MANAGEMENT OF HIGHWAY RUNOFF WATER QUALITY: AN EXAMINATION OF THE ISSUE AND POTENTIAL SOLUTIONS FOR PROVINCIAL HIGHWAYS IN THE GREATER VANCOUVER REGIONAL DISTRICT

by

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We accept this study as conforming
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ABSTRACT

The issue of highway runoff water quality, and the subsequent impact on the receiving environment in the Greater Vancouver Regional District (GVRD), is assessed and potential solutions and recommendations are presented. The highways located in the GVRD, and operated under the jurisdiction of the British Columbia Ministry of Transportation and Highways (MoTH), are used as a case study. Information is drawn from a wide variety of sources on both the impact of highway runoff quality and on solutions that have been undertaken in other regions similar to the GVRD. The report concludes that highway runoff quality is an important concern, and that there are many current Best Management Practices that can be utilized with the most cost-effective solutions being those that focus on sediment removal. The preferred solutions from most preferred to least preferred are grassed swales, ditches and vegetated buffer strips, wet ponds with enhanced vegetation, constructed wetlands, mechanical devices such as oil-water separators, and infiltration facilities. Based on the information reviewed and analyzed for this study, a draft policy on Highway Runoff Quality and a draft Technical Bulletin for the design of highway runoff facilities for the BCMoTH is presented.

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1.0 INTRODUCTION

In the nearly one hundred years since Henry Ford introduced his Model T in 1908, the automobile has gone from the luxury of the elite to the necessity of the masses. In order to accommodate this huge increase in automobile use, hundreds of thousands of kilometres of highways have been built.

In this transition from rural to urban, traffic congestion and lengthy commutes not only waste fossil fuels and other non-renewable resources, they increase the cost of goods, add stress to individuals and families, and degrade the quality of urban life (TAC, 1998). In an urban society, however, highways also perform many necessary functions including the movement of goods and services, the provision of emergency and medical service routes, and access and connectivity of disparate areas. Highways have become an integral part of our environment and they pervade every aspect of modern urban life.

2.0 DEFINITION OF THE PROBLEM

There are many problems associated with highways, one major concern is the change that occurs when paved roads are constructed and the natural infiltration of water into the soil is altered. Instead of rainwater being able to travel along a natural surface, which can reduce its velocity and allow for some ability for the water to penetrate the ground, the water on a paved surface cannot travel directly into the ground. Also, the velocity of runoff from a paved surface is usually much higher than for natural surfaces such as grass or other vegetative cover. Roads cover only a narrow strip of land, yet they generate significant amounts of runoff. The water that collects on a paved road must be removed before ponding creates safety hazards for travelling vehicles (usually because of the potential for hydroplaning at higher speeds), or before the excess water can freeze.

Largely because of safety-related issues, highway drainage is considered an essential element of an overall road design. Specific engineering requirements ensure that drainage is properly and effectively addressed. When designing highway drainage, calculations and designs typically utilize quantity and flow requirements to determine the most effective drainage solutions. In the design process, there is little consideration of the quality of highway runoff entering various drainage systems (Caltrans, 1999). Road safety issues are usually addressed by considering quantity characteristics only.

Typically, once collected highway runoff is directed into storm sewers or culverts, down the road side into ditches or watercourses, or simply allowed to sheet off the road and dissipate through the road shoulder or grass swales without consideration of water quality. In all cases, the highway runoff is mixed with other water sources, whether it is groundwater or surface water, and the quality of this runoff water impacts these watercourses. Highway runoff contains numerous contaminants that are deposited by vehicles, carried by the atmosphere, or generated by road maintenance activities. Contaminants include heavy metals, petroleum products, and organic materials. This type of contamination, which originates from dispersed sources, is considered non-point source (NPS) and can be difficult to control. While the levels of some of these contaminants may be low, there is sufficient cause for concern about the potential adverse impact to the receiving waters, as quality of highway runoff directly or indirectly affects watercourses and other sensitive receiving environments.

The protection of surface and groundwater from the impact of runoff has been recognized as important by researchers in the United Kingdom, the Federal Republic of Germany, Norway, the United States of America, and Canada. While progress towards implementing measures to reduce this impact vary with each country, the consensus is that something must be done to address this problem (Stotz, 1990; WSDOE, 1999a; WSDOT, 1997; Lorant, 1992; Hewitt, 1992; Ellis, J.B. et al, 1994).

In the 1960's the U.S. Geological Survey researched floods in suburban areas and the hydrological effects of urban land use (Carter, 1961; Leopold, 1968). The discovery of significant amounts of organics, herbicides, pesticides, and heavy metals in the urban runoff prompted changes to the Clean Water Act to require regional planning studies to include ways to reduce urban runoff pollution (ASCE, 1998). In the early 1980's, the US Environmental Protection Agency (EPA) funded a National Urban Runoff Program to look at the issue of urban runoff and the issue of contaminant sources and potential solutions. From this study, regulations were established in 1990 by the US EPA requiring municipalities to formulate stormwater management programs. It is under these requirements that transportation agencies such as the Washington State Department of Transportation (WSDOT, 1997) have formulated their stormwater management plans for the treatment of highway runoff. All of these legislative initiatives recognized that the issue of the quality of stormwater and highway runoff was significant and that solutions needed to be found.

In Canada, transportation agencies and other groups in the transportation sector are supported through associations such as the Transportation Association of Canada (TAC). TAC is a national non-profit association of more than 550 members, including provincial/territorial/municipal governments, passenger transport services, goods carriers, contractors, manufacturers, consultants, academics and research groups.

This important association has developed an Environmental Policy and Code of Ethics that recognizes that there must be a balance between transportation needs and the environment (TAC, 1992). In 1996, in an effort to ensure that roadway development is environmentally sustainable, they provided a guide for integrating environmental management principles into established codes of practice (TAC, 1996). Within their Environmental Policy and Code of Ethics they specifically address the issue of highway runoff quality as being a crucial component. In terms of surface and groundwater protection TAC (1992) states that:

> In recognition of the necessity of clean water to health, the economy, and the ecosystem, discharges of transportation-related contaminants to surface (fresh and salt water) and groundwater should be minimized.

This statement shows that TAC recognizes highway runoff quality is a serious problem.

Given the unprecedented growth of roads and automobiles, the environmental problems associated with highway runoff quality will continue to increase and solutions must be found. An effective place to begin defining and implementing solutions is in the actual design, construction, and operation of highways. Most transportation agencies control the design, the construction, and the operation of the highway system. Because of this, they can easily implement specific changes in these areas. If they choose to do so, then solutions for highway runoff quality can become a part of the overall transportation system.

3.0 STUDY RESEARCH FOCUS

3.1 Statement of Problem

Highway runoff quality is a serious environmental concern due to the fact that it contains many contaminants such as: heavy metals, petroleum products, and organic materials. This contaminated highway runoff lowers the water quality in any receiving body, and there must be solutions found to deal with this problem. The question then is:

> As highway runoff is a serious environmental concern lowering water quality in any receiving body, what can be done to reduce or avoid the problem in current and future highways?

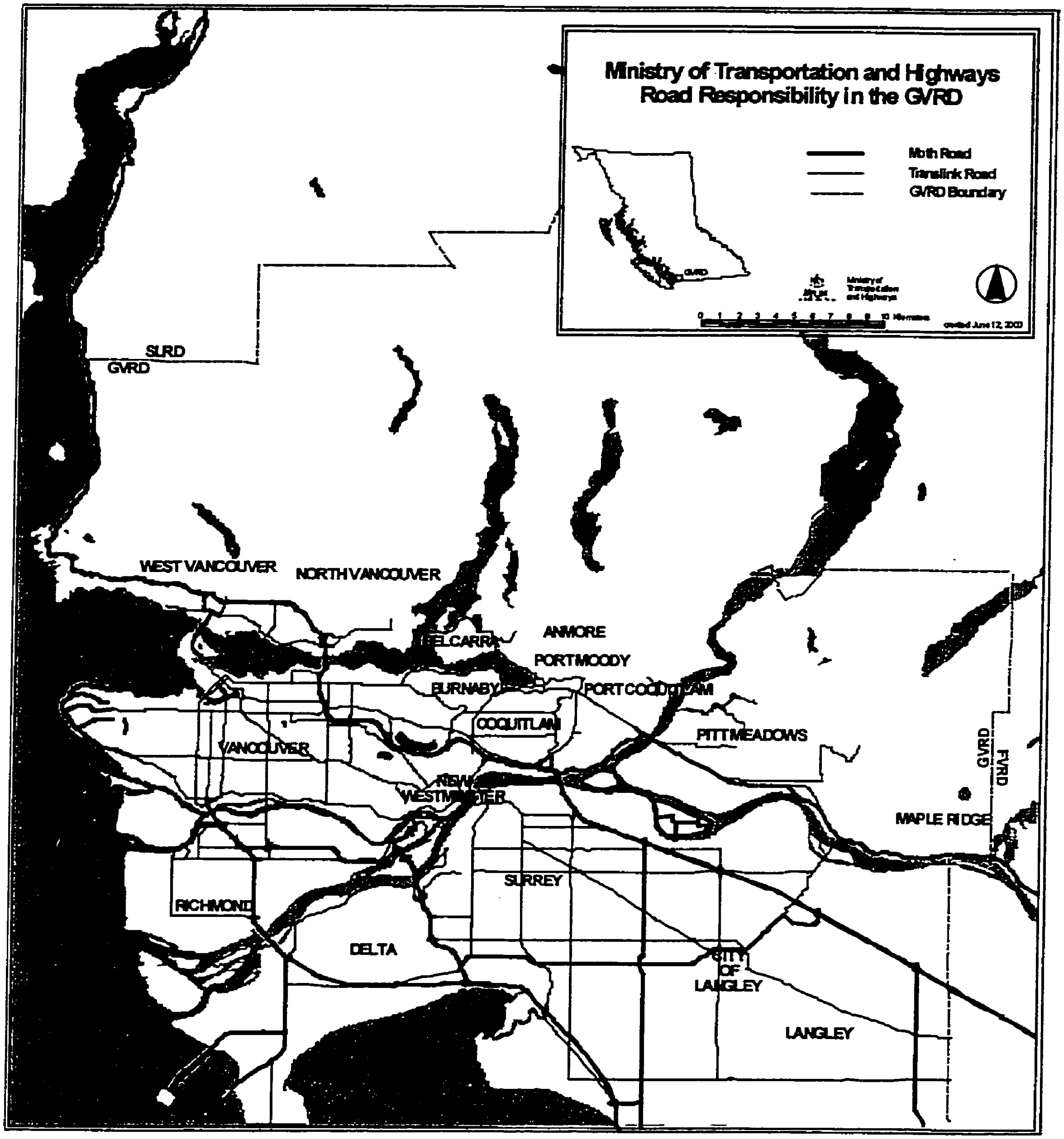
Although the problem of highway runoff quality is well documented, and there are many potential solutions to the problem available, there is little research available that examines the range of solutions and offers a way to integrate them within the design construction, and operation of highways. This is an essential step in reducing or avoiding the problem.

In order to conduct a timely and relevant study, a specific study area was chosen.

3.2 Study Area

The area chosen for the study of the quality and management of highway runoff was the Greater Vancouver Regional District (GVRD). The extent of the GVRD is shown in Figure 1, complete with the network of roads that are owned and operated by the British Columbia Ministry of Transportation and Highways (BCMoTH). The GVRD area and BCMoTH highways were chosen because they generated a large volume of environmental information including the effect of automobiles and their emissions. Also, paved roads in the GVRD cover a large land area and the majority of road runoff in the GVRD flows into fish-bearing streams and rivers where the quality of the runoff would have a major impact. The GVRD land area encompasses 282,066 ha (GVRD, 1999) and roads can cover from five to eight percent of urban watershed catchment area (Bein, 1997). In the GVRD, roads cover between 14,103 and 22,565 ha.

Figure 1: Highways in the GVRD owned and operated by British Columbia Ministry of Transportation and Highways



Source: BCMoTH, 2000.

3.3 Description of the Study Area

The GVRD is a complex area from both an organizational and physical standpoint, and this makes the area interesting for the examination of the quality and effect of highway runoff water. This region has the greatest population and highest provincial traffic volume in British Columbia (BCMoTH, 1999). The recent formation of TransLink, which has the broad responsibility for the planning and financing of the regional transportation system in the GVRD including transit, major roads, SeaBus, SkyTrain, West Coast Express, and the Albion Ferries, gives the GVRD a regional transportation group. This group provides an excellent mechanism for integrating all aspects of transportation, and the potential to reduce automobile traffic. For the first time, all of these transportation modes are under the direction of one organization. The goals in developing the GVRD transportation system include the preservation of green spaces, the reduction of urban sprawl, and the protection of air quality. The protection of water quality from transportation related impact is not explicitly stated in TransLink's goals.

As part of the provincial and national road network in the GVRD, the British Columbia Ministry of Transportation and Highways (BCMoTH) operates and maintains a number of highways (See Figure 1). While these highways are not under the specific jurisdiction of TransLink or the GVRD, it is important that BCMoTH and TransLink work closely together to ensure overall transportation needs and goals in the region are met. The roads under the jurisdiction of the BCMoTH generally carry the highest traffic volume in the GVRD, and provide the major transportation routes and links to outlying areas. Because of the high traffic volume on BCMoTH highways, and because of BCMoTH's long history of highway planning, design, operation, and maintenance within the GVRD and provincially, BCMoTH highway design provides an excellent case to study.

BCMoTH's commitment to highway runoff quality issues and solutions is well documented. In its environmental management plan (EMP) BCMoTH identifies water quality as a priority issue (BCMoTH, 1998b). The EMP evolved as an initiative of the Environmental Management System (EMS) which intends to better manage the BCMoTH's environmental responsibilities. The EMS identified twenty-eight topics, including water quality, and ranks them by priority for action in the categories of imperative, high, medium, and low. Water quality is listed in the EMP as having a medium priority. With this priority listing, the following strategic direction is identified in the EMP:

- improve the Ministry-wide perspective and data on how right-of-way management practices impact water quality; and
- systematically prevent impacts on water quality and water users (e.g., by improvements to stormwater management operations).

The proposed actions under the EMP for water quality include:
- develop policy and specific responsibilities for mitigating water quality impacts, including cumulative impacts;
- develop standards or Codes of Practice for water quality protection in capital projects, operations, and maintenance;
- supply and improve technical information and manuals; and
- Prepare a guideline, or Fact Sheet, on stormwater management for use by district development staff.

For this particular area, and for potential application to other transportation and municipal agencies, this report can provide some assistance in defining highway runoff quality issues and solutions.

3.4 Study Objectives

The following are the objectives of this study:
1. To define the issue of highway runoff quality;
2. To provide background on what has been accomplished to-date;
3. To describe cost-effective highway runoff quality measures that can be incorporated into the design of new and existing highways;
4. To provide a working draft of a highway runoff quality policy for BCMoTH;
5. To provide specific guidance to BCMoTH on when highway runoff water quality treatment is required for highways, and the priority of the methods to be used;
6. To provide guidance on information sources for design guidelines of water quality treatment options; and
7. To recommend future considerations for research in highway runoff quality.

4.0 DETAILED DESCRIPTION OF THE PROBLEM

This section will examine the context for the control of urban stormwater runoff quality with specific reference to non-point source (NPS) pollution. NPS pollution originates from dispersed sources. Because NPS pollution cannot be attributed to a specific source, it can be difficult to control. Examples of NPS pollution are urban stormwater runoff and highway runoff.

4.1 Non Point Source and Urban Stormwater Runoff Quantity/Quality Control

Consideration of the quality of stormwater has only occurred in the last 25 years. In the United States, awareness is largely due to the Nationwide Urban Runoff Program sponsored by the U.S. Environmental Protection Agency. This program was undertaken between 1978 and 1983 to obtain water quality data on stormwater discharges from residential, commercial, and light industrial areas. The data showed a higher concentration of contaminants in stormwater than in municipal wastewater discharges. In addition, many of the contaminants were on the EPA's "priority list" which identifies contaminants that have suspected or known human health concerns. In 1990, this led to regulation under the National Pollutant Discharge Elimination System that requires U.S. cities and industries to apply for permits for their stormwater discharges. The intention was to reduce the amount of NPS pollution in urban stormwater to the maximum extent practicable (CFR, 1993). This, in turn, led to many state transportation departments adopting a stormwater management plan. The Washington State Department of Transportation (WSDOT) has one of the most advanced Stormwater Management Plans.

In 1992, the British Columbia Ministry of Environment (BCMELP) published a document entitled "Urban Runoff Quality Control Guidelines for British Columbia" in which they state that:

> ...[I]t has become apparent that non-point sources (NPS), such as stormwater runoff from urban and agricultural areas, are the major continuing sources of pollution to receiving waters. Urban surface runoff is second only to agricultural runoff as a source of NPS. (BCMELP, 1992)

The BCMELP also reported that highway runoff, separate from that of "general urban runoff", had typically higher concentrations of hydrocarbons and metals. In the 1999 NPS Action Plan, the BCMELP suggests that NPS contaminants in aquatic ecosystems fall into five main categories (BCMELP, 1999):

- pathogens;
- oxygen depleting substances – mostly organic wastes;
- nutrients – mostly nitrogen and phosphorous;
- sediments; and
- Toxins.

Other studies have also shown that highway runoff can contain contaminants from all five of these categories (ASCE, 1998; Stotz, 1990; Lorant, 1992; BCMELP, 1992; EDOT et al, 1993). BCMELP suggests that the adverse economic consequences of NPS to society are high.

In its Action Plan, the BCMELP (1999) cites seven main causes of NPS in British Columbia. These are:

- land development/use (includes roads and construction);
- agriculture;
- stormwater runoff and combined sewer overflows;
- onsite sewage systems;
- forestry and range activities;
- atmospheric deposition; and
- Boating and marine activities.

Land development and the subsequent construction of roads and highways is one of main causes of NPS in the GVRD. Thus the control of both the quantity and quality of highway runoff is critical.

4.1.1 The Constituents of Highway Runoff

The constituents in urban stormwater are estimated based on general land-use categories (ASCE, 1998: BCMELP 1992; Caltrans, 2000). The same, or similar, estimates can be made regarding the constituents of highway runoff.

Table 1 presents a wide range of potential contaminants in highway runoff, identifies the key sources, and lists some key environmental concerns from both a human health and natural environment perspective. Note that the environmental concerns are dependent on several factors and the potential risk is addressed later in this report. Also, not all of the contaminants listed will be in all highway runoff samples. The actual amount and type of contaminants will depend on key factors such as the land use, traffic volume, weather, location, season, type of highway surface, and highway maintenance practices (Kobriger and Geinepolos, 1984). For example, Asplund et al (1982) reported that deposition of suspended solids on roadways from surrounding land use could be on the order of 22 to 400 kg/ha/yr in rural areas and 400 to 1200 kg/ha/yr in urban industrial areas.

Table 1: Typical Highway Runoff Contaminants and Sources

Constituent	Key Sources	Key Environmental Concerns
Particulate	Pavement wear, vehicles, vehicle exhaust, fuel spills, highway maintenance (includes sand applied in winter)	Largely a threat to human health for PM_{10} and smaller particles. Main carriers of many other contaminants including heavy metals and PAH's. Can also increase turbidity in receiving waters that can decrease prey capture for sight-feeding aquatic animals and/or clog gills.
Polynuclear Aromatic Hydrocarbons (PAHs)	Automobile exhaust as a by-product of combustion, and potential background emission from fuel spills, oil spills, and industrial sources.	Group of sixteen base/neutral compounds found in very small concentrations in highway runoff, mostly sorbed to the solid phase. Can be toxic to human and aquatic life. May bio-accumulate in the tissues of plants and animals.
Nitrates, Phosphorous (P)	Atmosphere, organic nutrients in roadside vegetation, fertilizer application	In their soluble form they can cause algal growth and reduce oxygen levels in receiving waterbodies, and can potentially cause fish kills. Largely a problem with urban and agricultural runoffs.
Lead (Pb)	Leaded gasoline, auto exhaust, tire wear, lead oxide filler material, lubricating oil and grease, bearing wear	Levels have decreased very significantly since the banning of lead in gasoline in Canada in 1990. Bio-accumulates. Human health effects related to central nervous system and brain (BCMELP).
Zinc (Zn)	Tire wear (filler material), motor oil (stabilizing additive), galvanized steel, grease.	Highly soluble but most appears to adhere to particles. Bio-accumulates, can cause unpleasant taste in drinking water. Can be toxic to aquatic organisms.
Iron (Fe)	Autobody rust, steel highway structures (guardrails, bridges etc.), moving engine parts	Causes staining, discoloring, nutrient for algae.
Copper (Cu)	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations	Can be toxic to aquatic species. Concentrates in sediments and can bio-accumulate BCMELP.

Table 1: Continued

Constituent	Key Sources	Key Environmental Concerns
Cadmium (Cd)	Tire wear (filler material), insecticide application, lubricants, auto exhaust, galvanized steel.	Carcinogenic if inhaled (USEPA, 2000). Can bioaccumulate.
Chromium (Cr)	Metal plating, moving engine parts, brake lining wear	Suspected carcinogen (USEPA, 2000).
Nickel (Ni)	Diesel fuel (exhaust) and lubricating oil, metal plating, bushing wear, brake-lining wear, asphalt paving.	Potentially carcinogenic (USEPA, 2000).
Manganese (Mn)	Moving engine parts and gasoline	Contributes to water hardness. Can be toxic (USEPA, 2000).
Bromide (Br)	Auto exhaust	Toxic.
Cyanide	Anti-cake compound (ferric ferrocyanide), prussian blue or sodium ferrocyanide, yellow prussiate of soda used to keep de-icing salt granular	Highly toxic to human and aquatic life. (Warrington, 1998)).
Sodium (Na), Calcium (Ca)	De-icing salts, grease	Ca contributes to water hardness. High concentrations of sodium in the soil and water may be toxic to plants. High concentrations of sodium in the human diet may lead to many conditions such as hypertension, cardiovascular disease, metabolic disorders, renal diseases and cirrhosis of the liver (Warrington, 1998).
Chloride (Cl)	De-icing salts	Chloride tends to be somewhat less toxic to animals and plants than sodium. However, too much chloride makes water unpalatable and eventually unfit to drink (Warrington, 1998).
Sulphates	Roadway beds, gasoline and diesel fuel, vehicle exhaust, de-icing salts	Can contribute to eutrophication and acidification of water.

Table 1: Continued

Constituent	Key Sources	Key Environmental Concerns
Petroleum products	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate, fuels	Many petroleum products are carcinogens and can contaminate groundwater.
Polychlorinated biphenyl (PCB), pesticides	Spraying of highway right-of-ways, background atmospheric depositions, PCB catalyst in synthetic tire	Bio-accumulate and are carcinogens.
Pathogenic bacteria	Soil, litter, bird droppings, trucks hauling livestock and stockyard waste	Can cause waterborne diseases.
Rubber	Tire wear	Largely aesthetics but may contain trace metals such as nickel and zinc.
Debris	Litter, materials and parts from vehicles and their loads, other solid materials deposited on roads	Largely aesthetics but may have specific environmental concerns.
Asbestos	Clutch and brake lining wear	Largely a threat to human health. Is a carcinogen (USEPA, 2000)

Source: Modified from Lorant, 1992; WSDOT, 1997; ASCE 1998.

4.2 Measuring Contaminant Levels

Typically, traffic volumes are utilized as an estimation of the level of contaminants that may be present on a given stretch of highway. Washington State Department of Highways (WSDOT) has utilized average daily traffic (ADT) volumes of >50,000 as the threshold at which treatment options are considered (WSDOT, 1995). The higher the ADT, the higher the expected level of contaminants. In their Highway Runoff Manual, WSDOT also requires water quality control for new projects that add more than 465 m^2 of impervious surface (WSDOT, 1995). The singular use of ADT volume is challenged by others, including the Colorado Department of Transportation (CDOT), who find no direct correlation between traffic volume and contaminant levels. CDOT, and others, recommend using a variety of factors such as climatic conditions and vegetation along with the ADT (also see Driscoll, 1990; Stotz, 1987; Mar, 1982; Kerri et al, 1985; CDOT, 1995). While ADT may not be a definitive method of measurement, it is prudent to consider ADT as a major determinant for selecting roads for highway runoff quality treatment.

Irish et al (1995) evaluated a number of factors that affect the quality of highway runoff in Austin, Texas. Their research concluded that conditions during the antecedent dry period (ADP) when material could accumulate on the roadway, and the intensity of the antecedent storm event have the greatest influence on the total suspended solids (TSS) storm loadings. Also, they found that the amount and intensity of rainfall are variables that determine levels of contaminants in the runoff.

A weak correlation between highway contaminant loads and ADP was reported by Kerri et al (1985) who suggest that a net accumulation on the road surface during a dry period does not necessarily occur. Vehicle movement and wind will naturally move material from the road, as will processes such as volatilization, biodegradation, and chemical decay. The measure found to be more closely correlated was the number of vehicles that travel on the highway during the rainstorm (VDS). The theory is offered that vehicle wash off removes contaminants more readily than other actions. However, ADT should not be used to estimate the VDS number, as this may be inaccurate because there may be fewer vehicles travelling due to the storm event.

As can be seen from the above, the literature on this subject suggest that there are numerous ways in which to estimate the potential amounts and types of contaminants that may be present in highway runoff. However, the element of time is not fully explained. While ADT measures the average number of vehicles in a day, and VDS measures the specific number of vehicles during a set range in time during a particular event (i.e. rainstorm), the potential for each vehicle to contribute to contaminant loading is not fully explicated.

Washington State also uses a specific amount of impervious surface as a trigger point for water quality treatment. This measurement is a useful measure providing that other factors such as ADT are also utilized. While it may not be cost-effective to provide treatment in an area with a low ADT, there may be other factors that need to be considered before treatment is rejected. These factors might include nearby sensitive environmental areas, regular use of pesticide, or heavy truck traffic on a steep incline.

In summary, there are many potential methodologies that can be used to determine contaminant loading. The use of a combination of ADT, VDS, and the amount of impervious surface is preferred, however, time and funds for data collection are limited. Transportation agencies do not normally collect VDS data but do continuously collect ADT data. Also, impervious surface area is easy to calculate. For these reasons, ADT and impervious surface area are appropriate for measuring contaminant loading for the present, provided VDS and other methodologies are developed, tested, and implemented in the future.

4.3 Categorizing Contaminants

In order to deal effectively with a long list of potential contaminants, it is necessary to categorize those that must be dealt with first. Washington State Department of Transportation (WSDOT, 1997) examined a general list of contaminants found in highway runoff and has highlighted several primary contaminants of concern. For regular monitoring of highway runoff sites WSDOT have analyzed runoff samples as shown in Table 2.

Table 2: WSDOT contaminants of concern and testing methods

Pollutant of Concern	Test	Frequency of Testing
Solids	Total Suspended Solids Total Dissolved Solids	Regular-all samples are tested
Metals	Cadmium (Total, Suspended) Copper (Total, Suspended) Lead (Total, Suspended) Zinc (Total, Suspended)	Regular-all samples are tested
Nutrients	Nitrate-Nitrogen Phosphorous (Total) Orthophosphates	Regular-all samples are tested
Oxygen demand	Biochemical Oxygen Demand (5 Day) Chemical Oxygen Demand	Regular-all samples are tested
Oil and Grease	Standard lab test	Test grab samples only
Total Petroleum Hydrocarbons	Standard lab test	Test grab samples only
PAH's	Standard lab test	Semi-annually
Ultimate (20 day) Biochemical Oxygen demand	Standard lab test	Semi-annually
Effluent Toxicity	Microtox™ Technique	Semi-annually

Source: Adapted from WSDOT (1997).

The WSDOT (1997) general categories of contaminants of concern as shown in Table 2 provide a very useful categorization of a complex subject. Using the first four of these categories, the following discussion provides an overview of each.

4.3.1 Solids

Kobriger and Geinepolos (1984) concluded that solids are the main carriers of contaminants in runoff, and that total suspended solids are strongly associated with total pollutant quantity. Also, Stotz (1990) reports that heavy metals measured in highway runoff in the Federal Republic of Germany are generally associated with solids. Onwumere (1999) analyzed road dirt from two highway sites in Richmond and Burnaby, B.C., and found that there was a considerable amount of metals in the samples. He concluded that road dirt is a significant source of metal pollution in highway stormwater runoff in this area. Given their direct association with heavy metals, solids must be included.

4.3.2 Metals

In regard to metals, Onwumere (1999) states that heavy metals in highway runoff are always associated with the fine particles, and that fine silt and clay fractions carry the largest amount of contaminants in runoff. These particles are easily mobilized by low intensity rainfall events and concentrations increase with high flow rates across the highway surface due to the scouring action. Concentrations of lead, cadmium, nickel and zinc decrease to essentially background levels within 35-50m from the edge of paved surfaces (Onwumere, 1999). This is supported by BCMoTH in the Lower Mainland (Scott Tomlinson, personal communication). This study indicates that lead levels along the Trans Canada Highway between Burnaby and Vancouver decrease to background levels within 30 m of the road edge. Also, lead was found only in the upper organic layer. The clay layer beneath showed no elevated lead levels because of its impermeability. Lagerwerff (1970) also found that concentrations of lead, cadmium, nickel, and zinc, in roadside soils (as measured from grass samples) decrease with the distance from the traffic, and with the depth of soil depending on the soil type.

4.3.3 Nutrients

Nutrients are generally found in the dissolved form in highway runoff, therefore cannot be removed by settling out solids (Onwumere, 1999). Vegetation can be used to uptake nutrients, provided there is sufficient retention time for this to occur. Typically, the levels of nutrients found in highway runoff are similar to that found in urban runoff; however, local site conditions can severely influence these levels. While it has been suggested that higher nutrient levels in highway runoff may be associated with agricultural areas, Onwumere (1999) suggests that this is inconclusive and more research is needed.

4.3.4 Oxygen Demand

Organic materials carried in highway runoff cause bacterial growth in receiving water bodies. This growth consumes oxygen and reduces the oxygen levels in the receiving waters below critical levels for aquatic organisms that utilize oxygen (Irish et al, 1995). Biological oxygen demand (BOD) and chemical oxygen demand (COD) are typically used to estimate the amount of oxygen consumed in the tested solution. Unfortunately, both parameters have major limitations when measuring urban and highway runoff. These limitations are because the measurements for COD and BOD are inhibited by the toxicity of the runoff and there is no way to predict delayed oxygen demands by the runoff in receiving waters (Marsalek, 1986; Schueler, 1987).

4.4 Factors affecting Highway Runoff Quality

The Colorado Department of Transportation (CDOT, 1995) is the only agency found during this study that attempts to categorize the factors affecting highway runoff contaminant loading. CDOT uses three important and relevant categories: high, medium, and low in their study.

CDOT suggests that factors having a high influence on contamination of highway runoff are climatic conditions, pavement quantity, ADT, right-of-way vegetation, highway drainage features, and surrounding land use. Contrary to other agencies, CDOT does not support the concept that ADT is the prime determinant. No direct correlation between ADT and pollutant concentrations has been detected and yet CDOT still includes ADT as a high contributing factor affecting highway runoff. According to CDOT, the least important factors are highway design and institutional characteristics that include litter laws, speed limit enforcement, and car emission regulations. Unfortunately, CDOT does not elaborate on its decision to categorize car emission regulations in this manner. Similarly, it categorizes vehicular inputs in the medium category. These choices contradict many other studies that suggest that both these items are of high importance (WSDOE, 1998; WSDOT, 1996; Onwumere, 1999). With the constant turn over of vehicle fleets and replacement with newer and less polluting vehicles every year, car emission regulations may not in fact be one of the most important factors.

Table 3 summarizes factors provided by CDOT (1995).

Table 3: Factors affecting highway runoff characteristics

Factor	Low	Medium	High
Climatic conditions			X
Atmospheric deposition		X	
Highway configuration		X	
Pavement composition/condition		X	
Pavement quantity			X
Highway design	X		
Right-of-way vegetation			X
Highway drainage features			X
Average daily traffic (ADT)			X
Vehicular inputs		X	
Maintenance practices		X	
Institutional characteristics	X		
Surrounding land use			X

Source: Adapted from CDOT (1995).

4.4.1 Surrogate Parameters for Forecasting Highway Stormwater Loads

Thomson et al (1997) recognizes that highway runoff constituents can be highly varied, and yet it is important to provide an accurate prediction for the purposes of planning roads and retrofitting existing ones. Unfortunately, the collection and testing for all possible constituents for each runoff event makes the cost prohibitively high. Thomson et al (1997) suggests that surrogate parameters utilizing a smaller data set could be used to make testing less complex. To develop these parameters an extensive highway stormwater quality database compiled in the late 1970's and early 1980's in Minnesota was used. This database provides information on over 400 runoff events over a seven-year period. Information was collected in four phases with each phase representing an individual site. The phases and sites are described below:

- Phase 1 - Urban 6-lane asphalt section (I-94 in St. Paul) with an ADT of 65,000 and a catchment area of 6.6ha. Surrounding land use primarily residential, some commercial.
- Phase 2 - Urban 6-lane concrete section (I-494 in Minneapolis) with an ADT of 82,000 and a catchment area of 142.4ha. Due to the length of the catchment area (6.4km) land use varied from industrial, to commercial and residential.
- Phase 3- Rural 4-lane concrete section (I-694 in St. Paul) with an ADT of 42,000 and a catchment area of 6.6ha. This is the only section that allowed for the runoff to pass through grassed medians and ditches prior to sampling.
- No indication of surrounding land use was provided.
- Phase 4- Urban 10-lane concrete section (I-94 in Minneapolis) with an ADT of 114,000 and a catchment area of 8.5ha. The surrounding land use was a mix of single-family homes, apartments, commercial and light industrial.

Thomson et al (1997) chose Phase 4 as the study site to develop the surrogate parameters, based on the fact that this site has the largest amount of information available. A statistical approach to the collected information was applied to describe the variations in the magnitude of constituents. For numerous metals, ionic species, and nutrients, the acceptable surrogates included:

- Total Suspended Solids (TSS);
- Total Dissolved Solids (TDS);
- Total Volatile Solids (TVS); and
- Total Organic Carbon (TOC).

The study further compared these results to the information from Phase 1, 2, and 3 sites to test applicability for near-site and far-site portability.

Near-site portability is defined as sites in close geographical proximity. In these sites environmental and road maintenance practices would be similar. Far-site portability are sites with considerable meteorological and geographical differences. For near-sites, ionic species relationships (chloride, sulphate, and sodium) were acceptable for all sites, but the metal (chromium, copper, iron, lead, zinc, nickel, cadmium, aluminum, and arsenic) and nutrient (Kjeldahl nitrogen, total nitrogen, combined nitrogen (N02 + N03), total phosphorous, and combined oxygen demand) measurements were useful only for the urban sites.

To determine far-site portability, Thomson et al (1997) utilized four urban sites that were similar in environmental conditions; these were selected from a study of water quality by Driscoll et al (1990). The sites are located in Milwaukee, Wisconsin; Denver, Colorado; Harrisburg, Pennsylvania; and Nashville, Tennessee. The study looked at zinc, lead, iron, and chloride as these were the most frequently reported constituents in the data from Driscoll et al (1990). The study concluded that:

- the chloride relationship was adequate when the TDS concentration was elevated;
- the iron and zinc relationships produced event mean concentration (EMC) values that matched well with the actual data; and
- The lead relationships produced values that only compared favourably with data from one of the four sites.

This study data suggests a good application of surrogates for near-sites, but that far-site portability is limited. This methodology may be adopted in the GVRD and considered as one near-site. Results show that this methodology may be applicable to BCMoTH and others.

Given that Thomson et al (1997) found that surrogates may be useful in certain situations, they also attempted to determine TSS, TDS, TVS, and TOC using different variables such as ADT, traffic count before and after an event, and various rainfall and flow characteristics. Results showed study limitations; therefore it was recommended that sampling for TSS, TDS, TVS, and TOC be conducted at the site and not predicted using this model.

4.5 Erosion and Sedimentation

Erosion and subsequent sedimentation caused by the movement of bare or unstable soils by highway runoff causes serious water quality concerns. While this issue is beyond the scope of this report, it is important to note that most transportation agencies in North America, including BCMoTH, have traditionally focused on only this aspect of water quality. In Canada, this focus on the control of sedimentation and erosion has been to comply with the Federal Fisheries Act that prohibits release of deleterious materials into fish-bearing waters, and carries substantial fines for non-compliance. As a result, significant progress in improving erosion control practices has been achieved. Most agencies have a good understanding of the requirements and have the tools to deal with it. While erosion and sedimentation is a major water quality issue, only highway runoff quality from hard surfaces will be considered here.

4.6 Summary

Existing literature shows that highway runoff contains a substantial amount of contaminants. In the British Columbia Environment Urban Runoff Quality Guidelines (BCMELP, 1992) lead, copper, zinc, PAH's, and petroleum products are all identified as constituents of highway runoff. The WSDOT Highway Runoff Manual (1996) has similar findings; it states that the amount of contaminants is related to the amount of traffic on a particular road. This criteria has been used by WSDOT to prioritize efforts to improve water quality. The threshold suggested is an average daily traffic volume of 50,000 vehicles and higher. More recently, WSDOT committed to water quality treatment for 100% of all new impervious surfaces created by new highway projects, and for redevelopment projects of existing highways that add impervious surfaces.

The British Columbia Environment Urban Runoff Quality Guidelines and the WSDOT Highway Runoff Manual identifies the potential impact of reduced water quality on vegetation and animals, particularly in the aquatic environment. Current literature shows that heavy metals and hydrocarbons above specific concentrations, along with other substances found in highway runoff, negatively impact receiving environments.

Thomson et al (1997) proposed that surrogate parameters of TSS, TDS, TVS, and TOC could be useful in predicting potential contaminant loadings of constituents in highway runoff, and that these methods would be far less expensive than testing for a full compliment of potential contaminants.

5.0 SOURCES OF CONTAMINANTS IN HIGHWAY RUNOFF

There are at least three easily identifiable sources for highway runoff contamination. The most obvious and the most important cause is vehicular traffic on roadways. Vehicles directly deposit hydrocarbons, petroleum products, various fluids, parts of vehicles, and a host of other metals and substances on the roadway. Vehicles also cause the traveled portion of the road to wear and this results in road material being loosened and carried off the roadway by precipitation, wind, or by turbulence beside and behind moving vehicles (saltation).

A second contributor is contaminants carried by the atmosphere that either self settle on the road surface, or are scrubbed by rainfall and then deposited on the road. These types of airborne contaminants are usually from vehicle exhausts from agricultural activities or from industrial or manufacturing plants. The most prevalent cause is vehicle exhaust and this will be examined in more detail in the next section.

A third contributor is from road maintenance activities such as winter salting and sanding, and asphalt paving and patching operations. These leave a variety of materials on the road surface or shoulders, which are then transported off the road via runoff water or wind.

Highway runoff contains a wide variety of contaminants from a variety of sources, as detailed in the following section.

5.1 Vehicles and Deposition of Highway Runoff Contaminants

Vehicular traffic along roadways is the greatest source of contaminants in highway runoff. This section deals with direct sources from vehicles.

The processes by which direct deposition occurs include:
- direct loss of fluids and lubricants from engines and other parts of the vehicle by drips or leaks;
- loss of metal from vehicles by rusting, bearing and bushing wear, brake lining wear, and direct loss of parts;
- windshield washer spray;
- tire wear;
- loss of fluids, parts, and spills of materials as a result of accident or loss of loads, and
- Particulates and gases deposited onto the surface from exhaust systems on direct exit or by entrainment in eddies behind the vehicle.

A wide variety of contaminants are attributed to vehicles. Any component of the vehicle or any fluid that the vehicle contains can end up on the road and subsequently be washed into receiving waters. When the road is wet the generation of splashing water removes contaminants from the outside surface of vehicles, from engines, fuel tanks, and all other components exposed to the spray.

5.2 Vehicle Air Emissions and the Relationship to Highway Runoff Quality

Air emissions are an important factor in understanding constituents present in highway runoff. Many air emissions are removed from the atmosphere via climatic conditions, and deposited on the roads and other surfaces. These contaminants remain on the road surface permanently or are removed by saltation (vehicle induced eddies), wind, or surface water runoff from rain (Hewitt, 1991). It is important to examine the types and amounts of air emissions released into the atmosphere, and gain an understanding of what to expect in highway runoff.

Table 4 below presents data compiled by the U.S. Environmental Protection Agency (EPA) for the annual emissions produced by an average passenger car or light truck. The numbers were generated from the EPA standard emission model using a 1997 model gasoline powered vehicle which is properly maintained. Average fuel economy is based on 36 kilometres per gallon for a passenger car and 24.4 kilometres per gallon for the light truck.

These numbers show that overall emissions from vehicles are significant. Given the vehicular traffic in the GVRD, emissions are a serious concern.

Table 4: Annual Emissions and Fuel Consumption for an Average Passenger Car and Light Truck

	Hydrocarbons (kg)	**Carbon Monoxide (kg)**	**Nitrogen Oxide (kg)**	**Carbon Dioxide (kg)**	**Gasoline (ltrs)**
Passenger Car[1]	36.3	275	18.6	4536	2082
Light Truck[2]	51.7	405.5	26.8	7620	3463

Source: Adapted from URL: http://www.epa.gov/oms/ann-emit.htm.

1. Based on 20,117 km per year
2. Based on 22,532 km per year

5.2.1 Vehicle Use and Air Emissions in the Lower Fraser Valley

The recent BCMELP non-point source pollution Action Plan (1999b) shows that the deterioration of water quality resulting from automobile use is of considerable concern. In its Action Plan, BCMELP states:

> Automobile use in an area greatly affects the atmospheric disposition of NPS [non-point source] contaminants, and this is a concern linked to urban sprawl. In the Greater Vancouver area between 1984 and 1991, the number of cars insured for driving to work increased twice as fast as the population. Greater Vancouver now has more cars per capita than Greater Los Angeles. An expanding population, expected to reach three million in the Lower Mainland by 2021, could mean a doubling of vehicle-kilometres traveled in the region....the Lower Fraser Valley airshed is now at or above its capacity to accept contaminants.

The GVRD's population of 2 million people is growing at a rate of 2.5% per year (Greater Vancouver Regional District, 1999). The number of registered vehicles in the GVRD in 1999 was just over 1.1 million, and it is estimated that these vehicles were driven over 15 billion kilometres. With a reduced speed of travel due to congestion (trip speed) and a subsequent increase in trip time, more cars are on the road for longer periods of time, therefore more emissions were released. This is further exacerbated by the increase in the number of Sport Utility Vehicles that are less efficient than an automobile. The GVRD has focused on air emissions rather than on related water quality impacts.

The most recent calculation by the GVRD (1999) estimate emission release by light-duty and heavy-duty vehicles is over 425,000 tonnes. These emissions, shown in Table 5 clearly show that private automobiles are the major air polluter in the GVRD, producing more than 74% of the total emissions from all measured sources. BCMELP (1998) reports that transportation sources account for 25% of fine particulates (PM_{10}) for the Lower Mainland. Fine particulates in the $PM_{2.5}$ range are the most hazardous to human health and are generated in vehicle emissions.

The GVRD 1998 Lower Fraser Valley (LFV) Ambient Air Quality Report, shows that overall air quality was only marginally worse than during the last few years. Overall, air quality was measured as "Good" on the Air Quality Index 95.8% percent of the time. Fine particulates have been reduced at the worst sites measured since 1991. Several factors have contributed to this reduction including a heavy vehicle testing program in the LFV, modernization of monitoring programs, continued phase-out of beehive burners, Smoke Control Regulations, and higher standards for wood stoves.

Table 5: Sources of Emissions in the GVRD for 1990

SOURCE SECTOR	**CONTAMINANT EMISSION (tonnes)**						
	CO	**VOC**	**NOx**	**SOx**	**PM**	**Road Dust**	**Total**
Motor Vehicles	346,866	36,981	18,531	716	1,385	44,202	**448,681**
• Light-Duty	9,275	1,398	8,125	970	2,006	6,414	**28,158**
• Heavy -Duty	17,352	4,283	14,671	2,172	1,083		**39,561**
Other Mobile Sources	6,527	8,576	8,811	3,766	11,969		**39,649**
	4,802	34,069	3,303	351	3,033		**45,558**
Point Sources							
Area Sources							
All Sources	**384,822**	**85,307**	**53,441**	**7,975**	**19,476**	**50,616**	**601,637**

Source: Adapted from GVRD, 1999.

Table 6 lists the contaminants from Table 5 (with the exception of road dust) and indicates long-term (ten-year) changes in measured concentration in the GVRD.

Table 6: Long-term pollutant trends in the GVRD

Pollutant	10 Year Trend (1989 to 1998)
Carbon Monoxide (CO)	Continuing downward trend. Higher than average readings obtained adjacent to major vehicular traffic routes.
Volatile Organic Compounds (VOC)	Ozone used as surrogate indicator. Maximum 1-hour values have declined, but annual mean levels increased slightly.
Nitrogen Dioxide (NOx)	A general decline but a leveling off since 1994. Highest levels measured in urban areas.
Sulfur Dioxide (SOx)	A steady decline over the ten-year period. Sulfur levels have decreased in gasoline and diesel fuel over that time].
Inhalable Particulate (PM_{10})	Only measured since 1994. No definite trend noted but levels appear to be consistent. Highest levels are during dry weather periods.
Fine Particulate ($PM_{2.5}$)	Only one monitoring station was in operation for this monitoring period (located in Chilliwack)-more stations are planned. Readings are available from 1995 to the present. No trend apparent yet (insufficient data) levels are highest during dry weather.

Source: Adapted from GVRD, 1999.

5.2.2 Vehicle Greenhouse Gas Emissions

Directly associated with the use of automobiles is the release of greenhouse gas emissions primarily in the form of carbon dioxide, nitrous oxide, ozone, and small amounts of methane. These emissions can contribute to the contaminants in highway runoff due to the removal from the atmosphere by rain and other climatic conditions. While GHG's are an essential part of the earth's atmosphere, human activities have significantly increased the amount of greenhouse gases. Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide have increased over 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%. This appears to have increased the global temperature between 0.3 and 0.6 degrees Celsius. The projection is for continued rise. Temperature increases cause changes in ocean levels, changes in precipitation events, and a host of other environmental problems. Global climate change is an accepted fact and action for drastic and immediate reductions in GHG emissions, especially carbon dioxide are called for. Motor vehicles account for over 15% of CO2 emissions; therefore any increase in the world vehicle fleet using fossil fuels is a major concern (WRI, 1999).

While this study does not deal directly with greenhouse gas emissions and the environmental impacts associated with this issue, the predicted changes in rainfall patterns due to global warming may render past rainfall data less useful for predictions. Also, carbon dioxide emissions account for 83% of British Columbia's contribution to greenhouse gases (GHG), and transportation is the single largest CO_2 source (BCMELP, 1998).

5.3 Other Sources of Highway Runoff Contaminants

A variety of other sources contribute to contaminants in highway runoff. Sources associated with the pavement itself include bitumens contained in the pavement rising to the surface due to natural heating with subsequent pick-up by vehicles and/or highway runoff. Pavement wear due to general deterioration, vehicle breaking, and normal or excessive wear from vehicle traffic or from heavier vehicles is another source. During the paving process, asphalt is vulnerable to leaching prior to completion of the final curing. Some types of pavement, such as open-graded asphalt that has more open pores for water dissipation, assists in reducing splash from the pavement and subsequently reduces the amount of material washed from passing vehicles.

Road maintenance is a source of contaminants, especially operations with repeated applications of large amounts of material. Road de-icing compounds such as salt and sand contribute to runoff contaminants. Also, maintenance activities include fertilizer and herbicide applications for roadside vegetation which also contribute to runoff. Although less toxic paints are becoming available, road-line painting can contribute contaminants depending upon the type of paint used, and when the painting is undertaken. Removal of these painted lines can also contribute to contaminants if not undertaken correctly.

Dustfall is also an important source of contaminants. Substances may be carried from sources away from the highway and deposited on the road. Similarly, rainfall may contain various contaminants that were generated away from the road. Land-use activities near the road contributes contaminants by way of air emissions/dustfall or by direct deposit of contaminants by vehicles and/or loss of material, or by the migration of contaminants from the surrounding area.

Other sources of contaminants can originate from watercourses or outfalls that drain into highway runoff ditches and carry contaminants from other sources into the highway runoff. This includes illegal dumping of materials into watercourses. Also, debris and other materials are illegally dumped on highway rights-of-way or thrown from vehicles and subsequently carried into the highway runoff.

Other potential contributors to highway runoff contaminants are bridges and other structures along the road. These structures rust and/or leech substances that end up in highway runoff. Also, certain bridge maintenance activities such as washing, sandblasting, and painting may also contribute materials to runoff water.

Thus, there are numerous sources of highway runoff contaminants both directly from vehicles and the roadway, and indirectly from a variety of sources.

5.4 Highway Runoff Quality and BCMoTH Issues

In the planning, design, and construction of new highways, BCMoTH has perceived highway runoff to be a problem of quantity, not quality. This has begun to change in recent years with the incorporation of water quality ponds on the new Vancouver Island Highway and some ad hoc installations of water quality treatment for some highway projects. However, the lack of a policy or specific operational strategies in BCMoTH has led to poor integration of water quality solutions for public highways.

The importance of this issue is highlighted because many roadside ditches in the GVRD and along BCMoTH highways contain, or support, salmonid species including the endangered coho salmon. The increased awareness of this species and its presence in roadside ditches has led fishery agencies to require water quality improvements for highway runoff. BCMELP (1999b) reports that of the 1750 known stormwater outfalls in the GVRD, over half discharge into fish bearing waters. Salmonid species are protected under the *Federal Fisheries Act* and it is unlawful to "deposit or permit the deposit of any deleterious substance into water frequented by fish" (*Federal Fisheries Act*, Section 35(2)). Potential penalties in severe cases, or those cases where due diligence is not demonstrated, carry a fine of up to $1,000,000 and/or imprisonment for a period of three years.

The fishery agencies require some form of highway runoff filtration on specific BCMoTH projects, but not on all projects. While it is unlikely that BCMoTH would be charged for allowing highway runoff containing contaminants to enter fish-bearing waters, it is still incumbent upon BCMoTH to ensure due diligence is demonstrated. In the future, questions are likely to be raised regarding this issue, especially as the fishery resource becomes increasingly threatened.

The issue of stormwater management quantity and quality is identified in the Land Development Guidelines (Chilibeck, 1992). These guidelines are intended to "protect fish populations and their habitat from the damaging effects of land development activities." The guidelines were written with specific reference to salmon, trout and char, but they also apply to other species of fish (Chilibeck, 1992). Given the growing concern over all types of environmental impacts, agencies are indicating that strict enforcement is inevitable.

Transportation agencies must show leadership in this area, and be proactive in developing reasonable strategies that work for the agency, and for the environment. When this issue becomes heavily regulated, an important opportunity for innovation and creativity may be lost. It is more difficult, and more expensive, to be reactive rather than pro-active.

5.5 Impacts Due to Highway Runoff Quality

In addition to the complexity and the variability of the constituents present in highway runoff, there are uncertainties concerning the impact to humans and other living organisms. In order to make effective decisions on the management of highway runoff with only limited scientific information, an ecological risk assessment must be used. This type of assessment examines the probability of an adverse effect occurring, and predicts if there is a reasonable possibility of increased risk (International Joint Commission, 1995). Given an absence of a proper risk assessment for highway runoff, it is proposed that the precautionary principle is an appropriate management approach at this time. The precautionary principle recognizes that:

> Where there are threats of serious or irreversible [environmental] damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (Rio Declaration, 1992).

This important concept applies to highway runoff because the variety and nature of the contaminants found in highway runoff are recognized as potential threats to the environment. Highway runoff is a complex mixture of substances and not a natural addition to the environment, therefore it will likely have adverse ecological effects. When undertaking any management practice, evaluation is necessary to ensure practical application.

Cobb (1999) looked at the cost of environmental damage from vehicles and highway runoff. He states that while the automobile has provided mobility and freedom, it comes with environmental, social, economic and political costs. Cobb feels that the reason for the costs is that private vehicles have not been required to bear the full burden of their use. After analysis of the various subsidies, Cobb (1999) estimates that in the United States in one year the costs imposed on third parties total over $184 billion – or about $1.60 per gallon of fuel consumed. Another significant cost included in Cobb's report is impacts to water quality from acid rain, runoff of deposited chemicals from pavement, herbicide spraying along rights-of-ways, and road salt. Of the $184 billion total, Cobb (1999) estimates about $6 billion can be attributed to water quality impacts. With respect to potential costs in Canada based on this figure and the difference in Canadian and United States populations, this would translate into $600 million. British Columbia's portion of this total could be as high as $60 million.

In a study undertaken for BCMoTH on the monetization of environmental impacts of roads, Bein (1997) estimates that the water pollution costs of roads are $0.01 per vehicle kilometre traveled. This figure is based on a number of studies completed in the United States and Washington State. The total estimate aggregated from these studies amounted to US$28.8 billion per year (Bein, 1997). He then divided this figure by the total number of vehicle kilometres traveled to get a figure of $0.01. If hydrological impacts are added to the total, Bein (1997) suggests that the number should be doubled to C$0.02.

Even if only a portion of these estimates are correct, serious questions can be raised about what can be done to alleviate these costs and the associated environmental impacts.

6.0 POTENTIAL SOLUTIONS TO THE PROBLEM

The goal of highway runoff quality management is to ensure that highway runoff quality concerns are avoided as far as possible within reasonable and practical parameters. These parameters must be based on specific and relevant criteria.

Burch et al (1985) defined three categories of management practices for avoiding contamination from highway runoff: (1) source management measures, which include planning measures, design and operations, and regulations, (2) post deposition measures, including street cleaning, ditch maintenance, debris removal, accident/spill cleanup, and (3) post-runoff measures, including designed and built-in vegetative controls, wetlands, detention ponds, filtration systems, flow attenuation/alteration, and catch basins.

These three categories represent a fundamental hierarchy. The most efficient measure is to first utilize source management measures to prevent the contamination (WSDOT, 1997). If source measures are impractical, or ineffective, then post-deposition and/or post-runoff measures are required.

Often, a combination of management measures is the most effective. While there is little doubt that source management is the long-term objective, transportation agencies must also recognize the existing problem and therefore post-deposition and post-runoff measures must be utilized immediately.

All of the highway runoff management measures identified by Burch et al (1985) can be described as Best Management Practices (BMPs). This term is widely used in pollution control and is commonly used with stormwater or highway runoff quality. While specific definitions of BMPs exist depending upon application, the following one from BCMELP (1999b) will be utilized for this study.

> BMPs are practices that describe the best available methods for preventing the transfer of contaminants from human activities into water. They can be policies, procedures, guidelines, technologies, or codes of practice that explain how to conduct an activity in a manner that prevents pollution. BMPs might be developed by a level of government, an industry association, or by a club or organization.

The following sections will address each category individually, and examine specific BMPs relevant to the category. To remain consistent with current literature, management measures will be referred to as controls.

6.1 Source Control Best Management Practices

Source control BMPs are activities, prohibitions of practices, managerial practices, maintenance procedures, or physical, structural or mechanical devices or facilities that prevent contaminants from leaving highway right-of-way. Source controls are the most appropriate way to avoid generating contaminants, as this eliminates the need for removal by other methods (WSDOE, 1997). While it makes sense to stop the problem at source, it is difficult to measure the effectiveness of many source controls, and some are difficult to implement.

Source controls include the use of biodegradable oils and greases in vehicles to eliminate the impact of petroleum based products, the use of alternative fuels such as ethanol, hydrogen, or natural gas, or the use of electric powered vehicles. Multi-modal or other forms of mass transportation that reduce automobile traffic are another source control. With fewer vehicles on the road, there will be less contaminated runoff, and other environmental benefits including a reduction in GHG emissions.

BCMELP (1999b) identifies the following key components of their non-point source Action Plan as they relate to source control BMPs:

- education and training;
- prevention at the site;
- land-use planning, coordination;
- assessment and reporting;
- economic incentives that may include: credit support incentives (loan assistance), property tax breaks, density bonuses, buy-back and retrofitting incentives (water efficiency), recognition incentives (e.g. corporate image), grants, environmental user fees, performance bonds, tickets and fines;
- legislation and regulation.

6.1.1 Categories of Source Control Best Management Practices

This section looks at broad categories of source controls as described by the American Society of Civil Engineers (1998), WSDOT (1997), Onwumere (1999), and others. These categories were originally developed for urban stormwater, but have been modified to reflect appropriate categories for highway runoff. Specific examples are provided for each category. The examples are intended to be comprehensive and representative but not exhaustive.

The following categories represent the range of source control BMPs currently available.

- **Public Education and Participation**: is described as a practice intended to change the way the general public utilizes opportunities to reduce the use of transportation modes that affect the amount or type of contaminants in highway runoff.
  - vehicle-use reduction;
  - staggered working hours (less congestion);
  - car pools;
  - bicycles;
  - walking; and
  - Mass transit.

- **Land Use Planning and Controls**: practices aimed at reducing runoff and discharge of contaminants through highway runoff, and are most effective when applied during the planning phase of new highways.
  - stream buffer requirements – no construction is permitted within a specified distance from stream channels without proper mitigation of impacts;
  - floodplain restrictions – development is restricted within specific floodplain boundaries;
  - steep slope restriction – no clearing or grading of steep slopes;
  - non-tidal wetland protection;
  - protection of environmentally sensitive areas;
  - upland and riparian tree cover requirements;
  - waterway disturbance permits;
  - open space requirements; and
  - Minimization of the amount of impervious surface area.

- **Materials Management**: includes control of the use, storage, and disposal of chemicals that could pollute runoff.
  - handling practices;
  - safer alternative products;
  - recycling depots; and
  - Material storage control.

- **Spill Prevention and cleanup**: includes programs to reduce the risk of spills during outdoor handling and transportation of chemicals and other materials.
  - vehicle spill control;
  - spill response training; and
  - Hazardous material identification.

- **Illegal Dumping controls**: is aimed at preventing individuals and businesses from dumping waste products into the drainage system.
  - used oil recycling;
  - storm drain system signs;
  - ordinances;
  - public education programs; and
  - Enforcement.

- **Roadway maintenance**: This applies to the removal of contaminants from paved areas and the maintenance of runoff quality controls that exist within the drainage system.
  - detention and infiltration device maintenance;
  - storm channel and creek maintenance;
  - vegetative controls;
  - elimination/reduction or use of environmentally friendly de-icing agents; and
  - Use of non-toxic and/or environmentally friendly cleaning and paint removal materials.

- **Illicit connection controls**: This applies to preventing, by ordinance, and eliminating by discovery and removal, connections to the drainage system that discharge any material except stormwater runoff. Specific examples include:
  - illicit connection prevention; and
  - Illicit connection – detection and removal.

- **Vehicle Reduction or controls**: this broad category of programs or controls is aimed at reducing the number of vehicles on the roads, traffic congestion, and the impact of vehicles.
  - alternative fuel vehicles;
  - elimination of oil-based products;
  - change in windshield washer solvents;
  - removal of gasoline and diesel;
  - improved vehicle inspection and maintenance;
  - toll installation;
  - intelligent traffic systems (ITS);
  - public transit;
  - high occupancy vehicle (HOV) lanes;
  - traffic laws and regulations (speed limits, traffic volume control and vehicle mix);
  - emission program/policy;
  - litter control by-laws; and
  - Park-and-ride.

6.1.2 Current use of Source Control Best Management Practices in BC Ministry of Transportation and Highways

The BCMoTH is involved in many highway runoff source controls activities and initiatives. While not all are directly related to this issue, many have important linkages or implications that by design or default constitute a source control. In some cases the source control is imposed by legislation or regulation, but in most cases it is an internal action or activity.

6.1.2.1 Public Education and Participation

In this area, the ministry participates in the Go Green committee. This committee involves partners working together on programs to educate British Columbia residents on their commuting choices and on ways to help improve air quality (URL www.gogreen.com). The commuting choices range from public transit, to cycling or walking. While it is difficult to measure the actual success of these programs in reducing vehicle usage, education may help to promote the issue, which may result in fewer vehicles on the road. Any reduction in vehicle use is considered a source control as the impacts associated with that portion of vehicle use are eliminated.

6.1.2.2 Land Use Planning and Controls

Under the category of land use planning and controls, the BCMoTH uses the applicable provisions under the Land Development Guidelines (Chillibeck, 1992) developed jointly by the BCMELP and the Fisheries and Oceans Canada (FOC). These guidelines are for the protection of aquatic resources. One of the recommendations from the Land Development Guidelines is vegetative buffers around streams of up to 30m for commercial development and 15m for residential/commercial development. These guidelines are used when planning new highway construction, and/or repairing or upgrading existing highways. While they are not officially mandated, they are widely used in the GVRD and are commonly referred to when environmental approvals are issued for construction or rehabilitation work. Specific stream buffers may become legislated when the regulations for the new *BC Fish Protection Act* are adopted. Along highways, these types of buffers can provide some water quality improvements to the local streams or watercourses by filtering highway runoff. BCMoTH maximizes the size of these buffers wherever possible and have undertaken a program to mark stream buffers with "no mowing" signs in an effort to retain riparian vegetation.

BCMoTH has also developed a highway environmental assessment process (HEAP) to assess the environmental impact of proposed highway projects (BCMoTH, 1997b). This process involves the early identification of environmental issues and concerns, and sets out consultation procedures with environmental agencies. Avoidance of environmental impacts is the primary focus, and compensation is then set out for unavoidable impacts. Although highway runoff is not specifically detailed in this document, it is implicit that it can be identified as an issue to be considered. Identification occurs in the early planning and design stage, and therefore is considered a form of source control.

6.1.2.3 Materials Management

In materials management several programs are in place to address highway runoff contamination. One example is the construction of special salt sheds to house road de-icing salts. Many ordinary storage facilities allow salt to leach into groundwater or surface water which causes contamination. In areas where this is a problem, specially designed salt sheds that prevent the release of salt are constructed. There are four sheds installed in the GVRD maintenance yards and two more will be completed in 2000/2001.

Within all areas of BCMoTH there is a growing understanding that many maintenance products and materials used are toxic to the environment. Thus, the BCMoTH Products Committee considers the potential environmental impact of all products when choosing a specific product. In certain cases, products require special handling, or an alternative, less toxic product will be used. Known carcinogens, such as lead, have special containment requirements and require special considerations when handling around watercourses. An example of this is bridges that were painted with a lead based paint. As the removal and disposal of lead-based paint is extremely costly, less toxic paint and better painting/containment methods are continuously investigated for potential use.

6.1.2.4 Roadway Maintenance

In roadway maintenance, BCMoTH is actively looking for ways to reduce the amount of roadway de-icing agents spread on the roads. Icing on highways is a serious safety hazard and the standard tool to remove or prevent ice build-up has been salt. When applied down to temperatures of –6C, salt lowers the freezing point of water breaking the ice-pavement bond. BCMoTH has examined the potential for reducing the amount of salt used on roads for de-icing and/or anti-icing with a technique known as pre-wetting (Gooding et al, 1994). The results indicate that salt reductions of up to 32% showed equivalent or better results than de-icing using only non-pre-wetted granular salt. By utilizing this technique, it is expected that BCMoTH will save up to 1100 tonnes of salt in one year in the GVRD area (based on estimated salt usage from 1994/95). Unfortunately, due to the high cost of converting standard salt and sanding trucks, pre-wetting is still not a standard practice on BCMoTH highways.

6.1.2.5 Vehicle Reduction or Controls

In the area of vehicle reduction or controls, BCMoTH has a number of initiatives in place. In the GVRD region, high occupancy vehicles (HOV) lanes have been implemented on a number of major routes. The HOV lanes allow vehicles with two or more occupants exclusive use of a dedicated lane that allows them to bypass the general traffic lanes, and reduce travel time. By encouraging two or more occupants in a vehicle the number of vehicles on the road will be reduced and speed will increase. This would then decrease the environmental impact with fewer vehicles. While the full HOV network has not yet been implemented, portions have been constructed and they appear to provide for fewer vehicles on the road.

Another initiative of the BCMoTH is the investigation of intelligent transportation systems (ITS). ITS has a broad range of applications in the transportation area and generally refers to the integration of all modes of transportation systems that move people and goods. For example, ITS can include the synchronization of complex traffic signal systems to reduce congestion. There are economic and environmental benefits from the use of ITS. It utilizes technologies to efficiently, and effectively, use current highway infrastructure in an attempt to delay or offset additional roads to accommodate traffic. By doing so, a subsequent reduction in vehicle emissions will translate into less atmospheric deposition and less material carried away by highway runoff. In the BCMoTH, the use of ITS is in the research and development stage and no permanent installation has been undertaken, although clearly BCMoTH will move in this direction in the future.

Another initiative within BCMoTH is related to the fleet of vehicles the ministry operates and the type of fuels utilized. It is now policy that all new cars and light duty trucks the Ministry acquires must either use natural gas or be equipped with the capability to use natural gas and/or conventional fuels. The duel fuel option was allowed because in many parts of British Columbia, natural gas for vehicles is not readily available. This policy was implemented under an initiative of the BCMELP in an attempt to address environmental issues associated with gasoline usage.

6.2 Post-Deposition Best Management Practices

These types of BMPs are used to remove contaminants after they have been deposited on the road surface, and prior to them being removed by runoff. These BMPs are widely utilized, but vary in application and effectiveness. They are generally physical practices or procedures as opposed to policies, rules, regulations, or prevention measures. They include:

- street sweeping/cleaning;
- ditch maintenance (removal of accumulated sediments and pollutant laden vegetation);
- debris removal and accident clean-up;
- catch basin cleaning; and
- Storm drain flushing.

6.2.1 Current use of Post-Deposition Best Management Practices in BC Ministry of Transportation and Highways

Post-deposition BMPs are currently undertaken on highways under the jurisdiction of BCMoTH and include pavement surface cleaning (including drainage appliance cleaning), ditch and watercourse maintenance, bridge structure cleaning, accident clean-up, catch basin cleaning and storm drain flushing (BCMoTH, 1995).

For paved surface cleaning, the current maintenance standard specifies cleaning methods which include power sweeping on non-curbed two lane paved roads and four-lane paved roads, and a pick-up broom or a flusher truck on freeways or other paved surfaces. Cleaning with anything other than a pick-up broom must be carried out on wet pavement just after a rainfall, or after pre-wetting the pavement to keep the dust to a minimum. All four-lane and urban highways are cleaned every 120 days, or if free draining of the pavement is impaired and cleaning is required to restore drainage. It is difficult to assess the efficiency of street sweeping, but it is not regarded as efficient for picking up finer particles that tend to carry heavy metals (Onwumere, 1999).

When undertaking ditch and watercourse maintenance, care must be taken to ensure that only vegetation which impedes proper drainage is removed, and that the work is undertaken during times of the year when there is minimal impact on fishery resources. Improper ditching can cause siltation concerns and beneficial vegetation can be removed unnecessarily. Any contaminated material removed must be disposed of properly. BCMoTH is currently working toward structuring ditch and watercourse maintenance programs to deal with these issues.

Bridge structure cleaning is undertaken by BCMoTH to remove accumulated debris and materials from the deck and superstructure of bridges (BCMoTH, 1995). This type of BMP prevents further deterioration of water quality by removing accumulated material before it is washed off the structure. Typically, the majority of material is removed by sweeping, collecting, and proper disposal of collected material. Once this is accomplished, many bridges are simply washed in the spring to remove any small amounts of debris and de-icing salts remaining. Cleaning is also required to protect the structure from rust. In undertaking this cleaning, different methods of debris containment are utilized based on bridge cleaning guidelines published by the Department of Fisheries and Oceans (Samis et al, 1991).

Accident clean-up is a standard part of BCMoTH's responsibilities, and is undertaken to ensure that spilled materials and substances are quickly and effectively contained, removed, and disposed of (BCMoTH, 1995). The Provincial Emergency Program directs the clean-up of hazardous spills and assists in identification of spilled substances and direction of clean-up methods.

Also, standard maintenance practices to remove accumulated trapped debris are undertaken for catch basin and storm drain cleaning and flushing (BCMoTH, 1995). This type of BMP helps to prevent materials from entering watercourses as well as assisting in maintaining proper highway drainage.

As can be seen, BCMoTH employs BMPs that are directed toward standard road maintenance activities, but which also serve to remove material before it enters watercourses.

6.3 Post-Runoff Best Management Practices

Post-Runoff BMPs are the most widely utilized of highway runoff quality control methods. Because of their popularity a lot of information is available. This popularity may be due to the fact that specific types of end-of-pipe BMPs have been successfully utilized by municipalities and others for large-scale stormwater water quantity control. Also, there is a long history of utilizing water quality ponds for treatment (ASCE, 1998). Consequently, the familiarity and history of use of post-runoff BMPs has translated into widespread use.

6.3.1 Post-Runoff Best Management Practices in Washington State

Washington State was chosen for more detailed examination because of its similarities to the GVRD in specific aspects such as the climate, rainfall, and general topography, and because they are leaders in this particular aspect of highway runoff treatment. In the WSDOE (1999) report on Stormwater Management in Washington State, several runoff treatment options are identified. From these, specific options are suggested for use with street and highway projects. The following section provides an overall sense as to how WSDOE sees the potential application of the treatment options. The WSDOE information is reproduced here in some detail because of the common application parameters that may assist in decision-making.

- ***Wetpool BMPs***: These ponds contain a permanent pool of water, and provide treatment by allowing settlement of particulates, biological uptake, and vegetative filtration.
- ***Biofiltration BMPs***: These use vegetation in conjunction with slow and shallow-depth flow for runoff treatment. They include swales and filter strips.
- ***Oil/Water Separator BMPs***: These mechanical devices are designed to remove oil floating on top of the water. They also include catch basin inserts, linear sand filters, and wetvaults modified with baffles.
- ***Pretreatment BMPs***: These wetpools or other BMPs can be used prior to runoff entering another BMP. Most types of runoff treatment BMPs provide pretreatment, including sand filters, biofiltration swales, and filter strips.
- ***Filtration***: These structures utilize various media such as sand, perlite, zeolite, and carbon for contaminant removal.
- ***"On-line" Systems***: These systems combine runoff treatment and flow control – they usually use wet pools.

WSDOE proposes the use of specific stormwater treatment options for streets/highways and other areas such as parking lots, residential areas, and commercial/industrial sites which are based on pollutant sources. These are presented in Table 7. For clarity, only the portion relevant to streets/highways is reproduced in Table 7.

While the categories shown in Table 7 are fairly broad, WSDOE (1999) has attempted to define both the amount and the type of contaminants expected for two potential levels of treatment. An enhanced treatment option is provided because basic treatment options do not meet water the quality objectives of the new Federal Clean Water Act (WSDOE, 1999). The proposed use of "treatment trains", meaning a combination of basic treatment options in series, may not be the only way to achieve enhanced treatment but may be a viable alternative in some situations. This type of train has limited application for streets and highways except in exceptional situations where sufficient space and money are available. Money and space are two critical considerations for determining BMPs for highways.

Table 7: Stormwater Treatment Options for Streets/Highways

Pollutant Sources	**Contaminants of Concern**	**Basic Treatment BMP**	**Enhanced Treatment BMP**
ADT>25000 (roads) *or* ADT>15000 (intersection)	Oil and Grease (high concentration for intersections), Total suspended solids, Zinc	Oil Water Separator/Innovative Alternative + Bio Filter/Wet Pond *or* Presettling Basin/Wet Vault +Oil Water Separator/Innovative alternative +Bio Filter/Wet Pond	Oil Water Separator/Innovative Alternative + Bio Filter/Wet Pond/Wet Vault/Constructed Wetlands + Sand Filter/Media Filter
ADT<25000 (roads) *or* ADT<15000 (intersection)	Low concentration Oil and Grease, Total suspended solids, Zinc	Bio Filter/Innovative Alternative	Innovative Alternative/Bio Filter/Wet Pond/Constructed Wetlands/Wet Vault + Sand Filter/Media Filter
Ultra-urban	High concentration Oil and Grease, Total suspended solids, Zinc	Oil Water Separator/Innovative Alternative *or* Wet Vault + Oil Water Separator/Innovative Alternative/Bio Filter	Oil Water Separator/Innovative Alternative + Sand Filter/Media Filter

Source: WSDOE, 1999. Adapted from Table 1.1 p.14.

6.3.2 Best Management Practices in the Washington State Department of Transportation

Washington State Department of Transportation (WSDOT) identifies several structural stormwater management practices. These include:

- **Biofiltration Swales**: These shallow, flat-bottomed vegetated channels remove contaminants by filtration, particle settling, infiltration, adsorption, and biological uptake. They provide water quality treatment and conveyance of stormwater. They are used extensively by WSDOT.

- **Vegetative Filter Strips**: Also known as vegetative buffer strips, are designed to accept sheet flow from the roadway which then passes through a section of gently sloping, vegetated land surface before entering a ditch or discharging to another BMP. These strips can be any type of vegetation from grassland to forest, but dense vegetation and shallow unconcentrated flow gives the best pollutant removal. Provides removal by detention, filtration, and infiltration.
- **Wet Pond**: A facility that treats stormwater by utilizing a permanent pool of water to remove contaminants through sedimentation, biological uptake, and plant filtration. Its ability to provide quantity control makes it a viable option in many situations.
- **Nutrient Control Wetpond**: Similar to a wet pond but includes an additional cell with a shallow wetland area that enhances the vegetative uptake of nutrients. Useful when discharging water to nutrient sensitive waterbodies.
- **Wet Vaults/Tanks**: Underground storage facilities that have two baffled cells with a permanent pool of water which acts as a settling basin. Only used when other methods are not available or practical. Not as effective for pollutant removal as open ponds because of the lack of detention time, vegetation, or soils.
- **Water Quality Infiltration Ponds**: A facility that provides water quality treatment by storing runoff and infiltrating it into the soil. Treatment is provided through particle settling, biological uptake, filtration, sorption, chelation, and ion exchange processes. Generally used for drainage areas of 2-50 ha.
- **Infiltration Trenches, and dry Vaults**: For drainage areas less than 2 ha an infiltration trench or a dry well is more suitable than an infiltration pond. A dry well is a deep slotted concrete sump designed to allow stormwater to infiltrate through well-drained soils.
- **Dry Pond**: A facility that contains excess runoff in a detention basin, and releases the water at a set rate through engineered orifices. May remove a small amount of stormwater contaminants, but is typically a water quantity control device. It must be used in conjunction with another BMP.

The following selected BMPs are considered experimental by WSDOT (1997) who is committed to testing and implementing any that prove feasible.

- **Ecology Ditch**: This is a modification of the standard biofiltration swale design for use in areas with very flat gradients (<2%). To provide drainage, the sub-base consists of highly pervious sand/gravel (ecology mix), and a perforated pipe subsurface drainage system. This sand base provides some filtration benefits. Solids removal will be between 25% to 90% depending upon the intensity of the rain event. To-date WSDOT has not constructed or tested this ditch.
- **Ecology Embankment**: This strip of roadside embankment receives stormwater runoff via sheet flow from the roadway. It is intended for use in areas where wetlands, riparian buffer zones, buildings, or structures do not allow sufficient space for conventional BMPs. It uses the same type of sub-base and under drain as the ecology ditch to provide infiltration of precipitation.
- **Ultra-Urban/Confined Space BMP**: This two-cell concrete vault can be covered or exposed; it consists of a sedimentation chamber and a filtration/sorption/ion exchange chamber. It is designed to remove solids and dissolved contaminants. A field test is underway beneath the Lake Union ship canal bridge in Seattle using a filtration medium of gravel separated by a geotextile.
- **Polyacrylamide (PAM) Coagulation/Flocculation Agents for Enhancing Pollutant Removal Rates in Detention Ponds**: These products are designed to enhance the removal rate of suspended solids by coagulation and flocculation and are applied by irrigation methods. PAM has the advantage that it is relatively non-toxic (still under testing) at the dosage required to permit good flocculation. WSDOT is still in the testing phase. However, they report that results look promising.
- **Biofiltration Swale Design Enhancements**: These include the addition of level spreaders for the water flow to ensure the water sheets off the road, and also incorporates wetland plants to increase the detention time of the water and enhance sediment removal.
- **Stormceptor™ Vault**: This commercially available dual-level vault is designed to enhance the removal of sediments and oil. Anticipated solids removal is about 85% at low flow rates with significantly less at high flow rates.
- **Swirl Concentrator Systems**: These multilevel baffled vaults induce centrifugal forces to create a low velocity zone in the center which allows sediments and debris to be deposited out of the opening. Designed to be used where dissolved constituents are not the primary concern.

WSDOT (1997) also commits to providing stormwater treatment for existing impervious surfaces based on at least four criteria:

- **The amount of WSDOT right-of-way available to construct BMPs.** Purchasing new right-of-way is always extremely expensive, and in many circumstances impossible because of existing land uses, urbanization, shorelines, wetlands/buffers etc.;
- **Configuration of existing hydraulic conduits.** In some cases, particularly when the stormwater drainage system has been extensively culverted, it may be extremely expensive and/or logistically and physically difficult to excavate and install new drainage systems to re-route stormwater to a new or expanded BMP;
- **Topography.** In many situations the topography and road grade may preclude draining stormwater runoff to a new BMP because WSDOT uses gravity as the driving force for all of its drainage systems and BMPs; and
- **Cost.** When the cost of treating impervious surfaces significantly raises the project budget, it is unlikely to be categorized as practicable.

Also of interest for BCMoTH are reports on activities in Washington State to inventory (1) all stormwater outfalls (sites where highway runoff is collected and discharged to surface water, groundwater, and municipal storm sewers), (2) all existing stormwater structures providing quantity and quality control; and (3) all potentially illicit off-site connections to the WSDOT drainage system (Shaftlein, 1996). This is in response to requirements under the US Federal Clean Water Act and municipal stormwater regulations that require WSDOT to complete all practicable BMP projects for stormwater treatment for highways with an ADT of 50,000 or greater by December 31, 2005 , and for all other highways by December 31, 2015. From two years (1993-95) of field survey in several Puget Sound counties, over 3068 outfalls were characterized. These were then prioritized based on several categories including water body type, beneficial uses of the water body (human and ecological), pollutant loading (directly related to ADT), percentage contribution of highway runoff to the watershed, cost/pollution benefit, and values trade-off. Over 25% of the outfalls were characterized as high priority for treatment. These outfalls were those:

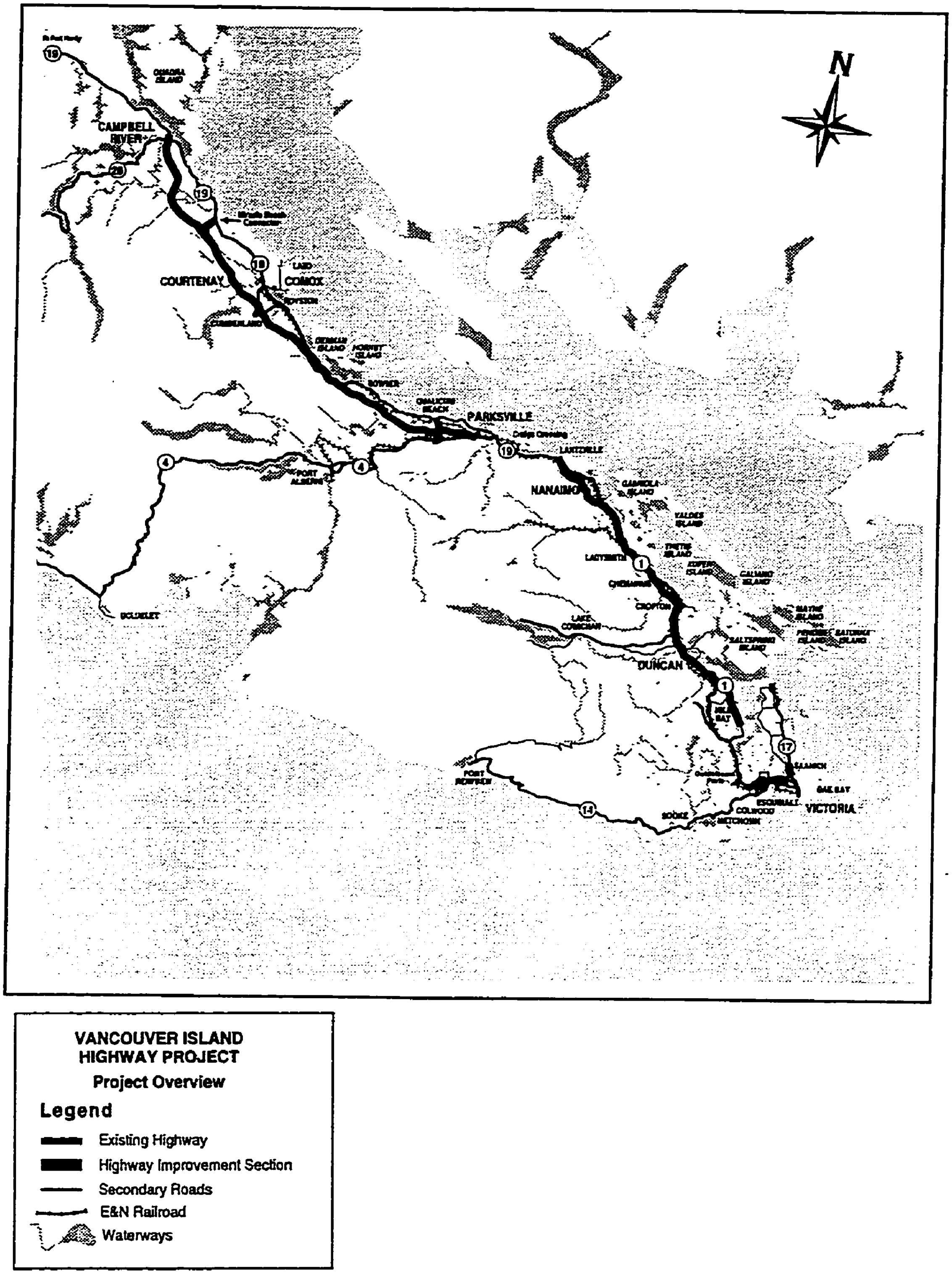
- on the highways with the highest ADT:
- threatening drinking water supplies;
- draining storm trunk systems and discharging to headwater streams;
- discharging dry wells to a sole source aquifer; or
- Presenting a significant risk of hazardous spills entering a water supply.

6.3.3 Current Use of Post-Runoff Best Management Practices in BCMoTH

The BCMoTH does not currently have specific requirements to include post-runoff quality controls in either new construction projects or in the rehabilitation of existing roads and bridges. As a result, the work completed in this area is entirely ad hoc. In many cases, specific BMPs were constructed at the request of environmental agencies. In other cases, BCMoTH took the initiative to construct BMPs even though they were not required by regulation. Also, by default, rather than by design, many BCMoTH highways retain vegetated ditches and/or buffers that act serendipitously as filters for the highway runoff. These provide significant water quality benefits. Finally, in some cases, ditches have been enhanced to further filter highway runoff. However, there are no specific programs or practices in place.

A current example where a BCMoTH project implemented some form of water quality treatment is the Vancouver Island Highway Project (VIHP). This project began in early 1990, and was intended to improve travel safety and relieve congestion between Victoria and Campbell River on Vancouver Island, B.C. The project involves the construction of approximately 150km of new four-lane highway and the upgrading of 80 km of existing sections of highway. Water quality was a consideration during the planning and design of the highway and VIHP chose to re-use construction sediment ponds as water quality treatment ponds.

Figure 2: Overview of Vancouver Island Highway Project



Source: URL: http://www.th.gov.bc.ca/bchighways/VIHP/182107.gif

The alignment for the VIHP crosses major rivers and streams upstream of water intakes and important fish hatcheries. During the construction phase of several sections, VIHP made extensive use of sediment ponds to control and capture sediment-laden runoff water from the construction sites. Typically, these ponds are designed for removal when construction is completed. The VIHP recognized that converting some ponds to an artificial wetland allows them to function as permanent water quality ponds. Initially, 22 ponds were identified for conversion. This included eight surface-flow wetlands, six sub-surface flow wetlands, six wet ponds and two infiltration basins. Eight ponds have been converted, and the remainder are slated for conversion within the next two years.

As part of the VIHP program, a multi-year monitoring program was put in place to determine the pond's effectiveness and to assess maintenance costs. Unfortunately, this monitoring program has been placed on hold due to budget pressures and this has jeopardized the future of the program. Also, the location of the ponds was selected by suitability of conversion to a wetland, rather than by suitability of location for water quality purposes. While the ponds are located near streams, they do not necessarily capture a large amount of direct road runoff and this severely limits their ability to generate large-scale water quality improvements. However, in most areas, grassed roadside ditches or swales are part of the general road design and these help filter highway runoff and provide some water quality improvement.

On a smaller scale, individual projects have utilized mechanical oil/water separation techniques, french drains, constructed wetlands, wet detention ponds, enhanced vegetation in highway ditches, and vegetative buffer strips. In all cases, these were installed to address specific concerns raised by outside agencies regarding water quality. One project that designated some form of water quality treatment is the rehabilitation of the Lions Gate Bridge in Vancouver, British Columbia. Roadway runoff on the portion of the road that travels through Stanley Park will be collected and treated using oil/water separators and biofiltration marshes with eventual discharge into the ocean.

Unfortunately, in most cases there is not any specific follow up to determine the effectiveness of many of these methods under local conditions. This causes a reliance on information from other geographic locations that may, or may not be useful, and there is no accumulation of relevant local data and experience. This, in turn, makes it difficult to justify one method over another, and it limits the ability to recommend any form of water quality treatment when real benefits cannot be proven. It is critical then that any strategy includes a mechanism for evaluation and testing. It is also critical that appropriate BMPs are selected according to local conditions.

7.0 SELECTING APPROPRIATE BEST MANAGEMENT PRACTICES AND THEIR APPLICATION AND LIMITATIONS

Many jurisdictions have examined the use of BMPs for both general stormwater quality management and for highway runoff quality management. This section will examine specific information from the New Jersey Department of Transportation (NJDOT), the Colorado Department of Transportation (CDOT), and other jurisdictions that have attempted to refine the process of selecting appropriate BMPs.

7.1 New Jersey Department of Transportation

The NJDOT (1996) commissioned a research study to evaluate the potential of existing and innovative pollution control technologies for highway runoff for use in four distinct physiographic regions of New Jersey. For the purposes of this report, only the results for the Coastal Plain region are examined as this is the most comparable region to the GVRD physiographically. The evaluation for all regions utilized the following criteria:

- Performance;
- Cost;
- Maintenance;
- failure rates;
- site requirements;
- contributing watershed drainage area; and
- Regional space availability.

Table 8 summarizes all of the pollution control technologies that NJDOT reviewed in their study, and indicates their assessment of the effectiveness for the Coastal Plain region. This information is directly applicable to BCMoTH as the physiography is similar to the New Jersey Coastal Plain area, and the techniques that are effective in this area are useful in considering for the BCMoTH. NJDOT rates oil grit separators, compost storm filters, infiltration trenches/basins and porous pavement as not effective and the reasons for this rating are also relevant for BCMoTH's situation. Similarly, the technologies rated as effective would be good choices for BCMoTH as well.

In addition to the information in Table 8, the New Jersey Department of Environmental Protection (NJDEP, 1994) examined the removal efficiencies of various stormwater management practices and related these to the factors affecting them. This information is shown in Table 9. This information helps to further define the most effective stormwater management practices and assess them against specific contaminants.

Table 8: Assessment of selected Pollution control technologies for the New Jersey Coastal Plain region

Pollution Control Technology	Effective	Not Effective	Comments
Oil Grit Separators		x	Not considered to be effective in any region due to poor performance, high maintenance, and high cost
Compost Stormwater Filters™		x	Cannot be retrofitted if it fails. Requires more study before it can be recommended
Constructed Wetlands	x		Considerations include appropriate site selection for soil and space considerations (among others).
Dry Detention Ponds	x		Requires deep soils, large depth to groundwater.
Wet Detention Ponds	x		Requires deep soils, clay loam liner/layer.
Multiple Pond System	x		Can be modified to work efficiently in any environment. Most efficient combination for the region needs to be researched.
Sand Filters	x		Adaptable for the region and are most suitable in urban areas with severe space restrictions. More research required on efficiency, maintenance, cost, and disposal of used sand. Will not be implemented until these issues are addressed.
Infiltration Trenches/Basins		x	Not acceptable in any region due to short life span, high maintenance requirements, and inability to be applied in cold climates.
Grass Swales	x		Can be effective and economical. Grass swales have historically been used in highway medians. Detention time affects pollutant removal capacity. Require minimal maintenance and have an indefinite life with proper maintenance.
Porous Pavement		x	Not acceptable in any Region due to high failure rates and ponding problems due to clogging of pores.

Source: Adapted from NJDOT, 1996.

Table 9: Removal Efficiencies of Stormwater Management Practices

Management Practice		**Removal Efficiency (%)**						**Factors**
		TSS	TP	TN	COD	Pb	Zn	
Infiltration basin	Average	75	65	60	65	65	65	Soil infiltration rate Size of watershed Seasonal variation Soil organic carbon
	Range	45-100	45-100	45-100	45-100	45-100	45-100	
Infiltration Trench	Average	75	60	55	65	65	65	Soil infiltration rate Storage volume Proximity to water table
	Range	45-100	40-100	0-100	45-100	45-100	45-100	
Grass Filter Strip	Average	85	90	No data	85	No data	85	Size of watershed Vegetation: height and thickness Dimensions Slope Velocity of inflow
	Range	70-100	70-100		65-100		60-100	
Grass Swale	Average	60	20	10	25	70	60	Vegetation: height and thickness Soil characteristics Slope Check dams
	Range	0-100	0-100	0-40	25	3-100	50-60	

Table 9: Continued

Management Practice		Removal Efficiency (%)						Factors
		TSS	TP	TN	COD	Pb	Zn	
Porous Pavement	Average Range	90 80-95	65 65	85 80-85	80 80	100 100	100 100	Soil infiltration rates Soil characteristics Continuous maintenance Slope Frost penetration Traffic load
Sand Filter	Average Range	80 60-95	50 0-90	35 20-40	55 45-70	80 30-90	70 50-80	Size of watershed
Wet Pond	Average Range	60 0-90	45 10-85	35 5-85	40 5-90	75 10-95	60 10-95	Detention time Proximity to water table Size of watershed Pool volume Vegetation: height/thickness
Constructed Wetland	Average Range	75 0-100	45 0-95	25 0-85	55 5-95	85 5-95	40 0-80	Vegetation: height/thickness Detention time Size of forebay Soil characteristics Dimensions

Source: Adapted from NJDEP, 1994.

Note:
TSS = Total suspended solids
TP = Total Phosphorous
TN = Total nitrogen
COD = Chemical Oxygen Demand

By utilizing the information from Table 8 and Table 9, the removal efficiencies of grass filter strips, grass swales, wet ponds, and constructed wetlands identify these practices as the best choices for potential use by BCMoTH.

7.2 Colorado Department of Transportation

The Colorado Department of Transportation (CDOT) published an Erosion Control and Stormwater Quality Guide (1995) which aids designers, field and maintenance personnel, consultants, and contractors in designing and implementing measures to protect water quality. In this guide, they have specifically distinguished between erosion, sedimentation and highway runoff as they affect water quality. All three issues are considered integral for a comprehensive stormwater management plan.

CDOT (1995) utilizes a variety of BMPs that are similar to those already described. One difference in their approach is that they include an evaluation of limitations of selected structural BMPs as they apply to new and existing highways. These limitations are in addition to limitations that may be imposed due to specific site conditions such as soils, topography etc. Table 10 is reproduced from CDOT (1995). While the categories are quite broad they do provide some distinction between options.

Table 10: Appropriateness of structural Best Management Practices and highway configuration

Management Measure	**Planned Highway Configuration**				**Existing Highway Retrofit**			
	Inter Change	Elevated	At-Grade	Lowered	Inter Change	Elevated	At-Grade	Lowered
Grass Lined Swale	High	Low	High	Low	Med	Low	High	Low
Grass Buffer Strip	Med	Low	High	Low	High	Low	High	Low
Detention Basins	High	Med	Med	Low	Med-to High	Med	Med	Low
Constructed Wetlands	Med to High	Low	Low	Low	Low-to Med	Med	Med	Low
Infiltration Basin	High	Low	Low	Low	Med-to High	Med	Low	Low
Infiltration Trench	High	Med	Med	Low	Med-to High	Med	Med	Low-to Med

Source: Adapted from CDOT (1995).

This information determines the most appropriate method for a particular style of highway configuration. For example, grass lined swales are in the high category for both planned and existing at-grade highway configurations, but for interchanges the planned configuration rates higher than the existing. This is just the opposite for grass buffer strips. This suggest the effectiveness of the management measure is dependent on the specifics of the highway configuration. BCMoTH must take this into consideration during the planning and design of both new and existing highways.

This proves useful when examining grass swales and grass filter strips, especially when combined with the information from NJDOT and NJDEP on removal efficiencies. Given that these BMPs are prevalent along most highways (although there may be the need for some design modifications), it can be seen that the removal efficiencies and the appropriateness are such that they become a viable option for highway runoff quality control.

7.3 Comparative Assessment of Methods of Stormwater Management

In a report generated by Westwater Research (McDonald et al, 1997) which looked at the Brunette River watershed in the GVRD, a comparative assessment of various methods of stormwater management was developed as part of the discussion section of the report. Table 11 presents the data collected for the various BMPs under consideration, and looks at the pollutant removal effectiveness, longevity, potential application, environmental concerns, wildlife habitat potential, comparative costs, and provides some comments where appropriate. This Table provides a good representation of the wide variety of variables needed to select appropriate BMPs.

Table 11 provides some interesting information with respect to urban BMPs and their potential application for highways. The first four options: wetlands, extended detention ponds, wet ponds, and multiple pond systems are all rated moderate to high in contaminant removal but all require a large drainage area to be effective. Also, they will generally require a large area to accommodate the pond(s). These options should not be ruled out however, for use along highways, as there can be large enough areas to accommodate these ponds in places such as at interchanges and with wide medians. It may also be possible to redesign ponds so that they are elongated rather than oval or round. The elongated shapes tend to fit more easily into a highway linear corridor and may provide similar removal rates. There are no known studies which investigated this issue.

Infiltration trenches/basins and porous pavement are shown to have a high failure rate within the first five years. Also, their application is severely restricted due to soil conditions and potential sediment input.

There is also a small risk of groundwater contamination as they are designed to infiltrate contaminated water through the soil. While the infiltration trenches/basins are moderate in contaminant removal effectiveness and the porous pavement is rated as high, the high failure rate and high maintenance costs would not make either a good choice for general use on highways.

The sand filter is considered to have a long life span (20+ years) and can provide moderate to high pollutant removal, although it can be costly to construct and maintain. There are possibilities for this type of BMP in localized situations, but each site must be carefully analyzed.

Water quality inlets are presumed to have a low contaminant removal effectiveness and the cost can be high. There appears to be little application for their highway use.

The last two BMPs, grassed swales and filter strips are the most prevalent type of BMP along highways, due to the fact that most standard highway designs utilize grassed swales or ditches where available, and avoid curbs and gutters (which perform no contaminant removal function). These types of BMPs may be limited in highly urbanized areas where there is no available area to be vegetated. Both of these BMPs are considered unreliable, and have low to moderate removal effectiveness. They are, however, low in cost and are recommended as one element of a BMP system. Although they have low to moderate removal capacities, they are widely used.

Many factors affect the use or non-use of a particular BMP. Each one has its merits in specific circumstances; the best solution is to combine methods. The proper combination provides effective removal with minimal maintenance.

Table 11: Comparative Assessment of Various Methods in Stormwater Management

BMP Option	Pollutant Removal Effectiveness	Longevity	Potential Application	Environmental Concerns	Wildlife Habitat Potential	Comparative Costs	Special Considerations
Wetlands	Moderate to High depending upon design	>20 years	Interchange areas Areas with enough space Environmentally Sensitive areas	May attract wildlife Stream warming, natural wetland alteration	High	Marginally higher than wet ponds	Recommended with design improvements and with the use of micro-pools and wetlands
Extended Detention Ponds	Moderate but not always reliable	>20 years but frequent clogging and short detention common	Interchange areas Areas with at least 10 acres of drainage area	Possible stream warming and habitat destruction	Moderate	Lowest cost alternative in price range	Recommended with design improvements and with the use of micro-pools and wetlands
Wet Ponds	Moderate to high	<20 years	Widely applicable but requires drainage area greater than 2 acres	Possible stream warming, trophic shifts, habitat	Moderate to high	Moderate high compared to conventional	Recommended with careful site evaluation
Multiple Pond Systems	Moderate to high, redundancy increases reliability	<20 years	Widely applicable	Selection of appropriate pond option minimizes overall environmental impact	Moderate to high	Most expensive pond option	Recommended

Table 11: Continued

BMP Option	Pollutant Removal Effectiveness	Longevity	Potential Application	Environmental Concerns	Wildlife Habitat Potential	Comparative Costs	Special Considerations
Infiltration Trenches	Presumed moderate	50% failure rate within five years	Highly restricted (soil, slope, groundwater, area sediment input)	Slight risk of groundwater contamination	Low	Cost effective on smaller sites. Rehab costs can be high.	Recommended with pretreatment and geo-technical evaluation
Infiltration Basins	Presumed moderate if working	60-100% failure within five years	Highly restricted (see infiltration trench)	Slight risk of groundwater contamination	Low to moderate	Construction cost moderate, but rehabilitation cost high	Not widely recommended until longevity improved
Porous Pavement	High (if working)	75% failure rate within 5 years	Extremely restricted (traffic, soils, groundwater, slope, area sediment input)	Possible groundwater impacts, uncontrolled runoff	Low	Cost-effective compared to conventional asphalt when working properly	Recommended in highly restricted applications with careful construction and effective maintenance
Sand Filters	Moderate to High	<20 years	Applicable for small developments	Minor	Low	Comparatively high construction costs and frequent maintenance	Recommended with local demonstration
Water Quality Inlets	Presumed low	<20 years	Small highly impervious catchments (<2 acres)	Resuspension of hydrocarbon loadings. Disposal of hydrocarbon and toxic residuals.	Low	High, compared to trenches and sand filters.	Not currently recommended as a primary BMP option.
Grassed Swales	Low to moderate but unreliable	<20 years	Low density development and roads	Minor	Low	Low compared to curb and gutter	Recommend with check dams as one element of a BMP system
Filter Strips	Unreliable in urban settings	Unknown, but may be limited	Restricted to low density area	Minor	Moderate if forested	Low	Recommend as one element of a BMP system

Source: Adapted from McDonald, 1997

7.4 Uptake and Filtration (Biofiltration) of Metals/Nutrients by Aquatic Plants

An important aspect of determining the pollutant removal effectiveness of many BMP options that utilize plants such as constructed wetlands, planted wet ponds, and grassed swales and vegetated filter strips, is the ability of specific plants to filter contaminants. This filtration takes place by direct capture of sediments and debris, or by biological processes where plants actually uptake the contaminant. The term biofiltration is often used when describing this process. Yu et al (1995) who completed extensive work on this subject for the United States Highway Administration, describes biofiltration as, "...the process of filtering polluted water through vegetation to remove pollutants. Pollutants may be removed through settling, infiltration, and adsorption to sediment and vegetation." Microbial action and the effect of ultra violet radiation from the sun can also contribute to pollutant breakdown and removal.

While this type of process, in the form of vegetated wetlands, is well utilized and documented for the treatment of point sources from municipal, industrial and agricultural effluents, there is little information on its use for highway runoff treatment (Ellis et al, 1994). The critical difference between these applications and their use for highway runoff (or stormwater runoff in general) is in retention time and size of the facility. If retention time and facility area are increased, then a substantial improvement in contaminant removal can be achieved. This is made possible by allowing for additional settling time and increasing the potential uptake by the plants directly, and by supply oxygen to the microorganisms which then use biochemical oxidation to remove contaminants (Ellis, et al). Typically, these are criteria that are limited in highway applications, so therefore it must be determined if biofiltration is a reasonable assumption in these situations.

As noted, Yu et al (1995) and a series of researchers who worked with Yu, investigated the use of biofiltration for highway runoff in the state of Virginia (Yu and Kaighn, 1995; Yu and Liao, 1995; Kaigan and Yu, 1995). The two primary objectives of their study was to determine the contaminant removal effectiveness of grass swales and buffer strips for the parameters of total suspended solids (TSS), chemical oxygen demand (COD), total phosphorous (TP), and zinc (ZN). A secondary objective was to determine the ability of some wetland species to remove the same contaminants using laboratory tests.

7.4.1 Grassed Swales

Yu et al (1995) chose two grassed swales along U.S. Route 29, one south of Charlottesville, Virginia with an ADT of 50,000 (29S), and one north of Charlottesville with an ADT of 30,000 (29N). Both of these sites were mowed. The 29N site was mowed once every two weeks and the 29S site was only mowed four times. Yu et al (1995) surmized that better removal capacities would result for the swale which was mowed less frequently (29S) but this was not the case. They attributed this finding to several factors, including the increased lateral flow of highway runoff into the 29S swale because of barrier damage. The swales were designed only to permit flow entry at the inlet and exit at the end of the 30m long swale. In fact, the 29S swale only allowed flow to enter laterally and this did not allow for runoff to travel through the swale. With this increased flow, the removal efficiencies were all less than 30%. In contrast, the rates for the 29N site were all over 90%.

Even if flow is not considered, the 29N site (the one mowed every two weeks) still showed better removal rates than the 29S site (mowed less frequently). Rather than this being a function of mowing frequency, Yu et al (1995) attributed this difference to the existence of a check dam at the outlet of the 29N swale which significantly improved the settling capability of this swale. Also, during this study, they observed that there was an anomaly from expected concentrations in the amount of suspended and dissolved contaminants at the inlet of the 29N swale. They found significantly more dissolved contaminants than suspended. They solved this by examining the edge of pavement runoff and realizing that the runoff went through a vegetated buffer strip before entering the swale. They concluded that this buffer strip was removing the larger particles, and the contaminants usually associated with these particles, before the water was reaching the swale.

This work came to several important conclusions and recommendations including:

- checkdams in swales can increase contaminant removal by ponding runoff and allowing contaminants to settle and the water to infiltrate;
- highway runoff is characterized by contaminants in suspended form which settle out of solution;
- buffer strips and grassed swales with check dams should be used where possible for contaminant removal; and
- Infiltration is a significant factor in contaminant removal.

These are important conclusions as the value of vegetation for filtering ability, and the vegetation that we typically see along the roadsides can be easily modified to provide substantial water quality benefits.

Lorant (1992) conducted field tests on Ontario's highway 401 to study the effects of grassed or impervious solid surface channels on highway runoff quality. Lorant (1992) chose to measure over 36 different water quality parameters ranging from pH, through conductivity, phosphorous and nitrates, calcium and magnesium, to heavy metals and hydrocarbons. While Lorant (1992) states that the results of the study were compromised due to the drastic reduction in the size of the grassed swale because of essential road work that took place, he found on average the contaminant concentrations were 63% lower than for the paved surface.

He concluded that grassed swales can provide a reasonable level of protection to receiving waters. He considered that grassed drainage channels do not require a lot of work to create, but they can reduce pollutant loads by three basic methods.

- Reduction of the volume of runoff by infiltration through the grassed surface into soils;
- Reduction in the flow velocity and, therefore, the runoff capacity to carry sediment; and
- Possible reductions in the amount of certain pollutants in the runoff by contact with grass blades and the resulting uptake of chemicals by the grass.

It is interesting to note that the California Department of Transportation (Caltrans) has recently undertaken a long-term statewide stormwater management program to be completed in 2002 which will look at cost-effective ways to treat highway runoff. They are considering a large number of BMPs similar to those undertaken by WSDOT, but they also have a number of biofiltration swales and strips that they are examining. The sites are quite varied throughout California and the results of this work will add considerably to the knowledge of these types of structures.

7.4.2 Uptake by Wetland Plants

The secondary objective of the study by Yu et al (1995), was to test specific wetland plant species to determine their potential for uptake of contaminants. This capability is commonly referred to as a mechanism of biofiltration, but the actual extent to which it occurs and the effect on water quality is not well documented for highway runoff situations. The work on this topic is detailed in the study by Yu and Liao (1995).

The species studied were cattails (*Typhia latifolia*), reeds (*Phragmites sp.*), and bulrushes (*Scirpus*) and the contaminants and properties monitored included total phosphorous (TP), orthophosphate (OP), Zinc (Zn), total suspended solids (TSS), and chemical oxygen demand (COD). The testing was undertaken in buckets and not in an actual field installation, although it was intended that field trials will follow. The study used varied retention times from 1 day to 21 days. The following conclusions were drawn from the study:

- the removal rates of the vegetation was highest for OP and lowest for COD;
- sedimentation was more important for TP, OP, and COD than for Zn;
- retention time was important for contaminant removal for TP, OP, and Zn but less so for COD;
- for COD reduction, the presence of vegetation was insignificant for all of the data;
- sedimentation and adsorption accounted for 40 to 60% of the contaminant removal and the plant uptake rate and suspended particle adsorption accounted for 40 to 60%;
- bulrush has the highest values of plant uptake and suspended particulate adsorption for TP and OP, and Zn;
- a combination of bulrush and cattail should be used; and
- The reeds were invasive and not recommended.

Yu and Liao (1995) report that these results are consistent with literature reviewed for their study. The results are significant in that they show that biofiltration by plant uptake does occur, but primarily it is a function of retention time. Without adequate retention time (i.e. more than four or five days) the main removal mechanisms are sedimentation and adsorption and plant uptake plays a less prominent role.

8.0 BRITISH COLUMBIA MINISTRY OF TRANSPORTATION AND HIGHWAYS CASE STUDIES -CONSTRUCTED POST RUNOFF BEST MANAGEMENT PRACTICES IN THE GVRD

This section presents two examples of post-runoff BMPs along BCMoTH highways in the GVRD. The first is a constructed wetland scrubber marsh that was designed to treat runoff from an upland urban area and from a section of urban highway (Jones, 2000). The second case study presents the results of a water quality monitoring program recently undertaken for a Ph.D. study (Onwumere, 1999) on two roadside sections, one along the Trans Canada highway and another along a major freeway in the GVRD. These two studies provide valuable information.

8.1 Constructed Wetland Scrubber Marsh Case Study

The marsh was part of a specific portion of the mitigation works undertaken by BCMoTH for a bridge project known as the Johnston/Mariner Connector. Because the bridge project was deemed by the environmental agencies to negatively impact the productive capacity of a fish-bearing stream, BCMoTH and the Department of Fisheries and Oceans Canada developed a Habitat Mitigation Agreement (HMA) that defined several environmental mitigation measures. These included re-vegetating the riparian area of the impacted creek, constructing two stormwater detention/treatment ponds within the bridge corridor, and constructing an off-channel fish habitat complex consisting of two stormwater treatment basins and an overwintering rearing channel for juvenile salmonids (BCMoTH, 1997a). Also, as part of the HMA, in the third year after construction, a one-year water quality sampling and analysis of the inlet and outlet of the stormwater treatment basins associated with the rearing channel was undertaken. This sampling was completed in January, 2000. However, prior to discussing the water quality testing and results, it is useful to fully describe the works constructed.

8.1.1 Treatment Basin Details

The treatment basins and the rearing channel are shown in Figure 3. As can be seen, water enters from a culvert system at the top of the treatment basin. This runoff is the main supply for a constructed fish-rearing channel. The marsh was designed to improve the water quality before it entered the rearing channel. The majority of this water is surface drainage from a low density residential development with a catchment area of approximately 12,700 square metres with some contribution from direct highway runoff. This catchment area is approximately 50 percent impermeable surfaces (rooftops and paved areas and 50 percent permeable surfaces (grassed areas). This drainage empties into a grass swale on the side of a major highway and is then conveyed under the highway by a culvert and into the treatment basin. The ADT for this section of highway is estimated at 42,000 (BCMoTH, 1999).

The treatment basins (described as scrubber marshes) consist of an initial marsh which is separated from the main scrubber marsh by a rock berm. In turn, the main scrubber marsh is separated from the rearing channel by another rock berm. The initial marsh is designed as the primary settling area for coarse particles, and the main scrubber marsh is designed to remove waterborne contaminants. The primary removal mechanisms for contaminants are physical processes such as sedimentation, filtration, absorption and adsorption. Secondary mechanisms include uptake and conversion of contaminants by plants and microbial degradation (Jones, 2000).

Within the wetted portion of the forebay marsh the only plantings consisted of approximately 600 tubers of cattail (*Typha latifolia*). The main scrubber marsh was planted with three alternating strips of wool grass (*Scirpus cyperinus*), soft rush (*Juncus effusus*), and small-fruited bullrush (*Scirpus microcarpus*). In total about 1200 15 cm by 15 cm tufts of wool grass and soft rush were planted, along with a thousand pieces 20 cm by 20 cm of small-fruited bullrush sod. Also, a mixed marsh bench was created along a portion of the channel with skunk cabbage (*Lysichiton americanum*) and small-fruited bullrush.

8.1.2 Water Quality and Testing Results

The water quality testing consisted of nine consecutive monthly tests (May, 1999 through to January, 2000) for the following water quality parameters:

- temperature;
- dissolved oxygen;
- pH;
- conductivity;
- total suspended solids;
- nitrate;
- total oil and grease;
- hydrocarbon oil and grease;
- ammonia nitrogen;
- ortho phosphorus; and
- Sulphide.

The samples were collected at the outlet of the culvert just as it entered the forebay scrubber marsh, and just prior to the outlet of the main scrubber marsh (See Figure 3). Temperature, pH, and dissolved oxygen were measured at the site then the sample was sent to the laboratory for analysis. In addition to the water samples, sediment samples were taken at the same locations and sent for laboratory analysis of the following parameters:

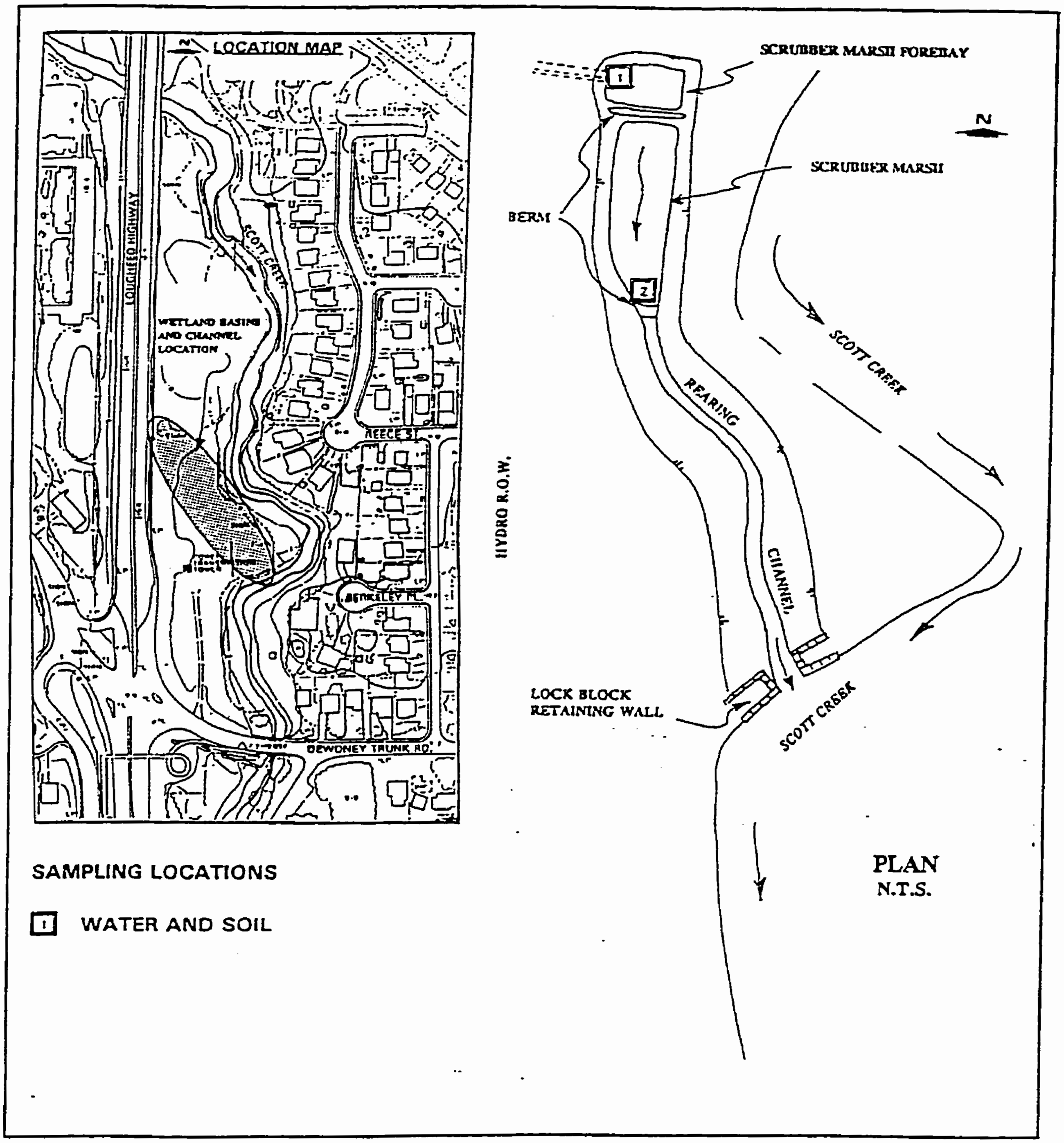
- total extractable hydrocarbons;
- polycyclic aromatic hydrocarbons; and
- Heavy metals.

After analysis, concentrations of water borne contaminants are less at the outlet of the marsh than at the inlet (Jones, 2000). Similarly, metals in the sediment samples show the same distribution. However, while many of the parameters for water borne contaminants show reductions for specific months, there is not a consistent trend. For example, total suspended solids (TSS) for October, 1999 were approximately 16 mg/L at the inlet and 7 mg/L at the outlet. However, in the first three months, the outlet TSS readings were all higher at the outlet yet no explanation is given. All other TSS readings by Jones (2000) showed a reduction at the outlet, although some of the reductions were slight, especially when the inlet TSS readings were below 6 mg/L. It appears that the higher the initial TSS loading, the greater the potential removal, until an apparent threshold is reached.

With the exception of July, October, and January, conductivity showed a decline between the inlet and the outlet samples. The largest change was in August which showed 146 µs/cm at the inlet and 100 µs/cm at the outlet. The highest conductivity reading was in June at 160 µs/mg. There does not appear to be a relationship between high readings and high rates of contaminant removal, and no discussion of this is provided by Jones (2000).

For total oil and grease, only two months (October and January) showed a reduction between the inlet and the outlet. For all other months, except December which showed an increase (no explanation provided in the report) oil and grease passed through the marsh unchanged. Further study and analysis are required to provide any definite conclusions. However, flow-through of these contaminants would be expected in this situation. Potentially, the reductions might be attributed to the capture of the substances on the surfaces of the vegetation and the increases due to the re-release during storm events, but those possibilities require further study. Hydrocarbon oil and grease were below the detectable limit of 2 mg/L for all months tested.

Figure 3: Treatment basin and rearing channel.



Source: Jones, 2000.

In the sediment samples, Zinc was found in high concentrations at the inlet sampling point. Jones (2000) attributed this to the possible leaching of zinc from the galvanized coating on the culvert that discharges into the scrubber marsh. This potential zinc source is strengthened by the findings of Budgen et al (1999). In a study for Canadian Heritage Parks Canada at Fort Rodd Hill in Victoria, British Columbia, Budgen et al (1999) concluded that elevated zinc levels in stormwater runoff from the study site were directly attributed to the galvanized culverts. The high levels of zinc found by Jones (2000) appear to be localized and are not exiting the marsh. No explanation was given for this other than the observation that the marsh appears to be "removing" the zinc. For all other metals analyzed in the soil sediment samples (a total of 25) only manganese consistently showed an increase from the inlet to the outlet of the main scrubber marsh. All other metals detected showed a decrease from inlet to outlet. In some cases, such as lead, the removal rate approached 90%. These findings are consistent with contemporary literature which shows wetlands are moderate to high in removal of heavy metals.

In this study, Jones provides an interesting observation regarding the grass swale that collects the water before it enters the culvert which then discharges into the scrubber marsh. Jones (2000) surmizes that the swale provides some water quality treatment by slowing velocities and facilitating removal of contaminants through physical processes. This observation is consistent with Onwumere's (1999) conclusions for grass ditches.

Testing did not include sampling of plant material to test for plant uptake of nutrients and other contaminants. The limitations of this study make specific conclusions on the effectiveness of selected plant material for water quality improvements difficult. Overall, however, the results show interesting trends that may be applicable to other installations of this type. More in-depth analysis needs to be undertaken.

8.1.3 Summary

Scrubber marshes appear to perform a useful function in removing, or containing, contaminants. The most predominant removal mechanisms are physical processes such as sedimentation, filtration, and adsorption. This is shown in testing the removal of heavy metals. These metals typically adhere to sediment particles. The removal of other waterborne contaminants was generally much less than for the heavy metals. Oil and greases were essentially not removed at all. In general, the findings were consistent with the literature. Unfortunately, the study of the grass swale was not within the scope of this study; it appears the swale may be a benefit to contaminant removal. The study provided some guidance on the removal rates for waterborne contaminants and for the potential design of future scrubber marshes.

8.2 Grassed Ditch - Case Study

Onwumere (1999), as part of his Ph.D. study (in press), studied highway runoff along two roadside sections of BCMoTH highways in the GVRD (see map). He produced some excellent data for the two locations that includes typical constituents of highway runoff in the specific area and, for one location, direct measurements of the pollutant removal effectiveness of a grassed ditch. He also analyzed road dirt, soil sediment, and grass clippings for their metal content.

The intent of the study was to:
- evaluate pollutant concentration variation with seasons;
- investigate the effectiveness of grassed drainage ditches in pollution reduction;
- evaluate different trace metal removal mechanisms-soil/sediment adsorption versus biological plant uptake;
- to contribute information required for developing BMPs by the BCMoTH in the GVRD; and
- To recommend planning approaches, design criteria, implementation and potential positive effects on highway runoff water quality.

The choice of study sites, based largely on convenience, was relevant. Table 12 summarizes the characteristics of each site based on specific site selection criteria. The Burnaby site discharges into the Brunette River which flows into the Fraser River and eventually into the Pacific Ocean. The Richmond site is not close to a major river, but the drainage eventually reaches the Fraser River.

As discussed previously, highway ditches in the GVRD can be important fish-bearing areas for both salmonids and/or cutthroat trout. Therefore, the Richmond site may be critical in terms of water quality impacts.

Onwumere (1999) analyzed the collected highway runoff for several parameters including suspended solids, metals, oil and grease, pH and conductivity. The specific metals were chosen because of their common association with vehicular-related urban/highway stormwater runoff pollution (Onwumere, 1999). The pH measurements were taken as toxicity of most metals increases with an increase in pH. The amounts of de-icing agents (commonly sodium chloride and/or calcium chloride) were not measured directly, but electrical conductivity was used to indicate the concentration of dissolved mineral salts. The higher the reading, the more de-icing agent present. Oil and grease, and total suspended solids are common constituents of highway runoff. Table 13 summarizes the concentrations in highway runoff and includes the freshwater maximum allowable concentration (MAC) guidelines from the Canadian Water Quality Guidelines (Environment Canada, 1987/95).

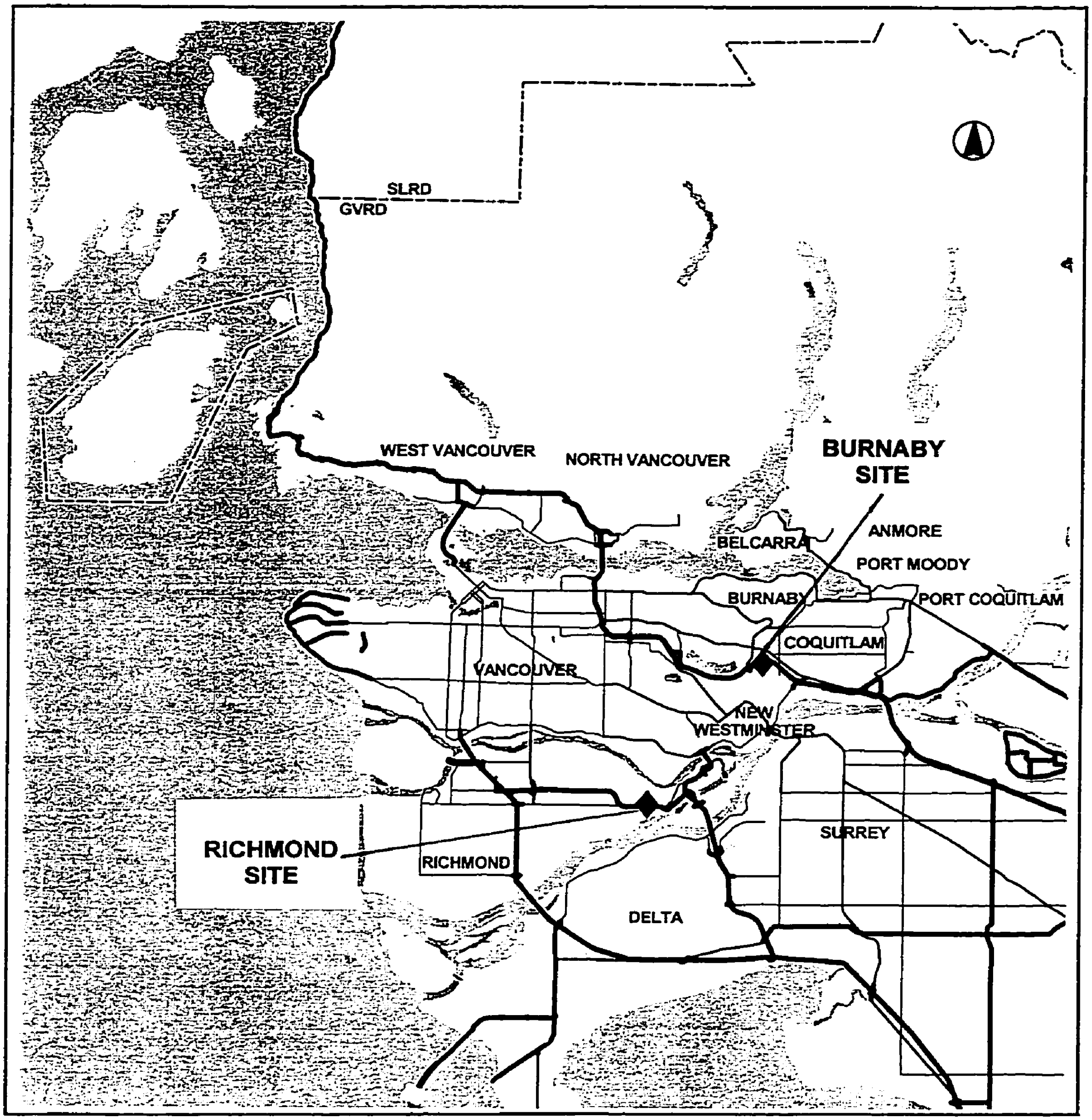
The concentration of contaminants at the Burnaby site, after they had passed the grassed ditch, were lower for all parameters except Ca and EC. Onwumere (1999) speculates that the increase in Ca may have been due to Na $^{2+}$ replacing Ca $^{2+}$ ions at the cation exchange sites in the soil and making them unavailable. This would also account for the increase in electrical conductivity. The overall pollutant removal efficiencies from highest to lowest are:

- TSS>Fe>Zn>Pb>Mn>Cu.

Onwumere (1999) found that these efficiencies were statistically significant for all contaminants except Mn. Overall, the author indicates that the grass drainage ditch was effective in pollutant reduction and these results were comparable or better than those in other similar research studies. Daphnia bioassays conducted by Onwumere (1999) on the runoff collected at these sites showed that the grass filtered highway runoff was non-toxic to aquatic species.

In addition to highway runoff sampling, road dirt, soil sediment, and grass clipping samples from both sites were analyzed for Cr, Cd, Ni, Cu, Zn, Pb, Fe, Mn, and Ca. . All of the listed parameters were found in the samples in varying concentrations, but Fe, and Zn had the highest concentrations of all of the metals. Soil sediment showed similar results to the road dirt analysis, but the highest concentrations were found near the end of the grassed drainage ditch. Onwumere (1999) suggests this is consistent with the findings that metals tend to adhere to finer sediments, and finer sediments settle out as the water moves down the ditch (provided the water velocity was sufficiently reduced). For the grass clippings a similar pattern to the sediment loading was found. Onwumere (1999) provides the same explanation for this result as he does for the sediment samples. He hypothesizes that the sedimentation process removes metals from the flowing water, and plant uptake removes the metals from the soils.

Figure 4: **Burnaby and Richmond site locations**



Source: Adapted from Onwumere, 1999.

Table 12: Characteristics of chosen sites based on selected criteria.

Criteria	Location	
	Burnaby	**Richmond**
Type	Urban	Urban
ADT (Average Daily Traffic)	89,2000 Vehicles	41, 967 Vehicles
Total Precipitation per Year	1,845 mm	1,233 mm
Drainage Area % Paved	100%	100%
Surface Pavement/Deck Type	Concrete/Asphalt	Concrete/Asphalt
Contributing Highway Surface Area	1,418 m^2	912 m^2
Watershed Area	5.8 ha	0.5 ha
Number of Lanes	2	2
Curb/Barrier in Place	Yes	Yes
Type of Section	Elevated	Elevated
Surrounding Land Use	Residential/Commercial/Industrial	Agricultural/Industrial
Regular Highway Maintenance	Yes	Yes
Ditch Drainage Surface Type	Grass	Grass
Date Highway Opened	1964	1989

Source: Adapted from Onwumere (1999).

Table 13: Average Water Quality Parameter Concentrations and their Guidelines.

Parameter	**Burnaby**		**Richmond**	**Established Guidelines for Freshwater Aquatic**
	Initial Concentration	**Concentration at 30m (Pollutant Removal Efficiency)**	**Initial Concentration**	
Cr (total)	--	-- (N/A)	--	0.002-0.02
Cd (total)	--	-- (N/A)	--	0.002-0.0018
Ni (total)	--	-- (N/A)	--	0.025-0.15
Cu	0.07	0.04 (48%)	0.04	0.002-0.004
Fe (total)	5.55	2.12 (64%)	3.37	0.30
Zn	0.25	0.12 (56%)	0.16	0.03
Mn	0.13	0.11 (49%)	0.12	N/A
Pb (total)	0.12[a]	-- (N/A)	0.48[a]	0.001-0.007
Ca	5.91	8.27 (N/A)	6.15	N/A
Oil/Grease	24.9	N/A (N/A)	9.25	N/A
TSS	155	50.6 (77%)	74.8	<10% of background levels>100 mg/L
pH	6.82	6.56 (N/A)	6.49	6.5-9.0
Electrical Conductivity (EC) (µS/cm)	190	281 (N/A)	125	N/A

Source: Adapted from Onwumere (1999).

Notes:

-- Undetectable limits
N/A – Not Available
[a]-- Only two detectable concentrations were observed

8.2.1 Summary

Onwumere (1999) concluded that grassed highway ditches are an important highway runoff feature, and that by running stormwater runoff from highways through grassed drainage ditches, the runoff water can be economically and effectively treated. The primary agents in removing trace metals were soil/sediment adsorption and biological plant uptake processes. This is based on the higher metal concentrations found in the soil sediment and grass clippings at 30 m along the drainage ditch than at the inlet to the ditch. This indicates that road dirt is a significant mechanism for pollutant transport and should be considered in selection of BMPs. The study provided useful information regarding grassed drainage ditches and contaminant removal, specific to the GVRD.

9.0 TOWARD AN INTEGRATED SOLUTION

Highway runoff quality is a complex problem, requiring complex and not singular solutions. There is the potential to reduce or eliminate the problem if highway runoff quality becomes an integral part of the way highways are planned, designed, and operated.

Transportation agencies, such as BCMoTH, must develop a process by which highway runoff quality can be effectively dealt with. This requires the integration of the concept of sustainability within the highway development process. This can start at the policy level and be developed through specific procedures. The following sections address sustainability and highways, and define a draft policy and specific highway design procedures that will assist in this integration process.

9.1 Sustainability and Highways

The concept of sustainable development, defined by WCED (1987) as "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs", has been generally accepted. Smith et al (1993) examined sustainable practices in the context of water resource management and the degree to which it had been implemented within the context of urban stormwater management. While they saw some progress towards defining sustainable water management, there were few practical local examples.

Transportation agencies must adopt the problem at a local level and work towards solutions. The ultimate goal toward a more sustainable and holistic view of transportation must include immediate issues. While transportation agencies are constantly challenged to look to the long-term future of transportation, including the incorporation of multi-modal forms of transportation, the stark reality is that transportation is currently dominated by fossil fuel vehicles and likely this will not change substantially in the near future. The increase of natural gas, propane, and electricity are an improvement and the development of other alternative fuels such as hydrogen fuel cells may not be far off. There is, however, still a need to deal with the existing issues.

One strategy for improvement is to incorporate water quality management into the highway right-of-way (ROW). Then highway runoff quality can be implemented at the operational level. Effective implementation should include policies as well as the empowering technical and operational specialties with the necessary knowledge and skills to address the problem.

9.2 Draft Policy on Highway Runoff Quality

To effectively incorporate highway runoff quality management within any organization, an overall policy is required. The following is a draft policy for BCMoTH, complete with a brief explanation.

HIGHWAY RUNOFF QUALITY MANAGEMENT POLICY (DRAFT)

The Ministry recognizes that highway runoff contains numerous contaminants that lower the water quality in the receiving body. Thus, the Ministry supports and undertakes efforts to prevent and reduce contaminants in highway runoff from being deposited on the road, at the source and before the highway runoff leaves the highway right-of-way.

1. The Ministry will promote policies to encourage an integrated multi-modal transportation system.

2. The Ministry supports agencies, municipalities, and other government organizations that promote vehicle-use reduction, and alternative transportation methods through public education.

3. The Ministry supports and encourages the use of practical alternative fuels in automobiles. All new Ministry automobiles and light trucks will use alternative fuels.

4. The Ministry continues to support annual emissions testing of all cars and trucks in the LFV and will consider expanding the program province-wide.

5. The Ministry supports efforts to reduce contaminants in fuels utilized for transportation.

6. The Ministry supports vehicle-use reduction methods such as Intelligent Traffic Systems (ITS), High Occupancy Vehicle (HOV) Lanes, commuter trains, SkyTrain, and buses. The Ministry continues to develop and promote new methods of moving people efficiently and practically.
7. The Ministry implements and investigates appropriate highway runoff water quality treatment on all new highways where highway runoff may impact sensitive environmental areas.
8. The Ministry implements highway runoff water quality treatment to the best extent practical on all modifications of existing highways that add over 500m^2 of new impervious surface, and where highway runoff impacts sensitive environmental areas.
9. The Ministry monitors all new highway runoff water quality systems on a continuing basis to ensure they are providing effective treatment.
10. The Ministry investigates and implements new methodologies and treatment systems on an ongoing basis.
11. The Ministry regularly monitors this policy and reviews it every 3 years.

9.2.1 Discussion

The intent of this policy is to recognize highway runoff quality as an issue that must be dealt with in a coordinated manner at all levels of government. As BCMELP (1998) recognized, governments cannot force people to live sustainably, or to use cars less, but they can provide incentives for a stewardship ethic. This policy, however, provides options to reduce travel times and congestion, as well as overall pollution levels. The challenge is to ensure that activities are coordinated within all levels of government, and that the public is aware of the programs and also of the opportunities to provide input into the planning of transportation networks. In this regard, TransLink, the Regional Transportation Agency for the GVRD, plays a crucial role and BCMoTH must ensure there is a close coordination between the agencies. If the intent of this policy is carried forward, then this link will become essential.

The adoption of this policy by the Ministry Executive will give staff direction and ability to implement changes, and to form strategic relationships with other agencies and groups. Some of the potential changes it enables are detailed in the following draft technical bulletin for highway design.

9.3 Technical Bulletin (TB) (Draft)

The ability to implement any specific methodological or procedural changes or solutions is greatly influenced by the standard highway design process utilized by the BCMoTH. Currently, roadway design details, procedures, and specifications are contained in the Highway Engineering Design Manual. In reviewing the Hydraulics and Structural Chapter, there is little reference to the consideration of highway runoff quality and the main focus is on runoff quantities. In order to implement changes in design practice, a TB is the usual mechanism. Changes to the BCMoTH Highway Engineering Design Manual are initially accomplished using a TB; in subsequent updates of the manual, this information is incorporated into the main text. The information presented below is a draft of a TB intended to add to the Hydraulics and Structures Chapter. This TB will be reviewed by engineering staff and must be accepted and approved by the Chief Engineer prior to inclusion in the manual.

TECHNICAL BULLETIN (DRAFT)

Subject:

HIGHWAY RUNOFF QUALITY CONTROL

Background:

Highway runoff contains numerous contaminants that are potentially harmful to the environment. These contaminants range from petroleum products, heavy metals, persistent organic pollutants, to road de-icers. Potential impacts of contaminated highway runoff are especially acute along highways that have high ADT levels (i.e. over 30,000 ADT) and/or are located near sensitive watercourses. The Ministry is developing an overall Highway Runoff Quality Management Policy that emphasizes the need to eliminate the problem at source, but it also recognizes that post-runoff measures are required as part of the highway design. It is post-runoff measures that are considered here.

General:

Numerous types of treatment facilities for highway runoff are available to highway designers. These include vegetated buffers, grass swales, grass lined ditches, artificial wetlands, and oil-water separators. Vegetative methods are preferred over mechanical options, and infiltration facilities are not recommended at this time. The type of facility is dictated by the constraints of the specific location. Often, water quality and water quantity features can be combined and this should be a goal. For example, grassed swales and/or highway ditches are designed to convey highway runoff, but they can also allow for the settling out of solids by filtering the water. This filtering capacity is further enhanced if weirs are strategically placed in the ditches to retain pools of water and allow for added settling time. This type of ditch must be designed to ensure that hydraulic capacity is adequate.

Design Guidelines:

In all cases, Environmental Staff should be consulted prior to design to assist in determining the precise water quality needs of the particular project. Every design must maximize the settling or filtering of sediments/particles in the runoff water. This can be achieved in many ways and guidance for the design of water quality treatment facilities can be found in the Washington State Department of Transportation Highway Runoff Manual (1995) and the Washington State Department of Ecology Stormwater Management Manuals (Draft) (1999). These manuals are currently under revision and new versions should be available by mid 2000. Also, the conversion of sediment ponds to constructed wetlands have been undertaken as part of the Vancouver Island Highway Project and can be a good source of information. Another example is the scrubber marsh developed for the Johnston Mariner Project. Environmental Staff can assist in providing information on these projects.

In addition, if the design utilizes a new ditch for water quality treatment and the ditch flows into a fish bearing watercourse, then the ditch must be designed to preclude fish access into the ditch. This is accomplished by having a drop of more than 1 m between the ditch and the watercourse. For existing ditches, if fish access exists then it must be maintained.

Treatment for highway runoff quality shall be considered for all new road and bridge designs when:

- the projected ADT is over 30,000; or
- the highway drainage flows into a sensitive environmental area (This can be determined in consultation with the Environmental Staff); or
- In all cases where treatment is required by environmental agencies as a condition of approval.

If the design is a modification to an existing highway then treatment for highway runoff quality shall be considered when:

- the ADT is over 30,000, or
- the modification adds over 500 square metres of new impervious surface; or
- In all case where treatment is required by environmental agencies as a condition of approval.

The following order of preferred treatment methods will be utilized. The list is presented from the most preferred to least preferred. Typically, this is also from least expensive to most expensive (comparative costs).

- grassed ditches, grassed swales, and vegetated buffer strips. Use of small in-line weirs with existing or new ditches, potentially with enhanced vegetation;
- wet ponds with enhanced vegetation;
- constructed wetlands;
- mechanical devices such as oil-water separators; and
- Infiltration facilities.

The most effective strategy is often to combine treatment options. New and innovative methods are always in development and should be investigated where appropriate.

Specific plants considered for water quality treatment facilities include:

- cattails;
- small fruited bullrush;
- wool grass; and
- Soft rush.

This list is revised as required by the Regional Vegetation Management Technician.

Methods redesigned or modified specifically for BCMoTH and approved by the Chief Engineer will be included in the Hydraulic and Structural Chapter of the BCMoTH Highway Design Manual for use in similar design situations.

9.3.1 Discussion

The TB presented contains a number of important concepts for the inclusion of water quality considerations in highway design. It details *when* to consider the inclusion of water quality treatment facilities, *what* types of treatment facilities are preferred, and *where* further information can be obtained. A critical element is the inclusion of the Environmental Staff in the process to ensure that environmental objectives are met. This aspect is important as designers may not have the environmental expertise.

Vegetative methods are preferred over mechanical ones largely due to maintenance concerns and higher costs for comparable contaminant removal rates. Infiltration facilities are only recommended as a last resort due to high cost, high maintenance, and high failure rates. Water quality and quantity can often be treated using the same facility. This encourages designers to look for these opportunities. Often, this dual design leads to more effective treatment.

The main goal of treatment is to maximize the settling or filtering of the runoff. By maximizing the removal of solids/particles, a significant reduction in contaminant loads can be achieved and this provides a very cost-effective solution. Designers should refer to the Washington State documents, as these are the most comprehensive and relevant information for this particular geographic area. However, other relevant information is also available.

The issue of fish utilization of highway ditches is also addressed. Most of the highway ditches in the GVRD contain, or support, fish. Highway runoff quality in the ditches is less than desirable for fish and most other aquatic organisms. Highway ditches serve important functions to both convey water and potentially to improve the water quality of the highway runoff, and they should be left to perform this function. Any fish habitat that is constructed must be away from transportation corridors and isolated from potential impacts to the water quality.

New highways requiring water quality treatment, are identified as having an ADT of 30,000, or as the existence of a sensitive environmental receiver. These two criteria are the most reasonable trigger points based on literature review. A similar trigger point of 30,000 ADT is utilized for modifications to existing highways, but another criteria is the addition of 500 square meters of impervious surface. This number is based on the WSDOT (1997) criteria for retrofits.

This TB must be reviewed and revised as required by the engineering and technical staff to ensure compliance with highway standards.

10.0 CONCLUSIONS AND RECOMMENDATIONS

10.1 Study Objectives

This study was initiated because highway runoff typically lowers the water quality in any receiving body, and because there is a need to identify what can be done to reduce the effect of highway runoff from current and future highways. Explication of specific issues follows.

1. What is the issue of highway runoff quality?

Literature reviewed for this study shows that highway runoff contains up to 25 different contaminants from a variety of direct and indirect sources. The primary source of contaminants is fossil-fuel powered vehicles. With an ever-increasing number of vehicles in the world, the amounts and concentrations of contaminants are increasing. Contaminants are transported off the road surface primarily by precipitation runoff. This runoff then carries the contaminants into watercourses and/or waterbodies. This substantially lowers the water quality of the receiving waters.

2. What has been accomplished to-date in the area of highway runoff quality management?

Major transportation agencies throughout the world recognize the problem of highway runoff water quality and are in various stages of implementing management measures. These measures are typically for post-runoff treatment, but many also utilize source and post-deposition measures as well. The most relevant material for BCMoTH, other than the internal studies undertaken, is best management practices (BMPs) in Washington State for stormwater management and highway runoff.

3. What cost-effective highway runoff quality measures can be incorporated into new and existing highways?

The most cost-effective measures utilize existing features of highway right-of-way and avoid mechanical methods. Collectively, all of these measures are referred to as BMPs, however heretofore they will be referred to more generically as treatment methods or measures. The most cost-effective measures utilize existing ditches and incorporate additional vegetation as filters for sediment. A key feature is allowance for maximization of settling times for the runoff water by utilizing methods such as check dams in grassed ditches, grassed swales, wet ponds, and constructed wetlands. Cost-effectiveness minimizes the need to acquire additional right-of-way for these features and maximizes contaminant removal within existing right-of-ways. To minimize the cost of testing highway runoff, surrogate parameters proposed by Thompson et al (1997) and detailed in section 4.4.1 should be utilized.

4. What specific guidance can be provided to BCMoTH to determine when highway runoff treatment is required, and the priority methods to be used?

The answer to this question is detailed in section 9.3.

10.2 Summary and Conclusions

Highway runoff quality is an issue with many social, economic, and environmental implications. Paved roads alter hydrology, and eliminate natural filtration through the paved surface. The runoff generated must travel over the surface of the pavement, and in doing so picks up numerous contaminants. This type of runoff is considered non-point source pollution, and together with agricultural and general runoff from urban areas is the major continuing source of receiving water contamination. Transportation agencies have an ethical responsibility to deal with this issue as effectively as possible. Although this broad issue is not entirely within their mandates, transportation agencies must foster a stewardship ethic to encourage people to use their cars less.

The major sources of contaminants are the fossil-fuel powered vehicle, contributions from environmental sources such as rainfall and dustfall, and highway maintenance activities including the use of herbicides and pesticides. Highway runoff contains over twenty-five different contaminants, many of which are toxic or carcinogenic. Given the potential for environmental effect, investigation and utilization of all opportunities to reduce and eliminate the impact is imperative. The problem must be solved at its source. This requires a reduction in the number of fossil-fuel powered vehicles and the impact of those vehicles on contaminant loading of highway runoff.

Furthermore, several methods have been designed to predict the contaminant loadings of highway runoff. It is extremely expensive and time consuming to test for a wide range of pollutants over vast networks of roads. Contaminants run off all roads, however, research shows that specific characteristics of certain roads will produce significantly higher contaminant loads than others. Measures such as average daily traffic (ADT) and vehicles during a storm (VDS) have been proposed, but neither fully predicts the potential for contaminants. Vehicle exposure time (VET), which is the total amount of time a vehicle is on the road, may be a better predictive tool. VET is proposed as a general concept needs further investigation to determine its validity as a predictor. Other factors that may effect highway runoff include climatic conditions, antecedent dry periods, and highway configuration. Surrogate parameters should be used for forecasting highway stormwater loads. This methodology reduces the cost of testing and provides more accurate prediction models.

Washington State previously used an ADT of 50,000 as the trigger point for treatment. In their latest Highway Runoff Manual (WSDOT, 1997) treatment will be provided for any new highway or redevelopment which adds impervious surface over 5000 square feet (453 square metres). This onerous task will cost a substantial amount of money to implement. To find a reasonably cost-effective point for potential treatment, the following trigger points are recommended. Treatment is proposed for any new highway with an ADT of 30,000 where the highway runoff flows into a sensitive receiving environment, and for a redevelopment where the ADT is over 30,000, and adds more than 500 square meters. For the GVRD area covered by this report almost all roads are over 30,000 ADT and most drain into sensitive receiving environments. Most require treatment, and, therefore, there is an urgent need for cost-effective solutions.

Transportation agencies have a responsibility to deal with the issue in the most effective way possible. This involves a wide range of solutions at the corporate and operational level. Specific measures identified in this study include maximizing the effectiveness of current road infrastructure to avoid congestion, implementing a variety of methods to reduce the number of vehicles on the road, and implementing specific treatment methods to minimize the impact of vehicles.

In examining the direction and progress of the BCMoTH which was utilized as the main case study, significant strides in the overall identification of highway runoff quality issues are evident; however, few enabling mechanisms allow for issues to be addressed or resolved. Within the organization, many activities are underway directly or indirectly linked to water quality issues, but they are not collectively captured and the associated linkages are not identified (see recommendation 2). As long as these activities are independent of one another, it will be impossible to provide effective integration. Most transportation agencies undertake a significant amount of work to benefit the environment which often result in reductions of highway runoff contaminants, but this is not communicated to the public effectively, nor are the efforts coordinated.

A number of reasonably effective measures can be utilized immediately to improve the situation. Unfortunately, the majority of transportation agencies examined for this study focus on post-runoff solutions. Highway runoff quality needs to be addressed, but the issues at the source of the problem are considered outside transportation agencies' control or mandate.

An example of integration and communication is the Intelligent Transportation Systems (ITS) which BCMoTH is currently examining for use in a number of areas. ITS are extremely beneficial in reducing congestion. This translates into significant reductions in vehicle emissions, and substantially less pollution. A pilot project by BCMoTH in Duncan, British Columbia, using real-time traffic signal control has demonstrated that improved traffic flows are possible using ITS systems. Further pilot projects are planned in the LM region (Zhou, et al, 1997). The promotion of these activities as being environmentally beneficial would assist both traffic flow and run off quality, especially if the public were well informed of the benefits.

Transportation agencies have only recently begun to look at the issue of highway runoff quality, but there have already been major strides in this area especially related to post-runoff measures. This report describes a number of measures available and concludes that the basic objective is to remove as many particles and as much sediment from the runoff as practical. This will provide for effective removal of contaminants such as heavy metals that adhere to these particles. Filtration methods that utilize vegetation and potentially enhance biological uptake of up to 90% of nutrients and other contaminants by plants, are preferred over mechanical methods. However, sometimes one, or both methods, are needed to ensure acceptable water quality objectives (see section 6.0 and 7.0).

Filtration using vegetative methods is preferred, and the majority of roadsides already consist of grassed swales and ditches with grassed banks. Many of these ditches provide water quality treatment.

With the ever-shrinking maintenance budgets of most transportation departments, high cost and high maintenance treatment methods are prone to failure if they cannot be maintained properly. As the maintenance budget shrinks, the focus necessarily moves to ensure safety and basic road maintenance. As a result, other activities considered “less important” may be curtailed or abandoned. The simpler, and the more cost effective treatment method, the better. New and better methods must be continuously developed while working towards source solutions.

Section 8.0 of this study looked at two case studies from BCMoTH. One that considers grassed swales and concluded that they are beneficial for water quality treatment, and another that examined constructed wetlands. In the case of the constructed wetlands it is less clear that runoff objectives are met, but given previous studies on these types of systems by other agencies, and their successful use on other BCMoTH highway projects, they are possibly good methods that should be considered for future use.

In section 9.0 it is proposed that an integrated solution is essential in working toward sustainable transportation. This includes a corporate policy that supports sustainable concepts, and the ability to implement changes at the local operational level. Given this, a draft corporate policy on highway runoff quality management is presented. This policy recognizes that integration at all levels of government and education of the public is essential to success. This policy focuses on source control as the key, but also enables immediate action to mitigate the current issue of highway runoff treatment.

The draft technical bulletin sets out guidelines for highway runoff treatment in the design of new and redeveloped highways. The policy and the technical bulletin attempt to integrate two essential elements: the need for an ultimate solution, and an interim immediate solution. Other solutions involve the re-examination of maintenance and other practices that effect highway runoff quality.

Transportation, and transportation needs will increase, and thus it is even more critical to find solutions and prevent problems wherever possible. Highway runoff quality is already a problem.

10.3 Recommendations

1. To continue research to develop effective source control measures.

2. To undertake a thorough examination of all activities, programs, and procedures that impact highway runoff quality.

3. To proceed with a review of proposed drafts to implement Highway Runoff Quality Management Policy and the Technical Bulletin for Highway Runoff Quality Control.

4. To define specific aquatic plants local to the area which may be beneficial for the uptake of nutrients and other contaminants in highway runoff.

5. To maximize the use of existing infrastructures such as highway ditches for water quality control and to avoid mechanical methods whenever possible.

6. To present environmental agencies who review and provide environmental approvals for highway projects in British Columbia with this report.

7. To re-examine maintenance and other practices that affect highway runoff quality to eliminate or significantly reduce their impact.

8. To establish or maintain vegetated buffer strips of at least 15 m where feasible along highways that are adjacent to, or which cross, watercourses.

9. To continue the monitoring program for VIHP water quality ponds and to utilize this data to improve future designs. It is essential that evaluation and testing be undertaken so specific information based on local conditions is collected.

10. Newly constructed highway ditches should preclude fish access. In areas that already have fish access, access must not be removed or altered unless approved by the environmental agencies.

11. Highway ditches not be allowed to carry stream flow to ensure that stream flow is distinct from highway runoff.

12. Investigation of the potential use of vehicle exposure time (VET) as a measure of contaminant loading of highway runoff be undertaken.

13. Production of a fact sheet on stormwater management for use by District Highways' staff.

14. Continuation of water quality monitoring of the two BCMoTH case study sites examined for this study be done.

15. Research should be conducted on the source and the fate of zinc in the Johnson/Mariner scrubber marsh.

16. Methods of increasing retention time of highway runoff without compromising highway drainage should be investigated.

17. Utilize a combination of bulrush and cattail to enhance contaminant uptake.

18. Check dams be utilized in buffer strips and grassed swales to increase retention time and to improve settlement of contaminants.

19. Best management practices combinations be considered.

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