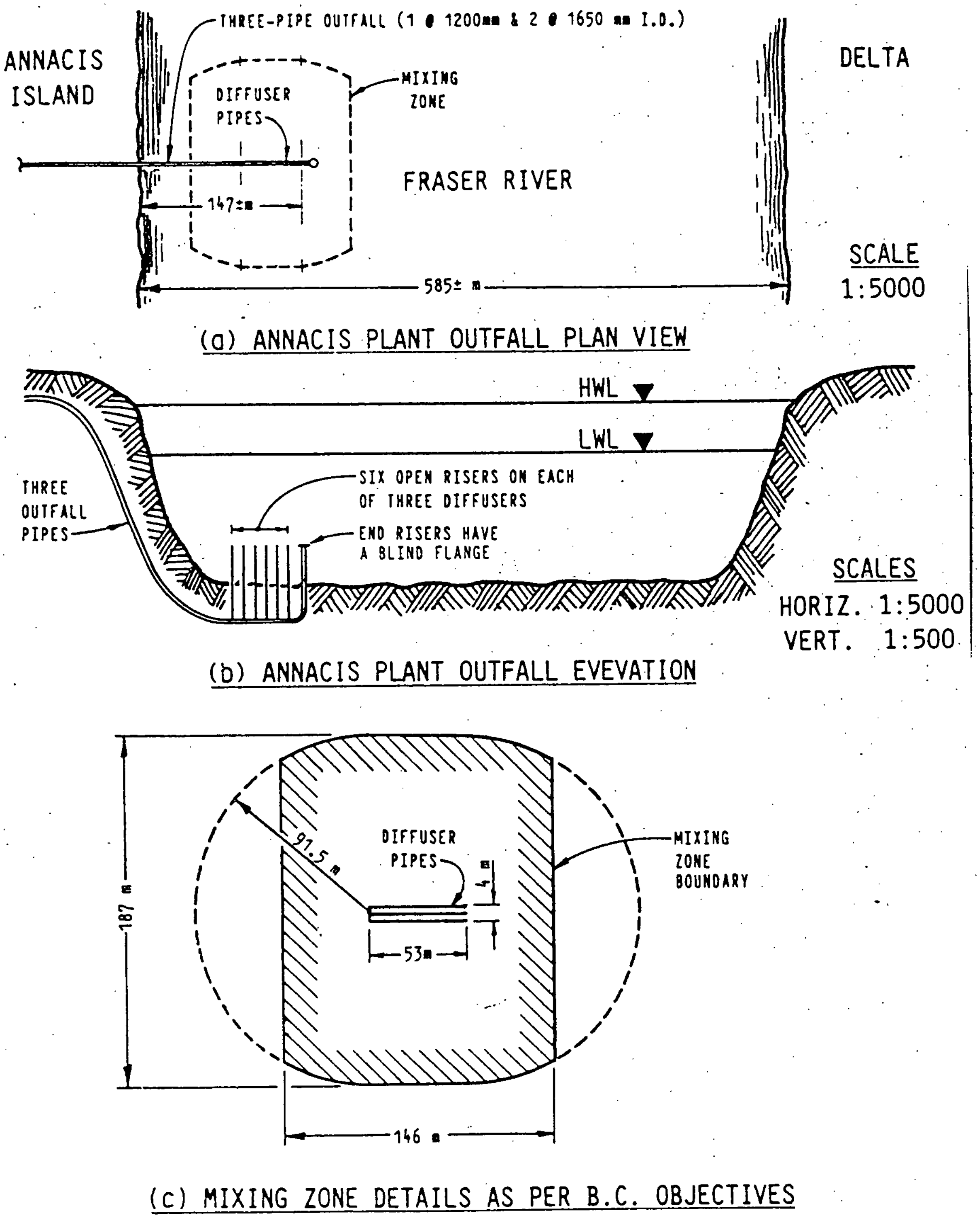
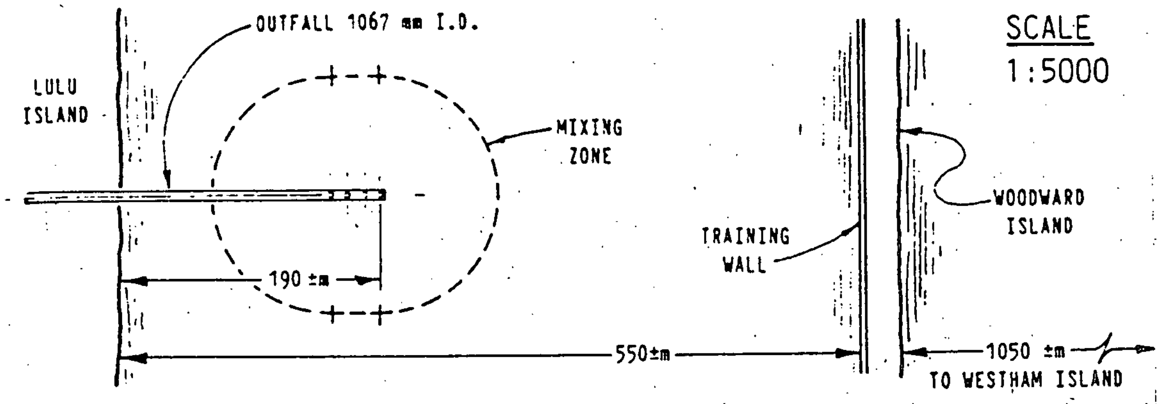
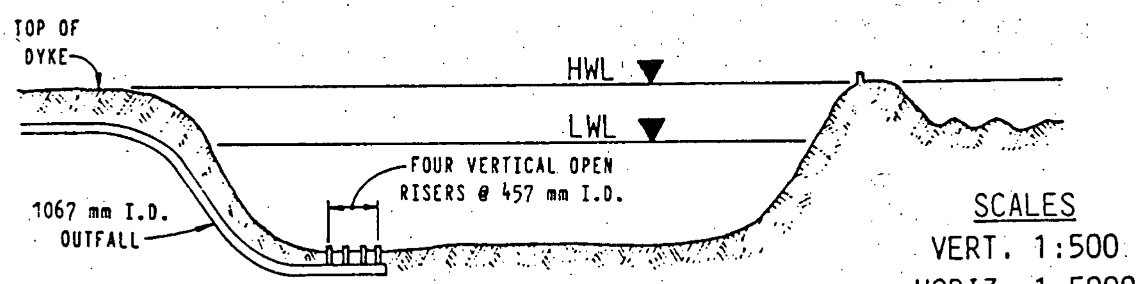


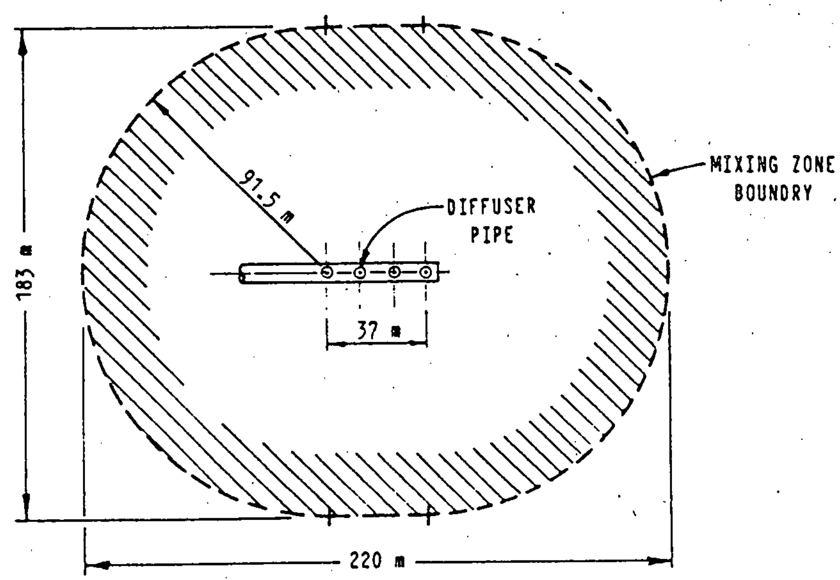
Figure 4.2: Lulu Island STP IDZ



(a) LULU ISLAND PLANT OUTFALL PLAN VIEW



(b) LULU ISLAND PLANT OUTFALL ELEVATION



(c) MIXING ZONE DETAILS IN ACCORD WITH B.C. OBJECTIVES

The flow rate ratios for the Lulu Island STP compared to the BCRI study are found in Table 4.2. The dilution factors were not corrected for the fact that the Lulu Island IDZ is larger than the Annacis Island IDZ; therefore, the dilution factors obtained for the Lulu Island IDZ are likely low-biased. The effect of the flow rate ratios on the transverse and longitudinal dilution factors measured by BCRI is summarised in Table 4.3 and Table 4.4.

Table 4.2: Flow and Flow Rate Ratios for Lulu Island STP

Scenario	Flow (m^3/s)	Flow Rate Ratio
1994	0.64	0.69
Scenario P_1	0.85	0.51
Scenario P_2	0.93	0.47
Scenario P_3	1.03	0.42

Table 4.3: Annacis Island Near-Field Dilution Factors

FSA	Dye Tracer Studies Dilution Factor		1994			Scenario 1		
			Flow rate ratio	Dilution Factor		Flow rate ratio	Dilution Factor	
Location	Avg.	Min		Avg.	Min		Avg.	Min
Transverse edge of IDZ	600	360	0.159	95	57	0.090	54	32
Downstream edge of IDZ	1000	250	0.159	159	40	0.090	90	23
Downstream of IDZ	n.q.	250	0.159	n.q.	40	0.090	n.q.	23
Upstream edge of IDZ	1100	250	0.159	175	40	0.090	99	23
Upstream of IDZ	n.q.	250	0.159	n.q.	40	0.090	n.q.	23

FSA	Dye Tracer Studies Dilution Factor		Scenario 2			Scenario 3		
			Flow rate ratio	Dilution Factor		Flow rate ratio	Dilution Factor	
Location	Avg.	Min		Avg.	Min		Avg.	Min
Transverse edge of IDZ	600	360	0.081	49	29	0.074	44	27
Downstream edge of IDZ	1000	250	0.081	81	20	0.074	74	19
Downstream of IDZ	n.q.	250	0.081	n.q.	20	0.074	n.q.	19
Upstream edge of IDZ	1100	250	0.081	89	20	0.074	81	19
Upstream of IDZ	n.q.	250	0.081	n.q.	20	0.074	n.q.	19

n.q. = Not Quantified

Table 4.4: Lulu Island Near-Field Dilution Factors

LISA	Dye Tracer Studies Dilution Factor		1994			Scenario 1		
			Flow rate ratio	Dilution Factor		Flow rate ratio	Dilution Factor	
	Avg.	Min		Avg.	Min		Avg.	Min
Transverse edge of IDZ	600	360	0.69	414	248	0.51	313	188
Downstream edge of IDZ	1000	250	0.69	690	173	0.51	521	130
Downstream of IDZ	n.q.	250	0.69	n.q.	173	0.51	n.q.	130
Upstream edge of IDZ	1100	250	0.69	759	173	0.51	573	130
Upstream of IDZ	n.q.	250	0.69	n.q.	173	0.51	n.q.	130

LISA	Dye Tracer Studies Dilution Factor		Scenario 2			Scenario 3		
			Flow rate ratio	Dilution Factor		Flow rate ratio	Dilution Factor	
	Avg.	Min		Avg.	Min		Avg.	Min
Transverse edge of IDZ	600	360	0.47	280	170	0.42	260	160
Downstream edge of IDZ	1000	250	0.47	470	120	0.42	430	110
Downstream of IDZ	n.q.	250	0.47	n.q.	120	0.42	n.q.	110
Upstream edge of IDZ	1100	250	0.47	520	120	0.42	470	110
Upstream of IDZ	n.q.	250	0.47	n.q.	120	0.42	n.q.	110

n.q. = Not Quantified

4.6.1.1 Cross-River Mixing

The minimum dilution factor obtained at the edge of the IDZ of the Annacis Island outfall, straight across river from the point of discharge, under low slack tide conditions was 360 and the average was about 600 in the BCRI study This translates to a minimum dilution factor of 52 and an average dilution factor of 95 at 1994 levels of discharge for Annacis Island and a minimum dilution of 27 and an average dilution factor of 44 under scenario P_3. The minimum dilution factor for Lulu Island is 410 and the average dilution factor is 250 at the transverse edge of the Dilution Zone. In Scenario P_3 the minimum dilution factor is 160 and the average dilution factor is 260 at the transverse edge of the Lulu Island STP IDZ. These dilution factors were calculated under the worst case conditions of slack water pooling. It is expected that the transverse dilution factor would be much higher under conditions other than at slack water.

4.6.1.2 Longitudinal River Mixing

BCRI, 1977, determined the dilution factors found within the concentrated plume both upstream and downstream of the outfall diffuser where the most severe impact of the discharge would be felt. Average dilution factors ranged from 1100 for samples collected at the edge of the specified dilution zone to 3200 at a distance of 700 m upstream. A minimum dilution of approximately 250 was found about 50 m upstream of the defined mixing zone within the drifting slack tide cloud. Average dilution factors downstream of the diffuser and outside of the mixing zone were generally greater than 1000. A minimum dilution factor of 250 was found in the drifting slack water cloud 1100 m downstream of the outfall.

The average dilution factors under 1994 flow conditions were calculated to be 160 for the downstream edge of the IDZ and 180 for the upstream edge of the Annacis Island IDZ. The average dilution factors under Scenario P_3 were found to be 74 for the upstream edge of the IDZ and 81 for the downstream edge of the Annacis Island IDZ. The minimum dilution factors were found to decrease from 40 under 1994 flow conditions to 19 under Scenario P_3 for both the upstream and downstream edges of the Annacis Island IDZ.

The average dilution factors under 1994 flow conditions were calculated to be 690 for the downstream edge of the IDZ and 760 for the upstream edge of the Lulu Island IDZ. The average dilution factors under Scenario P_3 were found to be 430 for the upstream edge of the IDZ and 470 for the downstream edge of the Annacis Island IDZ. The minimum dilution factors were found to decrease from 130 under 1994 flow conditions to 110 under Scenario P_3 for both the upstream and downstream edges of the Lulu Island IDZ.

4.6.2 Far-field Effects on Water Quality from STPs

Far-field effects on water quality were not measured by BCRI dye tracer studies. However, a water quality model by Seaconsult allows the prediction of far-field effects on water quality from the Annacis Island outfall by taking into consideration hydraulic and dispersion mechanisms, (Seaconsult, 1995b). Figure 3.4 and Figure 4.1 illustrate the position of each of the monitoring locations. The dilution factors for each of the locations in the model were calculated from the raw data in the report and are outlined in Table 4.5.

Table 4.5: Dilution Factors for a Conservative Tracer Derived from the Seaconsult Model

Location	Initial Conc. (mg/l)	Avg. Site Conc. (μg/l)	Max. Site Conc. (μg/l)	Avg. Dilution Factor	Minimum Dilution Factor
Patullo Bridge	25	17	190	1450	140
Annacis Channel	25	32	240	780	110
Tilbury Island	25	70	300	360	84
Woodwards Landing	25	50	210	500	120
Steveston	25	37	350	680	71

The flow rate ratio for each scenario were calculated by dividing the Seaconsult flow rate by the scenario flow rate and are found in Table 4.6. It was not possible to apply the far-field Annacis Island dilution factors to the Lulu Island outfall. The proximity of the Lulu Island outfall to the ocean and the difference in tidal conditions limits the scale at which the two outfalls may be compared. Scenario dilution factors for far field pollutant concentrations are outlined in Table 4.7.

Table 4.6: Flow Rate Ratios for Far-Field Effects

Scenario	Flow Rate (m^3/s)	Flow Rate Ratio
Seaconsult	4.0	1.00
1994	4.2	0.96
Scenario P_1	7.3	0.55
Scenario P_2	8.1	0.49
Scenario P_3	8.9	0.45

Table 4.7: Dilution Factors for a Conservative Tracer

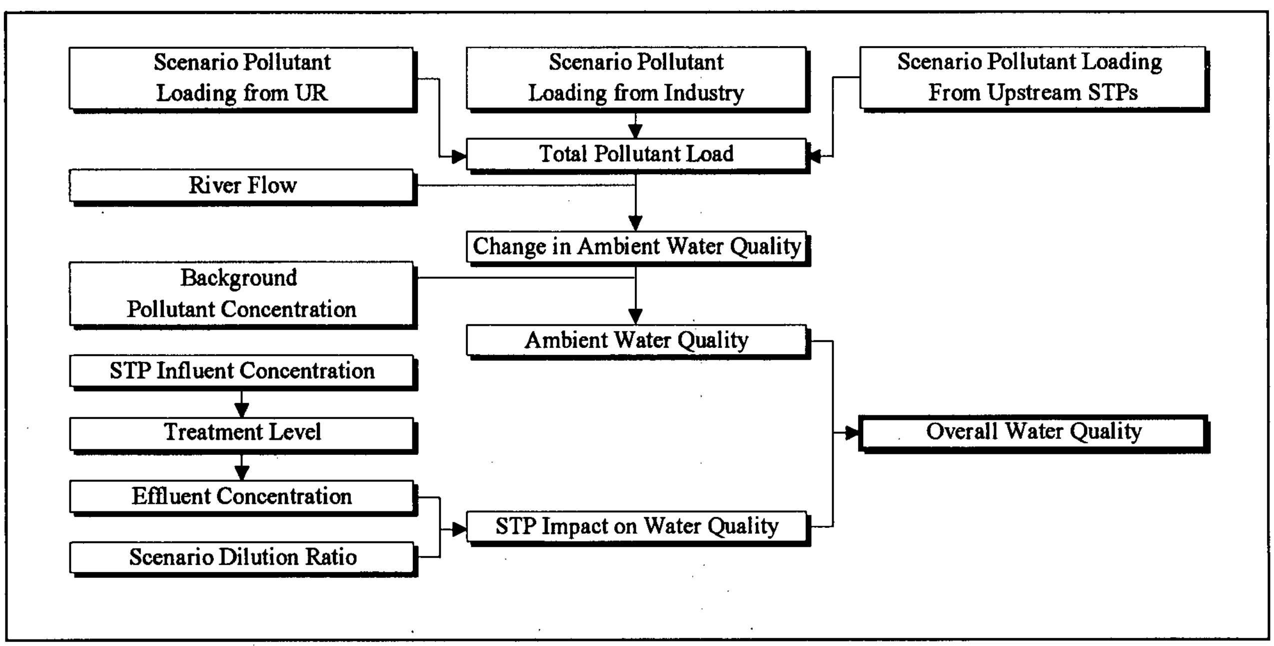
Location	1994		Scenario P_1		Scenario P_2		Scenario P_3	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	1400	130	800	74	710	66	650	61
Annacis Channel	750	100	430	58	380	51	350	47
Tilbury Island	340	81	200	46	170	41	160	38
Woodwards Landing	490	120	280	66	250	59	230	54
Steveston	660	68	380	39	340	35	310	32

Source: Seaconsult, 1995b

4.7 Summary

Methodology, to determine pollutant loading from Urban Runoff and Industrial sources, was outlined in Chapter 3. This chapter outlined the approach to determining water quality at various locations in the Fraser River. The approach is summarised in Figure 4.3.

Figure 4.3: Determination of Overall Water Quality



A simple dilution model was described to determine the change in ambient water quality at the Annacis Island and Lulu Island STP outfall as a result of future discharges from urban runoff, industrial discharges and upstream STPs. This was added to the background pollutant concentration to determine the ambient water quality. A combination of modelling approaches was used to determine the effect on water quality at Annacis and Lulu Island STP outfalls. The near-field change in water quality is determined by empirical dilution factors and the far-field effects are determined by adapting the results of a combined hydraulic dispersion model. The impacts on water quality are discussed in Chapter 5.

5. Pollutant Loading and Water Quality: Results and Discussion

The approach to determining future pollutant loading to the Fraser River in each scenario was outlined in Chapter 3. This Chapter summarises pollutant loading and the result on water quality from each pollutant source in each scenario. The methodology used to evaluate pollutant loading and water quality is also reviewed.

5.1 Industrial Pollutant Loading Scenarios

Industrial scenarios and their descriptions were outlined in Section 3.1. The pollutant loading resulting from these scenarios may be found in Table 5.1. This method of determining future pollutant loading has several limitations:

- The characteristic discharge/GDP may not be exact.
- Head offices rather than manufacturing plants may represent a significant proportion of the employment.
- Effluent characterisations may not be exact.
- The characteristic discharge/GDP and the characteristic pollutant concentration may change over time.
- There is no spatial allocation of industries in the LFB.

The characteristic discharge/GDP was drawn from Statistics Canada data published in 1991. The data was collected nation-wide and may not be exact for industrial water use in the LFB. However, this method of determining total discharges should be more accurate than assuming the actual discharges equal permitted discharges. The permits often reflect higher water use than actually occurs. This is the case if the permits reflect discharges from the plant at maximum capacity or if there is a safety factor built in to the permit so the company will not exceed the permitted level. Actual discharges from industries could be used if data were available. However, many industries are not metered and small discharges are often not monitored. This methodology allows small direct discharges to be evaluated without knowing the flow at every industrial source.

One potential significant source of error is the use of employment as a surrogate for GDP. The LFB has many head offices for resource companies whose operations may not be in the LFB. Assuming jobs are proportionate to GDP may lead to a disproportionately large estimate of discharges for these industries in the LFB. One can see that the discharge from Paper and Allied Products (SIC 29, 30) is much higher than would be expected from the level of activity in the LFB. See Table 3.5.

Table 5.1: Industrial Pollutant Loading Summary

Scenario	Total Discharges (m^3/day)	SS (Kg/day)	Chloride (Kg/day)	COD (Kg/day)	BOD (Kg/day)	Faecal Coliforms	TKN (Kg/day)	NO_3/NO_2-N (Kg/day)	NH_3-N (Kg/day)	Fluoride (Kg/day)
1994	87	1079	13907	2503	2603	n.q.	n.q.	7.7	60.2	9.9
I_1	127	1076	17154	814	468	n.q.	n.q.	14.9	22.3	12.2
I_2	133	1652	21291	1155	919	n.q.	n.q.	11.8	15.5	15.2
I_3	168	1652	21313	1155	919	n.q.	n.q.	17.7	27.2	16.5

Scenario	MBAS (Kg/day)	SO_4 (Kg/day)	Alkalinity (Kg/day)	P_{Total} (Kg/day)	$P_{Diss.}$ (Kg/day)	O&G (Kg/day)	Phenol (Kg/day)	CN_{Total} (Kg/day)	$Sulphide_{Diss.}$ (Kg/day)	Al_{Total} (Kg/day)
1994	n.q.	10428	4097	3.6	2.7	150	4.1	n.q.	n.q.	129
I_1	n.q.	9253	5884	4.8	3.3	n.q.	3.3	n.q.	n.q.	108
I_2	n.q.	15965	6273	5.4	4.1	n.q.	6.2	n.q.	n.q.	198
I_3	n.q.	16022	8156	8.0	4.1	n.q.	6.2	n.q.	n.q.	200

Scenario	$Al_{Diss.}$ (Kg/day)	As_{Total} (Kg/day)	Ba_{Total} (Kg/day)	$Ba_{Diss.}$ (Kg/day)	B_{Total} (Kg/day)	$B_{Diss.}$ (Kg/day)	Cd_{Total} (Kg/day)	$Cd_{Diss.}$ (Kg/day)	Cr_{Total} (Kg/day)	$Cr_{Diss.}$ (Kg/day)
1994	20	0.07	0.44	3.7	5.9	39	34	n.q.	n.q.	n.q.
I_1	17	0.14	0.56	3.1	6.5	33	27	n.q.	n.q.	n.q.
I_2	30	0.11	0.68	5.6	9.0	60	53	n.q.	n.q.	n.q.
I_3	32	0.19	0.69	5.6	9.0	60	53	n.q.	n.q.	n.q.

n.q. = Not Quantified

Table 5.1: Continued

Scenario	Co_{Total} (Kg/day)	$Co_{Diss.}$ (Kg/day)	Cu_{Total} (Kg/day)	$Cu_{Diss.}$ (Kg/day)	Fe_{Total} (Kg/day)	$Fe_{Diss.}$ (Kg/day)	Pb_{Total} (Kg/day)	$Pb_{Diss.}$ (Kg/day)	Mn_{Total} (Kg/day)	$Mn_{Diss.}$ (Kg/day)
1994	n.q.	n.q.	1.7	0.18	54	18	0.19	0.006	7.6	6.5
I_1	n.q.	n.q.	1.8	0.35	77	24	0.20	0.010	8.4	6.6
I_2	n.q.	n.q.	2.6	0.27	83	28	0.29	0.009	11.6	9.9
I_3	n.q.	n.q.	2.7	0.36	89	29	0.29	0.009	12.6	10.5

Scenario	Hg_{Total} (Kg/day)	Mo_{Total} (Kg/day)	$Mo_{Diss.}$ (Kg/day)	Ni_{Total} (Kg/day)	$Ni_{Diss.}$ (Kg/day)	Se_{Total} (Kg/day)	$Se_{Diss.}$ (Kg/day)	Ag_{Total} (Kg/day)	$Ag_{Diss.}$ (Kg/day)	Sn_{Total} (Kg/day)
1994	n.q.	n.q.	n.q.	0.06	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
I_1	n.q.	n.q.	n.q.	0.10	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
I_2	n.q.	n.q.	n.q.	0.09	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
I_3	n.q.	n.q.	n.q.	0.09	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Scenario	$Sn_{Diss.}$ (Kg/day)	Zn_{Total} (Kg/day)	$Zn_{Diss.}$ (Kg/day)	$Hydrocarbons_{Total}$ (Kg/day)	PAH (Kg/day)
1994	n.q.	3.3	1.9	n.q.	n.q.
I_1	n.q.	3.9	2.4	n.q.	n.q.
I_2	n.q.	5.1	2.9	n.q.	n.q.
I_3	n.q.	5.4	3.1	n.q.	n.q.

n.q. = Not Quantified

Characteristic pollutant concentrations were developed, but may not be exact. Effluent analyses from local industries were used whenever possible to characterise the effluent of an SIC code. However, due to data limitations, effluent analysis from a single company was used to characterise effluent from some SIC codes. In addition, effluent analysis from non-local operations was used to characterise effluent for SICs not analysed in local studies. These analyses may not be representative of local industries because non-local operations have to conform to regulations which may differ from those in the LFB. This may result in estimated effluent pollutant concentrations which may be higher or lower than those in the LFB. Estimates based on permit data are also limited: industrial discharge permits often do not address all of the pollutants of interest and permit levels are often conservative and actual pollutant concentrations may be lower. Estimates based on permit data may give inflated loadings of some pollutants and not address other pollutants of interest. Using characteristic pollutant concentrations may not be exact, but it can more fully address actual pollutant concentrations and parameters which are not listed.

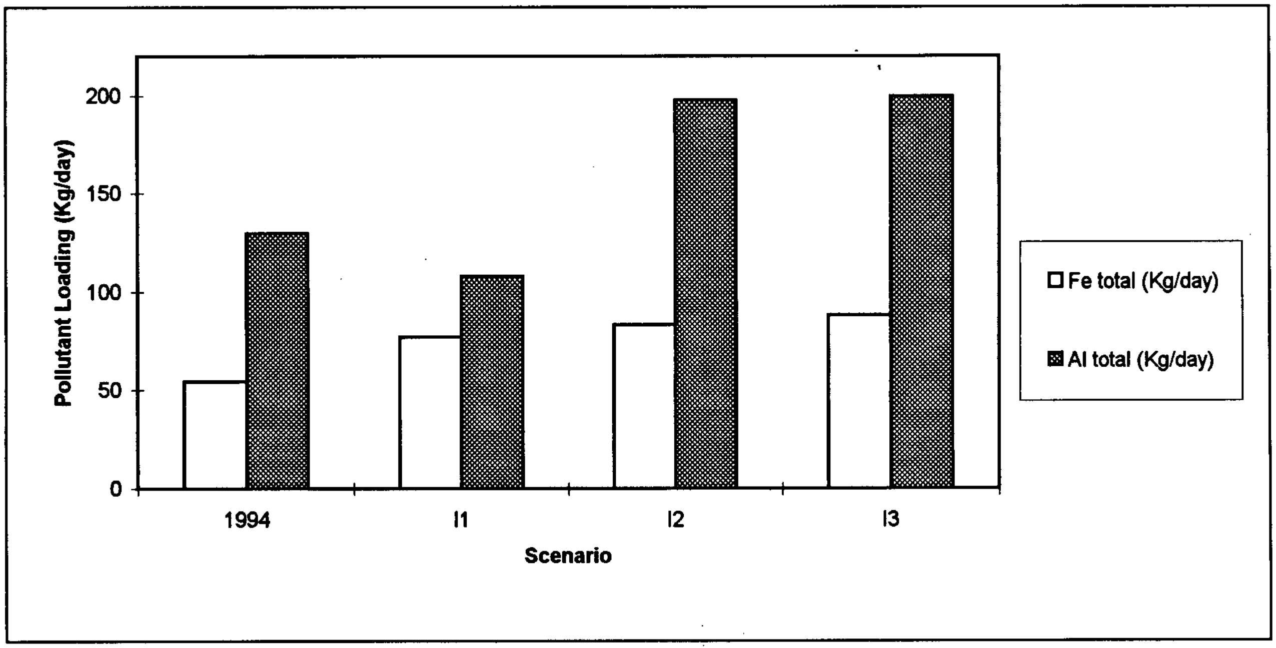
As industrial processes are improved and new treatment technologies are legislated, the water use/GDP and the characteristic pollutant concentration will change. Both will probably decrease, however, if new highly water intensive industries come to the region, both may increase. The levels of water use and pollutant concentration were assumed to remain constant in the scenarios over the period 1990 - 2030. This should give a 'worst case' estimate of pollutant loading due to industrial activity.

The discharges from industry were not spatially allocated. It was assumed the discharges would affect the ambient concentration of pollutants in the Fraser River at the Annacis Island and Lulu Island STP outfalls. This methodology was not designed to determine the spatial effects of industrial wastewater discharges, but rather how total future industrial discharges affect the decision to upgrade Annacis Island and Lulu Island STPs. Determining the spatial effect on water quality would require a detailed characterisation of each industrial discharge and its dispersion. This methodology was designed to avoid the expense of multiple detailed characterisations while allowing an estimate of the future increase in ambient pollutant concentration.

This methodology may be of interest to Input/Output modellers. Pollutant loading/GDP could be attached as a satellite account to industrial activity. The activity of each industry would be multiplied by the pollutant load/GDP to determine total pollutant loading. Satellite accounts exist for air emissions/GDP (Lonergan, 1995). Total emissions as a result of activity have been assessed. Evaluating discharges on a provincial or national scale may give a more accurate estimate of pollutant loading because the problem of linking jobs to GDP is avoided. Determining total water discharges may not be as useful as determining total air emissions due to the spatial variance in ability for water bodies to assimilate waste, whereas all air pollutants are discharged to the same receptacle. Therefore, determining total water discharges does not give as clear an idea of the environmental impact as total air emissions.

The major advantage of the approach is its sensitivity to changes in activity in individual sectors. Scenarios I_1 and I_3 illustrate the sensitivity of the method to growth in individual sectors. Scenario I_2 has the effect of multiplying the present level of pollutant loading by a scalar giving the same relative change in loading to every pollutant. Separating discharges by SIC codes and allowing activity in industrial sectors to change independently allows the loading of individual pollutants to change independently. Fe_{Total} and Al_{Total} illustrate the sensitivity of the approach. Figure 5.1 illustrates the relative loading of Fe_{Total} and Al_{Total} in 2021 compared to 1994 levels for scenarios I_1, I_2, and I_3.

Figure 5.1: Loading Comparison of Fe_{Total} and Al_{Total} in 2021



Fe_{Total} loading is relatively insensitive to the different scenarios analysed while Al_{Total} loading is dramatically lower in scenario I_1 than in I_2 or I_3. Discharges of Al_{Total} are highly dependent on activity in Paper and Allied Products industries (SIC27); therefore, changes in the activity of this sector have more of an effect on Al_{Total} loading than changes in other sectors. Scenario I_2 illustrates the limitations of scenarios which assume the same growth rate in all sectors. This results in the same percent change in pollutant loading for all pollutants. Uniform changes in activity of individual sectors is not probable. This method of determining pollutant loads is able to reflect the changing make-up of the economy.

It was assumed that permitted direct industrial discharges were not representative of actual direct discharges to the Fraser River. Therefore, methodology was developed to link direct industrial discharges to the level of manufacturing activity assuming the percentage of direct discharges from each SIC remains constant. The method yielded acceptable results for the determination of direct and indirect industrial discharges to the Fraser River for the purposes of this study however, there are limitations in accuracy. It is unlikely that the split between direct and indirect discharges will remain constant in the future or that the level of treatment will remain the same. This method is useful for assessing discharges from small sources, however, many of these sources, such as restaurants, discharge their waste to sewer and are not direct discharges. Therefore, assessing future discharges by the method of satellite accounts should be limited to determining economy-wide total industrial discharges. Efforts to determine industrial discharges to the Fraser River should concentrate on getting accurate flow data from all local industries. This would allow a very accurate determination of the pollutant loading as a result of industrial activity. Future direct discharges could be estimated by multiplying the current water use by the predicted percent increase.

5.2 Sewage Treatment Plant Scenarios

The future pollutant loading to the Fraser River as a result of population growth scenarios is outlined in Table 5.2. The methodologies to determine water quality and the impacts as a result of pollutant loading from STPs were discussed in Section 4.6.

Table 5.2: Loading From Sewage Treatment Plants for Various Scenarios

Loading From FSA STP with Primary Treatment

Year	Population	SS (tonne/day)	Chloride (tonne/day)	COD (tonne/day)	BOD (tonne/day)	Faecal Coliforms (10^12/day)	TKN (tonne/day)	NO_3/NO_2-N (kg/day)	NH_3-N (tonne/day)	Fluoride (kg/day)
1994	865479	21.5	18.6	95	49	115	9.7	n.q.	6.4	n.q.
2021 P_1	1538964	38.2	33.1	169	87	204	17.2	n.q.	11.5	n.q.
2021 P_2	1692860	42.0	36.4	186	96	224	18.9	n.q.	12.6	n.q.
2021 P_3	1862146	46.3	40.1	205	106	247	20.8	n.q.	13.9	n.q.

LISA STP Loading with Primary Treatment

Year	Population	SS (tonne/day)	Chloride (tonne/day)	COD (tonne/day)	BOD (tonne/day)	Faecal Coliforms Winter (10^12/day)	TKN (tonne/day)	NO_3/NO_2-N (kg/day)	NH_3-N (tonne/day)	Fluoride (kg/day)
1994	139435	3.1	4.0	16.0	8.3	17	1.6	n.q.	1.1	0.014
2021 P_1	184558	4.1	5.3	21.2	11.0	23	2.1	n.q.	1.4	0.018
2021 P_2	203014	4.5	5.9	23.3	12.1	25	2.3	n.q.	1.5	0.020
2021 P_3	223315	5.0	6.5	25.7	13.3	27	2.6	n.q.	1.7	0.022

FVSA Loading with Secondary Treatment

	Parameter Population	SS (tonne/day)	Chloride (tonne/day)	COD (tonne/day)	BOD (tonne/day)	Faecal Coliforms Winter (10^12/day)	TKN (tonne/day)	NO_3/NO_2-N (kg/day)	NH_3-N (tonne/day)	Fluoride (kg/day)
1994	111800	1.3	3.6	3.6	0.9	0.16	1.1	n.q.	0.6	n.q.
2021 P_1	223600	2.6	7.2	7.2	1.8	0.33	2.2	n.q.	1.2	n.q.
2021 P_2	245960	2.9	8.0	7.9	2.0	0.36	2.4	n.q.	1.4	n.q.
2021 P_3	279500	3.3	9.0	9.0	2.3	0.41	2.7	n.q.	1.6	n.q.

FSA Loading with Secondary Treatment

	Parameter Population	SS (tonne/day)	Chloride (tonne/day)	COD (tonne/day)	BOD (tonne/day)	Faecal Coliforms Winter (10^12/day)	TKN (tonne/day)	NO_3/NO_2-N (kg/day)	NH_3-N (tonne/day)	Fluoride (kg/day)
1994	865479	8.8	17.9	26.1	7.3	1.1	9.2	n.q.	6.0	0.029
2021 P_1	1538964	15.7	31.9	46.3	13.1	2.0	16.3	n.q.	10.7	0.051
2021 P_2	1692860	17.2	35.0	51.0	14.4	2.2	17.9	n.q.	11.7	0.056
2021 P_3	1862146	19.0	38.5	56.1	15.8	2.5	19.7	n.q.	12.9	0.062

LISA Loading Scenarios with Secondary Treatment

	Parameter Population	SS (tonne/day)	Chloride (tonne/day)	COD (tonne/day)	BOD (tonne/day)	Faecal Coliforms Winter (10^12/day)	TKN (tonne/day)	NO_3/NO_2-N (kg/day)	NH_3-N (tonne/day)	Fluoride (kg/day)
1994	139435	1.9	3.8	5.1	1.2	0.28	1.4	n.q.	1.0	0.014
2021 P_1	184558	2.6	5.0	6.7	1.7	0.37	1.8	n.q.	1.3	0.018
2021 P_2	203014	2.8	5.5	7.4	1.8	0.41	2.0	n.q.	1.4	0.020
2021 P_3	223315	3.1	6.0	8.1	2.0	0.45	2.2	n.q.	1.5	0.022

n.q. = Not Quantified

Table 5.2: Continued

Loading From FSA STP with Primary Treatment

Year	MBAS (kg/day)	SO_4 (tonne/day)	Alkalinity (tonne/day)	P_{Total} (kg/day)	$P_{Diss.}$ (kg/day)	O&G (tonne/day)	Phenol (kg/day)	CN_{Total} (kg/day)	$Sulphide_{Diss.}$ (kg/day)	Al_{Total} (kg/day)
1994	1147	12.5	44.4	1469	967	9.7	17.9	n.q.	n.q.	143
2021 P_1	2039	22.3	79.0	2612	1720	17.2	31.9	n.q.	n.q.	255
2021 P_2	2243	24.5	86.9	2873	1892	18.9	35.0	n.q.	n.q.	280
2021 P_3	2467	27.0	95.6	3161	2081	20.8	38.5	n.q.	n.q.	308

LISA STP Loading with Primary Treatment

Year	MBAS (kg/day)	SO_4 (tonne/day)	Alkalinity (tonne/day)	P_{Total} (kg/day)	$P_{Diss.}$ (kg/day)	O&G (tonne/day)	Phenol (kg/day)	CN_{Total} (kg/day)	$Sulphide_{Diss.}$ (kg/day)	Al_{Total} (kg/day)
1994	177	1.4	5.1	249	171	1.7	2.8	n.q.	n.q.	33.2
2021 P_1	234	1.8	6.7	329	227	2.2	3.7	n.q.	n.q.	43.9
2021 P_2	258	2.0	7.4	362	250	2.4	4.0	n.q.	n.q.	48.3
2021 P_3	283	2.2	8.1	399	275	2.7	4.4	n.q.	n.q.	53.1

FVSA Loading with Secondary Treatment

	MBAS (kg/day)	SO_4 (tonne/day)	Alkalinity (tonne/day)	P_{Total} (kg/day)	$P_{Diss.}$ (kg/day)	O&G (tonne/day)	Phenol (kg/day)	CN_{Total} (kg/day)	$Sulphide_{Diss.}$ (kg/day)	Al_{Total} (kg/day)
1994	n.q.	1.5	5.5	n.q.	n.q.	1.9	2.4	n.q.	n.q.	46.0
2021 P_1	n.q.	3.0	11.0	n.q.	n.q.	3.8	4.9	n.q.	n.q.	92.0
2021 P_2	n.q.	3.3	12.1	n.q.	n.q.	4.2	5.4	n.q.	n.q.	101.2
2021 P_3	n.q.	3.8	13.8	n.q.	n.q.	4.8	6.1	n.q.	n.q.	114.9

FSA Loading with Secondary Treatment

	MBAS (kg/day)	SO_4 (tonne/day)	Alkalinity (tonne/day)	P_{Total} (kg/day)	$P_{Diss.}$ (kg/day)	O&G (tonne/day)	Phenol (kg/day)	CN_{Total} (kg/day)	$Sulphide_{Diss.}$ (kg/day)	Al_{Total} (kg/day)
1994	n.q.	12.4	44	1433	943	9.7	19.5	n.q.	n.q.	158
2021 P_1	n.q.	22.1	79	2548	1677	17.2	34.7	n.q.	n.q.	281
2021 P_2	n.q.	24.3	87	2803	1844	18.9	38.2	n.q.	n.q.	309
2021 P_3	n.q.	26.7	96	3084	2029	20.8	42.0	n.q.	n.q.	340

LISA Loading Scenarios with Secondary Treatment

	MBAS (kg/day)	SO_4 (tonne/day)	Alkalinity (tonne/day)	P_{Total} (kg/day)	$P_{Diss.}$ (kg/day)	O&G (tonne/day)	Phenol (kg/day)	CN_{Total} (kg/day)	$Sulphide_{Diss.}$ (kg/day)	Al_{Total} (kg/day)
1994	n.q.	1.5	5.1	217	140	1.7	3.5	n.q.	n.q.	31
2021 P_1	n.q.	2.0	6.7	287	185	2.2	4.7	n.q.	n.q.	42
2021 P_2	n.q.	2.2	7.4	316	204	2.4	5.1	n.q.	n.q.	46
2021 P_3	n.q.	2.5	8.1	347	224	2.7	5.6	n.q.	n.q.	50

n.q. = Not Quantified

Table 5.2: Continued

Loading From FSA STP with Primary Treatment

Year	$Al_{Diss.}$ (kg/day)	As_{Total} (kg/day)	Ba_{Total} (kg/day)	$Ba_{Diss.}$ (kg/day)	B_{Total} (kg/day)	$B_{Diss.}$ (kg/day)	Cd_{Total} (kg/day)	$Cd_{Diss.}$ (kg/day)	Cr_{Total} (kg/day)	$Cr_{Diss.}$ (kg/day)
1994	n.q.	n.q.	10.4	3.6	57	50	n.q.	n.q.	2.9	n.q.
2021 P_1	n.q.	n.q.	18.5	6.4	102	89	n.q.	n.q.	5.1	n.q.
2021 P_2	n.q.	n.q.	20.3	7.0	112	98	n.q.	n.q.	5.6	n.q.
2021 P_3	n.q.	n.q.	22.4	7.7	123	108	n.q.	n.q.	6.2	n.q.

LISA STP Loading with Primary Treatment

Year	$Al_{Diss.}$ (kg/day)	As_{Total} (kg/day)	Ba_{Total} (kg/day)	$Ba_{Diss.}$ (kg/day)	B_{Total} (kg/day)	$B_{Diss.}$ (kg/day)	Cd_{Total} (kg/day)	$Cd_{Diss.}$ (kg/day)	Cr_{Total} (kg/day)	$Cr_{Diss.}$ (kg/day)
1994	n.q.	n.q.	2.0	0.55	8	7	n.q.	n.q.	1.2	0.50
2021 P_1	n.q.	n.q.	2.6	0.73	10	10	n.q.	n.q.	1.5	0.66
2021 P_2	n.q.	n.q.	2.9	0.81	11	11	n.q.	n.q.	1.7	0.72
2021 P_3	n.q.	n.q.	3.2	0.89	12	12	n.q.	n.q.	1.9	0.80

FVSA Loading with Secondary Treatment

	$Al_{Diss.}$ (kg/day)	As_{Total} (kg/day)	Ba_{Total} (kg/day)	$Ba_{Diss.}$ (kg/day)	B_{Total} (kg/day)	$B_{Diss.}$ (kg/day)	Cd_{Total} (kg/day)	$Cd_{Diss.}$ (kg/day)	Cr_{Total} (kg/day)	$Cr_{Diss.}$ (kg/day)
1994	n.q.	n.q.	2.4	0.6	8	9	0.006	n.q.	0.2	0.17
2021 P_1	n.q.	n.q.	4.7	1.1	16	18	0.011	n.q.	0.4	0.34
2021 P_2	n.q.	n.q.	5.2	1.3	17	20	0.012	n.q.	0.4	0.38
2021 P_3	n.q.	n.q.	5.9	1.4	20	23	0.014	n.q.	0.4	0.43

FSA Loading with Secondary Treatment

	$Al_{Diss.}$ (kg/day)	As_{Total} (kg/day)	Ba_{Total} (kg/day)	$Ba_{Diss.}$ (kg/day)	B_{Total} (kg/day)	$B_{Diss.}$ (kg/day)	Cd_{Total} (kg/day)	$Cd_{Diss.}$ (kg/day)	Cr_{Total} (kg/day)	$Cr_{Diss.}$ (kg/day)
1994	n.q.	n.q.	11	3.6	57	48	n.q.	n.q.	0.8	0.72
2021 P_1	n.q.	n.q.	20	6.4	101	85	n.q.	n.q.	1.4	1.3
2021 P_2	n.q.	n.q.	22	7.0	111	93	n.q.	n.q.	1.5	1.4
2021 P_3	n.q.	n.q.	24	7.7	122	103	n.q.	n.q.	1.7	1.5

LISA Loading Scenarios with Secondary Treatment

	$Al_{Diss.}$ (kg/day)	As_{Total} (kg/day)	Ba_{Total} (kg/day)	$Ba_{Diss.}$ (kg/day)	B_{Total} (kg/day)	$B_{Diss.}$ (kg/day)	Cd_{Total} (kg/day)	$Cd_{Diss.}$ (kg/day)	Cr_{Total} (kg/day)	$Cr_{Diss.}$ (kg/day)
1994	n.q.	n.q.	1.9	0.55	9	6.8	0.007	n.q.	0.3	0.30
2021 P_1	n.q.	n.q.	2.5	0.73	12	9.0	0.010	n.q.	0.5	0.40
2021 P_2	n.q.	n.q.	2.8	0.81	13	9.9	0.011	n.q.	0.5	0.44
2021 P_3	n.q.	n.q.	3.0	0.89	14	10.9	0.012	n.q.	0.5	0.49

n.q. = Not Quantified

Table 5.2: Continued

Loading From FSA STP with Primary Treatment

Year	Co_{Total} (kg/day)	$Co_{Diss.}$ (kg/day)	Cu_{Total} (kg/day)	$Cu_{Diss.}$ (kg/day)	Fe_{Total} (kg/day)	$Fe_{Diss.}$ (kg/day)	Pb_{Total} (kg/day)	$Pb_{Diss.}$ (kg/day)	Mn_{Total} (kg/day)	$Mn_{Diss.}$ (kg/day)
1994	n.q.	n.q.	50	25	850	440	2.9	n.q.	36	25
2021 P_1	n.q.	n.q.	90	45	1500	800	5.1	n.q.	64	45
2021 P_2	n.q.	n.q.	98	49	1700	870	5.6	n.q.	70	49
2021 P_3	n.q.	n.q.	108	54	1800	960	6.2	n.q.	77	54

LISA STP Loading with Primary Treatment

Year	Co_{Total} (kg/day)	$Co_{Diss.}$ (kg/day)	Cu_{Total} (kg/day)	$Cu_{Diss.}$ (kg/day)	Fe_{Total} (kg/day)	$Fe_{Diss.}$ (kg/day)	Pb_{Total} (kg/day)	$Pb_{Diss.}$ (kg/day)	Mn_{Total} (kg/day)	$Mn_{Diss.}$ (kg/day)
1994	n.q.	n.q.	9.4	4.4	100	51	0.50	n.q.	4.4	3.3
2021 P_1	n.q.	n.q.	12	5.9	130	67	0.66	n.q.	5.9	4.4
2021 P_2	n.q.	n.q.	14	6.4	140	74	0.72	n.q.	6.4	4.8
2021 P_3	n.q.	n.q.	15	7.1	160	81	0.80	n.q.	7.1	5.3

FVSA Loading with Secondary Treatment

	Co_{Total} (kg/day)	$Co_{Diss.}$ (kg/day)	Cu_{Total} (kg/day)	$Cu_{Diss.}$ (kg/day)	Fe_{Total} (kg/day)	$Fe_{Diss.}$ (kg/day)	Pb_{Total} (kg/day)	$Pb_{Diss.}$ (kg/day)	Mn_{Total} (kg/day)	$Mn_{Diss.}$ (kg/day)
1994	n.q.	n.q.	2.3	1.5	24	23	0.35	0.09	3.0	2.6
2021 P_1	n.q.	n.q.	4.5	2.9	48	46	0.70	0.18	6.1	5.2
2021 P_2	n.q.	n.q.	5.0	3.2	53	50	0.77	0.20	6.7	5.7
2021 P_3	n.q.	n.q.	5.7	3.6	60	57	0.88	0.23	7.6	6.5

FSA Loading with Secondary Treatment

	Co_{Total} (kg/day)	$Co_{Diss.}$ (kg/day)	Cu_{Total} (kg/day)	$Cu_{Diss.}$ (kg/day)	Fe_{Total} (kg/day)	$Fe_{Diss.}$ (kg/day)	Pb_{Total} (kg/day)	$Pb_{Diss.}$ (kg/day)	Mn_{Total} (kg/day)	$Mn_{Diss.}$ (kg/day)
1994	n.q.	n.q.	15	8.6	250	240	1.5	n.q.	26	26
2021 P_1	n.q.	n.q.	27	15.3	450	430	2.7	n.q.	47	46
2021 P_2	n.q.	n.q.	30	16.8	490	470	2.9	n.q.	52	51
2021 P_3	n.q.	n.q.	33	18.5	540	520	3.2	n.q.	57	56

LISA Loading Scenarios with Secondary Treatment

	Co_{Total} (kg/day)	$Co_{Diss.}$ (kg/day)	Cu_{Total} (kg/day)	$Cu_{Diss.}$ (kg/day)	Fe_{Total} (kg/day)	$Fe_{Diss.}$ (kg/day)	Pb_{Total} (kg/day)	$Pb_{Diss.}$ (kg/day)	Mn_{Total} (kg/day)	$Mn_{Diss.}$ (kg/day)
1994	n.q.	n.q.	3.7	2.0	31	25	0.29	n.q.	3.3	2.5
2021 P_1	n.q.	n.q.	4.9	2.6	41	34	0.38	n.q.	4.4	3.3
2021 P_2	n.q.	n.q.	5.4	2.9	45	37	0.42	n.q.	4.9	3.6
2021 P_3	n.q.	n.q.	6.0	3.2	49	41	0.46	n.q.	5.3	4.0

n.q. = Not Quantified

Table 5.2: Continued

Loading From FSA STP with Primary Treatment

Year	Hg_{Total} (kg/day)	Mo_{Total} (kg/day)	$Mo_{Diss.}$ (kg/day)	Ni_{Total} (kg/day)	$Ni_{Diss.}$ (kg/day)	Se_{Total} (kg/day)	$Se_{Diss.}$ (kg/day)	Ag_{Total} (kg/day)	$Ag_{Diss.}$ (kg/day)	Sn_{Total} (kg/day)
1994	n.q.	n.q.	n.q.	3.2	2.9	0.4	n.q.	1.1	n.q.	n.q.
2021 P_1	n.q.	n.q.	n.q.	5.7	5.1	0.6	n.q.	1.9	n.q.	n.q.
2021 P_2	n.q.	n.q.	n.q.	6.3	5.6	0.7	n.q.	2.1	n.q.	n.q.
2021 P_3	n.q.	n.q.	n.q.	6.9	6.2	0.8	n.q.	2.3	n.q.	n.q.

LISA STP Loading with Primary Treatment

Year	Hg_{Total} (kg/day)	Mo_{Total} (kg/day)	$Mo_{Diss.}$ (kg/day)	Ni_{Total} (kg/day)	$Ni_{Diss.}$ (kg/day)	Se_{Total} (kg/day)	$Se_{Diss.}$ (kg/day)	Ag_{Total} (kg/day)	$Ag_{Diss.}$ (kg/day)	Sn_{Total} (kg/day)
1994	n.q.	n.q.	n.q.	1.5	1.2	n.q.	n.q.	0.9	0.4	n.q.
2021 P_1	n.q.	n.q.	n.q.	2.0	1.6	n.q.	n.q.	1.2	0.6	n.q.
2021 P_2	n.q.	n.q.	n.q.	2.3	1.8	n.q.	n.q.	1.3	0.6	n.q.
2021 P_3	n.q.	n.q.	n.q.	2.5	1.9	n.q.	n.q.	1.4	0.7	n.q.

FVSA Loading with Secondary Treatment

	Hg_{Total} (kg/day)	Mo_{Total} (kg/day)	$Mo_{Diss.}$ (kg/day)	Ni_{Total} (kg/day)	$Ni_{Diss.}$ (kg/day)	Se_{Total} (kg/day)	$Se_{Diss.}$ (kg/day)	Ag_{Total} (kg/day)	$Ag_{Diss.}$ (kg/day)	Sn_{Total} (kg/day)
1994	0.014	n.q.	n.q.	0.5	0.4	n.q.	n.q.	n.q.	n.q.	n.q.
2021 P_1	0.029	n.q.	n.q.	1.0	0.8	n.q.	n.q.	n.q.	n.q.	n.q.
2021 P_2	0.031	n.q.	n.q.	1.2	0.9	n.q.	n.q.	n.q.	n.q.	n.q.
2021 P_3	0.036	n.q.	n.q.	1.3	1.0	n.q.	n.q.	n.q.	n.q.	n.q.

FSA Loading with Secondary Treatment

	Hg_{Total} (kg/day)	Mo_{Total} (kg/day)	$Mo_{Diss.}$ (kg/day)	Ni_{Total} (kg/day)	$Ni_{Diss.}$ (kg/day)	Se_{Total} (kg/day)	$Se_{Diss.}$ (kg/day)	Ag_{Total} (kg/day)	$Ag_{Diss.}$ (kg/day)	Sn_{Total} (kg/day)
1994	n.q.	n.q.	n.q.	3.3	2.9	0.36	n.q.	1.4	n.q.	n.q.
2021 P_1	n.q.	n.q.	n.q.	5.8	5.2	0.64	n.q.	2.6	n.q.	n.q.
2021 P_2	n.q.	n.q.	n.q.	6.4	5.7	0.70	n.q.	2.8	n.q.	n.q.
2021 P_3	n.q.	n.q.	n.q.	7.0	6.2	0.77	n.q.	3.1	n.q.	n.q.

LISA Loading Scenarios with Secondary Treatment

	Hg_{Total} (kg/day)	Mo_{Total} (kg/day)	$Mo_{Diss.}$ (kg/day)	Ni_{Total} (kg/day)	$Ni_{Diss.}$ (kg/day)	Se_{Total} (kg/day)	$Se_{Diss.}$ (kg/day)	Ag_{Total} (kg/day)	$Ag_{Diss.}$ (kg/day)	Sn_{Total} (kg/day)
1994	n.q.	n.q.	n.q.	2.1	1.9	n.q.	n.q.	1.0	0.4	n.q.
2021 P_1	n.q.	n.q.	n.q.	2.8	2.5	n.q.	n.q.	1.3	0.6	n.q.
2021 P_2	n.q.	n.q.	n.q.	3.1	2.8	n.q.	n.q.	1.4	0.6	n.q.
2021 P_3	n.q.	n.q.	n.q.	3.4	3.0	n.q.	n.q.	1.6	0.7	n.q.

n.q. = Not Quantified

Table 5.2: Continued

Loading From FSA STP with Primary Treatment

Year	$Sn_{Diss.}$ (kg/day)	Zn_{Total} (kg/day)	$Zn_{Diss.}$ (kg/day)	$Hydrocarbons_{Total}$ (kg/day)	PAH (kg/day)
1994	n.q.	29	18	n.q.	n.q.
2021 P_1	n.q.	51	32	n.q.	n.q.
2021 P_2	n.q.	56	35	n.q.	n.q.
2021 P_3	n.q.	62	39	n.q.	n.q.

LISA STP Loading with Primary Treatment

Year	$Sn_{Diss.}$ (kg/day)	Zn_{Total} (kg/day)	$Zn_{Diss.}$ (kg/day)	$Hydrocarbons_{Total}$ (kg/day)	PAH (kg/day)
1994	n.q.	5.5	2.8	n.q.	n.q.
2021 P_1	n.q.	7.3	3.7	n.q.	n.q.
2021 P_2	n.q.	8.1	4.0	n.q.	n.q.
2021 P_3	n.q.	8.9	4.4	n.q.	n.q.

FVSA Loading with Secondary Treatment

	$Sn_{Diss.}$ (kg/day)	Zn_{Total} (kg/day)	$Zn_{Diss.}$ (kg/day)	$Hydrocarbons_{Total}$ (kg/day)	PAH (kg/day)
1994	n.q.	1.3	2.3	n.q.	n.q.
2021 P_1	n.q.	2.7	4.6	n.q.	n.q.
2021 P_2	n.q.	2.9	5.1	n.q.	n.q.
2021 P_3	n.q.	3.3	5.8	n.q.	n.q.

FSA Loading with Secondary Treatment

	$Sn_{Diss.}$ (kg/day)	Zn_{Total} (kg/day)	$Zn_{Diss.}$ (kg/day)	$Hydrocarbons_{Total}$ (kg/day)	PAH (kg/day)
1994	n.q.	7.2	13	n.q.	n.q.
2021 P_1	n.q.	13	22	n.q.	n.q.
2021 P_2	n.q.	14	25	n.q.	n.q.
2021 P_3	n.q.	15	27	n.q.	n.q.

LISA Loading Scenarios with Secondary Treatment

	$Sn_{Diss.}$ (kg/day)	Zn_{Total} (kg/day)	$Zn_{Diss.}$ (kg/day)	$Hydrocarbons_{Total}$ (kg/day)	PAH (kg/day)
1994	n.q.	2.2	3.1	n.q.	n.q.
2021 P_1	n.q.	2.9	4.1	n.q.	n.q.
2021 P_2	n.q.	3.2	4.5	n.q.	n.q.
2021 P_3	n.q.	3.5	5.0	n.q.	n.q.

n.q. = Not Quantified

Future STP pollutant loading are the easiest to predict given the detailed monitoring of the STPs in the GVRD, however there is still some uncertainty with regard to:

- Unit loading
- Treatment Efficiencies
- Flow

Loading for future scenarios was calculated using 1994 unit loading values. Appendix E outlines the change in unit loading of some contaminants over the period 1985-1994. This illustrates the limitations of using a constant unit loading over the entire study period (1994-2021). Table 5.3 illustrates the contrast between assuming a constant unit loading versus assuming a constant rate of change in unit loading based on historical trends.

Table 5.3: Unit Loading in 2021 Assuming 1994 levels vs. Assuming a constant rate of change

Parameter	Units	Annacis Island STP		Lulu Island STP	
		1994 level	2021 Assuming a constant rate of change	1994 level	2021 Assuming a constant rate of change
BOD	(g/day/capita)	57	46	60	75
TKN	(g/day/capita)	11	11	12	12
NH_3-N	(g/day/capita)	7.5	8.9	7.5	7.3
Phenol	(mg/day/capita)	21	18	20	44
Al_{Total}	(mg/day/capita)	166	17	238	2.5
Cr_{Total}	(mg/day/capita)	3.3	n.q.	8.3	0.03
Cu_{Total}	(mg/day/capita)	58	50	67	90
$Cu_{Diss.}$	(mg/day/capita)	29	67	32	150
Fe_{Total}	(mg/day/capita)	985	1900	698	220
$Fe_{Diss.}$	(mg/day/capita)	513	1570	365	330
Pb_{Total}	(mg/day/capita)	3.3	0.019	3.6	0.015
Ag_{Total}	(mg/day/capita)	1.2	n.q.	6.4	n.q.
Zn_{Total}	(mg/day/capita)	33	3.0	40	1.2

Note: nq = not quantifiable. A constant rate of change can not be determined because 1985 data does not exist for this parameter

Neither assuming a constant unit loading or a constant rate of change in unit loading is entirely realistic. However, Table 5.3 illustrates that total pollutant loading may be significantly different than is predicted by assuming a constant unit loading. Some unit loadings remain approximately the same, however, very large changes in loading are predicted for Al_{Total}, $Cu_{Diss.}$, Fe_{Total}, $Fe_{Diss.}$ and Pb_{Total} by assuming a constant rate of change. It is impossible to predict whether these changes in loading will occur. However, a sensitivity analysis may be performed to determine whether assuming a constant rate of change in unit loading would significantly affect receiving water quality. Table 5.4 and Table 5.5 outline the pollutant loading resulting from changing unit loading. The impact on water quality is discussed in Section 5.4.

Table 5.4: Pollutant Loading for Scenario P_3 assuming changing unit loads: Primary Treatment

	Population	Flow MLD	BOD (tonne/day)	TKN (tonne/day)	NH_3-N (tonne/day)	Phenol (kg/day)	Al_{Total} (kg/day)	Cr_{Total} (kg/day)
Lulu Island	223315	88.6	10.7	2.6	2.0	3.8	5.4	n.q.
Annacis Island	1862146	771	132	20.8	13.5	84.8	3.2	n.q.

	Cu_{Total} (kg/day)	$Cu_{diss.}$ (kg/day)	Fe_{Total} (kg/day)	$Fe_{diss.}$ (kg/day)	Pb_{Total} (kg/day)	Ag_{Total} (kg/day)	Zn_{Total} (kg/day)
Lulu Island	13	16	301	249	0.005	1	1
Annacis Island	145	253	578	864	0.03	2	2

Table 5.5: Pollutant Loading for Scenario P_3 assuming changing unit loads: Secondary Treatment

	Population	Flow MLD	BOD (tonne/day)	TKN (tonne/day)	NH_3-N (tonne/day)	Phenol (kg/day)	Al_{Total} (kg/day)	Cr_{Total} (kg/day)
Lulu Island	223315	88.6	1.6	2.2	0.02	4.8	5.1	0.55
Annacis Island	1862146	771	19.8	19.7	12.5	92.5	3.6	1.70

	Cu_{Total} (kg/day)	$Cu_{diss.}$ (kg/day)	Fe_{Total} (kg/day)	$Fe_{diss.}$ (kg/day)	Pb_{Total} (kg/day)	Ag_{Total} (kg/day)	Zn_{Total} (kg/day)
Lulu Island	5.2	7.4	95	125	0.003	1.58	0.3
Annacis Island	44.0	86.7	170	467	0.013	3.12	0.5

The treatment efficiencies of the various technologies were derived from the literature. The pollutant removal reflects typical pollutant removal for each level of treatment. The actual pollutant removal efficiency of the plant will not be known until the plant is operational. The percent pollutant removal was not available for all pollutants of interest. Pollutant removals which could not be determined from the literature were assigned the same removal efficiency as primary treatment. Pollutants with no removal efficiency data were assigned a value of not quantifiable (n.q.). This is not a large problem because the removal efficiency was generally available for pollutants of concern.

There may be a significant change in flow to STPs as a result of water conservation efforts, reducing infiltration and mitigating CSO's. This may increase removal efficiency in the short term, but is unlikely to greatly affect unit loading from the STPs.

5.3 Urban Runoff Scenarios

The pollutant loading from urban runoff as a result of the scenarios outlined in Section 3.3 may be found in Table 5.6. The impacts on water quality as a result of future discharges from urban runoff are discussed in Section 5.4. This approach to estimating future levels of contaminant loading from urban runoff is affected by:

- Future population density
- Changing nature of urban runoff
- Degree to which BMPs are implemented
- First flush effect
- Spatial distribution

Scenarios A and B estimate urban runoff as a function of population density. A dramatic increase in population density may reduce total runoff. Scenario A describes a possible 'worst case' scenario in which runoff concentrations and per capita land use remain at current levels and set an upper boundary for pollutant loading. Scenarios involving other population densities may be evaluated easily.

Historically, the pollutant concentration in urban runoff has changed . Several factors have resulted in increased loading of some contaminants (e.g. Cd from increased traffic intensity, Hall, 1991) while other factors have reduced loading of some contaminants (e.g. Pb reduction due to unleaded gasoline). There is uncertainty when trying to forecast what the contaminant concentrations will be in 30 years. Generally, pollutant concentrations in urban runoff have decreased over the last 20 years. Bearing this in mind, the typical runoff concentrations for 1995 were used to evaluate the possible 'worst case' scenario of pollutant loading.

Urban runoff BMPs were outlined for new developments in the LFB. The effectiveness of these BMPs is dependent on a variety of factors. BMPs in high relief areas are generally less effective than BMPs in low relief areas. The pollutant removal used in scenario C reflects an average pollutant removal of all BMPs. The actual pollutant removal may differ significantly from this estimate. The urban runoff guidelines have not been legislated; therefore, it is possible that BMPs will not be universally installed at all new developments. Therefore, Scenario C reflects a 'best case' scenario of urban runoff pollutant loading from future development.

Table 5.6: Pollutant Loading from Urban Runoff

Scenario	Population	SS (tonne/day)	Chloride (tonne/day)	COD (tonne/day)	BOD (tonne/day)	Faecal Coliforms (10^12/day)	TKN (tonne/day)	NO_3/NO_2-N (kg/day)	NH_3-N (tonne/day)	Fluoride (kg/day)
1991	1116714	66	19	42	6	12694	0.3	233	5289	n.q.
P_1A	1947122	125	37	81	12	24290	0.7	445	10121	n.q.
P_1B	1947122	121	36	78	12	23482	0.6	430	9784	n.q.
P_1C	1947122	78	26	57	9	13965	0.5	315	7149	n.q.
P_2A	2141834	138	41	89	13	26719	0.7	490	11133	n.q.
P_2B	2141834	133	39	86	13	25830	0.7	474	10762	n.q.
P_2C	2141834	91	30	67	10	16182	0.6	368	8358	n.q.
P_3A	2364962	153	45	99	15	29659	0.8	544	12358	n.q.
P_3B	2364962	148	44	96	14	28682	0.8	526	11951	n.q.
P_3C	2364962	96	33	72	11	16849	0.6	396	8996	n.q.
P_3A-FF	2364962	371	45	198	35	59318	4.3	2941	12358	n.q.

Scenario	MBAS (kg/day)	SO_4 (tonne/day)	Alkalinity (tonne/day)	P_{Total} (kg/day)	$P_{Diss.}$ (kg/day)	O&G (tonne/day)	Phenol (kg/day)	CN_{Total} (kg/day)	$Sulphide_{Diss.}$ (kg/day)	Al_{Total} (kg/day)
1991	n.q.	n.q.	20	233	n.q.	5.3	14	n.q.	n.q.	n.q.
P_1A	n.q.	n.q.	39	445	n.q.	10.1	26	n.q.	n.q.	n.q.
P_1B	n.q.	n.q.	38	430	n.q.	9.8	25	n.q.	n.q.	n.q.
P_1C	n.q.	n.q.	27	315	n.q.	7.1	23	n.q.	n.q.	n.q.
P_2A	n.q.	n.q.	43	490	n.q.	11.1	29	n.q.	n.q.	n.q.
P_2B	n.q.	n.q.	41	474	n.q.	10.8	28	n.q.	n.q.	n.q.
P_2C	n.q.	n.q.	32	368	n.q.	8.4	27	n.q.	n.q.	n.q.
P_3A	n.q.	n.q.	47	544	n.q.	12.4	32	n.q.	n.q.	n.q.
P_3B	n.q.	n.q.	46	526	n.q.	12.0	31	n.q.	n.q.	n.q.
P_3C	n.q.	n.q.	35	396	n.q.	9.0	30	n.q.	n.q.	n.q.
P_3A-FF	n.q.	n.q.	47	989	n.q.	76.6	284	n.q.	n.q.	n.q.

n.q. = Not Quantifiable

Table 5.6: Continued

Scenario	$Al_{Diss.}$ (kg/day)	As_{Total} (kg/day)	Ba_{Total} (kg/day)	$Ba_{Diss.}$ (kg/day)	B_{Total} (kg/day)	$B_{Diss.}$ (kg/day)	Cd_{Total} (kg/day)	$Cd_{Diss.}$ (kg/day)	Cr_{Total} (kg/day)	$Cr_{Diss.}$ (kg/day)
1991	n.q.	14	n.q.	n.q.	n.q.	n.q.	0.42	0.18	7.7	1.6
P_1A	n.q.	26	n.q.	n.q.	n.q.	n.q.	0.81	0.34	14.8	3.0
P_1B	n.q.	25	n.q.	n.q.	n.q.	n.q.	0.78	0.33	14.3	2.9
P_1C	n.q.	23	n.q.	n.q.	n.q.	n.q.	0.70	0.30	12.9	2.6
P_2A	n.q.	29	n.q.	n.q.	n.q.	n.q.	0.89	0.38	16.3	3.3
P_2B	n.q.	28	n.q.	n.q.	n.q.	n.q.	0.86	0.37	15.7	3.2
P_2C	n.q.	27	n.q.	n.q.	n.q.	n.q.	0.83	0.35	15.2	3.1
P_3A	n.q.	32	n.q.	n.q.	n.q.	n.q.	0.99	0.42	18.0	3.7
P_3B	n.q.	31	n.q.	n.q.	n.q.	n.q.	0.96	0.41	17.4	3.6
P_3C	n.q.	30	n.q.	n.q.	n.q.	n.q.	0.92	0.39	16.7	3.4
P_3A-FF	n.q.	37	n.q.	n.q.	n.q.	n.q.	24.72	0.42	37.1	3.7

Scenario	Co_{Total} (kg/day)	$Co_{Diss.}$ (kg/day)	Cu_{Total} (kg/day)	$Cu_{Diss.}$ (kg/day)	Fe_{Total} (kg/day)	$Fe_{Diss.}$ (kg/day)	Pb_{Total} (kg/day)	$Pb_{Diss.}$ (kg/day)	Mn_{Total} (kg/day)	$Mn_{Diss.}$ (kg/day)
1991	n.q.	n.q.	36	31	270	n.q.	13	4.8	137	37
P_1A	n.q.	n.q.	69	59	516	n.q.	24	9.1	262	71
P_1B	n.q.	n.q.	67	57	499	n.q.	23	8.8	253	68
P_1C	n.q.	n.q.	60	51	449	n.q.	21	7.9	228	61
P_2A	n.q.	n.q.	76	65	568	n.q.	27	10.0	288	78
P_2B	n.q.	n.q.	73	62	549	n.q.	26	9.7	278	75
P_2C	n.q.	n.q.	71	60	529	n.q.	25	9.3	268	72
P_3A	n.q.	n.q.	84	72	630	n.q.	30	11.1	320	86
P_3B	n.q.	n.q.	81	69	609	n.q.	29	10.8	309	83
P_3C	n.q.	n.q.	78	66	585	n.q.	28	10.3	296	80
P_3A-FF	n.q.	n.q.	124	72	630	n.q.	494	11.1	320	86

n.q. = Not Quantifiable

Table 5.6: Continued

Scenario	Hg_{Total} (kg/day)	Mo_{Total} (kg/day)	$Mo_{Diss.}$ (kg/day)	Ni_{Total} (kg/day)	$Ni_{Diss.}$ (kg/day)	Se_{Total} (kg/day)	$Se_{Diss.}$ (kg/day)	Ag_{Total} (kg/day)	$Ag_{Diss.}$ (kg/day)	Sn_{Total} (kg/day)
1991	n.q.	n.q.	n.q.	3.5	1.5	n.q.	n.q.	n.q.	n.q.	n.q.
P_1A	n.q.	n.q.	n.q.	6.7	2.8	n.q.	n.q.	n.q.	n.q.	n.q.
P_1B	n.q.	n.q.	n.q.	6.5	2.7	n.q.	n.q.	n.q.	n.q.	n.q.
P_1C	n.q.	n.q.	n.q.	5.8	2.5	n.q.	n.q.	n.q.	n.q.	n.q.
P_2A	n.q.	n.q.	n.q.	7.3	3.1	n.q.	n.q.	n.q.	n.q.	n.q.
P_2B	n.q.	n.q.	n.q.	7.1	3.0	n.q.	n.q.	n.q.	n.q.	n.q.
P_2C	n.q.	n.q.	n.q.	6.8	2.9	n.q.	n.q.	n.q.	n.q.	n.q.
P_3A	n.q.	n.q.	n.q.	8.2	3.5	n.q.	n.q.	n.q.	n.q.	n.q.
P_3B	n.q.	n.q.	n.q.	7.9	3.3	n.q.	n.q.	n.q.	n.q.	n.q.
P_3C	n.q.	n.q.	n.q.	7.6	3.2	n.q.	n.q.	n.q.	n.q.	n.q.
P_3A-FF	n.q.	n.q.	n.q.	74.1	3.5	n.q.	n.q.	n.q.	n.q.	n.q.

Scenario	$Sn_{Diss.}$ (kg/day)	Zn_{Total} (kg/day)	$Zn_{Diss.}$ (kg/day)	$Hydrocarbons_{Total}$ (kg/day)	PAH (kg/day)
1991	n.q.	108	59	4.2	1.1
P_1A	n.q.	207	113	8.1	2.0
P_1B	n.q.	200	109	7.8	2.0
P_1C	n.q.	180	99	7.0	1.8
P_2A	n.q.	228	124	8.9	2.2
P_2B	n.q.	220	120	8.6	2.2
P_2C	n.q.	212	116	8.3	2.1
P_3A	n.q.	253	138	9.9	2.5
P_3B	n.q.	245	134	9.6	2.4
P_3C	n.q.	235	128	9.2	2.3
P_3A-FF	n.q.	494	138	9.9	29.7

n.q. = Not Quantifiable

The 'first flush' is a phenomena where accumulated pollutants run off impermeable surfaces as a plug discharge. This may have a significant effect on water quality in the local streams. However, it is not known whether this plug flow has a significant effect on water quality in the Fraser River. The pollutant loading that results from this increased pollutant concentration is summarised in Table 5.6 and the effects on water quality are discussed in Section 5.4.

Urban runoff is a diffuse pollutant source. This methodology was designed to determine the effect on ambient water quality in the Fraser River as a result of urban runoff. Detailed studies at a local level would have to performed to determine the local effects. The urban area that drains into the Fraser River from each municipality was the area that drained to either the North Arm or the Main Arm of the Fraser River. Only the runoff draining to the Main Arm will affect the water quality around the outfall. Therefore, the impact on water quality is likely less than forecast by the population increases evaluated here. This methodology of determining the future effect on ambient water quality as a result of urban runoff is conservative in that it assumes that no pollutants settle out or degrade in local streams en route to the Fraser River.

5.4 Changes in Water Quality

Even given the conservative approach to determining pollutant concentrations, it was found that the changes in ambient concentration resulting from the 'worst case' industrial and urban runoff discharges and large population growth in the FVSA should be below the detection limit for all pollutants. The change in ambient pollutant concentration for the 'first flush' of a storm event should also have a nearly immeasurable effect on the ambient water quality of the Fraser River. This is primarily due to the vast dilution capacity of the Fraser River. The change in ambient water quality from the 'worst case' urban runoff, upstream STPs and industrial scenarios are summarised in Table 5.7.

Table 5.7: Change in Ambient Pollutant Concentration in the Fraser River from I_3, FVSA P_3 and UR P_3A

	Scenario	SS (mg/L)	Chloride (mg/L)	COD (mg/L)	BOD (mg/L)	Faecal Coliforms Winter (MPN/100mL)	TKN (mg/L)	NO_3/NO_2-N (mg/L)	NH_3-N (mg/L)	Fluoride (mg/L)
Industry	I_3	2.1E-05	2.7E-04	1.5E-05	1.2E-05	n.q.	2.3E-07	3.5E-07	2.1E-07	n.q.
FVSA	P_3	4.3E-05	1.2E-04	1.2E-04	3.0E-05	5.3E-01	3.5E-05	n.q.	2.0E-05	n.q.
UR	P_3A	2.0E-03	5.8E-04	1.3E-03	1.9E-04	3.1E-01	1.0E-05	7.0E-06	1.6E-04	n.q.
Total		2.0E-03	9.7E-04	1.4E-03	2.3E-04	8.4E-01	4.5E-05	7.3E-06	1.8E-04	n.q.
UR (ff)	P_3A (ff)	4.8E-03	5.8E-04	2.5E-03	4.4E-04	4.1E-02	5.6E-05	3.8E-05	1.6E-04	n.q.
Total (ff)		4.8E-03	9.7E-04	2.7E-03	4.9E-04	1.2	9.1E-05	3.8E-05	1.8E-04	n.q.

	MBAS (mg/L)	SO_4 (mg/L)	Alkalinity (mg/L)	P_{Total} (mg/L)	$P_{Diss.}$ (mg/L)	O&G (mg/L)	Phenols (mg/L)	CN_{Total} (mg/L)	$Sulphide_{Diss.}$ (mg/L)	Al_{Total} (mg/L)
Industry	2.1E-04	1.0E-04	1.0E-07	5.2E-08	n.q.	8.0E-08	n.q.	n.q.	2.6E-06	4.1E-07
FVSA	5.0E-10	4.9E-05	1.8E-04	5.6E-09	4.2E-09	4.6E-05	7.1E-08	n.q.	n.q.	9.3E-07
UR	n.q.	n.q.	6.1E-04	7.0E-06	n.q.	1.6E-04	4.1E-07	n.q.	n.q.	n.q.
Total	2.1E-04	1.5E-04	7.9E-04	7.1E-06	4.2E-09	2.0E-04	4.8E-07	n.q.	2.6E-06	1.3E-06
UR (ff)	n.q.	n.q.	6.1E-04	1.3E-05	n.q.	9.9E-04	3.7E-06	n.q.	n.q.	n.q.
Total (ff)	2.1E-04	1.5E-04	7.9E-04	1.3E-05	4.2E-09	1.0E-03	3.7E-06	n.q.	2.6E-06	1.3E-06

	$Al_{Diss.}$ (mg/L)	As_{Total} (mg/L)	Ba_{Total} (mg/L)	$Ba_{Diss.}$ (mg/L)	B_{Total} (mg/L)	$B_{Diss.}$ (mg/L)	Cd_{Total} (mg/L)	$Cd_{Diss.}$ (mg/L)	Cr_{Total} (mg/L)	$Cr_{Diss.}$ (mg/L)
Industry	2.4E-09	8.9E-09	7.3E-08	1.2E-07	7.7E-07	6.8E-07	n.q.	n.q.	n.q.	n.q.
FVSA	n.q.	n.q.	5.3E-08	1.8E-08	2.5E-07	2.8E-07	1.8E-10	n.q.	5.7E-09	5.5E-09
UR	n.q.	4.1E-07	n.q.	n.q.	n.q.	n.q.	1.3E-08	5.4E-09	2.3E-07	4.8E-08
Total	2.4E-09	4.2E-07	1.3E-07	1.3E-07	1.0E-06	9.6E-07	1.3E-08	5.4E-09	2.4E-07	5.3E-08
UR (ff)	n.q.	4.8E-07	n.q.	n.q.	n.q.	n.q.	3.2E-07	5.4E-09	4.8E-07	4.8E-08
Total (ff)	2.4E-09	4.9E-07	1.3E-07	1.3E-07	1.0E-06	9.6E-07	3.2E-07	5.4E-09	4.8E-07	5.3E-08

n.q. = Not Quantifiable

Table 5.7: Continued

	Co_{Total} (mg/L)	$Co_{Diss.}$ (mg/L)	Cu_{Total} (mg/L)	$Cu_{Diss.}$ (mg/L)	Fe_{Total} (mg/L)	$Fe_{Diss.}$ (mg/L)	Pb_{Total} (mg/L)	$Pb_{Diss.}$ (mg/L)	Mn_{Total} (mg/L)	$Mn_{Diss.}$ (mg/L)
Industry	n.q.	3.5E-08	4.7E-09	1.1E-06	3.7E-07	3.7E-09	1.2E-10	1.6E-07	1.3E-07	n.q.
FVSA	n.q.	n.q.	7.3E-08	4.7E-08	7.7E-07	7.3E-07	1.1E-08	2.9E-09	9.8E-08	8.3E-08
UR	n.q.	n.q.	1.1E-06	9.2E-07	8.1E-06	n.q.	3.8E-07	1.4E-07	4.1E-06	1.1E-06
Total	n.q.	3.5E-08	1.2E-06	2.1E-06	9.2E-06	7.4E-07	3.9E-07	3.1E-07	4.3E-06	1.2E-06
UR (ff)	n.q.	n.q.	1.6E-06	9.2E-07	8.1E-06	n.q.	6.4E-06	1.4E-07	4.1E-06	1.1E-06
Total (ff)	n.q.	3.5E-08	1.7E-06	2.1E-06	9.2E-06	7.4E-07	6.4E-06	3.1E-07	4.3E-06	1.2E-06

	Hg_{Total} (mg/L)	Mo_{Total} (mg/L)	$Mo_{Diss.}$ (mg/L)	Ni_{Total} (mg/L)	$Ni_{Diss.}$ (mg/L)	Se_{Total} (mg/L)	$Se_{Diss.}$ (mg/L)	Ag_{Total} (mg/L)	$Ag_{Diss.}$ (mg/L)	Sn_{Total} (mg/L)
Industry	n.q.	n.q.	1.2E-09	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
FVSA	4.6E-10	n.q.	n.q.	1.7E-08	1.3E-08	n.q.	n.q.	n.q.	n.q.	n.q.
UR	n.q.	n.q.	n.q.	1.0E-07	4.4E-08	n.q.	n.q.	n.q.	n.q.	n.q.
Total	4.6E-10	n.q.	1.2E-09	1.2E-07	5.8E-08	n.q.	n.q.	n.q.	n.q.	n.q.
UR (ff)	n.q.	n.q.	n.q.	9.5E-07	4.4E-08	n.q.	n.q.	n.q.	n.q.	n.q.
Total (ff)	4.6E-10	n.q.	1.2E-09	9.7E-07	5.8E-08	n.q.	n.q.	n.q.	n.q.	n.q.

	$Sn_{Diss.}$ (mg/L)	Zn_{Total} (mg/L)	$Zn_{Diss.}$ (mg/L)	$Hydrocarbons_{Total}$ (mg/L)	PAH (mg/L)
Industry	6.9E-08	4.0E-08	n.q.	n.q.	n.q.
FVSA	n.q.	4.3E-08	7.4E-08	n.q.	n.q.
UR	n.q.	3.3E-06	1.8E-06	1.3E-07	3.2E-08
Total	6.9E-08	3.3E-06	1.9E-06	1.3E-07	3.2E-08
UR (ff)	n.q.	6.4E-06	1.8E-06	1.3E-07	3.8E-07
Total (ff)	6.9E-08	6.4E-06	1.9E-06	1.3E-07	3.8E-07

Notes: UR (ff) is the estimated pollutant concentration change in the Fraser River as a result of the 'first flush' event from Urban Runoff.
Total (ff) is the estimated total concentration change of pollutants in the Fraser River including the 'first flush' of Urban Runoff.

n.q. = Not Quantifiable

This does not imply that effect of urban runoff and industrial discharges on water quality is insignificant. Storm water runoff may have a deleterious effect on local streams and near the banks of the Fraser River. The detrimental local impacts may be augmented by higher concentrations of pollutants present in the 'first flush' of a storm event. Similarly, industrial discharges may have a significant effect on local water quality. However, the purpose of the methodology is to determine the effect on the ambient water quality in the Fraser River and to determine whether increased discharges from these sources has a significant effect on the decision to upgrade the sewage treatment plants.

The methodology is capable of predicting changes in pollutant loading to the Fraser River quickly. Quantifying pollutant loading is important for environmental monitoring and assessing progress toward sustainability. However, the change in ambient water quality determined using this methodology will not significantly affect the decision whether to upgrade the sewage treatment plants at Annacis and Lulu Island. This supports the approach taken by the GVRD LWMP which did not consider these pollutant sources in its evaluation of water quality changes at Annacis and Lulu Island sewage treatment plants.

The changes in water quality utilising the current level of wastewater treatment are summarised in Appendix J and the changes in water quality resulting from the conversion to secondary treatment are summarised in Appendix K for 1994 and Scenario P_3. The values in Appendix J and Appendix K represent the increases in pollutant concentration and must be added to the 1994 background concentrations, (DOE FRAP 1993-31, GVRD, 1994), (Appendix L) and the increase in ambient concentration attributable to urban runoff, industrial discharges and upstream STPs to determine the total pollutant concentration. Table 5.7 illustrates that the pollutant loading during the 'first flush' period may be greater than an order of magnitude higher than the average pollutant loading from urban runoff. Therefore, the 'worst case' scenario for pollutant loading from 'first flush' urban runoff discharges Scenario P_3A, high industrial growth Scenario I_3 and high upriver population growth Scenario P_3 should be used when determining the water quality at the Annacis Island outfall.

The calculated concentrations of pollutants at the Annacis Island and Lulu Island STP outfalls for 1994 and Scenario P_3 are summarised in Table 5.8 through Table 5.15. The pollutants which are of concern are those which typically are responsible for adverse effects on aquatic biota or are present in concentrations above the CCREM

Water Quality Guidelines. These pollutants are: BOD, Coliforms, NO_3/NO_2, NH_3-N, Phenol, Al_{Total}, Cd_{Total}, Cr_{Total}, Cu_{Total}, Fe_{Total}, $Fe_{Diss.}$, Pb_{Total}, Hg_{Total}, Ag_{Total} and Zn_{Total}. The concentrations of pollutants with changing unit loading, as discussed in Section 5.2, are outlined in Table 5.16 through Table 5.19. Only pollutants of concern with changing unit loading are outlined.

Scenario P_3 represents the high end for population growth. If Scenario P_3 demonstrates an acceptable level of water quality then it may be inferred that Scenarios P_1 and P_2 also produce acceptable water quality. Effluent from Annacis Island tends to pool at Steveston due to tidal effects. Therefore, the maximum pollutant concentration at the edge of the Lulu Island IDZ was determined by summing the Annacis Island maximum pollutant concentration at Steveston with the Lulu Island maximum at the edge of the IDZ. These conditions reflect a worst case scenario of 'double dosing'. It assumes that the effluent which pooled at the Annacis Island STP at slack water is stationary over the Lulu Island STP outfall during the next slack water period. This has not been modelled, but may be possible under some river flow conditions. The water quality near the Annacis Island STP outfall is discussed in Section 5.4.1 and the water quality near the Lulu Island STP outfall is discussed in Section 5.4.2.

Table 5.8: 1994 Primary Treatment at Annacis Island

Water Quality in the Fraser River at locations influenced by the Annacis Island STP Outfall and Urban Runoff Industrial Discharges and Upstream STPs

Location	BOD (mg/L)		Faecal Coliforms (MPN/100 ml)		NO_3/ NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.1	1.1	500	500	150	150	0.03	0.16	0.04	0.38	570	570	0.0004	0.004	0.01	0.06
Annacis Channel	0.2	1.4	500	500	150	150	0.04	0.20	0.07	0.49	570	570	0.0007	0.005	0.01	0.08
Tilbury Island	0.4	1.7	500	500	150	150	0.07	0.24	0.15	0.62	570	580	0.002	0.006	0.02	0.10
Woodwards Landing	0.3	1.2	500	500	150	150	0.06	0.17	0.10	0.43	570	570	0.001	0.004	0.02	0.07
Steveston	0.2	2.0	500	500	150	150	0.05	0.28	0.08	0.73	570	580	0.001	0.01	0.01	0.12
Transverse edge of IDZ	1.4	2.4	500	500	150	150	0.21	0.33	0.52	0.87	570	580	0.005	0.01	0.08	0.14
Downstream Edge of IDZ	0.9	3.4	500	500	150	150	0.13	0.47	0.31	1.3	570	580	0.003	0.01	0.05	0.20
Downstream of IDZ	n.q.	3.4	n.q.	500	n.q.	150	n.q.	0.47	n.q.	1.3	n.q.	580	n.q.	0.01	n.q.	0.20
Upstream Edge of IDZ	0.8	3.4	500	500	150	150	0.12	0.47	0.29	1.3	570	580	0.003	0.01	0.05	0.20
Upstream of IDZ	n.q.	3.4	n.q.	500	n.q.	150	n.q.	0.47	n.q.	1.3	n.q.	580	n.q.	0.01	n.q.	0.20

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.1	1.1	0.05	0.5	910	930	0.9	10	0.006	0.06	n.q.	n.q.	0.002	0.02	0.06	0.6
Annacis Channel	0.2	1.4	0.09	0.7	910	930	1.6	12	0.011	0.08	n.q.	n.q.	0.004	0.03	0.11	0.8
Tilbury Island	0.4	1.7	0.20	0.9	920	940	3.6	15	0.023	0.10	n.q.	n.q.	0.009	0.04	0.23	1.0
Woodwards Landing	0.3	1.2	0.14	0.6	920	930	2.6	11	0.016	0.07	n.q.	n.q.	0.006	0.03	0.16	0.7
Steveston	0.2	2.0	0.11	1.0	910	950	1.9	18	0.012	0.12	n.q.	n.q.	0.005	0.04	0.12	1.2
Transverse edge of IDZ	1.5	2.4	0.73	1.2	940	950	13.0	22	0.084	0.14	n.q.	n.q.	0.031	0.05	0.84	1.4
Downstream Edge of IDZ	0.9	3.5	0.44	1.8	930	970	7.8	31	0.050	0.20	n.q.	n.q.	0.019	0.08	0.50	2.0
Downstream of IDZ	n.q.	3.5	n.q.	1.8	n.q.	970	n.q.	31	n.q.	0.20	n.q.	n.q.	n.q.	0.08	n.q.	2.0
Upstream Edge of IDZ	0.8	3.5	0.40	1.8	920	970	7.1	31	0.046	0.20	n.q.	n.q.	0.017	0.08	0.46	2.0
Upstream of IDZ	n.q.	3.5	n.q.	1.8	n.q.	970	n.q.	31	n.q.	0.20	n.q.	n.q.	n.q.	0.08	n.q.	2.0

n.q. = Not Quantifiable

Table 5.9: 1994 Secondary Treatment at Annacis Island

Water Quality in the Fraser River at locations influenced by the Annacis Island STP Outfall and Urban Runoff Industrial Discharges and Upstream STPs

Location	BOD (mg/L)		Faecal Coliforms (MPN/100 ml)		NO_3/ NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.01	0.2	500	500	150	150	0.03	0.15	0.04	0.42	570	570	0.0001	0.001	0.002	0.017
Annacis Channel	0.03	0.2	500	500	150	150	0.04	0.18	0.07	0.54	570	570	0.0001	0.001	0.003	0.022
Tilbury Island	0.06	0.3	500	500	150	150	0.07	0.22	0.16	0.67	570	580	0.0002	0.001	0.006	0.027
Woodwards Landing	0.04	0.2	500	500	150	150	0.05	0.16	0.11	0.47	570	570	0.0002	0.001	0.005	0.019
Steveston	0.03	0.3	500	500	150	150	0.04	0.26	0.08	0.80	570	580	0.0001	0.001	0.003	0.032
Transverse edge of IDZ	0.21	0.4	500	500	150	150	0.19	0.31	0.57	0.95	580	580	0.0008	0.001	0.023	0.038
Downstream Edge of IDZ	0.13	0.5	500	500	150	150	0.12	0.44	0.34	1.4	570	580	0.0005	0.002	0.014	0.055
Downstream of IDZ	n.q.	0.5	n.q.	500	n.q.	150	n.q.	0.44	n.q.	1.4	n.q.	580	n.q.	0.002	n.q.	0.055
Upstream Edge of IDZ	0.12	0.5	500	500	150	150	0.11	0.44	0.31	1.4	570	580	0.0005	0.002	0.013	0.055
Upstream of IDZ	n.q.	0.5	n.q.	500	n.q.	150	n.q.	0.44	n.q.	1.4	n.q.	580	n.q.	0.002	n.q.	0.055

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.1	0.3	0.02	0.2	910	920	0.5	5	0.003	0.03	n.q.	n.q.	0.002	0.02	0.01	0.2
Annacis Channel	0.1	0.4	0.03	0.2	910	920	0.9	7	0.006	0.04	n.q.	n.q.	0.004	0.03	0.03	0.2
Tilbury Island	0.1	0.5	0.07	0.3	910	920	2.0	8	0.012	0.05	n.q.	n.q.	0.009	0.04	0.06	0.2
Woodwards Landing	0.1	0.4	0.05	0.2	910	920	1.4	6	0.009	0.04	n.q.	n.q.	0.006	0.03	0.04	0.2
Steveston	0.1	0.6	0.04	0.4	910	920	1.0	10	0.006	0.06	n.q.	n.q.	0.005	0.04	0.03	0.3
Transverse edge of IDZ	0.4	0.7	0.25	0.4	920	920	7.0	12	0.044	0.07	n.q.	n.q.	0.031	0.05	0.21	0.3
Downstream Edge of IDZ	0.3	1.1	0.15	0.6	910	930	4.2	17	0.026	0.11	n.q.	n.q.	0.019	0.08	0.13	0.5
Downstream of IDZ	n.q.	1.1	n.q.	0.6	n.q.	930	n.q.	17	n.q.	0.11	n.q.	n.q.	n.q.	0.08	n.q.	0.5
Upstream Edge of IDZ	0.2	1.1	0.14	0.6	910	930	3.8	17	0.024	0.11	n.q.	n.q.	0.017	0.08	0.11	0.5
Upstream of IDZ	n.q.	1.1	n.q.	0.6	n.q.	930	n.q.	17	n.q.	0.11	n.q.	n.q.	n.q.	0.08	n.q.	0.5

n.q. = Not Quantifiable

Table 5.10 Scenario P_3 with Primary Treatment at Annacis Island STP:

Water Quality in the Fraser River at locations influenced by the Annacis Island STP Outfall and Urban Runoff Industrial Discharges and Upstream STPs

Location	BOD (mg/L)		Faecal Coliforms (MPN/100 ml)		NO_3/ NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.2	2.3	500	500	150	150	0.05	0.31	0.04	0.4	570	580	0.001	0.01	0.012	0.13
Annacis Channel	0.4	2.9	500	500	150	150	0.07	0.40	0.07	0.5	570	580	0.002	0.01	0.023	0.17
Tilbury Island	0.9	3.6	500	500	150	150	0.13	0.49	0.16	0.7	570	580	0.003	0.01	0.050	0.21
Woodwards Landing	0.6	2.5	500	500	150	150	0.10	0.35	0.11	0.5	570	580	0.002	0.01	0.035	0.15
Steveston	0.4	4.3	500	500	150	150	0.08	0.58	0.08	0.8	570	580	0.002	0.02	0.026	0.25
Transverse edge of IDZ	3.1	5.1	500	500	150	150	0.42	0.69	0.57	1.0	580	580	0.01	0.02	0.18	0.30
Downstream Edge of IDZ	1.9	7.4	500	500	150	150	0.26	0.99	0.34	1.4	580	590	0.007	0.03	0.11	0.43
Downstream of IDZ	n.q.	7.4	n.q.	500	n.q.	150	n.q.	0.99	n.q.	1.4	n.q.	590	n.q.	0.03	n.q.	0.43
Upstream Edge of IDZ	1.7	7.4	500	500	150	150	0.24	0.99	0.31	1.4	580	590	0.006	0.03	0.098	0.43
Upstream of IDZ	n.q.	7.4	n.q.	500	n.q.	150	n.q.	0.99	n.q.	1.4	n.q.	590	n.q.	0.03	n.q.	0.43

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.2	2.3	0.11	1.2	910	950	1.9	20	0.012	0.13	n.q.	n.q.	0.005	0.05	0.12	1.3
Annacis Channel	0.4	3.0	0.20	1.5	920	960	3.5	26	0.023	0.17	n.q.	n.q.	0.009	0.06	0.23	1.7
Tilbury Island	0.9	3.7	0.44	1.9	930	980	7.8	33	0.050	0.21	n.q.	n.q.	0.019	0.08	0.50	2.1
Woodwards Landing	0.6	2.6	0.31	1.3	920	950	5.5	23	0.035	0.15	n.q.	n.q.	0.013	0.06	0.35	1.5
Steveston	0.5	4.4	0.23	2.2	920	980	4.0	39	0.026	0.25	n.q.	n.q.	0.010	0.09	0.26	2.5
Transverse edge of IDZ	3.2	5.3	1.6	2.6	960	1000	28	47	0.18	0.30	n.q.	n.q.	0.068	0.11	1.80	3.0
Downstream Edge of IDZ	1.9	7.6	0.95	3.8	940	1000	17	67	0.11	0.43	n.q.	n.q.	0.041	0.16	1.08	4.3
Downstream of IDZ	n.q.	7.6	n.q.	3.8	n.q.	1000	n.q.	67	n.q.	0.43	n.q.	n.q.	n.q.	0.16	n.q.	4.3
Upstream Edge of IDZ	1.7	7.6	0.86	3.8	940	1000	15	67	0.10	0.43	n.q.	n.q.	0.037	0.16	0.98	4.3
Upstream of IDZ	n.q.	7.6	n.q.	3.8	n.q.	1000	n.q.	67	n.q.	0.43	n.q.	n.q.	n.q.	0.16	n.q.	4.3

n.q. = Not Quantifiable

Table 5.11: Scenario P_3 with Secondary Treatment at Annacis Island STP

Water Quality in the Fraser River at locations influenced by the Annacis Island STP Outfall and Urban Runoff Industrial Discharges and Upstream STPs

Location	BOD (mg/L)		Faecal Coliforms (MPN/100 ml)		NO_3/ NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.03	0.3	500	500	150	150	0.04	0.29	0.08	0.82	570	580	0.0004	0.001	0.004	0.036
Annacis Channel	0.06	0.4	500	500	150	150	0.07	0.37	0.14	1.1	570	580	0.0005	0.002	0.006	0.047
Tilbury Island	0.13	0.5	500	500	150	150	0.12	0.46	0.31	1.3	570	580	0.0007	0.002	0.014	0.058
Woodwards Landing	0.09	0.4	500	500	150	150	0.09	0.33	0.22	0.93	570	580	0.0006	0.002	0.010	0.041
Steveston	0.07	0.6	500	500	150	150	0.07	0.54	0.16	1.6	570	580	0.0005	0.003	0.007	0.069
Transverse edge of IDZ	0.46	0.8	500	500	150	150	0.39	0.65	1.1	1.9	580	590	0.0019	0.003	0.050	0.083
Downstream Edge of IDZ	0.28	1.1	500	500	150	150	0.24	0.92	0.68	2.7	580	590	0.0013	0.004	0.030	0.12
Downstream of IDZ	n.q.	1.1	n.q.	500	n.q.	150	n.q.	0.92	n.q.	2.7	n.q.	590	n.q.	0.004	n.q.	0.12
Upstream Edge of IDZ	0.25	1.1	500	500	150	150	0.22	0.92	0.61	2.7	580	590	0.001	0.004	0.027	0.12
Upstream of IDZ	n.q.	1.1	n.q.	500	n.q.	150	n.q.	0.92	n.q.	2.7	n.q.	590	n.q.	0.004	n.q.	0.12

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.1	0.7	0.04	0.4	910	920	1.0	11	0.007	0.07	n.q.	n.q.	0.005	0.05	0.03	0.3
Annacis Channel	0.1	0.9	0.07	0.5	910	930	1.9	14	0.012	0.09	n.q.	n.q.	0.009	0.06	0.06	0.4
Tilbury Island	0.3	1.1	0.15	0.6	910	930	4.2	18	0.027	0.11	n.q.	n.q.	0.019	0.08	0.13	0.5
Woodwards Landing	0.2	0.8	0.11	0.4	910	920	3.0	12	0.019	0.08	n.q.	n.q.	0.013	0.06	0.09	0.4
Steveston	0.1	1.3	0.08	0.8	910	930	2.2	21	0.014	0.13	n.q.	n.q.	0.010	0.09	0.07	0.6
Transverse edge of IDZ	1.0	1.6	0.54	0.9	930	940	15	25	0.095	0.16	n.q.	n.q.	0.068	0.11	0.45	0.8
Downstream Edge of IDZ	0.6	2.3	0.32	1.3	920	950	9.1	36	0.057	0.23	n.q.	n.q.	0.041	0.16	0.27	1.1
Downstream of IDZ	n.q.	2.3	n.q.	1.3	n.q.	950	n.q.	36	n.q.	0.23	n.q.	n.q.	n.q.	0.16	n.q.	1.1
Upstream Edge of IDZ	0.5	2.3	0.30	1.3	920	950	8.2	36	0.052	0.23	n.q.	n.q.	0.037	0.16	0.25	1.1
Upstream of IDZ	n.q.	2.3	n.q.	1.3	n.q.	950	n.q.	36	n.q.	0.23	n.q.	n.q.	n.q.	0.16	n.q.	1.1

n.q. = Not Quantifiable

Table 5.12: 1994 Lulu Island STP with Primary Treatment

Water Quality in the Fraser River at locations influenced by the Lulu Island STP Outfall, Urban Runoff, Industrial Discharges and Upstream STPs

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/ NO_2-N (μg/L)		NH_3-N (mg/L)		Phenol (μg/L)		Al_{Total} (μg/L)		Cd_{Total} (μg/L)		Cr_{Total} (μg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.57	2.6	500	500	150	150	0.09	0.36	0.20	0.9	570	580	0.0008	0.007	0.063	0.20
Downstream Edge of IDZ	0.43	2.9	500	500	150	150	0.07	0.39	0.15	1.0	570	580	0.0008	0.007	0.043	0.24
Downstream of IDZ	n.q.	2.9	n.q.	500	n.q.	150	n.q.	0.39	n.q.	1.0	n.q.	580	n.q.	0.007	n.q.	0.24
Upstream Edge of IDZ	0.41	2.9	500	500	150	150	0.07	0.39	0.14	1.0	570	580	0.0008	0.007	0.040	0.24
Upstream of IDZ	n.q.	2.9	n.q.	500	n.q.	150	n.q.	0.39	n.q.	1.0	n.q.	580	n.q.	0.007	n.q.	0.24

Location	Cu_{Total} (μg/L)		$Cu_{Diss.}$ (μg/L)		Fe_{Total} (μg/L)		$Fe_{Diss.}$ (μg/L)		Pb_{Total} (μg/L)		Hg_{Total} (μg/L)		Ag_{Total} (μg/L)		Zn_{Total} (μg/L)l	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.6	2.7	0.3	1.3	920	950	4.1	22	0.034	0.15	n.q.	n.q.	0.043	0.11	0.36	1.6
Downstream Edge of IDZ	0.5	3.0	0.2	1.5	920	960	3.2	23	0.025	0.17	n.q.	n.q.	0.028	0.14	0.27	1.7
Downstream of IDZ	n.q.	3.0	n.q.	1.5	n.q.	960	n.q.	23	n.q.	0.17	n.q.	n.q.	n.q.	0.14	n.q.	1.7
Upstream Edge of IDZ	0.4	3.0	0.2	1.5	920	960	3.1	23	0.024	0.17	n.q.	n.q.	0.026	0.14	0.25	1.7
Upstream of IDZ	n.q.	3.0	n.q.	1.5	n.q.	960	n.q.	23	n.q.	0.17	n.q.	n.q.	n.q.	0.14	n.q.	1.7

n.q. = Not Quantifiable

Table 5.13: 1994 Lulu Island STP with Secondary Treatment

Water Quality in the Fraser at locations influenced by the Lulu Island STP Outfall, Urban Runoff, Industrial Discharges, upstream STPs and Primary Treatment at Annacis Island STP.

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/ NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.26	2.1	500	500	150	150	0.08	0.34	0.23	1.0	570	580	0.0011	0.008	0.027	0.14
Downstream Edge of IDZ	0.24	2.1	500	500	150	150	0.07	0.37	0.17	1.1	570	580	0.0010	0.008	0.021	0.15
Downstream of IDZ	n.q.	2.1	n.q.	500	n.q.	150	n.q.	0.37	n.q.	1.1	n.q.	580	n.q.	0.008	n.q.	0.15
Upstream Edge of IDZ	0.24	2.1	500	500	150	150	0.07	0.37	0.16	1.1	570	580	0.0009	0.008	0.020	0.15
Upstream of IDZ	n.q.	2.1	n.q.	500	n.q.	150	n.q.	0.37	n.q.	1.1	n.q.	580	n.q.	0.008	n.q.	0.15

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.4	2.3	0.2	1.2	920	950	3.0	20	0.025	0.14	n.q.	n.q.	0.043	0.11	0.22	1.3
Downstream Edge of IDZ	0.3	2.4	0.2	1.2	910	950	2.6	21	0.020	0.15	n.q.	n.q.	0.028	0.14	0.18	1.4
Downstream of IDZ	n.q.	2.4	n.q.	1.2	n.q.	950	n.q.	21	n.q.	0.15	n.q.	n.q.	n.q.	0.14	n.q.	1.4
Upstream Edge of IDZ	0.3	2.4	0.2	1.2	910	950	2.5	21	0.019	0.15	n.q.	n.q.	0.026	0.14	0.17	1.4
Upstream of IDZ	n.q.	2.4	n.q.	1.2	n.q.	950	n.q.	21	n.q.	0.15	n.q.	n.q.	n.q.	0.14	n.q.	1.4

n.q. = Not Quantifiable

Table 5.14: Scenario P_3 Lulu Island with Primary Treatment

Water Quality in the Fraser at locations influenced by the Lulu Island STP Outfall, Urban Runoff, Industrial Discharges, upstream STPs and Primary Treatment at Annacis Island STP.

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/ NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.83	4.9	500	500	150	150	0.13	0.66	0.29	1.8	570	590	0.0019	0.016	0.081	0.34
Downstream Edge of IDZ	0.68	5.2	500	500	150	150	0.11	0.70	0.24	1.9	570	590	0.0019	0.016	0.059	0.38
Downstream of IDZ	n.q.	5.2	n.q.	500	n.q.	150	n.q.	0.70	n.q.	1.9	n.q.	590	n.q.	0.016	n.q.	0.38
Upstream Edge of IDZ	0.66	5.2	500	500	150	150	0.10	0.70	0.23	1.9	570	590	0.0019	0.016	0.056	0.38
Upstream of IDZ	n.q.	5.2	n.q.	500	n.q.	150	n.q.	0.70	n.q.	1.9	n.q.	590	n.q.	0.016	n.q.	0.38

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.9	5.1	0.4	2.5	920	990	6.4	43	0.050	0.29	n.q.	n.q.	0.051	0.16	0.52	2.9
Downstream Edge of IDZ	0.7	5.4	0.4	2.7	920	1000	5.5	45	0.040	0.31	n.q.	n.q.	0.035	0.19	0.42	3.1
Downstream of IDZ	n.q.	5.4	n.q.	2.7	n.q.	1000	n.q.	45	n.q.	0.31	n.q.	n.q.	n.q.	0.19	n.q.	3.1
Upstream Edge of IDZ	0.7	5.4	0.4	2.7	920	1000	5.3	45	0.039	0.31	n.q.	n.q.	0.032	0.19	0.40	3.1
Upstream of IDZ	n.q.	5.4	n.q.	2.7	n.q.	1000	n.q.	45	n.q.	0.31	n.q.	n.q.	n.q.	0.19	n.q.	3.1

n.q. = Not Quantifiable

Table 5.15: Scenario P_3 with Secondary Treatment at Lulu Island

Water Quality in the Fraser at locations influenced by the Lulu Island STP Outfall, Urban Runoff, Industrial Discharges, upstream STPs and Primary Treatment at Annacis Island STP.

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/ NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.50	4.4	500	500	150	150	0.12	0.65	0.33	1.8	570	590	0.0022	0.016	0.042	0.28
Downstream Edge of IDZ	0.48	4.4	500	500	150	150	0.10	0.68	0.26	2.0	570	590	0.0021	0.017	0.036	0.29
Downstream of IDZ	n.q.	4.4	n.q.	500	n.q.	150	n.q.	0.68	n.q.	2.0	n.q.	590	n.q.	0.017	n.q.	0.29
Upstream Edge of IDZ	0.48	4.4	500	500	150	150	0.10	0.68	0.25	2.0	570	590	0.0021	0.017	0.035	0.29
Upstream of IDZ	n.q.	4.4	n.q.	500	n.q.	150	n.q.	0.68	n.q.	2.0	n.q.	590	n.q.	0.017	n.q.	0.29

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.6	4.7	0.3	2.3	920	990	5.2	41	0.04	0.27	n.q.	n.q.	0.051	0.16	0.37	2.7
Downstream Edge of IDZ	0.6	4.8	0	2.0	920	990	4.8	42	0.03	0.28	n.q.	n.q.	0.035	0.19	0.32	2.8
Downstream of IDZ	n.q.	4.8	n.q.	2.4	n.q.	990	n.q.	42	n.q.	0.28	n.q.	n.q.	n.q.	0.19	n.q.	2.8
Upstream Edge of IDZ	0.6	4.8	0.3	2.4	920	990	4.7	42	0.03	0.28	n.q.	n.q.	0.032	0.19	0.32	2.8
Upstream of IDZ	n.q.	4.8	n.q.	2.4	n.q.	990	n.q.	42	n.q.	0.28	n.q.	n.q.	n.q.	0.19	n.q.	2.8

n.q. = Not Quantifiable

Table 5.16: Scenario P_3 with Primary Treatment at Annacis Island and Changing Unit Loads

Water Quality in the Fraser at locations influenced by the Annacis Island STP Outfall, Urban Runoff, Industrial Discharges, upstream STPs and Primary Treatment at Annacis Island STP Assuming Changing Unit Loads.

Location	Phenol (µg/L)		Al_{Total} (µg/L)		Cu total (µg/L)		Cu diss. (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.04	0.4	570	571	0.1	1.4	0.3	3.3	915	964	8	88	0.0003	0.001	0.05	0.5
Annacis Channel	0.08	0.6	570	571	0.2	1.8	0.6	4.2	919	979	15	113	0.0003	0.001	0.09	0.7
Tilbury Island	0.17	0.7	570	571	0.5	2.2	1.3	5.3	931	997	33	141	0.0004	0.001	0.2	0.8
Woodwards Landing	0.12	0.5	570	571	0.4	1.6	0.9	3.7	924	971	23	99	0.0004	0.001	0.1	0.6
Steveston	0.09	0.8	570	572	0.3	2.7	0.7	6.3	921	1013	17	167	0.0003	0.001	0.1	1.0
Transverse edge of IDZ	0.60	1.0	571	572	1.9	3.2	4.5	7.5	984	1033	120	200	0.0010	0.002	0.7	1.2
Downstream Edge of IDZ	0.36	1.4	571	573	1.1	4.6	2.7	11	954	1087	72	288	0.0007	0.002	0.4	1.7
Downstream of IDZ	n.q.	1.4	n.q.	573	n.q.	4.6	n.q.	11	n.q.	1087	n.q.	288	n.q.	0.002	n.q.	1.7
Upstream Edge of IDZ	0.33	1.4	571	573	1.0	4.6	2.5	11	950	1087	65	288	0.0007	0.002	0.38	1.7
Upstream of IDZ	n.q.	1.4	n.q.	573	n.q.	4.6	n.q.	11	n.q.	1087	n.q.	288	n.q.	0.002	n.q.	1.7

n.q. = Not Quantifiable

Table 5.17: Scenario P_3 with Secondary Treatment at Annacis Island and Changing Unit Loads

Water Quality in the Fraser at locations influenced by the Annacis Island STP Outfall, Urban Runoff, Industrial Discharges, upstream STPs and Secondary Treatment at Annacis Island STP Assuming Changing Unit Loads.

Location	Phenol (µg/L)		Al_{Total} (µg/L)		Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.04	0.5	570	570	0.0	0.4	0.1	1.1	911	926	4	47	0.0003	0.001	0.01	0.1
Annacis Channel	0.08	0.6	570	570	0.1	0.5	0.2	1.5	913	930	8	61	0.0003	0.001	0.02	0.2
Tilbury Island	0.18	0.8	570	571	0.2	0.7	0.4	1.8	916	936	18	76	0.0003	0.001	0.1	0.2
Woodwards Landing	0.13	0.5	570	570	0.1	0.5	0.3	1.3	914	928	13	53	0.0003	0.001	0.0	0.1
Steveston	0.09	0.9	570	571	0.1	0.8	0.2	2.1	913	940	9	90	0.0003	0.001	0.0	0.2
Transverse edge of IDZ	0.66	1.1	571	571	0.6	1.0	1.5	2.6	932	946	65	108	0.0006	0.001	0.2	0.3
Downstream Edge of IDZ	0.39	1.6	570	571	0.3	1.4	0.9	4	923	962	39	156	0.0005	0.001	0.1	0.4
Downstream of IDZ	n.q.	1.6	n.q.	571	n.q.	1.4	n.q.	4	n.q.	962	n.q.	156	n.q.	0.001	n.q.	0.4
Upstream Edge of IDZ	0.36	1.6	570	571	0.3	1.4	0.8	4	922	962	35	156	0.0005	0.001	0.10	0.4
Upstream of IDZ	n.q.	1.6	n.q.	571	n.q.	1.4	n.q.	4	n.q.	962	n.q.	156	n.q.	0.001	n.q.	0.4

n.q. = Not Quantifiable

Table 5.18: Scenario P_3 with Primary Treatment at Lulu Island and Changing Unit Loads

Water Quality in the Fraser at locations influenced by the Lulu Island STP Outfall, Urban Runoff, Industrial Discharges, upstream STPs and Primary Treatment at Lulu Island STP Assuming Changing Unit Loads.

Location	Phenol (µg/L)		Al_{Total} (µg/L)		Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.49	1.6	570	571	1.3	2.8	2.9	6.6	915	943	11	92	0.0004	0.001	0.05	0.3
Downstream Edge of IDZ	0.33	1.9	570	571	0.8	3.7	1.8	8.5	914	944	10	93	0.0003	0.001	0.04	0.3
Downstream of IDZ	n.q.	1.9	n.q.	571	n.q.	3.7	n.q.	8.5	n.q.	944	n.q.	93	n.q.	0.001	n.q.	0.3
Upstream Edge of IDZ	0.31	1.9	570	571	0.7	3.7	1.7	8.5	914	944	10	93	0.0003	0.001	0.04	0.3
Upstream of IDZ	n.q.	1.9	n.q.	571	n.q.	3.7	n.q.	8.5	n.q.	944	n.q.	93	n.q.	0.001	n.q.	0.3

n.q. = Not Quantifiable

Table 5.19: Scenario P_3 with Secondary Treatment at Lulu Island and Changing Unit Loads

Water Quality in the Fraser at locations influenced by the Lulu Island STP Outfall, Urban Runoff, Industrial Discharges, upstream STPs and Secondary Treatment at Lulu Island STP Assuming Changing Unit Loads.

Location	Phenol (µg/L)		Al_{Total} (µg/L)		Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.60	1.8	570	571	0.6	1.6	1.4	4.1	914	941	10	91	0.0003	0.001	0.04	0.3
Downstream Edge of IDZ	0.40	2.1	570	571	0.4	2.0	0.9	5.0	913	942	10	92	0.0003	0.001	0.03	0.3
Downstream of IDZ	n.q.	2.1	n.q.	571	n.q.	2.0	n.q.	5.0	n.q.	942	n.q.	92	n.q.	0.001	n.q.	0.3
Upstream Edge of IDZ	0.37	2.1	570	571	0.3	2.0	0.9	5.0	913	942	10	92	0.0003	0.001	0.03	0.3
Upstream of IDZ	n.q.	2.1	n.q.	571	n.q.	2.0	n.q.	5.0	n.q.	942	n.q.	92	n.q.	0.001	n.q.	0.3

n.q. = Not Quantifiable

5.4.1 Annacis Island Water Quality Impacts

Some pollutants in some scenarios are present at concentrations above the CCREM guidelines for the protection of aquatic life or recreational use due to the Annacis Island STP outfall. A summary of the Guidelines for Freshwater Aquatic Life may be found in Appendix M. The guidelines were exceeded for NO_3/NO_2-N, phenol, Al_{Total}, Cu_{Total}, Fe_{Total}, Pb_{Total} and Ag_{Total}. There is no CCREM guideline for $Cu_{Diss.}$ or $Fe_{Diss.}$. The guidelines were not exceeded for any of the other pollutants of concern. The source and toxicity of each of these pollutants is discussed below.

NO_3/NO_2-N: No numerical guideline is given for the concentration of NO_3/NO_2-N by the CCREM. The only stipulation is that total concentrations of NO_3/NO_2-N should not promote excessive weed growth and the concentration of NO_2-N should not exceed 0.06 mg/l. The concentration of 150 μg/l NO_3/NO_2-N is attributable to the background measurement by BCMOE, 1993. The BCMOE study did not distinguish between NO_3-N and NO_2-N. NO_2-N was not detected in Annacis Island STP effluent. The typical concentration of NO_2/NO_3-N in urban runoff is 0.7 mg/l, however this is a small percentage of total flow. Since the Fraser River is well aerated, one may assume that all NO_3/NO_2-N is in the NO_3-N form. Therefore it is unlikely that the 0.06 mg/l guideline for NO_2-N is exceeded. The guideline requirement for NO_3-N is simply the level that will not result in eutrophication. This varies, but algal blooms tend to occur if the concentration of inorganic nitrogen is greater than 0.3 mg/l (Metcalf and Eddy, 1991). The change in the concentration of NO_3-N due to the Annacis Island STP is 4.1 percent of the background concentration. Secondary treatment does not significantly reduce the concentration of NO_3-N in STP effluent. These factors suggest that the addition of secondary treatment is unlikely to substantially improve water quality in the Fraser River with respect to eutrophication and NO_3/NO_2-N.

Phenol: The CCREM guideline for total phenols for the protection of tainting of fish is 1 μg/l. Pure phenol taints fish flesh at concentrations of 1-10 mg/l, however other phenols may taint fish flesh at concentrations approximately 3 orders of magnitude lower than pure phenol (U.S. EPA, 1973). This may be compared to the acute and chronic toxicities for phenol which occur at concentrations of 10.2 and 2.56 mg/l (U.S. EPA 1980a).The maximum concentration of phenol is expected to be greater than the CCREM guideline for all scenarios at nearly all locations in the river. The average concentration at the outfall also exceeds the guideline in all scenarios. The average concentration at the edge of the IDZ barely exceeds the guideline in population scenario P_3. Therefore, the average concentration of phenol outside the IDZ is generally not of concern.

The phenol removal efficiency found in the literature for secondary treatment was less than is being obtained by the current primary system. Phenol is a by-product of the degradation process undertaken in secondary treatment (DOE-FRAP 1993-08). Therefore, the addition of secondary treatment would likely increase the concentration of phenol in STP effluent. In these pollutant loading calculations, the removal efficiency from the current primary system was used.

Phenol loading to Annacis Island STP may be attributable to the industrial component of influent. If fish in the Fraser River were found to be tainted with phenol, source control programs could be initiated to mitigate against phenol contamination. The low incidence of exceeding the guideline, and the fact that secondary treatment would likely increase effluent phenol concentrations, suggests that source control programs may be a more effective method of mitigating against phenol contamination.

Aluminum: The CCREM guideline for Al_{Total} is 100 μg/l for waters with pH ≥ 6.5; Ca^{2+} ≥ 4.0 mg/l and DOC ≥ 2.0 mg/l which are the conditions in the Fraser River at the Annacis Island outfall. The background concentration of Al_{Total} under low flow conditions is approximately 570 μg/l. Other measurements of the background concentration of Al_{Total} at Mission range from 70 μg/l to 320 μg/l with a mean of 260 μg/l. Four of five background measurements were over the tentative guideline of 100 μg/l (DOE FRAP 1993-31). The maximum change in aluminum concentration attributable to the Annacis Island outfall for scenario P_3, with primary treatment, at the edge of the IDZ is 21.6 μg/l. Under low flow conditions, this amounts to 4 % of the background concentration of 570 μg/l for Al_{Total}.

Increasing the level of treatment will not improve the water quality in the Fraser River significantly with respect to Al_{Total}. This is due to the high background concentration of Al_{Total}. The small concentration change in the Annacis Island IDZ, relative to the concentration in the Fraser River, suggests that secondary treatment should not be installed on the basis of Al_{Total} water quality criteria.

Copper: The CCREM guideline for Copper is 2 μg/l with hardness less than 60 mg/l as $CaCO_3$. The hardness of the Fraser River is typically less than 60 mg/l as $CaCO_3$. The average value for hardness at Mission obtained by the DOE in the Fraser River Estuary Monitoring Study was 58 mg/l as $CaCO_3$ (DOE FRAP 1993-31). The average value calculated for Cu_{Total} outside the dilution zone was below the guideline for Scenario P_3 with primary treatment. However, the maximum concentration of Cu_{Total} was above the guideline at all locations with primary treatment for Scenario P_3. The maximum concentration at Steveston is as high as 4.4 μg/l. Upgrading the Annacis Island STP to secondary treatment would reduce the maximum Cu_{Total} concentration to near the guideline at the edge of the dilution zone for population scenario P_3.

Different scenarios may be analysed to determine the sensitivity of water quality to population. Cu_{Total} concentrations at various locations in the Fraser River for scenarios P_1 and P_2 may be found in Table 5.20. This illustrates that maximum Cu_{Total} concentrations will still be triple the CCREM guideline at the edge of the dilution zone with population P_1. The maximum concentrations at other locations are closer to the guideline, however, the Cu_{Total} concentration will still be double the guideline at Steveson. This demonstrates that population growth would have to be considerably lower than any of the developed population scenarios to meet the CCREM guideline with primary treatment at Annacis Island.

Table 5.20: Copper Concentrations for Scenarios P_1 and P_2

Scenario	P_1				P_2			
Treatment Level	Primary Treatment		Secondary Treatment		Primary Treatment		Secondary Treatment	
Location	Avg. (μg/L)	Max. (μg/L)	Avg. (μg/L)	Max. (μg/L)	Avg. (μg/L)	Max. (μg/L)	Avg. (μg/L)	Max. (μg/L)
Patullo Bridge	0.2	1.9	0.1	0.6	0.2	2.1	0.1	0.6
Annacis Channel	0.3	2.4	0.1	0.7	0.4	2.7	0.1	0.8
Tilbury Island	0.7	3.0	0.2	0.9	0.8	3.4	0.2	1.0
Woodwards Landing	0.5	2.1	0.2	0.6	0.6	2.4	0.2	0.7
Steveston	0.4	3.6	0.1	1.1	0.4	4.0	0.1	1.2
Transverse edge of IDZ	2.6	4.3	0.8	1.3	2.9	4.8	0.9	1.5
Downstream edge of IDZ	1.6	6.2	0.5	1.9	1.7	6.9	0.5	2.1
Downstream of IDZ	n.q.	6.2	n.q.	1.9	n.q.	6.9	n.q.	2.1
Upstream edge of IDZ	1.4	6.2	0.4	1.9	1.6	6.9	0.5	2.1
Upstream of IDZ	n.q.	6.2	n.q.	1.9	n.q.	6.9	n.q.	2.1

Historically, Cu_{Total} concentrations have been decreasing; therefore, one might expect that copper concentrations in the Fraser River may be less than those forecast by assuming constant Cu_{Total} concentrations in Annacis Island STP effluent. See Table 5.16 and Table 5.17. However, the concentrations of $Cu_{Diss.}$ have been increasing and $Cu_{Diss.}$ is the toxic form of copper. However, there are no CCREM guidelines for $Cu_{Diss.}$ The concentration of $Cu_{Diss.}$ must be monitored closely to ensure that $Cu_{Diss.}$ levels do not reach level which are toxic to fish.

The Ontario Ministry of the Environment (1984) recommends a 5 μg/l guideline for Cu_{Total}. The maximum concentration of Cu_{Total} would still exceed the guideline outside the IDZ under this criteria for all scenarios with primary treatment. The EPA established guidelines for 4 day and 1 hr average concentrations (US EPA, 1985) which are also hardness dependent. At hardness of 50, the guidelines for Cu_{Total} are 6.5 μg/l for a 4 day average and 9.2 μg/l for the 1 hr average. The concentration of Cu_{Total} does not exceed the EPA guidelines in any of the scenarios. However, the EPA guidelines do not stipulate whether an IDZ is permitted.

The presence of sewage has been found to ameliorate the toxicity of copper (Alabaster and Lloyd, 1982). It has been recommended that guidelines for copper should be adjusted upwards for surface waters with TOC concentrations significantly above 2-3 mg/l (US EPA 1985). However, the concentration of TOC in the Fraser River is approximately 2 mg/l which is too low to warrant increasing the guideline for copper.

Guidelines which allow a higher concentration of copper may reflect a different philosophy in the precautionary principle although they may also reflect a difference in the species being protected in each jurisdiction. The BC guidelines are amongst the lowest and reflect the strong precautionary principle. This is consistent with the BC guidelines for other pollutants which are also at the low end of the range of guideline values. The addition of secondary treatment would achieve copper concentrations in the Fraser River which adhere to the 'strong' precautionary principle. Maintaining the current level of treatment would achieve copper concentrations in the Fraser River which achieve the 'weak' precautionary principle. As discussed earlier, the 'strong' precautionary principle correlates loosely with the strong sustainability paradigm and the 'weak' precautionary principle loosely correlates with the weak sustainability paradigm. Therefore, the construction of secondary treatment achieves the goals of strong sustainability over the weak sustainability level currently being achieved.

Iron: The CCREM guideline for Fe_{Total} is 0.3 mg/l. The guideline is exceeded at all points in the river at all times. This is due to the high background concentration of Fe_{Total} of 910 μg/l at Mission measured by the DOE in March, 1993 (DOE FRAP 1993-31). The average concentration of Fe_{Total} in the Fraser River from January to March 1993 was 430 μg/l. The average concentration increase in Fe_{Total} outside the IDZ was approximately 9 μg/l. The maximum increase in Fe_{Total} outside the IDZ was 74 μg/l. The maximum increase in Fe_{Total} concentration, as a result of the sewage discharge, is significant compared to the average concentration of iron in the Fraser River. Secondary sewage treatment would reduce the maximum increase in iron concentration to 22 μg/l.

The criteria for Fe_{Total} varies dramatically. The Manitoba limit is 1000 μg/l which is the same as the U.S. EPA 1976 recommendation. More recent criteria documents published by the U.S. EPA have not included iron (CCREM, 1987). Toxicity studies have shown that the safe concentration for exposure of juvenile brook trout, based on the mortality of juveniles, was between 7.5 and 12.52 mg/l (Sykora et al. 1972). This may be similar for other salmonid species. The provisional water quality objectives set forth by Swain and Holms, 1985 do not include an objective for iron.

The concentration of iron in the Fraser River is naturally high. The percent increase in iron concentration is significant at 18 percent of the average background concentration, however, this is below the Manitoba objective of 1000 μg/l and far below the safe concentration for the exposure of juvenile trout of 7.5 mg/l.

Lead: The CCREM guideline for Pb_{Total} is 1 μg/l for water with a hardness less than 60 mg/l as $CaCO_3$. The maximum concentration of Pb_{Total} at the edge of the dilution zone is 0.43 μg/l while the average concentration is <0.050 μg/l for all locations outside the IDZ. Therefore, maintaining the current level of treatment should not lead to a problem with lead toxicity.

Silver: The CCREM guideline for silver is 0.1 μg/l. The guideline for silver is exceeded at the edges of the dilution zone where the maximum concentration may be as high as 0.16 μg/l. The maximum concentration at locations outside the dilution zone is below the guideline.

Silver is one of the most toxic metals to aquatic life (CCREM, 1987). The chronic toxicity concentration derived from early-life-stage tests rainbow trout was 0.12 μg/l. The chronic toxicity level is only exceeded at periods of slack tide at the edges of the dilution zone. Silver would have to be acutely toxic under these conditions. No data was available for the removal of silver from secondary treatment, however, some reduction would be expected.

Toxicity: The toxicity of Annacis Island effluent was determined by several methods by Environment Canada (DOE FRAP 1993-08). The results of the toxicity profiles indicate that the LC_{50} for Rainbow trout was 54.6 percent undiluted effluent or a 1.8:1 dilution. The LC_{50} for *Daphnia Magna* was found to be 100%. The TEC (Threshold Effect Concentration), which is an estimate of where toxic effects begin for the suppression of the reproduction of *Ceriodaphnia*, was 17.5% or a 5.7:1 dilution. The SOS-chromotest genotoxicity assay reveals the presence of carcinogens which require metabolic activation. The TEC for the SOS-chromotest for Annacis Island effluent was 4.4%. This requires 22.7 fold dilution with distilled water to render the test negative. This can be contrasted with the 99:1 dilution required for Northwood pulp mill effluent.

Dilution factors at the edge of the IDZ for the Annacis Island outfall may be found in Table 4.3. The average dilution at the edge of the IDZ is 74 under scenario P_3 and the minimum dilution is 19. The average dilution is much larger for points outside the IDZ. The average dilution at the edge of the IDZ would result in negative results for each of the toxicity tests. The minimum dilution would result in negative results for all of the tests except the SOS-chromotest for genotoxicity. This test is designed to determine whether mutagenic compounds are present in the water column. The minimum dilution occurs only about 2-13 percent of the time, unlike the constant conditions simulated in the toxicity tests. The result of this test suggests that mutagenic conditions do not occur outside the IDZ.

The most comprehensive assessment of Fraser River toxicity was carried out by Dutka, Tuominen, Churchland, Kwan, 1989, to determine which toxicity tests were the most sensitive to natural river conditions. The results of the SOS-chromotest were negative indicating the mutagenic compounds were below the detection limit for this test. The results of the Microtox EC_{50} were negative indicating no perceived reduction in light production. There was a

1 percent inhibition of ATP production, however this was barely above the detection limit for this test and may be a somewhat ambiguous result. The most significant result was an LC_{50} of 88 percent sample for *Daphnia Magna* indicating that 50 percent of the *Daphnia Magna* died over 48 hours with 88 percent of the sample and 12 percent distilled water. These result may be contrasted with the toxicity results of undiluted effluent. The undiluted effluent had an LC_{50} of 100% effluent and the SOS-chromotest indicated that a 22.7 dilution was required to render the test negative. The bioassay test of Fraser River water indicates that it is more acutely toxic than undiluted effluent and the SOS-chromotest indicates that the Fraser River water contains appreciably fewer carcinogens.

The toxicity of various effluent dilutions could be determined and compared to the toxicity of river water with the same effluent dilution. This would allow the component of toxicity attributable to STP effluent to be assessed. Long term toxicity tests have been proposed to determine the toxicity of water in locations near the Annacis Island outfall, but these have not been performed, Hall, 1996b. The water quality model predicts that the water quality outside the IDZ should be acceptable. Comprehensive toxicity testing could be used to verify the acceptability of water quality in the Fraser River near the Annacis Island IDZ.

5.4.2 Lulu Island Water Quality Impacts

The average concentration is below that stipulated in the CCREM Water Quality Guidelines for most pollutants. However, the guidelines for phenol, Cu_{Total} and Ag_{Total} are exceeded during periods of slack water.

Phenol: The maximum concentration of phenol at the Lulu Island outfall exceeds the CCREM guideline under the 'double dosing' scenario outlined above. It is unlikely that the installation of secondary treatment at Annacis Island STP or Lulu Island STP would reduce phenol concentrations because phenol is a metabolic by-product of the secondary treatment process. Source control may be a better alternative to reducing phenol toxicity in the Fraser River than upgrading the treatment plant to secondary treatment. This was discussed in section 5.4.1.

Aluminum and Iron: Aluminum and Iron concentrations exceed the CCREM Guideline. However, the contribution from the Lulu Island STP is small in comparison to the ambient concentration and the loading from the Annacis Island STP. Upgrading the Lulu Island STP would have a small effect on reducing Al_{Total} and Fe_{Total} concentrations in the Fraser River.

Copper: The maximum Cu_{Total} concentration at the edge of the Lulu Island IDZ is similar to that near the Annacis Island IDZ. The maximum concentration of 5.1 μg/l exceeds the CCREM guideline of 2 μg/l, but it is still below the level required in other jurisdictions (See section 5.4.1). The maximum concentration at the Lulu Island outfall would drop significantly if secondary treatment were installed at Annacis Island. This is summarised in Table 5.21. The maximum predicted concentration at the Lulu Island outfall under this scenario is 2.4 μg/l. This value is very conservative and reflects a specific interaction of tidal and river flow conditions. Therefore, it is unlikely that the maximum predicted copper concentration would be realised in the Fraser River.

Table 5.21: Cu_{Total} Concentration at Lulu Island outfall with secondary treatment at Annacis Island

Location Scenario P_3	Cu_{Total} (μg/L) Avg.	Max.
Transverse edge of IDZ	0.6	2.1
Downstream Edge of IDZ	0.4	2.4
Downstream of IDZ	0.1	2.4
Upstream Edge of IDZ	0.4	2.4
Upstream of IDZ	0.1	2.4

Lead: The maximum concentration of lead does not exceed the CCREM guideline.

Silver: The maximum concentration of silver (~2 μg/l) at the Lulu Island outfall exceeds the CCREM guideline. The maximum concentration change attributable to the Lulu Island outfall is 0.1 μg/l. If secondary treatment were installed at the Annacis Island plant, the concentration of Ag_{Total} at the edge of the IDZ would be below the CCREM guideline approximately 97 percent of the time.

Toxicity: There is no published data on the toxicity of Lulu Island Effluent. There have been bioassay tests performed on samples taken near the Lulu Island STP outfall. Therefore, no conclusions may be made regarding Lulu Island STP effluent toxicity in the Fraser River. If the effluent is assumed to have the same toxicity characteristics as the Annacis Island effluent, sufficient dilution is achieved to render the SOS-chromotest negative. No other toxicity data is available.

5.5 Implications for Sustainability

The provincial government ordered the upgrade under the assumption that aquatic life would be protected. The study has shown that the water quality at the edge of the Annacis Island IDZ forecast by 'worst-case' growth in population, urban runoff and industrial activity should be acceptable for all parameters except copper. The average concentration of copper should meet water quality objectives and maximum concentration would be acceptable in other jurisdictions. A strong argument could be made that no increase in treatment is required under the forecast changes in water quality.

A very weak sustainability approach would be to charge a fee to the treatment plant for the use of the pollution absorption capacity of the river. The GVRD could then decide whether attaining the ambient objectives set forth by the province is cheaper to attain by building a larger diffuser and paying the user fee, or upgrading the treatment plant and paying a lower fee. Formulating permit requirements within this framework may be more economically efficient than the current unidirectional approach.

The weak sustainability paradigm would argue for the monetary compensation of the loss of productivity attributable to the sewage treatment plant discharges. The weak sustainability legislative approach would argue for the compensation of the loss of natural capital. An approach to compensating the loss of natural capital would be through increased licensing fees or the creation of shadow projects. A classic example of a shadow project is the 'Clunker Junker' program in California. In this program industries buy old working vehicles and remove them from service instead of reducing the emissions from their own stacks. The removal of these autos results in a more cost-effective reduction of pollution than installing costly pollution abatement equipment. Air emissions are not as spatially dependent as water discharges. Efforts to reduce the impact of Annacis Island effluent by shadow projects of this nature would have to focus on the reduction of discharges from many small sources in the vicinity of the outfall. Since copper, the primary pollutant of concern, comes primarily from the Annacis Island STP, shadow projects of this nature are not likely to be successful. However, shadow projects could be envisioned similar to the 'No net loss' program for wetlands in the U.S. An example of a project of this nature would be salmon habitat restoration. The restoration of upset habitat due to anthropogenic activity could compensate for the loss of habitat due to the discharges from the Annacis Island STP and the Lulu Island STP. Expenditures to recover habitat, restock spawning grounds, operate a hatchery or reduce the impact of small discharges in sensitive areas may be many orders of magnitude lower and have a larger effect. Programs of this nature would have a measurable direct positive effect on the fishery rather the uncertain effect which will result from the upgrade of the Annacis Island Sewage Treatment Plant. Projects, such as the ones described above, could be financed either by increased licensing fees or managed by the company or municipality concerned.

The requirements for the weak sustainability world view would be the least restrictive 'safe minimum standard' for water quality. The 'safe minimum standard' recognised by the provincial government are the levels in the CCREM guidelines which are more restrictive than those set forth in other jurisdictions. Copper is the only pollutant predicted to exceed current BC water quality objectives in any scenario. Water quality at the edge of the Annacis Island IDZ would meet EPA criteria until the year 2021.

The strong sustainability paradigm would argue for the preservation of natural capital. Shadow projects may also reflect strong sustainability. Strong sustainability advocates 'no net loss of natural capital'. Shadow projects could be developed to counter the lost habitat due to the STP outfall. This differs from the weak sustainability approach to shadow projects which would concentrate on compensating for the lost economic productivity of the river due to STP discharges. This no net loss of natural capital may have some ironic results. Under this world view, the lost productivity of the land appropriated for sewage treatment must be considered. Secondary treatment plants require more than double the land area of primary treatment plants due to the increased system area and sludge handling facilities (GVRD, 1988). The sludge settling facilities alone, at the current treatment plant, occupy an area of 6.9 ha. This will approximately double with the implementation of secondary treatment. This may be compared to the 1.3 ha of river the Annacis Island IDZ occupies. Obviously, it is impossible to equate river habitat loss to land habitat loss, but it is a consideration under this world view.

Strong sustainability would also advocate the use of a stronger 'safe minimum standard'. This concept conforms more closely to the decision to upgrade the Annacis Island STP. The maximum concentrations of copper at the edge of the IDZ will likely exceed the CCREM guidelines in future scenarios. However, there has not been testing to prove that copper concentrations or toxicity levels in the Fraser River currently exceed CCREM guidelines. Therefore, the decision to upgrade the Annacis Island and Lulu Island STPs were made under a technology-based approach to managing risk, similar to that taken by the EPA in its BATT program. Alternative, risk-based regulations may be used to manage ambient objectives. Treatment options which could be used to reach the ambient objective include: treating only part of the waste stream, construction of an improved diffuser, reducing copper concentrations in the water supply by adding alkalinity during water treatment or enhanced primary treatment. Secondary treatment is not required at all sewage treatment plants in the lower mainland suggesting that some form of risk-based regulation is already in place. The administrative simplicity of this approach is not as high as for technology-based regulation, however there is a slight gain in economic efficiency.

The thermodynamic sustainability world view would argue for the installation of the highest level of treatment regardless of cost. Higher levels of treatment include nitrogen and phosphorus removal. These forms of treatment would be very expensive to install and maintain. However, there are several paradoxes when trying to establish a thermodynamic approach to sustainability water quality management. The appropriated land required for high levels of sewage treatment may result in a greater loss of habitat than that preserved by improving treatment. Thermodynamic sustainability would also advocate treating waste to a higher level to preserve the balance of resources. However, the increased level of treatment would require large inputs of energy which would likely not be recovered in the form of methane or resources.

The requirement put forward in the Fisheries Act, Section 50 is 'no person shall deposit or permit the deposit of a deleterious substance...in waters frequented by fish...'. The toxicity assays confirm the effluent from Annacis Island and Lulu Island STP is toxic to fish. However, the regulations in British Columbia allow for an initial dilution zone and that water outside the IDZ must meet the provincial guidelines. With primary treatment, the average concentration outside the Annacis Island IDZ is below the guidelines for all pollutants, however the maximum concentration of Cu_{Total} and Ag_{Total} at the edges of the IDZ exceeds the CCREM guideline. However, the concentration is still below that required in other jurisdictions. Similarly for the Lulu Island IDZ, with primary treatment at both Annacis Island and Lulu Island STPs, the average concentration outside the IDZ is below the guideline for all pollutants. However, the maximum concentration of Cu_{Total} and Ag exceeds the CCREM guideline.

Different sustainability world views are reflected in a variety of approaches to environmental management. The weak sustainability world view would be reflected in a risk-cost approach with the least conservative level of 'safe minimum standard'. A risk-cost approach to environmental management may have resulted in the installation of an improved diffuser or treatment of only part of the wastewater stream to reduce pollutant concentrations in the river to acceptable levels. However, a strong case could be made that water quality is acceptable without any increase in the level of treatment. Another regulatory approach that could be taken under the weak sustainability paradigm is the implementation of shadow projects. Since the environmental impact of the outfall is unlikely to be large, environmental mitigation projects could be undertaken at different locations to offset the damage done at the site of the outfall. Salmon habitat restoration, dredging toxic sediments or treating urban runoff discharges with large local impacts all represent shadow projects. These projects could all result in similar increases in environmental productivity to upgrading the Annacis Island STP at a fraction of the cost.

The upgrade of the Lulu Island STP appears to have been made using technology-based standards. After secondary treatment is installed at Annacis Island STP, the CCREM criteria will not be exceeded at the edge of the IDZ for the Lulu Island outfall. The construction of the Lulu Island plant will not serve to protect aquatic life and one must wonder under what criteria the decision was made. One must wonder whether the same decision would have been taken with a private firm or if some alternative could have been found. A strong argument could be made that no upgrade is necessary at the Lulu Island STP with primary treatment at Annacis Island in 2021. The criteria for the protection of aquatic life is exceeded, only at the edge of the IDZ between 2 to 13 percent of the time. The maximum level is still below that required in other jurisdictions.

5.6 Summary

Industrial scenario, I_3, represents the 'worst case' scenario for industrial loading. The pollutant loading from urban runoff and population growth in the 'best case' scenarios are much larger than the loading values under the 'worst case' scenario for industrial pollutant loading for all pollutants except Al_{Total}. Future industrial discharges are unlikely to have a significant effect on ambient water quality compared to discharges from urban runoff and STPs. Therefore, the decision to upgrade the treatment plants at Annacis and Lulu Islands is unlikely to be affected by the change in ambient water quality due to future industrial discharges. Industrial discharges may have local impacts which might affect the decision to upgrade the sewage treatment plants. However, if the only reason the sewage treatment plants needed to be upgraded was due to a large industrial source, it may be less expensive to treat the industrial source than the sewage.

Urban runoff scenarios were derived as a subset of the population scenarios; therefore, it is only necessary to compare urban runoff loading to STP loading for one population scenario. The relative loading for urban runoff scenarios for P_2 and P_3 may be inferred from the relationships between P_1 and P_1A, P_1B and P_1C. Urban runoff is the largest source of SS, NO_3-N/NO_2-N, Cd, Cr, Pb, Ni, Zn and PAHs and a significant source of COD, total phosphorus, Cu and Fe. It is interesting to note the changes in pollutant loading which result from the three urban runoff scenarios. Scenario A, the 'worst case' only results in 14 percent more pollutants than the best case scenario, Scenario C. This indicates that even with large-scale implementation of urban runoff BMPs and densification, there is likely to be a dramatic increase in pollutants from urban sources with increased population. However, pollutant loading in future urban runoff scenarios is unlikely to affect ambient water quality enough to affect the decision to upgrade the Annacis or Lulu Island STPs. Therefore, the decision whether to upgrade the Annacis or Lulu Island STPs is not affected by increased ambient concentrations of pollutants from urban runoff in future scenarios.

The future discharges from STPs in the FVSA were evaluated. The overall change in ambient water quality attributible to future loading from STPs in the FVSA should not affect ambient water quality enough to affect the decision to upgrade the Annacis and Lulu Island STPs.

Discharges from urban runoff, industrial sources and STPs in the FVSA were all evaluated as conservative pollutants. This may not be the case for pollutants such as NH_3-N, SS, BOD, COD total metals and others. This approach was taken to determine the maximum change in ambient water quality. The collective changs in ambient water quality under these conservative assumptions was still not sufficient to affect the decision to upgrade the Annacis Island or Lulu Island STPs.

Annacis Island and Lulu Island STPs are the largest source of all pollutants except SS, NO_3-N/NO_2-N, Cd, Cr, Pb, Ni, Zn, PAHs, and Al. Pollutant loading from these two sources could more than double over the next 25 years. Secondary treatment is generally installed to reduce SS and the BOD of the effluent. In addition, faecal coliforms are greatly reduced and there are potentially large reductions in total metals and surfactants. Secondary treatment at the Annacis Island and Lulu Island STPs provides the simplest solution for reducing total pollutant loading to the Fraser River Estuary.

The impact on water quality around the treatment plant outfalls was determined by using dilution coefficients at various locations. The dilution coefficients were adapted from literature and modified for the future levels of flow predicted by the three scenarios. The pollutant concentration in the plumes was added to the ambient pollutant concentration to determine the overall water quality at each location in each scenario.

It was found that the maximum concentration for some parameters at the edge of the Annacis Island IDZ would exceed the CCREM guidelines in all scenarios. The pollutants with a maximum concentration above the guideline are: Cu_{Total}, Ag_{Total} and phenol. The concentration of Cu_{Total} was still below that required in other jurisdictions. The installation of secondary treatment would reduce the concentration of Cu_{Total} and Ag_{Total} to near CCREM guideline concentrations at the edge of the Annacis Island IDZ. The maximum concentration of phenol was above the guideline for the prevention of tainting of fish flesh. However, it was not near the toxic limit for the protection of aquatic life. The installation of secondary treatment would not reduce phenol concentrations. The average concentration for all other pollutants was below the CCREM guidelines except for Fe_{Total} and Al_{Total}, whose background concentrations were above the CCREM guideline.

During low river flow periods, slack water following an ebb tide lasts for approximately one hour before upstream movement began. The maximum interval between a flood and an ebb tide is half an hour (BCRI, 1978). Therefore, the conditions for pooling of effluent over the outfall occur approximately 13 percent of the time. Minimum river velocities (0.03 m/s), which correspond to the minimum dilution at the outfall, only occur 2 to 3 percent of the total time (GVRD, 1988). Fluctuating water quality, as a result of tidal effects, was not considered in the formulation of the CCREM Water Quality Guidelines. Fluctuating river velocities in the region of the Annacis Island outfall result in the guidelines being exceeded between 2 to 13 percent of the total time. The copper concentration is still below the level considered safe in other jurisdictions. Perhaps British Columbia should review water quality objectives for tidal regions of the Fraser River in light of the fact that pooling of effluent occurs for approximately 3 hours per day under low flow conditions. A system similar to that suggested by the EPA, recommending 1 hour and 4 day average concentrations, could be developed in conjunction with comprehensive toxicity rewuirements.

The maximum concentration of Cu_{Total}, Ag_{Total} and phenol exceeded the CCREM guidelines at the edge of the Lulu Island IDZ with primary treatment at both Annacis Island and Lulu Island STPs. The maximum concentration for Cu_{Total} was still below that required in other jurisdictions. The maximum calculated concentration would be reached very rarely as it requires very specific tidal and flow interactions. The same water which pooled under the Annacis Island outfall would have to pool again at the Lulu Island outfall. Installation of secondary treatment at Annacis Island would result in Cu_{Total} and Ag_{Total} concentrations below the guideline even with primary treatment at Lulu Island STP. The concentration of all other parameters was below the CCREM guideline except for Fe_{Total} and Al_{Total} whose background concentration was above the CCREM guideline and phenol which is not reduced with secondary treatment. The upgrade of the Lulu Island STP should have been delayed until more complete studies of the environmental impacts of the treatment plant options had been assessed. Some studies which could have been undertaken include comprehensive water quality testing at locations near the Lulu Island STP outfall, toxicity testing of various effluent dilutions and long-term toxicity tests in the Fraser River. The results of these tests might have shown that not upgrading the Lulu Island STP to secondary treatment presents an acceptable envirionmental risk.

6. CONCLUSIONS

The provincial government recently ordered the upgrade to secondary treatment of the Annacis Island and Lulu Island STPs. Currently these treatment plants discharge primary treated effluent to the Fraser River. However, studies have shown that acceptable water quality should exist until the year 2030 with increased flows and the current level of treatment. This thesis expanded on previous studies to ascertain the importance of uncertainty regarding population growth and other pollutant sources on water quality around the Annacis Island and Lulu Island STP outfalls. The decision to upgrade the STPs was evaluated in the context of sustainability and the results of the water quality determination.

Methodology was developed to determine future levels of industrial and urban runoff discharges under several scenarios which were developed to illustrate different potential growth patterns in the LFB. The loading changes were fed into a water quality model to determine the effect of the discharges on ambient water quality. The changes in ambient water quality were added to the future change in near-field water quality due to increased discharges from the Annacis and Lulu Island STPs. Earlier studies designed to predict future water quality at the Annacis Island and Lulu Island outfalls ignored the potential impacts of future discharges from these sources.

Permit data has been used in the past to determine industrial discharges and pollutant loading. However, permits often do not cover all pollutants of interest and the actual flow may be significantly different from the permitted flow. Methodology was developed to link industrial discharges to levels of economic activity. The level of economic activity in each industrial sector was multiplied by the discharges per GDP to determine total discharges. A characteristic pollutant concentration was tied to each industrial sector and was multiplied by the discharge from each sector to determine total pollutant loading. It is also possible to determine the proportion of the effluent from each sector which flows directly to the Fraser river and the proportion which flows to municipal STPs.

The methodology to determine industrial pollutant loading had several weaknesses which are attributable to the scale of the study.

1. Employment was used as a surrogate for GDP which may not be accurate at the scale of the LFB. The GDP for each sector is determined at a provincial level and it was assumed that employment/GDP was the same across

the entire province. Therefore, employment in each sector in the LFB was used to determine the GDP in each sector in the LFB. However, the pulp and paper industry illustrates the limits of this approach. There are many people employed in the pulp and paper sector in the LFB, however, there are not any pulp mills in the LFB. This may be due to the presence of corporate head-offices in the LFB. The result is a much higher predicted discharge for the pulp and paper sector than is permitted. The pulp and paper sector was the only industry with obvious discrepancies between permitted and calculated discharges.

2. Each SIC code covers a wide range of industries and therefore a wide variety of effluents. Characteristic effluent concentrations were developed from available literature values, however, data did not exist for every industrial discharge in the LFB. Therefore, some industries in each SIC may be represented to a greater or lesser degree by the characteristic effluent concentrations.

This methodology of determining industrial pollutant loading to the Fraser River is likely more accurate than the conventional method of using permitted flows and pollutant concentrations. However, the most reliable method of determining industrial pollutant loading to the Fraser would be to collect accurate flow and effluent characterisation data for each industrial discharger in the LFB. This data does not currently exist in any accessible form for all industrial discharges in the LFB.

It is desirable to link industrial discharges to economic activity to determine economy-wide discharges. The use of GDP at the provincial or national level would circumvent the problem of unequal employment per GDP in each region and would more accurately reflect all of the industries within an SIC. Secondary discharges could also be determined using Input/ Output methodology. This would identify industries requiring highly water-intensive inputs. Highly pollutant intensive industries or goods could be targeted for increased licensing fees or increased taxation.

Methodology was developed to determine the effect of population increases, density changes and urban runoff BMPs on urban runoff pollutant loading. Total runoff was determined by multiplying the runoff coefficient by the area by the average annual rainfall. Pollutant loading was determined by multiplying total runoff by the typical pollutant concentration. This method can be rapidly used to determine pollutant loading for several different development scenarios. There were several factors affecting pollutant loading estimates of urban runoff.

1. Pollutant concentrations were developed for average runoff and for the 'first flush' effect to evaluate the effect of elevated pollutant concentrations on ambient water quality. This addresses the possibility of having elevated pollutant concentrations in the Fraser River over what would normally be expected from urban runoff.
2. The pollutant concentration in urban runoff has changed over time. There are many factors influencing the quality of urban runoff and it impossible to determine what the future pollutant concentrations in urban runoff will be. In this thesis, the changing nature of urban runoff was not explored. The characteristic values for 1991 were used in all scenarios.
3. The implementation of urban runoff BMPs can dramatically reduce pollutant loading. It was estimated that the implementation of BMPs could reduce pollutant loading by approximately 75 percent of some pollutants. However, BMPs are not universally implemented and the degree to which old developments will be retrofitted is in question. Therefore the results of pollutant loading estimates for the 'best case' scenario may differ dramatically from actual pollutant loading.

There are several levels of uncertainty with respect to urban runoff pollutant loading. There is uncertainty regarding the degree of urbanisation and the type of development. There is also uncertainty regarding urban runoff quality. Future concentrations of pollutants in urban runoff may differ dramatically from current concentrations. This may be due to technological advances in fuel type and combustion efficiency or the degree to which we rely on single occupant vehicles. The methodology developed here only addressed uncertainty regarding the degree of urbanisation and the type of development. Potential changes in urban runoff quality were ignored due to the difficulty in determining the cause of the changes.

Urban runoff pollutant loading estimates were made to determine whether increased levels of loading would affect the decision to upgrade the Annacis and Lulu Island STPs. Therefore, conservative assumptions regarding settling, degradation and volatilisation were made to determine the maximum impact on water quality in the Fraser River. Urban runoff is a diffuse pollutant source, however, large drainage basins may result in large impacts on local streams. This methodology may be adapted to determine pollutant loading at the sub-basin level and subsequently prioritise the implementation of urban runoff BMPs.

Future pollutant loading from STP's upstream of the GVRD were also estimated to determine the likely effect on ambient water quality. Currently, all of the these treatment plants perform secondary treatment and it was assumed they would continue to do so in future scenarios. Estimates of population growth showed that the effect of these discharges on ambient water quality should be small.

Pollutant loading from Annacis and Lulu Island STPs was evaluated by multiplying the per capita loading by the population. Several treatment options were explored to determine the effect on pollutant loading. Uncertainty was addressed by evaluating several levels of population and allowing per capita unit loading to change at historical rates. There were some limitations on the accuracy of the pollutant loading estimates.

1. Future concentrations of pollutants were estimated in two ways a) based on the 1994 influent concentrations and b) the pollutant concentration change from 1985-1994 was extrapolated to 2021. Neither approach is totally satisfactory. However, using both approaches addresses a wide range of uncertainty. The best way to determine future influent quality would be to determine the cause of historical changes in influent quality. Unfortunately, the GVRD did not start permitting industrial discharges to municipal sewers until 1991. Therefore it is impossible to determine the relationship between changes in industrial loading and STP influent.
2. The removal efficiency of secondary treatment plants had to be estimated from literature values. The actual pollutant removal will not be known until the upgraded treatment plants are fully operational.

The methodology developed to determine pollutant loading from STPs is probably the most accurate of the three. There is only one major source of uncertainty regarding future pollutant loading from STPs which differs from urban runoff and industrial pollutant loading which have several sources of uncertainty. The major source of uncertainty regarding pollutant loading from urban runoff and industrial discharges that is not present when evaluating STPs is technological innovation. The technological component of STP pollutant loading is limited to the indirect discharges from industries and combined sewers. These are relatively small compared to the domestic sewage component which has a fairly consistent character.

Urban runoff was found to be the most significant source of NO_3-N/NO_2-N, Cd, Cr, Pb, Ni, Zn and PAHs. The combined loading from Annacis Island and Lulu Island STPs was higher for all other pollutants. The contribution from industrial discharges and upstream STPs was relatively small in comparison to discharges from urban runoff and Annacis and Lulu Island STPs. Pollutant loading from Annacis and Lulu Island was still higher for all pollutants, other than the aforementioned, even with the installation of secondary treatment at both treatment plants.

Industrial, urban runoff and upriver STP discharges were not spatially allocated. It was assumed that the effect on ambient water quality at the Annacis and Lulu Island STP outfalls, from industrial discharges, urban runoff and upriver STPs, could be approximated by assuming these discharges completely mixed. None of the methodologies were designed to assess local impacts, but rather focused on the role of potential future upriver discharges in decision-making for large-scale pollution mitigation projects. It was found that pollutant loading from future discharges from urban runoff, industry and upriver STPs should not change ambient water quality enough to affect the decision to upgrade the Annacis and Lulu Island STPs. This finding held even in scenarios without implementing urban runoff BMPs and giving consideration to the 'first flush' of pollutants. This is congruent with other studies which ignored pollutant contributions from these sources when evaluating water quality changes near the outfalls of the two sewage treatment plants.

Urban runoff, upstream STPs and industrial discharges do not affect the ambient water quality enough to affect the decision to upgrade the Annacis Island and Lulu Island STPs due to the dilution capacity of the Fraser River. In other areas with lower river flow, higher industrial development and/or heavy urbanisation, the decision to construct large water quality mitigation projects may be heavily influenced by these variables. It is also important to have a general idea of the quantities and sources of all pollutants in an aquatic system so that mitigation may be undertaken quickly if there is found to be a problem with respect to specific pollutants. The methodologies developed to determine pollutant loading are useful for identifying priority sources of specific pollutants and for developing integrated water quality management plans.

The water quality at the edges of the Lulu Island and Annacis Island STPs IDZs was determined. It was found that copper will be the only pollutant present at concentrations above the CCREM guidelines in any scenario. The concentration of copper is probably close to the CCREM guideline concentration now at the edge of both IDZs under conditions of slack water, but this has not been confirmed empirically. Copper concentrations exceed the CCREM guidelines in scenarios with more rapid population growth by progressively greater degrees. However, none of the scenarios exceed the EPA guideline for copper concentration.

Several other pollutants are predicted to be above the CCREM guideline in some scenarios, however, there are several factors which suggest that increasing the level of sewage treatment will not improve water quality in the Fraser River with respect to these pollutants. Phenol concentrations should exceed the guideline under some conditions, however, phenol is not toxic to fish at the predicted concentrations. It is also not known whether the predicted concentration of phenol will taint fish flesh. Furthermore, the installation of secondary treatment would not reduce phenol concentrations dramatically. In fact secondary treatment may result in higher phenol concentrations due to the fact that phenol is a metabolic by-product of secondary sewage treatment. The maximum concentration of silver will also likely exceed the CCREM guidelines in some scenarios with primary treatment. Data was not available on the removal efficiency of silver in secondary sewage treatment plants. The removal efficiency of silver will depend on whether silver is present in dissolved or particulate form.

Al_{Total} and Fe_{Total} concentrations at the edge of the IDZ will also exceed the CCREM guideline under most scenarios. This is due to the high ambient concentrations of Al_{Total} and Fe_{Total} in the Fraser River. Secondary sewage treatment will reduce the concentrations of these pollutants, however, due to the high background concentration, the reduction in pollutant concentration will be less than four percent of the total.

It was found that the concentration of Cu_{Total}, Fe_{Total}, Al_{Total}, Ag_{Total} and phenol will exceed the CCREM guidelines at the edge of the Lulu Island STP IDZ. In the case of Cu_{Total}, Ag_{Total} and phenol, the guidelines are only exceeded during periods where the same the slack water which pooled at the Annacis Island STP outfall pools again at the Lulu Island STP outfall. This occurrence has not been documented and it would require very specific interactions of tides and river flow. Even if this double dose occurs, the pollutant concentration of CuTotal would still be below the EPA criteria.

The concentration of copper exceeded the guideline at the edges of both the Annacis and Lulu Island STPs with primary treatment at Annacis Island. However, the installation of secondary treatment at Annacis Island should result in acceptable copper concentrations at the edge of the Lulu Island STP IDZ with primary treatment at Lulu Island. Upgrading Annacis Island STP to secondary will not affect whether Fe_{Total}, Al_{Total} or phenol meet or exceed the CCREM guidelines at the edge of the Lulu Island STP IDZ.

Comprehensive toxicity assays have not been performed on water samples taken from around the Annacis Island or Lulu Island IDZ. Comprehensive toxicity tests have also not been performed on varying dilutions of sewage treatment plant effluent to determine a non-toxic threshold. Therefore it is impossible to verify whether the dilutions achieved at the edge of the IDZ for each treatment plant are non-toxic. The SOS-chromotest was the only toxicity test which produced a required dilution value. The SOS-chromotest tests for the presence of carcinogenic compounds. The criteria for this chronic toxicity test are met inside the Annacis Island STP IDZ where it is unlikely organisms would be subjected to chronic exposure. More comprehensive toxicity assays of water near the sewage treatment plant outfalls should have been undertaken to determine whether toxicity was an issue.

The results of the scenario analysis indicate that water quality in the Fraser River will likely meet EPA water quality criteria. However, there is uncertainty as to whether the prescribed pollutant concentrations will meet long-term toxicity objectives. Uncertainty regarding long-term toxicity could be addressed by long-term bioassay tests. Controlled in-situ bioassay tests could have been performed at various locations in the Fraser River to determine the impact of sewage treatment plant effluent on aquatic biota. Toxicity testing could also have established baseline toxicity data in the Fraser River prior to installation of the treatment plant upgrade. The toxicity comparison of before and after could provide valuable information which could be used in other water quality management decisions. The results of the scenario analysis suggest that water quality at Lulu Island will meet CCREM criteria for all pollutants if the Annacis Island STP is upgraded to secondary treatment. Toxicity testing could have been used to confirm the water at the edge of the Lulu Island STP was toxic to aquatic life before the upgrade of the treatment plant was ordered. Toxicity testing could have addressed some uncertainty and allowed a management decision based on environmental risk to have been made.

The goals of sustainable water quality management may differ depending on the sustainability world view. The decision to upgrade the Annacis and Lulu Island STP was made to conform to the provincial criteria of an IDZ and ambient water quality criteria set forth by the CCREM. This decision was not backed by comprehensive studies to demonstrate deteriorating water quality. However, this thesis demonstrated that future copper concentrations in the Fraser River will likely exceed CCREM guidelines at the edges of the Annacis Island and Lulu Island IDZs.

The CCREM guidelines represent the strong precautionary principle and set forth strict standards for water quality and it is likely that the installation of secondary treatment will lower the concentration of some pollutants below CCREM guideline levels. However, the Lulu Island STP is being upgraded despite evidence which suggests that pollutant concentrations will meet provincial objectives at the edge of the Lulu Island STP with the installation of secondary treatment at Annacis Island STP. Therefore, the decision to upgrade the treatment plants was made under the strong sustainability world view with emphasis on technological requirements rather than precautionary principle. The high cost of environmental mitigation projects suggests that criteria other than technological requirements may be more appropriate. The decision-making framework under the strong sustainability world view may be based on the concept of safe minimum standards rather than on a technological requirement. In the case of the Lulu Island STP, the CCREM criteria would be met at the edge of the Lulu Island STP with the installation of secondary treatment at Annacis Island and no increase in the level of treatment at the Lulu Island STP. This would result in a cost savings of approximately $150 million.

The decision to upgrade the sewage treatment plants under the weak sustainability world view would change the level of the safe minimum standard and prioritise risk management over mandatory implementation of specified technologies. Under this sustainability world view it is likely that no upgrade of the treatment plants would be made. The results of the water quality scenarios indicate that the impact on water quality at the edge of the IDZ is likely to be within the EPA guidelines (a potential set of weak sustainability criteria); therefore, other forms of compensation may be made other than upgrading the two treatment plants. Compensation for the loss of could be undertaken in the form of shadow projects to offset the damage done at the site of the outfall. Salmon habitat restoration, dredging toxic sediments or treating urban runoff discharges with large local impacts all represent shadow projects. These projects could all result in similar increases in environmental productivity as upgrading the Annacis Island STP at a fraction of the cost.

The criteria for water quality management under the thermodynamic world view is difficult to meet. It is probably impossible to meet under any population growth scenario. The thermodynamic world view would advocate the implementation of the highest level of water treatment. However, construction of a treatment plant to achieve this level of treatment would likely appropriate more area than is affected by STP discharges. The highest level of thermodynamic sustainability would advocate the recovery of discharged nutrients and energy to prevent shifts in resource balances. However, it is unlikely that the same amount of energy could be recovered as is required to treat the waste stream. This series of Catch-22s makes it impossible to make water quality management decisions consistent with all the values of the thermodynamic sustainability world given the current structure of our society.

The primary factor to support the upgrade of the Annacis Island STP in all future scenarios was copper toxicity with silver toxicity as a secondary factor. The results of the water quality scenarios support the upgrade of the Annacis Island STP under the strong sustainability world view. However, the results also suggest that the upgrade of the Lulu Island STP is not required under the same sustainability world view using water quality criteria as the decision-making factor.

The decision to upgrade the plants was brought into question due to their great cost. It was found that the water quality at the edge of the IDZs for both plants should meet the EPA guidelines, which represent a weak sustainability world view. Negative comprehensive toxicity testing would suggest neither sewage treatment plant needs to be upgraded under this sustainability world view. Compensation for the lost productivity of the river could be made through shadow projects or increased permit fees.

The decision to construct mitigation projects may be based on hard guidelines as it was in the case of the Annacis Island STP. However, solutions such as shadow projects, partial treatment or fees put toward improving water quality may have a much greater environmental benefit at a fraction of the cost. The expense of preliminary studies is small in comparison to the construction and maintenance costs of environmental mitigation projects. The upgrade of the Lulu Island STP was made without full knowledge of the impacts on water quality in the future or with increased levels of treatment. The construction of environmental mitigation projects should be supported by evidence that the monetary expenditure will be reflected by improvements in environmental quality.

7. Recommendations

A water quality scenario generator and decision making criteria were developed in an attempt to evaluate the decision to upgrade the Annacis and Lulu Island Sewage Treatment plants. Several recommendations can be made regarding improving the water quality scenario generating tool and utilising the decision - making criteria in water quality management.

There was minimal impact of urban runoff, industrial discharges and upstream STP on the decision to upgrade the Annacis Island and Lulu Island STPs; therefore, these pollutant sources may be ignored in future water quality management decisions related to sewage treatment plants. The developed pollutant loading methodologies are still useful from a monitoring perspective and to illustrate the relative size of pollutant loading from various sources.

The industrial pollutant loading estimate could have been made more accurate with better flow and effluent characterisation data on industrial discharges in the LFB. Currently, all industrial flows are estimated and effluent characterisations do not exist for all industrial sources in the LFB. This industrial pollutant loading methodology is more useful on a provincial or national level to roughly determine total pollutant loading from industrial sources.

The urban runoff methodology is particularly useful in predicting the local water quality impacts from urban development. Where possible, local runoff data should be collected to determine the specific nature of the impact.

The scenarios suggest that the EPA water quality criteria should be met for all parameters, however, the CCREM guideline for copper is likely to be exceeded in all scenarios. Ammonia toxicity is not expected to be a problem outside the dilution zone under any scenario. Toxicity tests could determine whether the EPA copper guideline is acceptable under the conditions of the Fraser River. The size of the toxic plume in each of the population scenarios could be determined by performing toxicity tests on effluent dilutions representing various locations in the Fraser River.

Comprehensive long term *in situ* toxicity tests should be undertaken around the sewage treatment plant IDZs, and at several monitoring locations, for several reasons. A positive result on a toxicity test would support the decision to upgrade the sewage treatment plants. Toxicity testing would also allow an estimate of the damage being caused by the sewage treatment plants and the size of the toxic plume. Toxicity tests would also allow the determination of the baseline toxicity. When the treatment plants are upgraded, the baseline toxicity data would allow the toxicological improvement in water quality to be monitored. This may provide information that could be used in future water quality management decisions

The possibility of shadow projects should be explored when considering large water quality mitigation projects. It seems likely that the same amount of money spent on stream restoration or storm water management rather than upgrading the two sewage treatment plants could have produced a larger improvement in environmental quality. However, consideration must be given to the fact that shadow projects may not improve local water quality. Therefore, shadow projects would only be considered in situations where there is marginal or acceptable impact on local water quality.

Water pollution control regulations were not designed to reflect sustainability world views. Several examples of conflicts in the regulations were discussed. Water pollution regulations should be re-evaluated to be consistent with a set of sustainability criteria. The current set of regulations dictates whether or not an environmental mitigation project must be undertaken. Risk-based regulations would assess whether mitigation projects should be undertaken based on site-specific environmental risk and the potential environmental benefit.

Water pollution control decisions appear to be made independent of one another. Two examples can be drawn from this thesis: 1) the addition of drinking water treatment may result in an improvement in wastewater quality particularly with respect to copper; 2) the upgrade of the Annacis Island will result in improved water quality at the Lulu Island STP outfall. Shadow projects are another way that water quality decision-making may be integrated. The potential interaction between environmental improvement projects should be assessed before large scale projects are undertaken.

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Appendix A Effluent Quality Objectives

Portion of Effluent being Discharged	Level	Receiving Waters: Streams, Rivers & Estuaries — Dilution ≤20:1 <200:1 (3)	≤200:1 <2000:1	≤2000:1	Lakes	Marine (1): Open	EMBAYED	Parameter (Numerical values in mg/l).
		AVERAGE DWF ≤10,000 G.P.D.						
Effluent quality required for all flows up to 3 times AVG DWF	AA	30 40 Yes Yes <0 05 1.5 (5)	45 60 Yes No 0.5-1.0 1.5 (5)	100 100 Yes No 0.5-3.0 -	30 40 Yes No (4) 0.5-1.0 1.5 (5)	130 130 Yes No 0.5-1.0 -	45 60 Yes No 0.5-1.0 1.5 (5)	BOD_5 SS DISINFECTION DECHLORINATION Chlorine Residual Total Phosphorus
	BB	45 60 Yes No 0.5-1.0	130 130 Yes No 0.5-1.0	130 130 Yes No 0.5-3.0	45 60 Yes No 0.5-1.0	130 130 No - -	130 130 Yes No 0.5-1.0	BOD_5 SS Disinfection Dechlorination Chlorine Residual
Requirements for all flows greater than the multiple of avg. DWF shown	AA	SCREENING 8	screening 6	screening 3	screening 8	none 3	screening 6	Treatment of overflow Multiple of avg DWF
	BB	screening 6	none 3	none 3	screening 6	none 3	none 3	Treatment of overflow Multiple of avg. DWF
Effluent quality required for intermediate DWF multiples	AA	45 60 Yes 0.1-1.0	130 130 No -	- - - -	45 60 Yes 0.1-1.0	- - - -	130 130 Yes 0.1-1.0	BOD_5 SS Disinfection Chlorine Residual
	BB	130 130	- -	- -	130 130	- -	- -	BOD_5 SS
		AVERAGE DWF <10,000 G.P.D.						
All flows	AA	45 60 Yes (8) 0.2-0 5	130 130 Yes (9) 0.2-1.0	130(7) 130 Yes (9) 0.5-3.0	45 60 Yes (9) 0.2-1.0	typical septic tank effluent (10)	45 60 Yes 0.2-1.0	BOD_5 SS Disinfection Chlorine Residual
	BB	45 60	typical septic tank effluent (10)	typical septic tank effluent (10)	45 60	typical septic tank effluent (10)	typical septic tank effluent (10)	BOD_5 SS

Source: Department of Lands, Forest and Water Resources, 1975

Appendix B Limits for Effluent Parameters That may be of Concern

Parameter		Maximum Concentrations (2) mg/l (except pH and TL_m)	
		Level AA	Level BB
Methylene Blue Active Substances		5	-
Oil and Grease		15	30
pH		6.5 - 8.5	6.5 - 8.5
Phenol		0.2	0.4
TL_m (96 hr)		100%	75%
Aluminum	(Total)	2.0	4.0
Arsenic	(Total)	0.05	0.25
Barium	(Dissolved)	1.0	1.0
Boron	(Dissolved)	5	5
Cadmium	(Dissolved)	0.005	0.01
Chromium	(Total)	0.1	0.3
Cobalt	(Dissolved)	0.1	0.5
Copper	(Dissolved)	0.2	0.5
Cyanide	(Total)	0.1	0.5
Fluoride	(Dissolved)	5.0	-
Iron	(Dissolved)	0.3	1.0
Lead	(Total)	0.05	0.1
Manganese	(Dissolved)	0.05	0.5
Mercury	(Total)	0.0006	0.002
Molybdenum	(Total)	0.2	0.5
Nickel	(Dissolved)	0.3	0.5
Nitrogen		-	-
Resin Acid Soaps		5	-
Selenium	(Total)	0.05	0.1
Silver	(Total)	0.1	1.0
Sulphate	(Dissolved)	50	250
Sulphide	(Dissolved)	0.5	1.0
Tin	(Total)	5	10
Zinc	(Total)	0.5	5.0

Source: Department of Lands, Forest and Water Resources, 1975

Appendix C Receiving Water Quality Maintenance Objectives

Parameter	Objective
Dissolved Oxygen	Decrease not to exceed 10%
Residual Chlorine	Below detectable limits (amperometric method)
Nutrients	No detectable increase in site-specific productivity-limiting parameters (2) (5)
Coliforms--receiving waters	(3)
--shellfish meat	(3)
Toxicity	No increase above background (4)
Settleable Solids	Negligible increase
Floatable Solids and Scum	Negligible increase
Oil	None visible on water surface
Organisms	No change in productivity or development of nuisance conditions (5)
Heavy Metals	Negligible increase

Source: Department of Lands, Forest and Water Resources, 1975

Appendix D Characteristic Pollutant Concentrations from Direct Discharging Industries

Industry	SIC	SS (mg/L)	Chloride (mg/L)	COD (mg/L)	BOD (mg/L)	Faecal Coliforms (MPN/100mL)	TKN (mg/L)	NO_3/NO_2-N (mg/L)	NH_3-N (mg/L)	Fluoride (mg/L)
Fish Processing and Food	10	25	n.q.	250	200	n.q.	n.q.	n.q.	5	n.q.
Wood and Wood Products	25,26	17	n.q.	n.q.	n.q.	n.q.	n.q.	0.182	0.095	n.q.
Paper and Allied Products	27	27	26	n.q.	25	n.q.	n.q.	0.017	0.016	0.09
Metal and Metal Products	29,30	n.q.	2.2	n.q.	n.q.	n.q.	n.q.	0.086	0.045	0.13
Non-Metallic Mineral Industries	35	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	0.204	0.445	n.q.
Chemical Products Industries	37	n.q.	498	n.q.	n.q.	n.q.	n.q.	0.099	0.130	0.27

SIC	MBAS (mg/L)	SO_4 (mg/L)	Alk. (mg/L)	P_{Total} (mg/L)	$P_{Diss.}$ (mg/L)	O&G (mg/L)	Phenol (mg/L)	CN_{Total} (mg/L)	$Sulphide_{Diss.}$ (mg/L)	Al_{Total} (mg/L)
10	n.q.	n.q.	n.q.	n.q.	n.q.	15	n.q.	n.q.	n.q.	n.q.
25,26	n.q.	n.q.	15.2	n.q.	n.q.	n.q.	0.02	n.q.	n.q.	0.28
27	n.q.	339	65.6	0.1	n.q.	n.q.	0.16	n.q.	n.q.	4.98
29,30	n.q.	5.9	46.5	0.26	n.q.	n.q.	n.q.	n.q.	n.q.	0.2
35	n.q.	n.q.	56.8	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
37	n.q.	85	56.5	n.q.	0.1	n.q.	n.q.	n.q.	n.q.	0.22

SIC	$Al_{Diss.}$ (mg/L)	As_{Total} (mg/L)	Ba_{Total} (mg/L)	$Ba_{Diss.}$ (mg/L)	B_{Total} (mg/L)	$B_{Diss.}$ (mg/L)	Cd_{Total} (mg/L)	$Cd_{Diss.}$ (mg/L)	Cr_{Total} (mg/L)	$Cr_{Diss.}$ (mg/L)
10	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
25,26	0.06	0.0006	0.0003	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
27	0.76	0.0008	0.0003	0.138	0.078	1.47	1.43	n.q.	n.q.	n.q.
29,30	0.2	0.0015	0.0015	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
35	n.q.	0.0025	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
37	n.q.	0.0004	0.0160	0.014	0.15	0.15	n.q.	n.q.	n.q.	n.q.

Sources: Developed from DOE FRAP (1994-09), DOE FRAP (1994-13), DOE FRAP (1993-05), DOE FRAP (1993-06), DOE FRAP (1993-08)

Appendix D Continued

SIC	Co_{Total} (mg/L)	$Co_{Diss.}$ (mg/L)	Cu_{Total} (mg/L)	$Cu_{Diss.}$ (mg/L)	Fe_{Total} (mg/L)	$Fe_{Diss.}$ (mg/L)	Pb_{Total} (mg/L)	$Pb_{Diss.}$ (mg/L)	Mn_{Total} (mg/L)	$Mn_{Diss.}$ (mg/L)
10	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
25,26	n.q.	n.q.	0.03	0.01	2.75	0.90	0.006	0.001	0.14	0.10
27	n.q.	n.q.	0.06	n.q.	0.58	0.26	0.005	n.q.	0.22	0.21
29,30	n.q.	n.q.	n.q.	n.q.	0.18	0.08	n.q.	n.q.	0.03	0.02
35	n.q.	n.q.	0.004	0.004	0.14	0.01	n.q.	n.q.	0.03	0.01
37	n.q.	n.q.	n.q.	n.q.	0.33	0.07	n.q.	n.q.	0.02	n.q.

SIC	Hg_{Total} (mg/L)	Mo_{Total} (mg/L)	$Mo_{Diss.}$ (mg/L)	Ni_{Total} (mg/L)	$Ni_{Diss.}$ (mg/L)	Se_{Total} (mg/L)	$Se_{Diss.}$ (mg/L)	Ag_{Total} (mg/L)	$Ag_{Diss.}$ (mg/L)	Sn_{Total} (mg/L)
10	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
25,26	n.q.	n.q.	n.q.	0.0057	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
27	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
29,30	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
35	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
37	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

SIC	$Sn_{Diss.}$ (mg/L)	Zn_{Total} (mg/L)	$Zn_{Diss.}$ (mg/L)	$Hydrocarbons_{Total}$ (mg/L)	PAH (mg/L)
10	n.q.	n.q.	n.q.	n.q.	n.q.
25,26	n.q.	0.103	0.071	n.q.	n.q.
27	n.q.	0.087	0.043	n.q.	n.q.
29,30	n.q.	0.0090	n.q.	n.q.	n.q.
35	n.q.	0.0088	0.0085	n.q.	n.q.
37	n.q.	n.q.	n.q.	n.q.	n.q.

Sources: Developed from DOE FRAP (1994-09), DOE FRAP (1994-13), DOE FRAP (1993-05), DOE FRAP (1993-06), DOE FRAP (1993-08)

Appendix E Influent Unit Loading to Annacis and Lulu Island STPs

Part A: Annacis Island STP

	Annacis Island STP Influent concentration		Pollutant Loading to Annacis Island		Unit Loading to Annacis Island		Change in Unit Load from 1985 to 1994
Year	1985	1994	1985	1994	1985	1994	
Avg Daily Flow (MLD)	278	358.3	278	358.3	278	358.3	
Population	635321	865479	635321	865479	635321	865479	
Parameter	Concentration (mg/l)		Loading (Kg/day)		Unit Loading (g/day/person)		
SS	199	164	55322	58761	87	68	-22%
Chloride	38	50	10564	17915	17	21	24%
COD	454	404	126212	144753	199	167	-16%
BOD	171	205	47538	73452	75	85	13%
TKN	28	32	7784	11466	12	13	8%
NO_3/NO_2-N	2	0.05	556	18	0.88	0.02	-98%
NH_3-N	13.7	19	3808.6	6808	6.0	7.9	31%
Fluoride	0.15	0.08	41.7	29	0.07	0.03	-50%
MBAS	1.6	3.5	444.8	1254	0.70	1.45	107%
SO_4	35	35	9730	12541	15	14	-5%
Alkalinity	110	139	30580	49804	48	58	20%
P_{Total}	5.1	5	1417.8	1792	2.2	2.1	-7%
$P_{Diss.}$	2.9	2.7	806	967	1.27	1.12	-12%
O&G	41	38	11398	13615	18	16	-12%
Phenol	0.07	0.06	19	21	0.03	0.02	-19%
CN_{Total}	0.02	0.02	5.6	7.2	0.009	0.008	-5%
$Sulphide_{Diss.}$	n.q.	0.05	n.q.	18	n.q.	0.021	n.q.
Al_{Total}	1.3	0.7	361	251	0.57	0.29	-49%
$Al_{Diss.}$	0.5	0.1	139	36	0.219	0.041	-81%
As_{Total}	0.02	0.001	5.6	0.36	0.0088	0.0004	-95%
Ba_{Total}	n.q.	0.044	0	16	0.000	0.018	n.q.
$Ba_{Diss.}$	0.05	0.01	13.9	3.6	0.022	0.004	-81%
$Boron_{Total}$	n.q.	0.16	0	57	0.000	0.066	n.q.
$Boron_{Diss.}$	0.29	0.14	81	50	0.13	0.058	-54%
Cd_{Total}	0.0009	0.0005	0.25	0.18	0.0004	0.0002	-47%
$Cd_{Diss.}$	0.0005	0.0005	0.14	0.18	0.0002	0.0002	-5%

Sources: GVS&DD, 1995, GVRD, 1988, Statistics Canada, 1996

n.q.= Not Quantifiable

Appendix E Continued

Part A: Annacis Island Continued

	Annacis Island STP Influent concentration		Pollutant Loading to Annacis Island		Unit Loading to Annacis Island		Change in Unit Load from 1985 to 1994
Year	1985	1994	1985	1994	1985	1994	
Avg Daily Flow (MLD)	278	358	278	358	278	358	
Population	635321	865479	635321	865479	635321	865479	
Parameter	**Concentration (mg/l)**		**Loading (Kg/day)**		**Unit Loading (g/day/person)**		
Cr_{Total}	0.05	0.011	14	3.9	0.022	0.005	-79%
$Cr_{Diss.}$	0.05	0.004	14	1.4	0.022	0.002	-92%
Co_{Total}	0.05	0.02	14	7.2	0.022	0.008	-62%
$Co_{Diss.}$	0.05	0.02	14	7.2	0.022	0.008	-62%
Cu_{Total}	0.19	0.17	53	61	0.083	0.070	-15%
$Cu_{Diss.}$	0.04	0.06	11	21	0.018	0.025	42%
Fe_{Total}	2.38	2.8	662	1003	1.0	1.2	11%
$Fe_{Diss.}$	0.78	1.34	217	480	0.34	0.55	63%
Pb_{Total}	0.069	0.012	19	4.3	0.030	0.005	-84%
$Pb_{Diss.}$	0.01	0.004	2.8	1.4	0.004	0.002	-62%
Mn_{Total}	0.11	0.11	31	39	0.048	0.046	-5%
$Mn_{Diss.}$	0.07	0.08	19	29	0.031	0.033	8%
Hg_{Total}	n.q.	0.0005	n.q.	0.2	n.q.	0.000	n.q.
Mo_{Total}	0.03	0.03	8.3	11	0.013	0.012	-5%
$Mo_{Diss.}$	0.03	0.03	8.3	11	0.013	0.012	-5%
Ni_{Total}	n.q.	0.013	n.q.	4.7	n.q.	0.005	n.q.
$Ni_{Diss.}$	n.q.	0.009	n.q.	3.2	n.q.	0.004	n.q.
Se_{Total}	0.025	0.001	7.0	0.36	0.011	0.0004	-96%
$Se_{Diss.}$	0.025	0.001	7.0	0.36	0.011	0.0004	-96%
Ag_{Total}	0.02	0.005	5.6	1.8	0.009	0.002	-76%
$Ag_{Diss.}$	0.02	0.002	5.6	0.72	0.009	0.001	-91%
Sn_{Total}	1	0.3	278	107	0.44	0.12	-72%
$Sn_{Diss.}$	1	0.3	278	107	0.44	0.12	-72%
Zn_{Total}	0.13	0.1	36	36	0.057	0.041	-27%
$Zn_{Diss.}$	0.06	0.05	17	18	0.026	0.021	-21%

Sources: GVS&DD, 1995, GVRD, 1988, Statistics Canada, 1996

n.q.= Not Quantifiable

Appendix E Continued

Part B: Lulu Island STP

	LISA Influent Loading Concentrations		LISA Pollutant Loading to Lulu Island STP		LISA Unit Loading to Lulu Island		Change in Unit Loading from 1985 to 1994
Year	1985	1994	1985	1994	1985	1994	
Avg Daily Flow (MLD)	41.4	55.3	41.4	55.3	41.4	55.3	
Population	108492	139435	108492	139435	108492	139435	
Parameter	**Concentration (mg/l)**		**Loading in (Kg/day)**		**Unit Loading in (g/day/person)**		
SS	258	234	10681	12940	98	93	-6%
Chloride	68	68	2815	3760	26	27	4%
COD	545	509	22563	28148	208	202	-3%
BOD	218	226	9025	12498	83	90	8%
TKN	34	31	1408	1714	13	12	-5%
NO_3/NO_2-N	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
NH_3-N	20.5	18	849	995	7.8	7.1	-9%
Fluoride	0.14	0.25	6	14	0.05	0.10	86%
MBAS	2	3.1	83	171	0.76	1.23	61%
SO_4	35	28	1449	1548	13	11	-17%
Alkalinity	123	106	5092	5862	47	42	-10%
P_{Total}	5.8	4.9	240	271	2.2	1.9	-12%
$P_{Diss.}$	3.1	2.6	128	144	1.2	1.0	-13%
O&G	49	46	2029	2544	19	18	-2%
Phenol	0.05	0.07	2.1	3.9	0.02	0.03	46%
CN_{Total}	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Sulphide_{Diss.}$	n.q.	0.8	n.q.	44	n.q.	0.317	n.q.
Al_{Total}	3.3	0.9	137	50	1.26	0.36	-72%
$Al_{Diss.}$	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
As_{Total}	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Ba_{Total}		0.049	0.0	2.7	0.000	0.019	n.q.
$Ba_{Diss.}$	n.q.	0.01	n.q.	1	n.q.	0.004	n.q.
$Boron_{Total}$		0.16	0	9	0.000	0.063	n.q.
$Boron_{Diss.}$	0.33	0.13	13.7	7.2	0.13	0.052	-59%
Cd_{Total}	0.0023	0.0009	0.10	0.05	0.0009	0.0004	-59%
$Cd_{Diss.}$	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Sources: GVS&DD, 1995, GVRD, 1988, Statistics Canada, 1996

n.q.= Not Quantifiable

Appendix E Continued

Part B: Lulu Island Continued

	LISA Influent Loading Concentrations		LISA Pollutant Loading to Lulu Island STP		LISA Unit Loading to Lulu Island		Change in Unit Loading from 1985 to 1994
Year	1985	1994	1985	1994	1985	1994	
Avg Daily Flow (MLD)	41.4	55.3	41.4	55.3	41.4	55.3	
Population	108492	139435	108492	139435	108492	139435	
Parameter	**Concentration (mg/l)**		**Loading (Kg/day)**		**Unit Loading (g/day/person)**		
Cr_{Total}	0.17	0.031	7.0	1.7	0.065	0.012	-81%
$Cr_{Diss.}$	n.q.	0.011	n.q.	0.61	n.q.	0.004	n.q.
Co_{Total}	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Co_{Diss.}$	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Cu_{Total}	0.2	0.27	8.3	15	0.076	0.107	40%
$Cu_{Diss.}$	0.04	0.09	1.7	5.0	0.015	0.036	134%
Fe_{Total}	3.23	2.23	134	123	1.2	0.9	-28%
$Fe_{Diss.}$	1.16	0.92	48	51	0.44	0.36	-18%
Pb_{Total}	0.1	0.015	4.1	0.83	0.038	0.006	-84%
$Pb_{Diss.}$	0.014	n.q.	0.6	n.q.	0.005	n.q.	n.q.
Mn_{Total}	0.1	0.09	4.1	5.0	0.038	0.036	-6%
$Mn_{Diss.}$	0.06	0.05	2.5	2.8	0.023	0.020	-13%
Hg_{Total}	0.0006	n.q.	0.02	n.q.	0.000	n.q.	n.q.
Mo_{Total}	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Mo_{Diss.}$	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Ni_{Total}	0.18	0.055	7.5	3.0	0.069	0.022	-68%
$Ni_{Diss.}$	0.14	0.038	5.8	2.1	0.053	0.015	-72%
Se_{Total}	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Se_{Diss.}$	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Ag_{Total}	n.q.	0.022	n.q.	1.2	n.q.	0.009	n.q.
$Ag_{Diss.}$	n.q.	0.008	n.q.	0.44	n.q.	0.003	n.q.
Sn_{Total}	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
$Sn_{Diss.}$	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Zn_{Total}	0.47	0.2	19	11	0.18	0.079	-56%
$Zn_{Diss.}$	0.16	0.08	6.6	4.4	0.061	0.032	-48%

Sources: GVS&DD, 1995, GVRD, 1988, Statistics Canada, 1996

n.q.= Not Quantifiable

Appendix F Pollutant Loading to Annacis Island STP from Burn's Bog Landfill

	Units	16-Nov-95	14-Dec-95	11-Jan-95	08-Feb-95	15-Mar-95	10-Apr-95	10-May-95	07-Jun-95	Average Loading
Total Phenols	(Kg/day)	0.6	0.7	0.6	0.6	0.9	0.3	0.1	0.01	0.5
Ammonia	(Kg/day)	438	596	661	734	511	911	369	207	553
Aluminum	(Kg/day)	3.2	n.q.	12.2	1.0	4.9	10.6	1.0	1.3	4.9
Copper	(Kg/day)	0.25	0.06	0.21	0.10	0.24	0.20	0.05	0.06	0.15
Iron	(Kg/day)	35.8	41.5	73.0	56.7	70.6	119.8	33.0	26.1	57.1
Lead	(Kg/day)	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Zinc	(Kg/day)	0.3	0.2	0.8	0.4	0.6	0.5	0.2	0.1	0.4

Appendix G Monthly Rainfall Data for Municipalities in the LFB (mm/yr)

Sewerage District	Municipality	January	February	March	April	May	June	July	August	September	October	November	December
FSA	Burnaby	214	182	161.7	115	86.4	71.6	53.9	65	105.9	200.8	238.3	266.1
	Coquitlam	210.6	178.1	157.2	119.2	83.9	74.4	50.3	62.5	97.7	193.2	230.5	268.2
	Delta	110.6	85.9	70.3	47	38.2	39.3	25.9	35.8	51.6	88.5	123.2	133.1
	Langley City	192.4	169	151.9	114.6	84.8	74.2	52	69.2	102.4	174.5	212.5	243.9
	Maple Ridge	219.8	184.2	167.9	122.3	96.5	85.9	60.4	73	114.6	187	237.4	264.3
	New Westminster	182.2	149.1	131.3	90.8	72.8	63.7	42.1	57	89.3	170.1	197	226.6
	Pitt Meadows	229.4	181.4	154.6	105.5	81	62.4	51.9	65.9	111.5	178	237	273.2
	Port Coquitlam	226.3	186.9	161.6	120.5	83.6	71.8	53.9	67.3	107.1	194.1	244.9	282.7
	Surrey	159.7	136.1	118	83.8	61.9	52	43.2	54.4	79.5	141.7	178.2	198.6
LISA	Richmond	142.4	118.1	105.6	68.9	54.4	49.1	35.5	45.6	73.4	129.4	162.8	183.8
FVSA	District of Abbotsford	192	163.3	149.7	116.6	88.1	69.1	47	63	98.3	166.4	205.8	230.8
	District of Chilliwack	166.8	138	120.8	98.6	82.4	69	45.9	59.4	96.6	155	190.3	213.3
	Township of Langley	192.4	169	151.9	114.6	84.8	74.2	52	69.2	102.4	174.5	212.5	243.9
	District of Matsqui	178	152.5	134	106.6	81.6	69.5	45.1	61.1	95	160.2	196.3	218.9
	District of Mission	174.4	165.5	151.2	122.5	101.9	91.8	52.7	74.7	111.9	180.6	213.8	225.3

Source: DOE FRAP 1993-19

Appendix H Per Capita Areas for Urban Runoff Scenarios A and B

Sewerage District	Municipality	Scenario A: Land Area per Capita (ha)			Scenario B: Land Area per Capita (ha)		
		Industrial	Commercial	Residential	Industrial	Commercial	Residential
FSA	City of Burnaby	0.00588	0.00409	0.04589	0.00560	0.00390	0.04370
	City of Coquitlam	0.00871	0.00290	0.03040	0.00830	0.00277	0.02895
	Corporation of Delta	0.03315	0.00506	0.02810	0.03158	0.00482	0.02676
	City of Langley	0.00531	0.01093	0.01988	0.00506	0.01041	0.01894
	District of Maple Ridge	0.00729	0.00209	0.05824	0.00694	0.00199	0.05546
	City of New Westminster	0.00248	0.00142	0.01939	0.00236	0.00135	0.01847
	District of Pitt Meadows	0.01247	0.00269	0.04324	0.01188	0.00256	0.04118
	City of Port Coquitlam	0.00525	0.00201	0.04495	0.00500	0.00192	0.04281
	District of Surrey	0.00515	0.00021	0.01611	0.00491	0.00020	0.01534
LISA	City of Richmond	0.03348	0.00221	0.05165	0.03189	0.00211	0.04919
FVSA	District of Abbotsford	0.01988	0.00371	0.10576	0.01893	0.00353	0.10072
	District of Chilliwack	0.00612	0.00113	0.03257	0.00583	0.00108	0.03101
	Township of Langley	0.01714	0.00296	0.04838	0.01632	0.00282	0.05714
	District of Matsqui	0.00242	0.00213	0.02897	0.00231	0.00203	0.02759
	District of Mission	0.00937	0.00301	0.07577	0.00892	0.00286	0.07217

Source: DOE FRAP 1993-19

Appendix I Scenario C Urban Runoff Coefficients for Scenarios P_1, P_2 and P_3

Sewerage District	Municipality	Residential Winter Runoff Coefficient Scenario P_1	Residential Winter Runoff Coefficient Scenario P_2	Residential Winter Runoff Coefficient Scenario P_3	Residential Summer Runoff Coefficient Scenario P_1	Residential Summer Runoff Coefficient Scenario P_2	Residential Summer Runoff Coefficient Scenario P_3
FSA	Burnaby	0.61	0.67	0.73	0.30	0.33	0.37
	Coquitlam	0.50	0.50	0.50	0.25	0.25	0.25
	Delta	0.41	0.41	0.41	0.21	0.21	0.21
	Langley City	0.58	0.64	0.70	0.29	0.32	0.35
	Maple Ridge	0.50	0.50	0.50	0.25	0.25	0.25
	New Westminster	0.51	0.56	0.62	0.26	0.29	0.32
	Pitt Meadows	0.50	0.50	0.50	0.25	0.25	0.25
	Port Coquitlam	0.61	0.67	0.73	0.30	0.33	0.37
	Surrey	0.43	0.43	0.43	0.22	0.22	0.22
LISA	Richmond	0.43	0.43	0.43	0.22	0.22	0.22
FVSA	District of Abbotsford	0.47	0.47	0.47	0.24	0.24	0.24
	District of Chilliwack	0.43	0.43	0.43	0.22	0.22	0.22
	Township of Langley	0.50	0.50	0.50	0.25	0.25	0.25
	District of Matsqui	0.47	0.47	0.47	0.24	0.24	0.24
	District of Mission	0.50	0.50	0.50	0.25	0.25	0.25

Appendix J Water Quality Changes Around the Annacis Island Outfall

Scenario 1994 FSA: Water Quality Changes resulting from Primary Treatment and current discharges from industry and urban runoff

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.1	1.1	0.0	0.2	0.05	0.52	0.01	0.14	0.04	0.38	0.3	3.1	0.0004	0.004	0.01	0.06
Annacis Channel	0.2	1.4	0.0	0.3	0.09	0.67	0.02	0.18	0.07	0.49	0.5	4.0	0.0007	0.005	0.01	0.08
Tilbury Island	0.4	1.7	0.1	0.4	0.20	0.84	0.05	0.22	0.15	0.62	1.2	4.9	0.0015	0.006	0.02	0.10
Woodwards Landing	0.3	1.2	0.1	0.3	0.14	0.59	0.04	0.16	0.10	0.43	0.8	3.5	0.0010	0.004	0.02	0.07
Steveston	0.2	2.0	0.1	0.5	0.10	0.99	0.03	0.26	0.08	0.73	0.6	5.8	0.0008	0.007	0.01	0.12
Transverse edge of IDZ	1.4	2.4	0.3	0.6	0.71	1.19	0.19	0.31	0.52	0.87	4.2	7.0	0.0052	0.009	0.08	0.14
Downstream Edge of IDZ	0.9	3.4	0.2	0.8	0.43	1.71	0.11	0.45	0.31	1.26	2.5	10.1	0.0031	0.013	0.05	0.20
Downstream of IDZ	n.q.	3.4	n.q.	0.8	n.q.	1.71	n.q.	0.45	n.q.	1.26	n.q.	10.1	n.q.	0.013	n.q.	0.20
Upstream Edge of IDZ	0.8	3.4	0.2	0.8	0.39	1.71	0.10	0.45	0.29	1.26	2.3	10.1	0.0029	0.013	0.05	0.20
Upstream of IDZ	n.q.	3.45	n.q.	0.8	n.q.	1.71	n.q.	0.45	n.q.	1.26	n.q.	10.1	n.q.	0.013	n.q.	0.20

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.1	1.1	0.1	0.5	2	18	1	10	0.01	0.06	0.0	0.0	0.00	0.02	0.06	0.61
Annacis Channel	0.2	1.4	0.1	0.7	3	24	2	12	0.01	0.08	0.0	0.0	0.00	0.03	0.11	0.79
Tilbury Island	0.4	1.7	0.2	0.9	7	29	4	15	0.02	0.10	0.0	0.0	0.01	0.04	0.23	0.99
Woodwards Landing	0.3	1.2	0.1	0.6	5	21	3	11	0.02	0.07	0.0	0.0	0.01	0.03	0.16	0.69
Steveston	0.2	2.0	0.1	1.0	4	35	2	18	0.01	0.12	0.0	0.0	0.00	0.04	0.12	1.17
Transverse edge of IDZ	1.5	2.4	0.7	1.2	25	42	13	22	0.08	0.14	0.0	0.0	0.03	0.05	0.84	1.40
Downstream Edge of IDZ	0.9	3.5	0.4	1.8	15	60	8	31	0.05	0.20	0.0	0.0	0.02	0.08	0.50	2.01
Downstream of IDZ	n.q.	3.5	n.q.	1.8	n.q.	60	n.q.	31	n.q.	0.20	n.q.	0.0	n.q.	0.08	n.q.	2.01
Upstream Edge of IDZ	0.8	3.5	0.4	1.8	14	60	7	31	0.05	0.20	0.0	0.0	0.02	0.08	0.46	2.01
Upstream of IDZ	n.q.	3.5	n.q.	1.8	n.q.	60	n.q.	31	n.q.	0.20	n.q.	0.0	n.q.	0.08	n.q.	2.01

n.q.= Not Quantifiable

Appendix J Continued

Scenario 1994 FSA: Water Quality Changes resulting from Secondary Treatment and current discharges from industry and urban runoff

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.0	0.2	0.0	0.0	0.04	0.38	0.01	0.13	0.04	0.42	0.3	3.4	0.0001	0.001	0.00	0.02
Annacis Channel	0.0	0.2	0.0	0.0	0.07	0.49	0.02	0.17	0.07	0.54	0.6	4.4	0.0001	0.001	0.00	0.02
Tilbury Island	0.0	0.3	0.0	0.0	0.15	0.62	0.05	0.21	0.16	0.67	1.3	5.4	0.0002	0.001	0.01	0.03
Woodwards Landing	0.0	0.2	0.0	0.0	0.10	0.43	0.03	0.14	0.11	0.47	0.9	3.8	0.0002	0.001	0.00	0.02
Steveston	0.0	0.3	0.0	0.0	0.08	0.73	0.03	0.24	0.08	0.80	0.7	6.4	0.0001	0.001	0.00	0.03
Transverse edge of IDZ	0.2	0.4	0.0	0.0	0.52	0.87	0.18	0.29	0.57	0.95	4.6	7.7	0.0008	0.001	0.02	0.04
Downstream Edge of IDZ	0.1	0.5	0.0	0.0	0.31	1.26	0.11	0.42	0.34	1.37	2.8	11.1	0.0005	0.002	0.01	0.06
Downstream of IDZ	n.q.	0.5	n.q.	0.0	n.q.	1.26	n.q.	0.42	n.q.	1.37	n.q.	11.1	n.q.	0.002	n.q.	0.06
Upstream Edge of IDZ	0.1	0.5	0.0	0.0	0.29	1.26	0.10	0.42	0.31	1.37	2.5	11.1	0.0004	0.002	0.01	0.06
Upstream of IDZ	n.q.	0.5	n.q.	0.0	n.q.	1.26	n.q.	0.42	n.q.	1.37	n.q.	11.1	n.q.	0.002	n.q.	0.06

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.0	0.3	0.0	0.2	1	5	0	5	0.00	0.03	0.0	0.0	0.00	0.02	0.01	0.15
Annacis Channel	0.1	0.4	0.0	0.2	1	7	1	7	0.01	0.04	0.0	0.0	0.00	0.03	0.03	0.20
Tilbury Island	0.1	0.5	0.1	0.3	2	9	2	8	0.01	0.05	0.0	0.0	0.01	0.04	0.06	0.25
Woodwards Landing	0.1	0.4	0.0	0.2	1	6	1	6	0.01	0.04	0.0	0.0	0.01	0.03	0.04	0.17
Steveston	0.1	0.6	0.0	0.4	1	10	1	10	0.01	0.06	0.0	0.0	0.00	0.04	0.03	0.29
Transverse edge of IDZ	0.4	0.7	0.3	0.4	7	12	7	12	0.04	0.07	0.0	0.0	0.03	0.05	0.21	0.35
Downstream Edge of IDZ	0.3	1.1	0.2	0.6	4	18	4	17	0.03	0.11	0.0	0.0	0.02	0.08	0.13	0.50
Downstream of IDZ	n.q.	1.1	n.q.	0.6	n.q.	18	n.q.	17	n.q.	0.11	n.q.	0.0	n.q.	0.08	n.q.	0.50
Upstream Edge of IDZ	0.2	1.1	0.1	0.6	4	18	4	17	0.02	0.11	0.0	0.0	0.02	0.08	0.11	0.50
Upstream of IDZ	n.q.	1.1	n.q.	0.6	n.q.	18	n.q.	17	n.q.	0.11	n.q.	0.0	n.q.	0.08	n.q.	0.50

n.q.= Not Quantifiable

Appendix J Continued

Scenario P_3 FSA: Water Quality Changes resulting from Primary treatment and discharges from industry Scenario I_3 and urban runoff Scenario A

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.2	2.3	0.6	1.0	0.11	1.12	0.03	0.30	0.08	0.82	0.6	6.6	0.0010	0.008	0.01	0.13
Annacis Channel	0.4	2.9	0.6	1.2	0.20	1.44	0.05	0.38	0.14	1.06	1.1	8.5	0.0017	0.011	0.02	0.17
Tilbury Island	0.9	3.6	0.7	1.3	0.43	1.80	0.11	0.48	0.31	1.32	2.5	10.6	0.0034	0.013	0.05	0.21
Woodwards Landing	0.6	2.5	0.6	1.1	0.30	1.26	0.08	0.33	0.22	0.93	1.8	7.4	0.0024	0.010	0.04	0.15
Steveston	0.4	4.3	0.6	1.5	0.23	2.13	0.06	0.56	0.16	1.57	1.3	12.5	0.0019	0.016	0.03	0.25
Transverse edge of IDZ	3.1	5.1	1.2	1.7	1.54	2.56	0.41	0.68	1.13	1.88	9.0	15.0	0.0115	0.019	0.18	0.30
Downstream Edge of IDZ	1.9	7.4	0.9	2.2	0.92	3.68	0.24	0.97	0.68	2.70	5.4	21.6	0.0070	0.027	0.11	0.43
Downstream of IDZ	n.q.	7.4	n.q.	2.2	n.q.	3.68	n.q.	0.97	n.q.	2.70	n.q.	21.6	n.q.	0.027	n.q.	0.43
Upstream Edge of IDZ	1.7	7.4	0.9	2.2	0.84	3.68	0.22	0.97	0.61	2.70	4.9	21.6	0.0064	0.027	0.10	0.43
Upstream of IDZ	n.q.	7.4	n.q.	2.2	n.q.	3.68	n.q.	0.97	n.q.	2.70	n.q.	21.6	n.q.	0.027	n.q.	0.43

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.2	2.3	0.1	1.2	4	39	2	20	0.01	0.13	0.0	0.0	0.00	0.05	0.12	1.32
Annacis Channel	0.4	3.0	0.2	1.5	7	50	4	26	0.02	0.17	0.0	0.0	0.01	0.06	0.23	1.70
Tilbury Island	0.9	3.7	0.4	1.9	15	63	8	33	0.05	0.21	0.0	0.0	0.02	0.08	0.50	2.12
Woodwards Landing	0.6	2.6	0.3	1.3	10	44	5	23	0.04	0.15	0.0	0.0	0.01	0.06	0.35	1.48
Steveston	0.5	4.4	0.2	2.2	8	74	4	39	0.03	0.25	0.0	0.0	0.01	0.09	0.26	2.51
Transverse edge of IDZ	3.2	5.3	1.6	2.6	54	89	28	47	0.18	0.30	0.0	0.0	0.07	0.11	1.80	3.00
Downstream Edge of IDZ	1.9	7.6	0.9	3.8	32	129	17	67	0.11	0.43	0.0	0.0	0.04	0.16	1.08	4.33
Downstream of IDZ	n.q.	7.6	n.q.	3.8	n.q.	129	n.q.	67	n.q.	0.43	n.q.	0.0	n.q.	0.16	n.q.	4.33
Upstream Edge of IDZ	1.7	7.6	0.9	3.8	29	129	15	67	0.10	0.43	0.0	0.0	0.04	0.16	0.98	4.33
Upstream of IDZ	n.q.	7.6	n.q.	3.8	n.q.	129	n.q.	67	n.q.	0.43	n.q.	0.0	n.q.	0.16	n.q.	4.33

n.q.= Not Quantifiable

Appendix J Continued

Scenario P_3 FSA: Water Quality Changes resulting from Secondary treatment and discharges from industry Scenario I_3 and urban runoff Scenario A

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.0	0.3	0.5	0.5	0.08	0.83	0.03	0.28	0.08	0.82	0.6	6.6	0.0004	0.001	0.00	0.04
Annacis Channel	0.0	0.4	0.5	0.5	0.15	1.06	0.05	0.35	0.14	1.06	1.1	8.5	0.0005	0.002	0.01	0.05
Tilbury Island	0.1	0.5	0.5	0.5	0.32	1.33	0.10	0.44	0.31	1.32	2.5	10.6	0.0007	0.002	0.01	0.06
Woodwards Landing	0.1	0.4	0.5	0.5	0.22	0.93	0.07	0.31	0.22	0.93	1.8	7.4	0.0006	0.002	0.01	0.04
Steveston	0.1	0.6	0.5	0.5	0.17	1.57	0.05	0.52	0.16	1.57	1.3	12.5	0.0005	0.003	0.01	0.07
Transverse edge of IDZ	0.5	0.8	0.5	0.5	1.13	1.88	0.38	0.63	1.13	1.88	9.0	15.0	0.0019	0.003	0.05	0.08
Downstream Edge of IDZ	0.3	1.1	0.5	0.5	0.68	2.71	0.23	0.90	0.68	2.70	5.4	21.6	0.0013	0.004	0.03	0.12
Downstream of IDZ	n.q.	1.1	n.q.	0.5	n.q.	2.71	n.q.	0.90	n.q.	2.70	n.q.	21.6	n.q.	0.004	n.q.	0.12
Upstream Edge of IDZ	0.3	1.1	0.5	0.5	0.62	2.71	0.21	0.90	0.61	2.70	4.9	21.6	0.0012	0.004	0.03	0.12
Upstream of IDZ	n.q.	1.1	n.q.	0.5	n.q.	2.71	n.q.	0.90	n.q.	2.70	n.q.	21.6	n.q.	0.004	n.q.	0.12

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Patullo Bridge	0.1	0.7	0.0	0.4	1	12	1	11	0.01	0.07	0.0	0.0	0.00	0.05	0.03	0.33
Annacis Channel	0.1	0.9	0.1	0.5	2	15	2	14	0.01	0.09	0.0	0.0	0.01	0.06	0.06	0.43
Tilbury Island	0.3	1.1	0.2	0.6	4	19	4	18	0.03	0.11	0.0	0.0	0.02	0.08	0.13	0.53
Woodwards Landing	0.2	0.8	0.1	0.4	3	13	3	12	0.02	0.08	0.0	0.0	0.01	0.06	0.09	0.37
Steveston	0.1	1.3	0.1	0.8	2	22	2	21	0.01	0.13	0.0	0.0	0.01	0.09	0.07	0.63
Transverse edge of IDZ	1.0	1.6	0.5	0.9	16	26	15	25	0.09	0.16	0.0	0.0	0.07	0.11	0.45	0.75
Downstream Edge of IDZ	0.6	2.3	0.3	1.3	9	38	9	36	0.06	0.23	0.0	0.0	0.04	0.16	0.27	1.08
Downstream of IDZ	n.q.	2.3	n.q.	1.3	n.q.	38	n.q.	36	n.q.	0.23	n.q.	0.0	n.q.	0.16	n.q.	1.08
Upstream Edge of IDZ	0.5	2.3	0.3	1.3	9	38	8	36	0.05	0.23	0.0	0.0	0.04	0.16	0.25	1.08
Upstream of IDZ	n.q.	2.3	n.q.	1.3	n.q.	38	n.q.	36	n.q.	0.23	n.q.	0.0	n.q.	0.16	n.q.	1.08

n.q.= Not Quantifiable

Appendix K Water Quality Changes due to the Lulu Island STP Outfall

Scenario 1994 Lulu Island STP with Primary Treatment
Water Quality Changes At the Lulu Island Outfall including pollutant loading from Annacis Island 1994 with primary treatment.

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.6	2.6	0.1	0.6	0.1	1.0	0.1	0.3	0.2	0.9	2.1	8.3	0.001	0.01	0.1	0.2
Downstream Edge of IDZ	0.4	2.9	0.1	0.6	0.1	1.0	0.1	0.4	0.1	1.0	1.5	9.3	0.001	0.01	0.0	0.2
Downstream of IDZ	n.q.	2.9	n.q.	0.6	n.q.	1.0	n.q.	0.4	n.q.	1.0	n.q.	9.3	n.q.	0.01	n.q.	0.2
Upstream Edge of IDZ	0.4	2.9	0.1	0.6	0.1	1.0	0.1	0.4	0.1	1.0	1.4	9.3	0.001	0.01	0.0	0.2
Upstream of IDZ	n.q.	2.9	n.q.	0.6	n.q.	1.0	n.q.	0.4	n.q.	1.0	n.q.	9.3	n.q.	0.01	n.q.	0.2

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.6	2.7	0.3	1.3	7.9	41.9	4.1	21.8	0.03	0.2	0.0	0.0	0.04	0.1	0.4	1.6
Downstream Edge of IDZ	0.5	3.0	0.2	1.5	6.2	45.0	3.2	23.5	0.03	0.2	0.0	0.0	0.03	0.1	0.3	1.7
Downstream of IDZ	n.q.	3.0	n.q.	1.5	n.q.	45.0	n.q.	23.5	n.q.	0.2	n.q.	0.0	n.q.	0.1	n.q.	1.7
Upstream Edge of IDZ	0.4	3.0	0.2	1.5	5.9	45.0	3.1	23.5	0.02	0.2	0.0	0.0	0.03	0.1	0.3	1.7
Upstream of IDZ	n.q.	3.0	n.q.	1.5	n.q.	45.0	n.q.	23.5	n.q.	0.2	n.q.	0.0	n.q.	0.1	n.q.	1.7

n.q.= Not Quantifiable

Appendix K Continued

Scenario 1994 Lulu Island STP with Secondary Treatment
Water Quality Changes At the Lulu Island Outfall including pollutant loading from Annacis Island 1994 with primary treatment.

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.3	2.1	0.05	0.5	0.1	1.0	0.1	0.3	0.2	1.0	2.0	8.1	0.001	0.01	0.03	0.1
Downstream Edge of IDZ	0.2	2.1	0.05	0.5	0.1	1.0	0.1	0.4	0.2	1.1	1.4	9.1	0.001	0.01	0.02	0.2
Downstream of IDZ	n.q.	2.1	n.q.	0.5	n.q.	1.0	n.q.	0.4	n.q.	1.1	n.q.	9.1	n.q.	0.01	n.q.	0.2
Upstream Edge of IDZ	0.2	2.1	0.05	0.5	0.1	1.0	0.0	0.4	0.2	1.1	1.4	9.1	0.001	0.01	0.02	0.2
Upstream of IDZ	n.q.	2.1	n.q.	0.5	n.q.	1.0	n.q.	0.4	n.q.	1.1	n.q.	9.1	n.q.	0.01	n.q.	0.2

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.4	2.3	0.2	1.2	5.0	37.0	3.0	20.0	0.02	0.1	0.0	0.0	0.04	0.1	0.2	1.3
Downstream Edge of IDZ	0.3	2.4	0.2	1.2	4.4	38.0	2.6	20.8	0.02	0.1	0.0	0.0	0.03	0.1	0.2	1.4
Downstream of IDZ	n.q.	2.4	n.q.	1.2	n.q.	38.0	n.q.	20.8	n.q.	0.1	n.q.	0.0	n.q.	0.1	n.q.	1.4
Upstream Edge of IDZ	0.3	2.4	0.2	1.2	4.4	38.0	2.5	20.8	0.02	0.1	0.0	0.0	0.03	0.1	0.2	1.4
Upstream of IDZ	n.q.	2.4	n.q.	1.2	n.q.	38.0	n.q.	20.8	n.q.	0.1	n.q.	0.0	n.q.	0.1	n.q.	1.4

n.q.= Not Quantifiable

Appendix K Continued

Scenario 3 Lulu Island STP with Primary Treatment
Water Quality Changes At the Lulu Island Outfall including pollutant loading from Annacis Island Scenario 3 with primary treatment.

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/NO_2-N (μg/L)		NH_3-N (mg/L)		Phenol (μg/L)		Al_{Total} (μg/L)		Cd_{Total} (μg/L)		Cr_{Total} (μg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.8	4.9	0.7	1.6	0.2	2.1	0.1	0.6	0.3	1.8	2.9	15.1	0.002	0.02	0.1	0.3
Downstream Edge of IDZ	0.7	5.2	0.7	1.7	0.2	2.1	0.1	0.7	0.2	1.9	2.2	16.3	0.002	0.02	0.1	0.4
Downstream of IDZ	n.q.	5.2	n.q.	1.7	n.q.	2.1	n.q.	0.7	n.q.	1.9	n.q.	16.3	n.q.	0.02	n.q.	0.4
Upstream Edge of IDZ	0.7	5.2	0.6	1.7	0.2	2.1	0.1	0.7	0.2	1.9	2.2	16.3	0.002	0.02	0.1	0.4
Upstream of IDZ	n.q.	5.2	n.q.	1.7	n.q.	2.1	n.q.	0.7	n.q.	1.9	n.q.	16.3	n.q.	0.02	n.q.	0.4

Location	Cu_{Total} (μg/L)		$Cu_{Diss.}$ (μg/L)		Fe_{Total} (μg/L)		$Fe_{Diss.}$ (μg/L)		Pb_{Total} (μg/L)		Hg_{Total} (μg/L)		Ag_{Total} (μg/L)		Zn_{Total} (μg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.9	5.1	0.4	2.5	12.3	82.1	6.4	42.8	0.05	0.3	0.0	0.0	0.05	0.2	0.5	2.9
Downstream Edge of IDZ	0.7	5.4	0.4	2.7	10.5	85.5	5.5	44.5	0.04	0.3	0.0	0.0	0.03	0.2	0.4	3.1
Downstream of IDZ	n.q.	5.4	n.q.	2.7	n.q.	85.5	n.q.	44.5	n.q.	0.3	n.q.	0.0	n.q.	0.2	n.q.	3.1
Upstream Edge of IDZ	0.7	5.4	0.3	2.7	10.2	85.5	5.3	44.5	0.04	0.3	0.0	0.0	0.03	0.2	0.4	3.1
Upstream of IDZ	n.q.	5.4	n.q.	2.7	n.q.	85.5	n.q.	44.5	n.q.	0.3	n.q.	0.0	n.q.	0.2	n.q.	3.1

n.q.= Not Quantifiable

Appendix K Continued

Scenario 3 Lulu Island STP with Secondary Treatment
Water Quality Changes At the Lulu Island Outfall including pollutant loading from Annacis Island Scenario 3 with primary treatment.

Location	BOD (mg/L)		Faecal Coliforms (MPN/100mL)		NO_3/NO_2-N (µg/L)		NH_3-N (mg/L)		Phenol (µg/L)		Al_{Total} (µg/L)		Cd_{Total} (µg/L)		Cr_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.5	4.4	0.6	1.5	0.2	2.1	0.1	0.6	0.3	1.8	2.8	15.0	0.002	0.02	0.04	0.3
Downstream Edge of IDZ	0.5	4.4	0.6	1.5	0.2	2.1	0.1	0.7	0.3	2.0	2.2	16.1	0.002	0.02	0.04	0.3
Downstream of IDZ	n.q.	4.4	n.q.	1.5	n.q.	2.1	n.q.	0.7	n.q.	2.0	n.q.	16.1	n.q.	0.02	n.q.	0.3
Upstream Edge of IDZ	0.5	4.4	0.6	1.5	0.2	2.1	0.1	0.7	0.3	2.0	2.1	16.1	0.002	0.02	0.03	0.3
Upstream of IDZ	n.q.	4.4	n.q.	1.5	n.q.	2.1	n.q.	0.7	n.q.	2.0	n.q.	16.1	n.q.	0.02	n.q.	0.3

Location	Cu_{Total} (µg/L)		$Cu_{Diss.}$ (µg/L)		Fe_{Total} (µg/L)		$Fe_{Diss.}$ (µg/L)		Pb_{Total} (µg/L)		Hg_{Total} (µg/L)		Ag_{Total} (µg/L)		Zn_{Total} (µg/L)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Transverse edge of IDZ	0.6	4.7	0.3	2.3	9.2	76.9	5.2	40.8	0.04	0.3	0.0	0.0	0.05	0.2	0.4	2.7
Downstream Edge of IDZ	0.6	4.8	0.3	2.4	8.6	78.0	4.8	41.7	0.03	0.3	0.0	0.0	0.03	0.2	0.3	2.8
Downstream of IDZ	n.q.	4.8	n.q.	2.4	n.q.	78.0	n.q.	41.7	n.q.	0.3	n.q.	0.0	n.q.	0.2	n.q.	2.8
Upstream Edge of IDZ	0.6	4.8	0.3	2.4	8.5	78.0	4.7	41.7	0.03	0.3	0.0	0.0	0.03	0.2	0.3	2.8
Upstream of IDZ	n.q.	4.8	n.q.	2.4	n.q.	78.0	n.q.	41.7	n.q.	0.3	n.q.	0.0	n.q.	0.2	n.q.	2.8

n.q.= Not Quantifiable

Appendix L Background Pollutant Concentrations

Background Water Quality	BOD (mg/l)	Faecal Coliforms (MPN/100mL)	NO_3/NO_2-N (µg/l)	NH_3-N (mg/l)	Phenol (µg/l)	Al_{Total} (µg/l)	Cd_{Total} (µg/l)	Cr_{Total} (µg/l)
	n.q.	500	150	0.018	n.q.	570	<0.1	<5

Background Water Quality	Cu_{Total} (µg/l)	$Cu_{Diss.}$ (µg/l)	Fe_{Total} (µg/l)	$Fe_{Diss.}$ (µg/l)	Pb_{Total} (µg/l)	Hg_{Total} (µg/l)	Ag_{Total} (µg/l)	Zn_{Total} (µg/l)
	<1	<1	910	30	<3	<.05	n.q.	<10

Source: DOE FRAP 1993-31
Data for 03/22/93 at Mission

Appendix M CCREM Guidelines for the Protection of Aquatic Life

Parameter	Guideline	Comments
Inorganic parameters		
Aluminum[1]	0.005 $mg \cdot L^{-1}$	pH<6.5; $[Ca^{2+}]$<4.0 $mg \cdot L^{-1}$; DOC<2.0 $mg \cdot L^{-1}$
	0.1 $mg \cdot L^{-1}$	pH≥6.5; $[Ca^{2+}]$≥4.0 $mg \cdot L^{-1}$; DOC≥2.0 $mg \cdot L^{-1}$
Antimony	ID[2]	
Arsenic	0.05 $mg \cdot L^{-1}$	
Beryllium	ID	
Cadmium	0.2 $\mu g \cdot L^{-1}$	Hardness 0-60 $mg \cdot L^{-1}$ ($CaCO_3$)
	0.8 $\mu g \cdot L^{-1}$	Hardness 60-120 $mg \cdot L^{-1}$ ($CaCO_3$)
	1.3 $\mu g \cdot L^{-1}$	Hardness 120-180 $mg \cdot L^{-1}$ ($CaCO_3$)
	1.8 $\mu g \cdot L^{-1}$	Hardness >180 $mg \cdot L^{-1}$ ($CaCO_3$)
Chlorine (total residual chlorine)	2.0 $\mu g \cdot L^{-1}$	Measured by amperometric or equivalent method
Chromium	0.02 $mg \cdot L^{-1}$	To protect fish
	2.0 $\mu g \cdot L^{-1}$	To protect aquatic life, including zooplankton and phytoplankton
Copper	2 $\mu g \cdot L^{-1}$	Hardness 0-60 $mg \cdot L^{-1}$ ($CaCO_3$)
	2 $\mu g \cdot L^{-1}$	Hardness 60-120 $mg \cdot L^{-1}$ ($CaCO_3$)
	3 $\mu g \cdot L^{-1}$	Hardness 120-180 $mg \cdot L^{-1}$ ($CaCO_3$)
	4 $\mu g \cdot L^{-1}$	Hardness >180 $mg \cdot L^{-1}$ ($CaCO_3$)
Cyanide	5.0 $\mu g \cdot L^{-1}$	Free cyanide as CN^-
Dissolved oxygen	6.0 $mg \cdot L^{-1}$	Warm-water biota – early life stages
	5.0 $mg \cdot L^{-1}$	– other life stages
	9.5 $mg \cdot L^{-1}$	Cold-water biota – early life stages
	6.5 $mg \cdot L^{-1}$	– other life stages
Iron	0.3 $mg \cdot L^{-1}$	
Lead	1 $\mu g \cdot L^{-1}$	Hardness 0-60 $mg \cdot L^{-1}$ ($CaCO_3$)
	2 $\mu g \cdot L^{-1}$	Hardness 60-120 $mg \cdot L^{-1}$ ($CaCO_3$)
	4 $\mu g \cdot L^{-1}$	Hardness 120-180 $mg \cdot L^{-1}$ ($CaCO_3$)
	7 $\mu g \cdot L^{-1}$	Hardness >180 $mg \cdot L^{-1}$ ($CaCO_3$)
Mercury	0.1 $\mu g \cdot L^{-1}$	
Nickel	25 $\mu g \cdot L^{-1}$	Hardness 0-60 $mg \cdot L^{-1}$ ($CaCO_3$)
	65 $\mu g \cdot L^{-1}$	Hardness 60-120 $mg \cdot L^{-1}$ ($CaCO_3$)
	110 $\mu g \cdot L^{-1}$	Hardness 120-180 $mg \cdot L^{-1}$ ($CaCO_3$)
	150 $\mu g \cdot L^{-1}$	Hardness >180 $mg \cdot L^{-1}$ ($CaCO_3$)
Nitrogen		
Ammonia (total)	2.2 $mg \cdot L^{-1}$	pH 6.5; temperature 10°C (see Table 3-12)
	1.37 $mg \cdot L^{-1}$	pH 8.0; temperature 10°C
Nitrite	0.06 $mg \cdot L^{-1}$	
Nitrate		Concentrations that stimulate prolific weed growth should be avoided
Nitrosamines	ID	
pH	6.5-9.0	
Selenium	1 $\mu g \cdot L^{-1}$	
Silver	0.1 $\mu g \cdot L^{-1}$	
Thallium	ID	
Zinc[3]	0.03 $mg \cdot L^{-1}$	
Organic parameters		
Acrolein	ID	
Aldrin/dieldrin	4 $ng \cdot L^{-1}$ (dieldrin)	

Source: CCREM, 1987

[1] Concentrations of heavy metals reported as total metal in an unfiltered sample.
[2] ID = insufficient data to recommend a guideline.
[3] Tentative guideline.