Identifying Sensitive Receiving Environments at Risk from Road Runoff

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An important note for the reader

Land Transport New Zealand is a Crown entity established under the Land Transport New Zealand Amendment Act 2004. The objective of Land Transport New Zealand is to allocate resources in a way that contributes to an integrated, safe, responsive and sustainable land transport system. Each year, Land Transport New Zealand invests a portion of its funds on research that contributes to this objective.

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Abbreviations and Acronyms

AADT	Annual Average Daily Traffic volume
ADT	Average Daily Traffic
ANZECC	The Australian and New Zealand Environment and Conservation Council
Cu	Copper
CU	Central Urban
g	Gram
gis	Geographic Information System
HCV	Heavy Commercial Vehicle (>=3.5 tonnes)
km	Kilometre
Land Transport NZ	Land Transport New Zealand
LCV	Light Commercial Vehicle (<3.5 tonnes)
LoS	Level of Service
mg	Milligram [1/1000 g]
MO	Motorway
MoT	Ministry of Transport
ng	Nanogram [1/10^9 g]
PAH	Polycyclic aromatic hydrocarbons
Pf	Pathway factor
Ppm	Parts per million
RAMM	Road Assessment & Maintenance Management system
RE	Receiving environment
RH	Rural Highway
SRE	Sensitive receiving environment
SRf	Sensitivity rating factor
SS	Suspended Solids
SU	Suburban
TPH	Total Petroleum Hydrocarbons
Transit	Transit New Zealand
Transfund	Transfund New Zealand
µg	Microgram [1/10^6 g]
VCLM	Vehicle contaminant load model
VFEM	Vehicle Fleet Emissions Model
VKT	Vehicle Kilometres Travelled [AADT x Road Length]
VPD	Vehicles per Day
Zn	Zinc

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Executive summary

Introduction and Approach

Road runoff contains vehicle-derived contaminants, such as heavy metals and hydrocarbons, which can adversely affect the ecology of receiving environments and/or the human uses or values associated with them. However, receiving environments differ widely in their inherent sensitivity and their risk from road runoff depends on a variety of factors apart from traffic levels. In addition, funds for remedial measures are necessarily limited, indicating the need to prioritise areas requiring treatment.

The purpose of the research project was to develop and validate a GIS-based tool for identifying and ranking sensitive receiving environments (SREs) at risk from road runoff, and therefore assist in prioritising sections of the road network that may require installation/upgrade of treatment systems for road runoff. The project was funded under the 2005-2006 Research Programme of Land Transport New Zealand.

The SRE screening tool is built around the *source – pathway – receptor* risk model. The *source* is the road network that generates a contaminant load in runoff and the *receptor* is the receiving environment (waterbody). The *pathway* is the route taken by runoff from where it leaves the road to its point of discharge to the waterbody. The risk to the receiving environment depends on the \`strength' of the source term, the \`connectivity' of the pathway, and the \`sensitivity' of the receiving environment. Risk factors for these three components are defined for a given road network/SRE combination and combined to give an overall measure of pollution risk for ranking purposes. Risk assessment of a given SRE/road network is determined on a catchment basis and uses a tiered approach. The following aspects are included in the methodology:

- Applicable both to state highways (SH) and local roads.
- Conceptually simple, using a comparative (not absolute) assessment of risk.
- Permits rapid screening (Tier 1) with follow-up for high-risk areas (Tier 2).
- GIS-based to facilitate regional application using nationally consistent datasets.

A key assumption to applying the method in the context of New Zealand roads is that the particulate fraction of the contaminant load is the appropriate point of focus and consequently the primary factor determining the impact of this component of runoff is the degree to which the immediate receiving environment is *depositional.*

Assessing receiving environment sensitivity

The framework for rating the sensitivity of receiving environments (RE) to road runoff is based on a hierarchical system where the RE is sequentially classified according to three attributes:

1. Physical 'type sensitivity' (depositional vs. dispersive),
2. Ecological values, and
3. Human use values (including cultural values).

For each attribute, the RE is classified as 'high' (H), 'medium' (M), or 'low' (L) sensitivity and assigned a numerical score. The overall sensitivity rating is the sum of scores for type sensitivity, ecological value and human use value, with high ratings indicating high sensitivity. The rating system is intended as a ranking tool to flag the potential for adverse effects on the receiving environment. Existing contamination or disturbance is not included in the rating system but remains a significant factor in determining the need or otherwise for prioritising runoff treatment.

Source characterisation

A literature review was conducted to determine the significance of risk factors to SREs at source i.e. within the road network. The review found that pollution from road runoff is very variable and has a complex relationship with runoff quality. While traffic levels are a major risk factor, the local influence of road characteristics and driving conditions on vehicle emission factors (and hence pollutant load), and the potential further reduction of load by highway drainage, are also important factors requiring consideration. A contaminant load model that factored in these dependencies was therefore included in the methodology for identifying SREs at risk from road runoff.

Screening tools for impact assessment of road networks on receiving waterbodies were briefly reviewed as part of this project. Traffic levels measured as AADT are a poor proxy for runoff quality. A more robust indicator of traffic risk is vehicle kilometres travelled (VKT), which is determined as the product of AADT and road length. The total VKT estimated to affect an SRE will reflect both direct and indirect contributions from the road network in the catchment and will include cumulative effects, therefore providing a better indication of the overall risk to the waterbody. A VKT catchment-based approach was adopted in the Tier 1 screening tool.

Vehicle contamination load model

An Excel-based vehicle contaminant load model (VCLM) was developed to estimate the relative source strength, expressed as annual mass loads (kg/VKT/yr) of specific pollutants (particulate matter, zinc and copper) from road networks. Loads are derived from traffic flow (AADT), service level (speed/congestion), vehicle type and pollutant emission rates (i.e. brake, tyre and road surface wear, oil leakage and exhaust emissions). The model equations are full documented and are derived primarily from vehicle emission data within the Ministry of Transport's published research on land transport effects on aquatic ecosystems. The model allows user selection of existing and future highway drainage features (e.g. sumps) which attenuate stormwater load.

Initial validation of the VCLM was achieved for copper and zinc using published field data and road characteristics for the Richardson Road site in Auckland. The predicted emission factors from the VCLM (mg/VKT) are within a factor of two (for copper) and four (for zinc) compared with factors established for this site. In both cases the VCLM overestimates the contaminant load. Considerable uncertainty in model source data means that predictions must be treated as `order of magnitude' estimates of contaminant load. The VCLM should be used to estimate contaminant loads on a comparative rather than absolute basis. In this mode it may be used to determine relative contaminant loads from different road types (e.g. state highways v local roads within a catchment) that may affect a given receiving environment. (Note: a working version of the VCLM is available as an output of this research project.)

Pathway considerations

The pathway is the route taken by road runoff from the point it leaves the road drainage system (e.g. sump, catchpit) to the point it is discharged into the depositional receiving environment. In the context of particulate matter in road runoff, three generic types of pathway have been defined, depending on their `connectivity' to the receiving environment. Direct pathways occur where road runoff is discharged directly to an SRE. Road runoff that first enters a stream or river before reaching an SRE is considered an indirect pathway. Diffuse pathways are characterised for road sections without stormwater collection systems in which runoff is allowed to freely drain to adjacent land. The risk of a given pathway to the SRE is defined in terms of its pathway factor (Pf) which represents the degree of attenuation of particulate load in runoff between source and receptor. Nominal order of magnitude figures were chosen. Although the approach is simplistic it is considered satisfactory for use in a screening tool.

Risk assessment methodology

The risk model is defined on a catchment basis in order to assess the cumulative impact of traffic-sourced contaminants in runoff from all sections of a road network to a given waterbody. The same methodology is applied to local roads and state highways. A two-tiered approach has been developed for identifying and characterising the risk to SREs:

- Tier 1: A screening tool for identifying potential `hot spots' - areas of high traffic density that may have an adverse impact on water quality - based on total VKT by sub-catchment.

- Tier 2: A source-based model for predicting vehicle-derived contaminant loads in the identified `higher risk' road sections that factors in the effects of varying road/traffic conditions and highway drainage.

Tier 1 is used to screen SREs (or particular runoff discharge locations to an SRE) that may be at risk and identify road sections in the catchment which are the source of the risk. The process is relatively easy to apply and requires minimal data preparation. The key GIS data files required are SREs, subcatchments, traffic flow data (AADT) and the road network in the area under study. The use of VKT as a proxy for pollutant load is a simplifying assumption, however the output is a useful pointer to areas of potential concern.

Tier 2 provides an overall risk rating for a given road network/SRE combination, taking account of the pollutant load, pathway and sensitivity rating of the waterbody. The source risk term is the total vehicle contaminant load discharging to the SRE (e.g. mg

Zn/day). The load is determined by applying the VCLM to those parts of the road network that drain to the SRE. Tier 2 therefore takes account of the effects of traffic and road characteristics, as well as any stormwater treatment devices in the road network, which will collectively affect the pollutant load in runoff. Tier 2 requires considerably more data preparation than Tier 1. This includes mapping of stormwater subcatchments, identification and assignment of source-pathway-receptor linkages, identification of RAMM data for the pollutant load model and aggregation of pollutant loads from road section within the network.

Pilot study

A pilot study was conducted to test the methodology in an urban environment. The vicinity of Porirua Harbour within the Wellington Region was chosen as it has a suitable mix of local roads, state highways and SREs. Tier 1 screening was applied to the sections of state highway (SH1 and SH58) in the study area. The Tier 2 assessment process was tested on a small part of the study area comprising the local roads and state highway SH58 that discharge runoff along the southern coastline of Pauatahanui Inlet. The VKT values at the point of discharge to the SRE (determined from Tier 1) were found to correlate well with the relative vehicle pollutant load in runoff estimated under Tier 2. Findings from the Tier 2 risk assessment conducted for roads discharging into the southern coastline of the Pautahanui Arm have been interpreted on the basis of sediment quality data for Porirua Harbour determined from surveys commissioned by Greater Wellington Regional Council.

Conclusions

A GIS-based method has been successfully developed for identifying and ranking SREs at risk from road runoff. The methodology incorporates the source-pathway-receptor risk concept to spatially link areas of high traffic intensity, runoff discharge routes and sensitive downstream environments potentially at risk. Both local roads and state highways can be accommodated. Use of GIS is an essential requirement for application at the regional/national level.

The methodology has been tested in a pilot study in the Porirua area of Wellington. The study demonstrated that the Tier 1/Tier 2 process provides meaningful spatial analysis of relative pollutant loads by catchment that can be used to identify and rank areas of a sensitive waterbody potentially most at risk from road runoff, and which parts of the road network are contributing to this risk. The tool can also determine the relative contributions of pollution in road runoff from state highways and local roads.

The tool has application both for existing roads (e.g. identifying potential need for retrofitting stormwater treatment) and for new roads (e.g. corridor studies to identify any SREs close to proposed alignments). It may also be used as a planning tool for predicting the distribution of contaminant loads based on future traffic forecasts.

The tool should be of assistance to Transit New Zealand and territorial local authorities in their efforts to improve the management of road runoff. The concept of using a risk-based approach to classify receiving environments may also assist regional councils in the development of an improved regime for the regulation of stormwater discharges.

Scope of Application

Development of the method has required a number of simplifying assumptions that limit its scope of application, and which should be highlighted to intended users. The methodology only considers vehicle-derived contaminants in road runoff. The contribution from vehicles is only one component of stormwater pollution and may be small compared with other sources, particularly in urban areas e.g. zinc from galvanised roofs or heavy metals from industrial effluent.

While the method focuses on the particulate load, it is recognised that dissolved contaminants from road runoff (e.g. copper and zinc in urban streams) can exceed guideline limits with potentially adverse effects on sensitive ecosystems. The tool does not provide information on whether a waterbody is actually polluted by road runoff, nor does it provide data to permit direct comparison with environmental standards e.g. sediment quality.

The screening tool developed under this project is intended for the specific purpose of ranking SREs at risk from road runoff. The methodology is intended to be used on a comparative rather than absolute basis for assessing road networks and their effects on receiving environments. In this respect it is intended to guide decision-makers on the management of road runoff. Risks to receiving environments identified by the tool, and the potential need for stormwater treatment, should be assessed in the context of local knowledge and professional judgement.

Abstract

A GIS-based screening tool is described for identifying and ranking sensitive receiving environments (SREs) at risk from road runoff from state highways and local roads in New Zealand. The tool focuses on the particulate fraction of runoff and the risk this poses to `depositional' receiving environments.

The tool uses the source-pathway-receptor concept and is applied on a catchment basis. Source strength is expressed either in vehicle kilometres travelled (VKT) or relative pollutant load. Pathways are assigned an attenuation factor in terms of 'connectivity' to the receiving environment. Receiving environment sensitivity is based on depositional characteristics of the waterbody type, with secondary attributes covering ecological and human use values.

Tier 1 identifies SREs potentially at risk using VKT per sub-catchment. Tier 2 further assesses risk using a model to estimate vehicle contaminant load (particulate matter, zinc and copper) for comparing road networks. Risk factors are combined to give an overall measure of relative pollution risk for ranking road networks on a comparative basis.

The paper outlines the method and findings from a pilot study in the Porirua area of Wellington. The tool is intended to assist roading authorities in prioritising areas that could benefit from installation/upgrade of treatment systems for road runoff.

1. Introduction

1.1 Purpose and objective

The purpose of the research project was to develop and validate a GIS-based screening tool for identifying and prioritising sensitive receiving environments (SREs) that are potentially at risk from stormwater runoff from state highways and local roads in New Zealand.

The primary objective of developing this tool has been to assist with the planning and implementation of remedial measures aimed at reducing the adverse effects of runoff from land transport networks on the most sensitive receiving environments. An underlying objective was to bring a degree of national consistency to the identification and assessment of sensitive receiving environments.

Preliminary findings from this research project were presented with the approval of Land Transport New Zealand at the NZWWA Conference in Rotorua in May 2006 (Gardiner & Armstrong 2006).

1.2 Background

Road runoff can have potentially significant adverse effects on the ecological, cultural and human-use values associated with certain types of receiving environments. Contaminants in discharges from the national road network are complex and include fuels, additives, oil, grease and brake residues containing a variety of toxic and ecotoxic components, including heavy metals and organic compounds.

Research indicates that the low energy depositional environments in enclosed harbours and estuaries are most susceptible to such effects. However, there is also evidence that the values associated with certain types of streams, wetlands and lakes can also be adversely affected in the long run (i.e. from cumulative effects) by road runoff. The situation is expected to deteriorate with time due to new highway construction and traffic growth.

Remedial measures (e.g. oil interceptors and/or provision of stormwater treatment systems) are required to eliminate or mitigate the effects of contaminated runoff on sensitive receiving environments. However, the available funds for mitigation are necessarily limited and the choice of which sections of the road network to treat is not clear-cut.

Receiving environments differ widely in their inherent sensitivity. The risk to these waterbodies from road runoff also depends on a number of factors, including the traffic intensity, the mode of discharge (e.g. catchpit or swale) and whether or not a pathway links the discharge to the receiving environment.

1.3 Context for research

The research was undertaken within the context of a number of legislative and policy drivers, viz:

- The Land Transport Management Act 2003, the purpose of which is to contribute to the aim of achieving an integrated, safe, responsive and sustainable land transport system;
- The provision of the Local Government Act 2002 requiring local authorities to take a sustainable approach in performing their roles;
- The Resource Management Act 1991 which, amongst other things, requires persons exercising responsibility under it to promote the "sustainable management" of natural and physical resources and imposes a duty on all persons to avoid remedy or mitigate adverse effects; and
- The goals of the New Zealand Transport Strategy, which, amongst other things sets an objective of ensuring environmental sustainability.

The need for the research relates to the fact that road runoff contains vehicle-derived contaminants, such as heavy metals and hydrocarbons, which can adversely affect the ecology of receiving environments and/or the human uses or values associated with them.

The underlying reason for developing the screening tool is to assist with the planning and implementation of measures aimed at avoiding, mitigating or remedying the adverse effects of runoff from roads on the most sensitive receiving environments. Such measures could include the installation of treatment systems or the diversion of runoff.

The research was divided into 5 stages:

1. Literature review of SRE assessment/classification systems.
2. Development of SRE screening methodology.
3. Risk assessment of SREs from road runoff.
4. Pilot study tool application (development of GIS tool).
5. Documentation of risk-based methodology.

Details of the methodology for each stage are set out in Section 2.

1.4 Scope of application

The screening tool developed under this project is intended for the specific purpose of ranking SREs at risk from road runoff. Development of the method has accordingly required a number of simplifying assumptions that limit its scope of application, and which should be highlighted to intended users:

1. The contaminant load model developed as part of the screening tool only considers vehicle-derived contaminants in road runoff. The contribution from vehicles is only one component of stormwater pollution and may be small compared with other urban sources e.g. zinc from galvanised roofs or heavy metals from industrial effluent.

2. The method focuses on the particulate load of road runoff and attendant risks from long-term contaminant build-up in depositional environments. However, it is recognised that dissolved contaminants in road runoff (e.g. copper and zinc) can exceed guideline limits with potentially adverse effects on sensitive aquatic ecosystems e.g. urban streams.

3. The methodology identifies which receiving environments are sensitive to runoff and which areas of an SRE are at greatest risk from road network discharges (state highways and local roads). It does not provide information on the absolute levels of pollution in runoff nor does it provide data to permit direct comparison with environmental standards e.g. sediment quality.

For the above reasons, the methodology is to be used on a *comparative* rather than absolute basis for screening and ranking road networks and their effects on receiving environments. In this respect it is intended to guide decision-makers on the management of road runoff.

The method described in this report provides a framework for the screening tool. Local data, knowledge and expertise (e.g. data on road and traffic networks, ecological, human use and cultural attributes, and ability to link to existing GIS system) are needed to apply the tool in the area of application.

Risks to receiving environments identified by the tool, and the potential need for stormwater treatment, should be assessed in the context of professional judgement and discretion on the part of the user.

1.5 Report structure

This report sets out the approach and process that was followed in developing the methodology underlying the SRE screening tool, together with a synthesis of how the tool is to be applied to road networks.

Included are results of a pilot study that was used to develop and test the method by application to an urban state highway and local road network in the Wellington region. This report (Volume I) is divided into eight sections:

1. Introduction
2. Approach and methodology
3. Assessing receiving environment sensitivity
4. Source and pathway considerations

5. SRE risk assessment methodology
6. Pilot study
7. Conclusions
8. References

Volume II (Appendices) includes detailed supporting technical information. A glossary of terms used in the report is provided in Appendix F.

2. Approach and methodology

2.1 Approach

The SRE screening tool is built around the *source – pathway – receptor* risk model.

In the context of this research project (i.e. discharge of runoff to the aquatic environment), the *source* is the road network that generates a contaminant load in runoff and the *receptor* is the waterbody (referred to as the receiving environment). The *pathway* is the route taken by contaminated runoff from the point it leaves the road to the point it reaches the receiving environment.

For a risk to be present to the receptor, all three components must exist i.e. there must be a *source* of traffic to generate a contaminant load in runoff, a *pathway* for transporting the contaminated runoff and a sensitive receiving environment that is the *receptor* of the runoff.

Whether a particular receiving environment is at risk is determined by a consideration of the overall risk from the source-pathway-receptor combination, not the individual components. Thus a waterbody in close proximity to a busy road will not be at risk if there is no pathway, irrespective of the traffic flow or sensitivity of the receiving environment.

The magnitude of the risk to the receiving environment depends on the `strength' of the source term, the `connectivity' of the pathway, and the `sensitivity' of the receiving environment. A potential high-risk scenario would equate to a heavily trafficked road that discharges directly to a receiving environment of high sensitivity.

The approach therefore centred on the following elements:

- **Source:** Developing a method for quantifying the `source strength' of road runoff based on traffic and road characteristics of the network.
- **Pathway:** Consideration of pathway issues, including the extent to which the type or nature of the pathway can influence the risk to receiving environments.
- **Receiving environment:** Devising a method for classifying receiving environments and ranking them according to their sensitivity, that is the risk they will be adversely affected by road runoff.
- **Synthesis of the above elements**: Preparing an overall conceptual model and stepwise methodology for the identification of those receiving environments most at risk from road runoff.

A key assumption in the approach to applying the method in the context of New Zealand roads has been the importance of the particulate fraction (i.e. suspended contaminant load) of road runoff in determining risk of adverse effects to waterbodies.

The corollary that `depositional' receiving environments are the type most susceptible to risk from contaminant build-up in sediments is therefore central to the methodology.

The following aspects were recognised as being of importance to end-users and were included in the project design:

- Applicable both to state highways (SH) and local roads.
- Conceptually simple, using a comparative (not absolute) assessment of risk.
- Permit rapid screening (Tier 1) with follow-up for high-risk areas (Tier 2).
- GIS-based to facilitate regional application using nationally consistent datasets.
- Method to be tested in a pilot study of an urban environment.

Details of the project methodology are given in the following section.

2.2 Methodology

The project was divided into 5 interrelated stages:

- Stage 1: Literature review of receiving environment sensitivity.
- Stage 2: Development of SRE screening methodology.
- Stage 3: Develop method for assessing risks to SREs from road runoff.
- Stage 4: Pilot study (application of screening tool).
- Stage 5: Documentation of risk-based methodology.

2.2.1 Stage 1 – Literature review of receiving environment sensitivity

A review of local and overseas research in this area was undertaken to provide insight into the factors and criteria defining the sensitivity of different receiving environments. In other words, what makes receiving environments `sensitive' and how is `sensitivity' characterised?

This stage attempted to identify and assess all of the main factors relevant to receiving environment sensitivity. These included ecological/biodiversity value, potential to impact on human health, cultural/Maori significance, and existing levels of disturbance/contamination. Other factors relevant to ranking sensitivity were also considered e.g. size of water body, water movement and existing contaminant levels in sediments.

The following tasks were completed under this stage:

- Initial project start up and consultation with LTNZ/Steering Group.
- Literature review of SRE classification and sensitivity studies.
- Assess factors relevant to receiving environment sensitivity.
- Prepare summary report and recommendations.

The output from this stage was a review of existing classification systems for receiving environments (e.g. ANZECC guidelines) and the main factors that determine their sensitivity.
The output from this stage is described in Section 3 and Appendix A.

2.2.2 Stage 2 – Develop SRE screening methodology

Stage 2 involved developing a screening methodology for evaluating the sensitivity of different types of receiving environments. This included a `sensitivity rating system' based on key attributes i.e. receiving environment type, ecological value, and human use (including cultural) value, identified under Stage 1.

The following key tasks were completed during this stage:

- Review of the nature, transport and fate of contaminants in road runoff.
- Review of the effects of road runoff on receiving environments.
- Develop a framework for rating the sensitivity of receiving environments.
- Prepare user guidance for applying the rating system.
- Prepare an interim report on the SRE rating method.

The output from this stage is described in Section 3 with supporting information in Appendix B. The proposed framework for rating the sensitivity of receiving environments to road runoff, and user guidance to apply the procedures in a stepwise manner, is described in Appendix C.

2.2.3 Stage 3 – Assessing risk to SREs from road runoff

The purpose of this stage was to identify the source risk factors that contribute to SREs being adversely affected by road runoff so as to allow development of an appropriate risk-based screening tool Four components were examined:

1. A review of source factors affecting the quality of road runoff (e.g. traffic, roads).
2. The type of pathways potentially connecting the road discharge to the SRE.
3. Development of a contaminant load model.
4. Representation of network data and risk factors using GIS.

This stage comprised the following tasks:

- Literature review of risk factors to SREs from road runoff.
- Characterising source risk factors for runoff generation.
- Characterising pathway risk factors for runoff dispersal.
- Developing a vehicle contaminant load model.
- Developing a GIS model for depicting network data and risk factors.
- Preparing an interim report on the risk assessment process.

The output from this stage is described in Section 4. Further information is given in Appendix D (Literature review of factors affecting road runoff quality) and Appendix E (Vehicle contaminant load model).

2.2.4 Stage 4 – Pilot Study

The purpose of this stage was to test the methodology developed under Stages 2 and 3 to an urban area in the Wellington region selected in consultation with the Steering Group.

The following key tasks were undertaken during this stage:

- Identify suitable region for pilot study.
- Prepare GIS base plan (e.g. road networks, SREs).
- Identify and assess receiving environment sensitivity.
- Map stormwater sub-catchments on GIS base plan (local roads).
- Map highway catchment areas on GIS base plan (state highways).
- Interface contaminant load model to GIS database.
- Test Tier 1 screening tool on selected area and prepare GIS output.
- Test Tier 2 assessment tool on selected area and prepare GIS output.

The output from this stage is described in Section 6.

2.2.5 Stage 5 – Documentation of methodology

The purpose of this stage was to document the research and pilot study findings showing the scope and application of the proposed SRE screening tool and any qualifications in its use or interpretation of outputs. The research report is to include user guidance on how to apply the SRE screening tool in a GIS-based environment.

The following tasks were completed during this stage:

- Synthesis of the risk assessment methodology for SREs.
- Prepare consolidated draft final report for peer review.
- Finalise report based on peer review comments.

The SRE risk assessment methodology developed under this project is described in Section 5. The output from this stage is the subject of this research report.

2.3 Steering Group

An external Steering Group was convened to guide the project direction and to ensure that end users have a direct involvement in the development of the research output. Table 2.1 lists the organisations and their representatives who comprised the Group.

The Steering Group meetings were programmed to take place at appropriate stages in the work programme. The Group met on a formal basis on four occasions:

- 1st meeting: 11 August 2005 (project start-up),
- 2nd meeting: 18 November 2005 (progress review),
- 3rd meeting: 24 February 2006 (progress review), and
- Final meeting: 21 September 2006 (review of draft final report).

Minutes were taken of the meetings and distributed to Steering Group representatives and Land Transport NZ.

Table 2.1 Steering Group members and affiliation.

Organisation	Representative	Title
Transit New Zealand	Yvette Kinsella [(a)]	Environmental Policy Advisor
Wellington Regional Council	John Sherriff [(b)]	Manager, Resource Investigations
Consultant	Alan Watton	Chairman Stormwater Group, RCAF [c]

(a) Substituted Debbie Firestone (on maternity leave) from March 2006

(b) Substituted by Bruce Croucher for final Steering Group meeting; c) Road Controlling Authorities Forum

3. Assessing receiving environment sensitivity

3.1 Introduction

Stormwater runoff from the road network discharges directly to both freshwater and marine waters. These `receiving environments' include rivers, lakes, wetlands, estuaries, harbours and the open coastline.

The physical characteristics of each of these different types of receiving environment influence the way in which contaminant inputs are assimilated and therefore their sensitivity. Each type will exhibit varying degrees of sensitivity depending on their bio-physical characteristics, the uses that are made of them, and the values attached to them.

Stage 1 involved a literature review of overseas and New Zealand literature (both research and management documents) relating to methods of classifying and rating the sensitivity of receiving environments.

The review was undertaken to provide insight into the factors and criteria defining the sensitivity of different receiving environments. In other words, what makes receiving environments `sensitive' and how is `sensitivity' characterised. The objective was to identify and assess the main factors that either individually or collectively determine receiving environment sensitivity and to provide a recommended approach to the rating of receiving environments according to their sensitivity.

Details from the literature review are given in Appendix A and address the following topics:

- Types of receiving environments and their physical characteristics,
- Methods for classifying receiving environments, and
- Determinants of receiving environment sensitivity.

Further review (reported in Appendix B) was conducted during Stage 2 to clarify inter-relationship between the following aspects that have a bearing on the sensitivity of waterbodies to runoff:

- The phases (dissolved and particulate fractions) of runoff,
- The fate of contaminants in road runoff, and
- The effects of road runoff on receiving environments.

The following sections provide a summary of key points from the literature review that shaped the sensitivity rating system and conclude with an overview of the proposed methodology.

3.2 Importance of particulate fraction in runoff

Contaminants in road runoff such as heavy metals can be transported as either *dissolved* species or by being chemically or physically bound to sediment particles (*particulate* contaminants).

In the UK, studies carried out on the polluting effects of road runoff have focused on the dissolved fraction of contaminants and on riverine receiving environments. The principal factors determining the sensitivity of a receiving environment to adverse effects are the available dilution and the quality of the receiving water.

The main concern in New Zealand (amongst resource managers and researchers) has been the potential for build-up of contaminants in sediments adjacent to urban stormwater outfalls and road runoff outfalls, with a particular focus on sheltered marine receiving environments. In this regard, considerable effort is being directed to controlling inputs of particulate material into freshwater and marine receiving environments in some urban areas, particularly Auckland.

A caveat to the above is that dissolved zinc and copper from road runoff in urban streams in New Zealand can reach levels that are above guideline limits and may lead to adverse effects, particularly with high quality ecosystems. Furthermore, in many urban streams, ecosystems are degraded by high temperatures and peak flows, which may be more significant than the effects of road runoff.

Nevertheless, the available scientific evidence for New Zealand (see Appendix B) indicates the importance of managing the particulate fraction of runoff.

3.3 Fate of particulate contaminant fraction

In contrast to dissolved contaminants, particulate-associated contaminants will tend to settle and accumulate in the nearest downstream depositional receiving environment.

If the immediate receiving environment is *strongly depositional* (e.g. a deep, sheltered inner harbour subject to limited water movement, a low gradient stream, or a lake) a high proportion of the particulate load will be deposited in the immediate vicinity of the outfall. In this event there will be high potential for the concentration of contaminants to build up in the sediments to ecologically significant levels.

If the receiving environment is *moderately depositional* (e.g. rivers of moderate gradient periodically flushed by flood-flows, or estuaries subject to moderate flushing by tide or wave-induced currents), then contaminants have less potential to accumulate and may be dispersed over a wider area. This can lead, for example, to contaminants discharged from roads to the upper parts of estuaries being gradually dispersed seawards; this effect may lower the potential for exceedance of sediment quality criteria in the medium term but perhaps increase the potential for significant widespread contamination in the longer term.

If the immediate receiving environment is *dispersive* (e.g. a high energy shallow fast-flowing river or an open coastline), particle-associated contaminants will tend to be transported rapidly downstream. The particles will eventually settle in a depositional area (distant receiving environment). In this case there will be a tendency for them to be dispersed and therefore lower potential for build-up to ecologically significant levels in sediments.

The above considerations suggest that the particulate fraction of the contaminant load is the appropriate point of focus and consequently the primary factor determining the impact of this component of runoff is the degree to which the immediate receiving environment is *depositional.*

3.4 Criteria for rating sensitivity of receiving environments

The literature review has shown that receiving environment sensitivity to adverse effects can be determined by one or a combination of several factors. These include:

- The physical characteristics of the waterbody.
- The natural/ecological values associated with the waterbody.
- Human uses and values associated with the waterbody.
- The existing degree of contamination or disturbance.

Further analysis of the relative importance of these factors has identified the following criteria as being of significance in developing a sensitivity rating system for waterbodies to road runoff:

- The primary role that water movement plays in determining whether or not a receiving environment is ‘depositional’ or ‘dispersive’ and hence its assimilative capacity/susceptibility to contaminant build-up in sediments.
- The important, but secondary, role that natural/ecological values play in determining the sensitivity of receiving environments.
- The important, but tertiary, role that human uses or values play in determining the sensitivity of a receiving environment.

It was concluded that the existing degree of contamination or disturbance should preferably be left out of a rating system that seeks to determine the intrinsic sensitivity of a waterbody. However, existing contamination should remain a significant factor in determining the need or otherwise for prioritising runoff treatment measures.

This approach has guided development of a framework for rating the sensitivity of receiving environments and ranking them according to their sensitivity to road runoff, as described in the subsequent section.

3.5 SRE rating framework

A preliminary framework for rating the sensitivity of receiving environments to road runoff is given in Table 3.1. A summary of the rating system is provided below. Guidance on application of the framework is given in Appendix C.

A schematic of the SRE rating framework is shown in Figure 3.1.

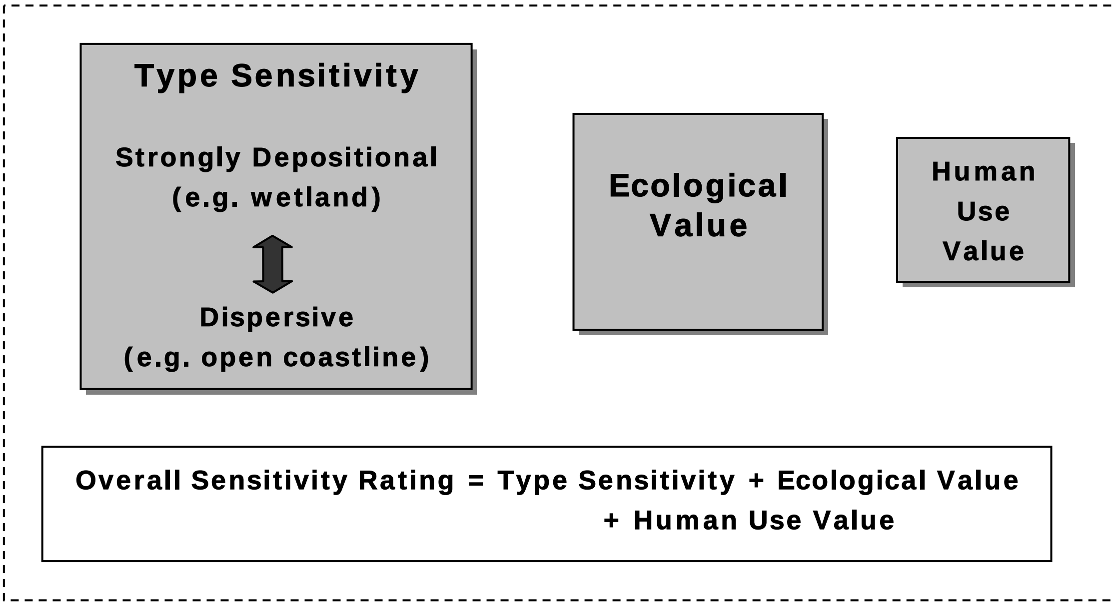

Figure 3.1 Schematic of SRE rating framework.

The proposed method is based on a hierarchical system whereby the receiving environment (RE) is sequentially classified according to three attributes:

1. Physical 'type sensitivity' (depositional vs. dispersive),
2. Ecological values,
3. Human use values (including cultural values).

Within each of the above attributes, the receiving environments are classified as being of 'high' (H), 'medium' (M), or 'low' (L) sensitivity and assigned a numerical score accordingly (see 2nd and 3rd column of Table 3.1).

The overall sensitivity rating for each receiving environment is calculated by adding the scores for the type sensitivity, ecological value and human use value. The sensitivity rating is grouped under three broad categories, based on the total score, with high ratings indicative of high sensitivity, as follows:

- High sensitivity (high potential risk from road runoff): Total score >40
- Medium sensitivity (moderate potential risk from runoff): Total score 20-40
- Low sensitivity (low potential risk from road runoff): Total score <20

Table 3.1 Framework for assessment of the sensitivity of receiving environments to road runoff.

A. Primary classification: receiving environment type.

<table>
<tr><th>Type of Receiving Environment</th><th>Sensitivity</th><th>Score</th><th>Information Sources</th></tr>
<tr><td>Strongly Depositional
• Enclosed/sheltered harbour, embayment
• Estuaries
• Low gradient/velocity streams or rivers
• Small lakes, some larger lakes
• Wetlands</td><td>H</td><td>30</td><td rowspan="3">Visual observation
Map Inspection
GIS Databases</td></tr>
<tr><td>Moderately Depositional
• Semi-enclosed harbours, embayments
• Moderate gradient/velocity streams or rivers
• Large lakes</td><td>M</td><td>20</td></tr>
<tr><td>Dispersive
• Open/exposed coastal environment
• High gradient/velocity streams or rivers</td><td>L</td><td>5</td></tr>
</table>

Table 3.1 (continued) Framework for assessment of the sensitivity of receiving environments to road runoff.

B. Secondary classification: ecological values.

Ecological Values	Sensitivity	Score	Information Sources
• Water body has high formal conservation status e.g. within a national park, reserve, marine reserve, wildlife refuge, protected natural area or identified as regionally or naturally significant, or • Rare, threatened, endangered species present (flora or fauna), or • Plant or animal community with high species diversity, or • Rare habitat or good representative example for region, or • Particularly valuable habitat e.g. whitebait spawning area, or • Particularly high quality habitat/water present e.g. upper reaches of some streams or springs.	**H**	**20**	Regional Councils Regional Plans Regional Registers or Databases Department of Conservation NZ Fish and Game Environmental Groups Iwi
• No formal conservation status, and • Absence of rare, threatened, endangered species, and • Moderate species diversity, and • Moderate habitat diversity, and • Habitat values moderate.	**M**	**10**	
• No formal conservation status, and • Absence of rare, threatened, endangered species, and • Low species diversity, and • Low habitat diversity, and • Habitat values low e.g. significant physical modification and/or contaminant inputs from sources other than road runoff.	**L**	**5**	Regional Councils Regional Plans Regional Registers or Databases Department of Conservation NZ Fish and Game Environmental Groups Iwi

Table 3.1 (continued) Framework for assessment of the sensitivity of receiving environments to road runoff.

C. Tertiary classification: human uses and values [a].

Uses/Values	Sensitivity	Score	Information Sources
• Highly used or valued for food gathering including traditional Maori food sources (e.g. shellfish, koura, watercress), or • High use for contact recreation (e.g. swimming, paddling), or • High use for non-contact recreation (e.g. fishing, canoeing, windsurfing, boating), or • High cultural/spiritual values associated with water body, or • Downstream water supply, or • High economic value e.g. tourism.	**H**	**10**	Regional Councils Iwi Recreational Groups
• Highest status reasonably assigned to the receiving water, in terms of all of the above uses or values is "moderate" (see guidance in text).	**M**	**5**	
The status reasonably assigned to the receiving water, in terms of all of the above uses or values, is "low" (see guidance in text).	**L**	**2**	

TOTAL SCORE		(minimum 20 and maximum 60)

Notes: Overall Sensitivity Rating:

high sensitivity	=	total score >40
medium sensitivity	=	total score 20-40
low sensitivity	=	total score <20

(a) Some users of the methodology may wish to remove aspects concerning Maori culture/values from the weighting table (and hence from assessment of human values) and treat this as a separate qualitative decision-making criterion

Based on the range of scores available for each attribute (assigned in Table 3.1), the total scores will vary from a minimum of 12 to a maximum of 60, with overlap between adjacent categories.

The scores are weighted differently within each category to reflect the relative importance of receiving environment type, ecological values, and human uses/values. Scores are arbitrary but reflect the relative weighting of the three attributes. The rationale for ranking and scoring of the three attributes acknowledges that:

- Type sensitivity is the key criterion for depositional effects from runoff.
- Protection of ecological attributes will assure human use values.

The rating system is not intended to provide a detailed analysis of such effects on the receiving environment. The approach is `high level' and intended as a ranking tool to distinguish the potential for adverse effects.

[Note that the *actual* risk to a highly or moderately sensitive receiving environment will depend on the contaminant load generated in the runoff catchment (*source*) and the existence and type of *pathway* for contaminant transport between the road and the receiving environment. A risk assessment methodology addressing this aspect is the subject of Section 5.]

Table 3.2 illustrates application of the sensitivity rating system to two types of receiving environments. In both cases, the receiving waterbodies are reserves of high ecological value and therefore have the same ecological value.

Table 3.2 Example sensitivity ratings for two receiving environments.

Example	Attribute score			Total score
	Type sensitivity	Ecological value	Human use	Overall sensitivity rating
A. Wetland reserve; low human value	30	20	2	**52**
B. Open coastline marine reserve; high human value	5	20	10	**35**

The wetland reserve (Example A: score 52) has a higher overall sensitivity rating compared with the marine reserve (Example B: score 35), despite the latter having a higher human use value.

The wetland in Example A is a `high sensitivity' category of receiving environment compared with the `medium sensitivity' category for the marine reserve. The reason is that the wetland reserve (as a sensitive depositional environment) is at higher risk of adverse effects from contaminants in the particulate fraction of road runoff compared with a marine reserve situated on a dispersive open coastline.

4 Source and pathway considerations

4.1 Introduction

Identification of the source and pathway risk factors is an essential step in developing a method for assessing risk to SREs from road runoff. These factors essentially comprise two components:

1) The strength of the source term (i.e. pollutant load in road runoff).
2) The nature of pathways potentially connecting the road runoff to the SRE.

Development of these aspects was conducted under Stage 3 of the project that included a literature review of the following topics:

- Factors affecting road runoff quality.
- Approaches to modelling road runoff pollution.
- Screening criteria used in traffic impact assessment of waterbodies.

Findings from the literature review are given in Appendix D.

A summary of key points from the review and the rationale behind the source and pathway risk factors that were adopted within the risk assessment methodology is given below. This includes an overview of the vehicle contaminant load model that was developed to estimate pollutant loads in runoff from road networks (see Appendix E for full details of the model).

4.2 Source factors affecting quality of road runoff

Road traffic is an obvious source of contaminants in road runoff. However, contaminants on roads may have other sources apart from vehicles e.g. washout of atmospheric contaminants.

Road runoff itself may be also influenced by contaminant contributions from outside the road environment e.g. zinc in roof runoff. Furthermore, a fraction of particulate contaminants that build up on road surfaces may subsequently be dispersed by winds before they become washed into the road drainage system. In urban areas, the process of street cleaning will also reduce the contaminant load in road runoff.

The main factors affecting quality of road runoff from the perspective of a screening tool for estimating vehicle-derived contaminants are discussed below in terms of:

- Traffic and road characteristics
- Rainfall and runoff patterns
- Highway drainage infrastructure

4.2.1 Traffic and road characteristics

While the primary traffic-related risk factor affecting contamination in road runoff is the level of traffic, more recent research has clarified the influence of related variables such as road terrain, road configuration and traffic congestion.

Road and traffic conditions influence the degree of vehicle acceleration and braking which, in turn, result in differences in wear rates for brake linings (affecting copper), tyres (zinc) and road surfaces (particulates). This changes the vehicle emission factor (expressed as mass of contaminant per VKT) and hence the contaminant load in runoff from a given section of road.

Road terrain (hills, bends) has a marked effect on contaminant load. For example, Kennedy et al. (2002) quote tyre wear rates that vary from straight and level driving (representing 100% of tyre life) to 76% on slightly hilly and curvy roads, and to 50% on hilly and curvy roads. Thus, compared with level sections, roads in more hilly terrain with a larger number of tight bends will result in greater tyre wear (increased zinc) and more braking (higher copper).

Likewise, traffic congestion has a strong influence on the quality of road runoff. Congestion is a function of traffic flows and road capacity, and is influenced by road type (e.g. suburban road or highway), road layout (e.g. intersections and traffic lights), and traffic type (e.g. heavy vehicles). Compared with free flow conditions, a heavily congested section of road will therefore generate more pollutant load from increased braking and acceleration, in addition to the load from higher traffic flows.

The vehicle contaminant load model developed under this project has been designed to take account of the above factors.

4.2.2 Rainfall and runoff patterns

Rainfall is the medium for removing pollutants that have built up on the road surface and is therefore a key aspect affecting the concentration of contaminants in road runoff.

The relationship of rainfall to surface water quality has been extensively studied. The relationship is complex and a function not only of the amount of rainfall but other related variables such as the intensity and duration of rainfall during storm events, and the number of preceding dry days.

The concept of `first flush' is that a large fraction of the contaminant material accumulating on an impervious road surface is flushed off into the drainage network during the early stage of a storm.

The occurrence of a first flush is mainly dependent on the long-term build up of materials on the road surface and the magnitude of the rainfall event (Lee et al. 2002). The first flush may also be influenced by material from previous storm events that are flushed from road drains e.g. catchpits or stormwater pipes (Kennedy 2003).

The significance of first flush has been used to advantage by designing stormwater drainage systems that capture the initial runoff, and thus are able to remove the fraction of discharge containing the highest concentrations of contaminants (Barrett et al. 1998).

Rainfall and runoff patterns are key risk factors in the quality of runoff from individual storm events. However, in the context of this project, and as discussed in Appendix B, environmental impacts from road runoff are more aligned to the cumulative build-up of contaminants in sediments within the receiving waterbody. Over the long term, therefore, they are relatively insensitive to whether the pollutants that build up on a road surface are washed off in a single large storm event or a series of smaller events. In the long term it may be assumed that all such contaminants are washed off into runoff.

Accordingly, for the comparison and ranking of roads that may adversely affect sensitive receiving environments, it is appropriate only to consider the relative pollutant load corresponding to the estimated quantity of contaminant in runoff, independent of the contaminant concentration, rainfall or runoff pattern.

4.2.3 Highway drainage infrastructure

The type of highway drainage (e.g. kerb and channel, catchpit, swale) plays a key role in controlling the contaminant load in runoff leaving the road, and therefore the risk to downstream receiving environments. Evaluating the source strength in terms of contaminant load needs to take account of road drainage characteristics in order to determine the actual load entering the receiving environment.

For example, kerb and channel drainage systems collect high volumes of runoff and discharge these via a point source, thereby potentially increasing the impact of pollutant loads on the downstream receiving environment. For this reason, catchpits and sumps are commonly used in urban road networks to remove a proportion of the contaminant load.

On the other hand, a significant proportion of rural state highways in New Zealand have no stormwater collection system with the result that runoff is more diffuse and the quantity and impact of pollutant load entering nearby water bodies is reduced. The benefit of using swales alongside highway verges to reduce stormwater pollutant loads is well documented.

The vehicle contaminant load model developed under this project was designed to take account of the moderating effects of highway drainage.

4.3 Screening of traffic-related impacts on waterbodies

Screening tools for impact assessment of road networks on receiving waterbodies were briefly reviewed as part of this project and the findings are described in Appendix D.

Tools developed overseas typically incorporate AADT banding as a means to differentiate risks from roads and are generally based on effects on water quality at the discharge point rather than the impact of pollutant load on depositional receiving environments.

Traffic levels measured as AADT are a poor proxy for runoff quality. A further limitation with AADT as a screening tool for effects on depositional environments is that it is primarily designed for direct impacts on a waterbody, and will not include indirect contributions that may occur higher up the catchment. It also does not take into account cumulative impacts from road sections that fall below the AADT threshold and which discharge to the same waterbody.

A more robust screening indicator of source risk (i.e. pollutant load) from traffic is vehicle kilometres travelled (VKT), which is determined as the product of AADT and road length.

Published research indicates that VKT at the sub-catchment level is a promising approach for identification of road networks where runoff may potentially have elevated contaminant loads. For example, Brown and Affum (2002) describe a GIS-based environmental modelling system (TRAEMS) that uses total VKT on roadways within a catchment (or sub-catchment) as a surrogate measure of potential vehicle pollution. The assumption is made that roadway emissions within a particular catchment will largely be washed off within that catchment.

The total VKT estimated to affect an SRE from a road network will reflect both direct and indirect contributions from the road network in the catchment and will include cumulative effects, therefore providing a better indication of the overall risk to the waterbody.

A VKT catchment-based approach was adopted in the Tier 1 screening tool for identification of potential `hot spots' - areas of road network likely to have elevated contaminant loads (see Section 5.4.1). These were subject to more detailed scrutiny with a contaminant load model under Tier 2 (see Section 5.4.2).

4.4 Modelling road runoff pollution

Models for estimating road runoff contaminant load use emission factors for vehicle-derived pollutants as a function of traffic density e.g. expressed as mg/VKT. The contaminant load is calculated by multiplying the contaminant emission factor by the vehicle flow and the length of the road.

Models for road runoff have been developed in New Zealand to provide estimates of contaminants (e,g. copper, zinc and lead) expressed in terms of mg/VKT. The models are either empirical (i.e. relationship based on field measurements of the variables) or source-based (i.e. relationship developed from assumptions on pollutant emission factors for different source components).

Contamination load rates within empirical models generally ignore or otherwise do not adequately account for differing road types or traffic characteristics that have a defining influence on pollutant load. For this reason a source-based model is the preferred approach in the context of this study.

The Ministry of Transport's research programme (road transport impacts on aquatic environments to predict vehicle-derived pollutant loads in the environment from road runoff) included development of a source-based model (VFEM-W), as described in Moncrieff & Kennedy (2004).

A published study on validation of this model in Waitakere City showed that load predictions were weakly correlated to measured levels of copper and zinc from road surfaces (Kennedy & Gadd 2003). No working model was issued from this programme and the equations relating emission factors and road/traffic conditions to contaminant loads have not been published.

4.5 Adopted approach to evaluate source risk factors

The literature review (Appendix D) considered the significance of risk factors to SREs at source i.e. within the road network before transport of runoff along the pathway to the receiving environment. The main findings are summarised below.

The literature indicates that pollution from road runoff is very variable in nature and has a complex relationship with runoff quality. Traffic is the main source of road runoff pollution with the main contaminants of concern being heavy metals (notably copper and zinc) and PAH.

Road characteristics and driving conditions have a strong local influence on vehicle emission rates, and hence contaminant loads. Models for estimating vehicle-derived contaminant loads in road runoff need to factor in these dependencies.

For the current project, the contaminant load (mass) rather than contaminant concentration is the key information required from the perspective of determining the risk posed by traffic (the source component) to depositional environments. This requirement indicates the need for incorporation of a contaminant load model in the overall methodology for identifying SREs at risk from road runoff.

An extensive and recent body of New Zealand research (published in 2001-2004) has been developed under the Ministry of Transport's programme on road transport and its effects on aquatic ecosystems. It is intended to use this research as the principal source of information on sources of contaminants and related vehicle emission factors applicable to New Zealand conditions.

Derivation of a working source-based model to estimate contaminant loads on a comparative rather than absolute basis, and based on the MoT's extensive published data, has been the approach adopted for the current project.

On the basis of the above findings, the following two-tiered approach was adopted for identifying and characterising the risk to SREs from traffic-sourced contaminants in road runoff:

i) A screening tool for identifying potential `hot spots' - areas of high traffic density that may have an adverse impact on water quality; this is to be based on total

VKT by sub-catchment and to be developed for both state highways and local road networks.

ii) A source-based model for predicting vehicle-derived contaminant loads (to include copper, zinc and PAH) in the identified `higher risk' road sections, based on emission factors from the MoT's research programme, and factoring in the effects of varying road/traffic conditions.

The tier risk assessment method is discussed in Section 5.4. The vehicle contaminant load model is described in the following section.

4.6 Vehicle contaminant load model

With the focus on depositional environments discussed above, assessment of contaminant load (rather than concentration) was seen as a pre-requisite for determining the source risk from road traffic.

The local influence of road characteristics and driving conditions on vehicle emission factors and hence pollutant load, and the potential further reduction of load by highway drainage, were also important factors requiring consideration.

A Vehicle Contaminant Load Model (VCLM) that factored in these dependencies was developed as part as part of the methodology for identifying SREs at risk from road runoff.

This section provides an overview of the model, together with user inputs, validation and limitations in use. Full details of the model, including assumptions, model equations, worked examples and initial validation are described in Appendix E.

4.6.1 Model overview

The Excel-based VCLM estimates mass loads of vehicle-derived contaminants (e.g. particulate matter, zinc and copper) in road runoff. Pollutant loads are derived from traffic flows and contaminant emission rates (expressed as mg/VKT) which take into account traffic speed/congestion, vehicle type and road terrain.

Emission factors are derived from contaminant concentrations and emission rates. For example, the vehicle pollutant load to the road surface from zinc is derived from the sum of individual contributions from tyre wear, oil leakage and exhaust emissions. The tyre wear contribution is estimated from the average zinc concentration in tyres and the average tyre wear rate.

The runoff contaminant load on a section of road prior to any treatment device is calculated by multiplying the emission factor by the vehicle flow and the length of the road section. The model has provision for user selection of existing stormwater treatment devices (e.g. catchpits) to allow for load attenuation. The total load in road runoff to the receiving environment is obtained by summing over all road sections in the network.

The vehicle emission factors used in the VCLM are based on data published under the Ministry of Transport's research programme on effects of transport on the aquatic environment (Kennedy et al., 2002).

4.6.2 User inputs and model application

Inputs required to run the VCLM are listed in Table 4.1. The majority of these can be accessed directly by the GIS system from the RAMM database, or otherwise calculated from look-up tables, without user intervention.

Table 4.1 User inputs to the Vehicle Contaminant Load Model.

Variable Name	RAMM Table[(a)]
AADT (vehicle/day)	Traffic (use ADT)
Road Type	Carriageway
Level of Service (LoS)	Calculate from AADT and road capacity
HCV (%)	Loading
No of Lanes	Carriageway
Road Length (km)	Carriageway
Horizontal Terrain (deg/km)	High speed geometry
Vertical Terrain (m/km)	High speed geometry
No of Seal Layers	Surface structure
ALD (mm)	Surface structure
Treatment device	Drainage (or user specified)

(a) New Zealand's Road Asset Maintenance Management system

Local roads in each stormwater sub-catchment are grouped into `highway catchments' – road surfaces that collectively discharge runoff to a common point (e.g. sump). The pathway and receiving environments for each of these discharges are determined from a GIS plan of the stormwater drainage network.

A polygon is created around the road/stormwater network that includes the pathway to the SRE and the discharge point on the SRE, thus defining the source-pathway-receptor linkage.

A table of required model inputs for each local road section (e.g. road type, level of service, %HCV etc) in created in GIS from the RAMM database and read by the VCLM. The VCLM is applied in turn to each of the roads in the polygon to derive a total contaminant load.

The section loads are summed to obtain the sub-catchment loading. A similar process is followed for state highways in which the `highway catchments' comprise a linear set of adjacent sections of road with common drainage.

The model is applied under the Tier 2 assessment to provide a comparative measure of risk to SREs from traffic on road networks (see Section 5.2 for the stepwise methodology and Section 6.4 for example applications to state highways and local roads).

4.6.3 Model validation and limitations

Initial validation of the VCLM for copper and zinc has been achieved by applying the model to published field data and road characteristics for the Richardson Road site in Auckland (Timperley et al., 2003). The predicted emission factors from the VCLM (mg/VKT) are within a factor of two (for copper) and four (for zinc) compared with factors established for this site. In both cases the VCLM overestimates the contaminant load.

There is considerable uncertainly in the derivation of emission factors in the model, given the wide variability in source data, hence the model predictions must be treated as only `order of magnitude' estimates of contaminant load. In addition, the model is restricted to estimating emissions from road vehicles. Road runoff is likely to contain contaminants from other sources (e.g. urban or industrial discharges), which contribute to the overall stormwater pollutant load.

Accordingly, the VCLM should be used to estimate contaminant loads from road networks on a comparative rather than absolute basis. It is also capable of distinguishing the relative contributions of contaminant loads from different road types (e.g. state highways vs. local roads within a catchment) that may affect a given receiving environment.

4.7 Pathway considerations

The pathway is the route taken by road runoff from the point it leaves the road drainage system (e.g. sump, catchpit) to the point it is discharged into the depositional receiving environment i.e. the downstream place, such as an estuary, where the main contaminant load is deposited.

The pathway may be obvious in some circumstances (e.g. a stormwater discharge into an estuary from a highway drain). In other cases, there will be no obvious route (e.g. water seeping into the roadside verge). Physical field inspection of the road section together with knowledge of the local topography and surface water drainage will be required to identify the pathway.

In the context of discharge of particulate matter in road runoff, three generic types of pathway have been defined, depending on their `connectivity' to the receiving environment. Examples of each are given in Table 4.2 for local roads and state highways.

4.7.1 Direct pathways

Direct pathways occur where road runoff is discharged directly to an SRE. A typical situation for local roads is for runoff to be piped down the catchment in the stormwater system and discharged via an outfall into an estuary (the SRE).

If the stormwater is discharged first into a fast-flowing stream before connecting further down the catchment to the estuary, this would be classified as an indirect pathway. If the road runoff was discharged to adjacent land and left to infiltrate the subsurface (i.e. not discharged to a waterbody), this is considered a diffuse pathway.

Table 4.2 Pathway types and examples of runoff discharge to SREs.

Pathway type	Example	
	Local road	**State highway**
Direct	Storm runoff piped to outfall at SRE (e.g. estuary or wetland).	Storm runoff piped directly to adjacent SRE (e.g. estuary or slow river).
Indirect	Runoff discharged into stormwater drainage system, then into a fast stream leading to SRE.	Urban highway with sump and culvert discharging to fast stream leading to SRE.
Diffuse	Runoff discharged to adjacent land and left to infiltrate the subsurface (i.e. not discharged to SRE).	Rural highway with stormwater allowed to run off carriageway onto verge (i.e. no kerb and channel collection system).

4.7.2 Indirect pathways

Road runoff that first enters a stream or river before reaching an SRE is considered an indirect pathway. In the above example, if runoff is discharged first into a fast-flowing stream before connecting further down the catchment to the estuary, this would be classified as an indirect pathway.

The situation with indirect pathways via streams or rivers needs qualification. Whilst there may be potential for retention and accumulation of contaminants in riverine sediments, with consequent adverse effects on exposed benthic organisms, it should be assumed that contaminants discharged to streams and rivers will eventually end up in the estuary/sea. In other words, streams and rivers essentially act as pipelines to the sea.

A further qualification is needed for the case of discharges to slow rivers as these may themselves act as a depositional environment, particularly in the reach just before an estuary. Identification of the appropriate receiving environment for considerations of risk needs to be assessed on a case-by-case basis.

4.7.3 Diffuse pathways

Certain sections of road do not have stormwater collection systems (e.g. surface water channels, sumps, culverts) that collect and discharge runoff to a nearby water body. Runoff in this instance is allowed to freely drain to adjacent land and infiltrate the subsurface. Alternatively, stormwater treatment systems may be installed that remove a large fraction of the particulate matter (e.g. detention pond, soak pit). Such pathways are considered diffuse and present a low risk of particulates reaching a nearby SRE.

5. SRE risk assessment methodology

5.1 Introduction

This section presents a synthesis of the SRE risk assessment methodology by drawing together the source, pathway and receptor risk concepts (discussed in earlier sections). It defines the risk factors for each component, how they are estimated and how they are combined to provide an overall risk for the SRE and the road network.

A tiered approach is used for the screening and assessment of risk to receiving environments with the same methodology applied to local roads and state highways.

5.2 Spatial considerations

Application of the source-pathway-receptor concept to identifying which SREs are at risk from road runoff requires an understanding of the area of influence of a road network on a receiving water body i.e. the spatial boundaries over which to apply the model.

In the absence of a pumped system, road runoff will flow under gravity from a high point to the lowest part of the network (generally the receiving environment). In terms of a waterbody at risk from stormwater discharge, the boundaries of the source-path-receptor configuration are therefore constrained by the catchment in which the road and SRE reside. In other words, only roads that are situated (and which discharge) within an SRE catchment need be considered as a risk to that SRE.

Within the area of influence, the pathway may embrace a number of interconnected sub-catchments. A section of road discharging runoff without treatment to an adjacent SRE (e.g. lake, estuary) represents a direct pathway and has an obvious local influence. However, other sections of the same road (e.g. higher up the same catchment) may also discharge contaminants via streams/rivers to the same SRE (an indirect pathway). In instances where the catchment is large, the contaminant load to the upper catchment may be many kilometres from the SRE but will eventually find its way to this distant receiving environment.

The risk model must therefore be defined on a catchment basis for a given SRE/road network rather than by an arbitrary distance of the road from the receiving environment. For this reason the methodology for assessing risk from road runoff is determined spatially at the catchment/sub-catchment level in order to assess the cumulative impact of runoff from all sections of road to a given waterbody.

5.3 Source, pathway and receptor risk factors

5.3.1 Source risk factors

The source risk factor (source `strength') is measured in terms of the pollutant load (quantity of traffic-derived contaminants) in road runoff discharged from a given section of road or a road network.

Two source risk factors may be used:

1. To a first approximation, the source strength may be determined by VKT, which is a proxy for traffic density, and therefore vehicle-derived pollutant load (see Section 4). In this case, the source strength of a road section is expressed in terms of daily VKT. For a road network it is the sum of daily VKT for the individual roads in that network. This approach is used for Tier 1 screening (see below).

2. The source strength is expressed in terms of contaminant mass per unit time (e.g. mg Zn/day) from a given road section or road network (taking account of any treatment device on the road e.g. sump), as determined using the vehicle contaminant load model (Appendix E). This approach is used for Tier 2 assessment (see below).

5.3.2 Pathway risk factors

The pathway is the route taken by road runoff from the point it leaves the road drainage system (e.g. sump, catchpit) to the point it is discharged into the final receiving environment (RE).

The risk of a given pathway in terms of connectivity to the RE is defined in terms of its pathway factor (Pf). This represents the degree of attenuation of *particulate* load in runoff between source and receptor. Nominal order of magnitude figures were chosen. Although the approach is simplistic it is considered satisfactory for use in a screening tool. Pathway factors for the three pathway types are given in Table 5.1.

Table 5.1 Pathway types and factors for particulates in runoff.

Pathway type	Pathway factor (Pf)
Direct	1.0
Indirect	0.8
Diffuse	0.05

Direct pathways are assumed to result in no attenuation of particulate load in runoff after it leaves the road and represent a high-risk scenario. An arbitrary value of 1 is therefore assigned to this type.

Indirect pathways are given a nominal attenuation factor of 0.8. As discussed above, streams and rivers are effectively conduits to the estuary and sea. Thus the discharge of runoff to a fast flowing stream or river is a high-risk scenario for the downstream (depositional) receiving environment. The slightly lower value compared with a direct pathway reflects the risk that a portion of the contaminant load will be held `in transit' to the SRE.

Diffuse pathways result in almost complete attenuation of suspended load with consequently a low risk. These are given a nominal pathway factor of 0.05.

5.3.3 Receptor risk factors

The sensitivity of a receiving environment is defined in terms of the sensitivity rating (SR) of the waterbody (see Section 3). The three categories of SR (low, medium, high sensitivity) have a rating score from a low of 12 to a high of 60 (Table 5.2).

Table 5.2 Receiving environment sensitivity rating and factor.

Receiving environment sensitivity rating (SR)		Sensitivity rating factor (SRf) [(a)]
Qualitative	Rating score (range)	
Low	12-20	1.0 – 1.7
Moderate	20-40	1.7 – 3.3
High	41-60	3.4 – 5.0

(a) SR score divided by 12

Receptor risk is defined by the sensitivity rating factor (SRf). The value of SRf is calculated by dividing the SR value by 12 (the lowest SR score). Values of SRf range from 1 (low risk factor) to 5 (high risk factor), spanning the full range of receiving environments.

This process is required to normalise the sensitivity rating score so that it may be combined with the source and pathway terms to give an overall risk for assessment purposes. The sensitivity rating factor is an arbitrary term but its value remains proportional to the sensitivity of the receiving environment.

5.3.4 Combining risk factors

The source, pathway and receptor risk factors for a given road network/SRE combination and pollutant type are combined to give an overall measure of pollution risk (R in arbitrary units) for ranking purposes.

High values of R are associated with high pollution risk:

$$R = (S) \times (Pf) \times (SRf) \qquad \textit{(Equation 5.1)}$$

Where S = source strength
Pf = pathway factor
SR = sensitivity rating factor of receptor waterbody

The source strength reflects the relative pollution potential of the road network but takes no account of the pathway or receiving environment sensitivity. The pathway and receiving environment risk factors allow the source strength (expressed as VKT or pollutant load) to be increased or diminished depending on the pathway characteristics and sensitivity of the receiving waterbody. Allowable values for the pathway factor (0.05 to 1) and receptor sensitivity rating factor (1-5) provide a 100-fold range in variation for the pollution risk to the receptor.

Table 5.3 gives an example calculation of the pollution risk rating (`R' in arbitrary units) for road runoff with source strength of 200 mass units (e.g. 200 mg Zn/day), for a range of pathways and SREs. The pollution risk varies from a high of 1000 (direct discharge to waterbody with the highest sensitivity rating of 60) to a low of 10 (diffuse discharge to a waterbody with the lowest sensitivity rating of 12).

Table 5.3 Example of combining risk factors to derive pollution risk.

Source strength (S) [(a)] (mass/day)	Pathway		Receiving environment sensitivity		Pollution risk rating $R^{(b)}$ (arb. Units)
	Type	Factor Pf	SR	SRf (SR/12)	
200	Direct	1.0	60	5.0	1 000
200	Indirect	0.8	24	2.0	320
200	Diffuse	0.05	12	1.0	10

(a) Contaminant load in runoff leaving the road (including effect of any treatment device)

(b) R = (S) x (Pf) x (SRf)

The pollution risk described above is the risk at the point of runoff discharge to the SRE. In practice, SREs (e.g. an estuary) may receive multiple discharges at different locations from the same road network or discharges from different networks, depending on their size and configuration. The runoff may also come from either local roads, or state highways or a combination of both.

In such circumstances, each network is assessed as a whole to provide an individual pollution risk for each point of discharge (e.g. outfall in the case of direct discharges; or the lower reach of a stream or river at the point this meets the estuary for indirect discharges). These individual risks may then be combined to determine the cumulative impact of road runoff to the waterbody.

The process described above allows SREs in a given area to be ranked on a comparative basis in terms of their pollution risk from the road network. Recommendations may then be made on prioritising which sections of road should be given further consideration in terms of stormwater treatment.

5.4 Tiered risk assessment

A tiered approach has been developed for the assessment of the pollution risk to receiving environments from road runoff (state highway or local roads):

- Tier 1 - screening to identify potential `hot spots' on the road network.
- Tier 2 - risk assessment using the pollutant load model.

Tier 1 is used to screen SREs (or particular runoff discharge locations to an SRE) that may be at risk. It also identifies the sections of road in the catchment which are the source of the risk. The process is simple and requires only a basic GIS capability. Tier 2 is used to assess the pollution risk of `hot spots' identified by Tier 1 in a more rigorous method using the vehicle contaminant load model.

The different source-pathway-receptor risk factors used for Tier 1 and Tier 2 are summarised in Table 5.4.

Table 5.4 Risk factors used in Tier 1 and Tier 2 assessment.

Level	Risk factors for component:		
	Source	**Pathway**	**Receptor**
Tier 1	Daily VKT by subcatchment	Assumed `direct'	Type Sensitivity (M or H)
Tier 2	Contaminant load (S mg/day)	Pathway factor (Pf)	Sensitivity Rating Factor (SRf)
	Tier 2 pollution risk rating: R = (S) x (Pf) x (SRf)		

Under Tier 1 screening, the measure of source risk is total daily VKT in the catchment area that drains to a particular discharge point on the SRE. Waterbodies at potential risk from road runoff in the catchment are identified in terms of their type sensitivity (Type H or M) rather than by a fuller analysis of their sensitivity rating. The conservative assumption is made that all runoff pathways from the road to the SRE are direct.

Tier 1 is designed to be used as a screening tool. It is relatively easy to apply and requires minimal data preparation. The key GIS data files required are SREs, subcatchments, traffic flow data (AADT) and the road network in the area under study. The use of VKT as a proxy for pollutant load is a simplifying assumption, however the output is a useful pointer to areas of potential concern, as illustrated by examples from the Pilot Study (Section 6).

Tier 2 provides an overall risk rating for a given road network/SRE combination, taking account of the pollutant load, pathway and sensitivity rating of the waterbody. The source risk term is the total contaminant load discharging to the SRE (e.g. mg Zn/day), as determined by applying the vehicle contaminant load model to those parts of the road network that drain to the SRE. Tier 2 therefore takes account of the effects of traffic and road characteristics, as well as any stormwater treatment devices in the road network, which will collectively affect the pollutant load in runoff.

Tier 2 requires considerably more data preparation than Tier 1. This includes mapping of stormwater subcatchments (i.e. areas of the road network that drain to a common discharge), identification and assignment of source-pathway-receptor linkages, identification of RAMM data for the pollutant load model and aggregation of pollutant loads from road section within the network.

For local road networks, application of Tier 2 is best applied after Tier 1 screening so that only priority areas that present a significant risk from runoff need be assessed.

For state highways, where the road network is a simpler linear feature, and where a large part of the data processing may be automated once the model is interfaced to the road network, a case may be made for eliminating the screening step and proceeding directly to the Tier 2 assessment.

A description of the stepwise methodology for applying Tier 1 and Tier 2 to road networks is given below.

5.4.1 Tier 1 screening process

A flowchart of the Tier 1 process is given in Figure 5.1.

A GIS base map of the area is initially developed with layers including topography, catchments/sub-catchments, waterbody receiving environments (e.g. streams, rivers, lakes, estuaries etc), road network and traffic data.

The screening process identifies areas of high traffic activity (shown as the sum of VKT in each sub-catchment) and these are range grouped and colour coded on the base plan. (Note: sub-catchments containing roads are generally a good approximation to the spatial distribution of the stormwater drainage).

Sensitive receiving environments of Type M (medium risk) or H (high risk) are identified that lie within the influence of the road network i.e. adjacent to or otherwise downstream of the road. These are also marked up and colour coded. (Note: the process automatically screens out low risk, dispersive receiving environments as well as SREs that are not hydraulically connected to a road network).

The flow direction of drainage in the catchment is used to identify which SREs are potentially at risk from road networks spread across multiple sub-catchments. The values of VKT for these sub-catchments are grouped and summed. The total VKT values are labelled on the base plan on the sub-catchment closest to the affected SRE.

An example output from applying Tier 1 screening to a local road network is illustrated in Figure 6.3 and discussed in Section 6 (Pilot Study).

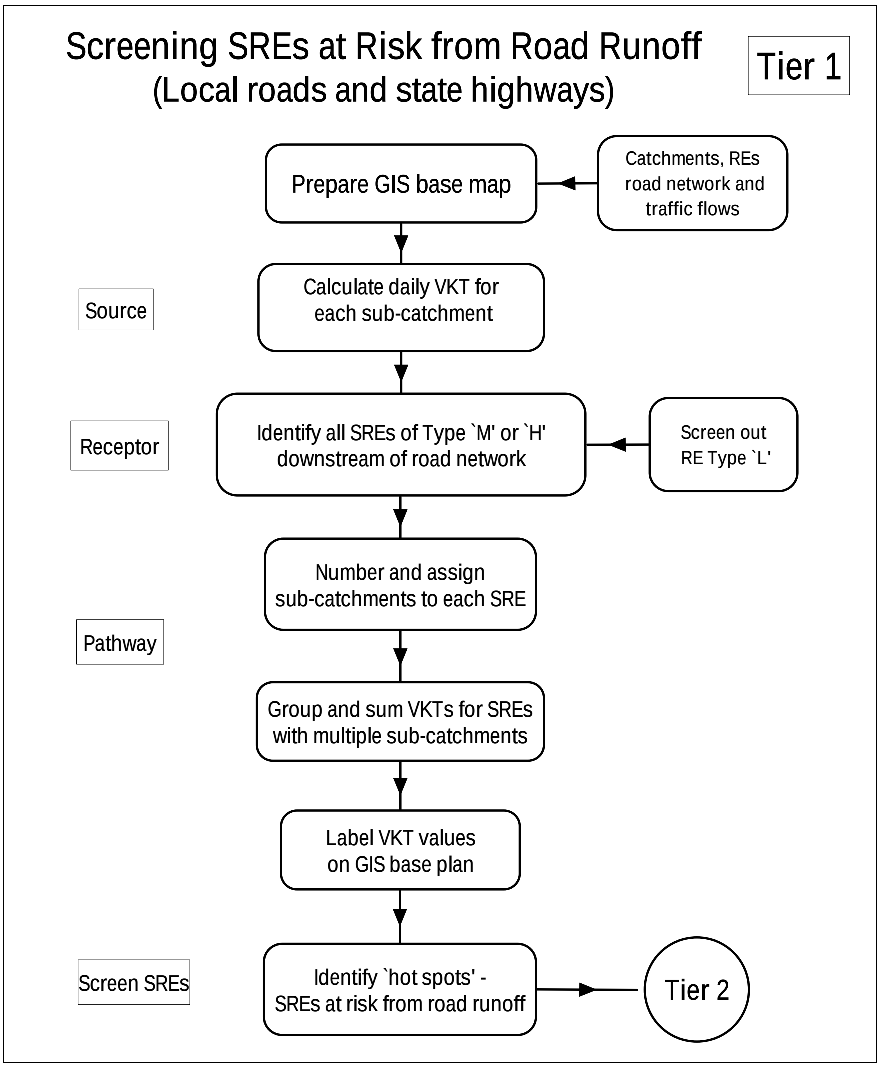

Figure 5.1 Tier 1 flowchart for screening SREs at risk from road runoff.

5.4.2 Tier 2 assessment process

A flowchart for the Tier 2 process is given in Figure 5.2.

The Tier 2 process assesses the risk to each SRE in turn. For a given SRE, the source-pathway-receptor configurations are initially identified and mapped. This allows identification of the road sections that individually (or collectively) drain to the discharge point(s) on the SRE.

Figure 5.3 and the following discussion illustrate how Tier 2 is applied to a GIS depiction of stormwater sub-catchments in a local road network.

The road and stormwater drainage networks are divided into a set of polygons (shown in white in Figure 5.3) that are mapped on the GIS base plan. Each polygon is a uniquesource-pathway-receptor linkage with the pathway represented by the stormwater sub-catchment that connects road runoff to a discharge point on the SRE. Contours (2 m interval) are used to assist grouping of sections of road to each sub-catchment.

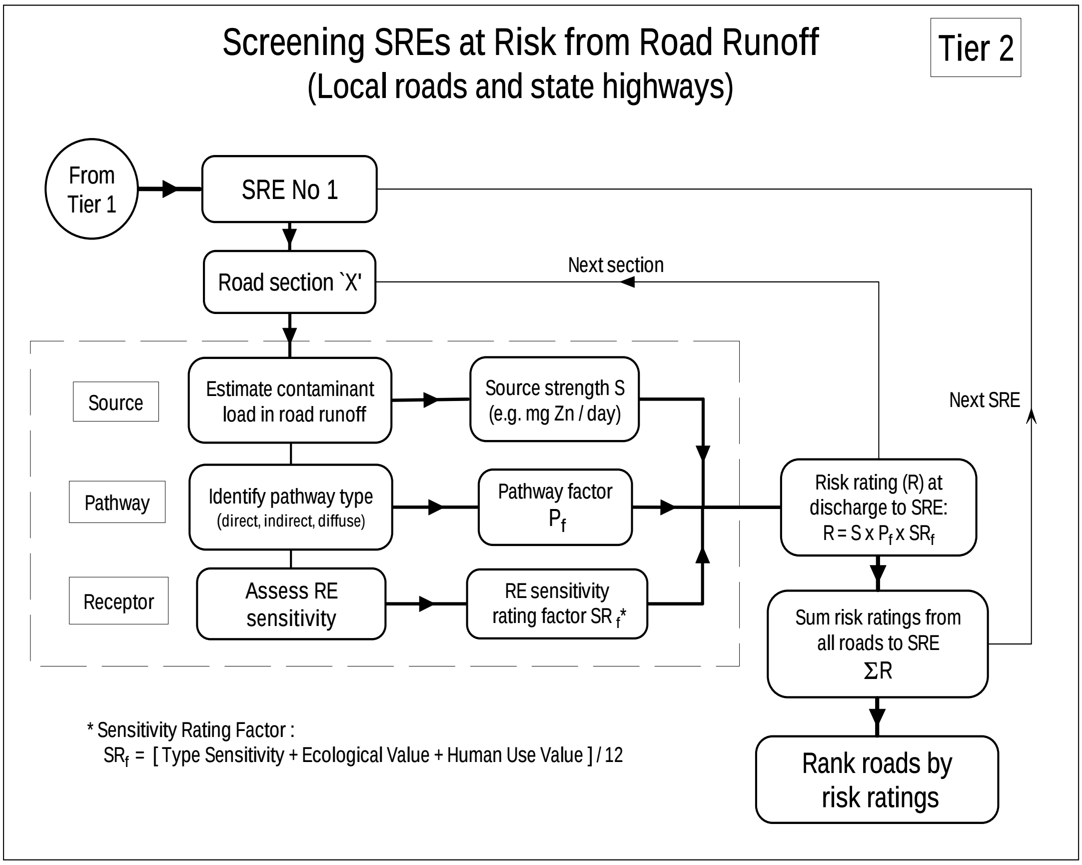

Figure 5.2 Tier 2 flowchart for screening SREs at risk from road runoff.

The contaminant load model is applied sequentially to all roads in the polygon and the individual loads are summed to give the total contaminant load in road runoff from the subcatchment.

The risk rating (R) at the discharge to the SRE is determined by combining the total contaminant load, pathway factor and sensitivity rating factor of the waterbody according to Equation 5.1. The overall risk from road runoff to the SRE is obtained from the sum of risk ratings for individual discharge points.

Direct and indirect discharges to the SREs are treated in the same way. In the case of direct pathways, the discharge point is the outfall to the SRE. For indirect pathways (discharge to SRE via one or more streams/rivers), the discharge point is notionally set at the confluence of river and final receiving environment (e.g. estuary).

Example outputs from applying a Tier 2 assessment are discussed in Section 6 (Pilot Study), and illustrated separately for a state highway (Figure 6.7) and local road networks (Figure 6.8).

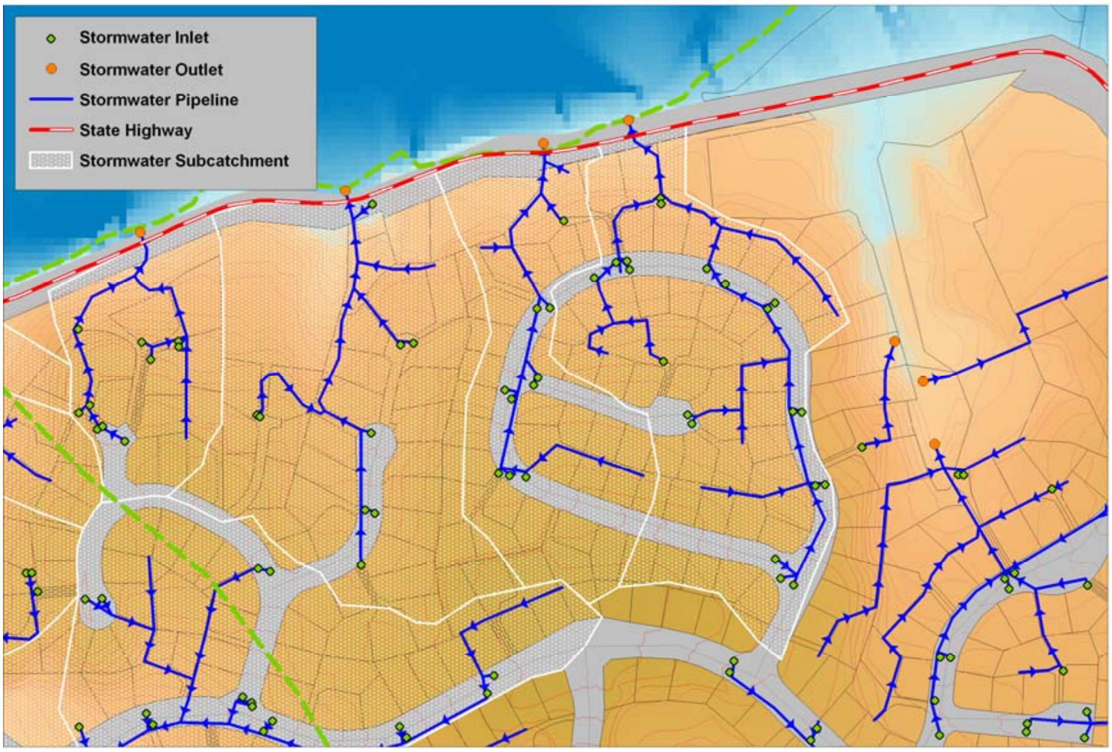

Figure 5.3 Tier 2 analysis of stormwater sub-catchments for local roads.

6. Pilot study

6.1 Introduction

A pilot study was conducted in a selected area in the Wellington region to evaluate practical application of the SRE risk assessment methodology for identifying and ranking SREs at risk from road runoff, as described in Section 5.

The pilot study was designed to illustrate potential application of the tool in identifying and ranking the relative risks to SREs from the road network. A further objective was its ability to distinguish relative contributions of contaminant loads from state highways and local roads that may affect a given receiving environment.

The Tier 1 and Tier 2 processes described above were evaluated in the study area. Regional GIS datasets at the 1:50,000 scale were provided by Wellington Regional Council. Porirua City Council provided additional GIS data covering the stormwater reticulation network showing road drainage features (drains, sumps, pipework, outlets etc) and the local road traffic network (including road type, AADT and %HCVs from the RAMM database).

6.2 Study area

The pilot study was situated in an area around Porirua Harbour, about 25 km north of Wellington City (see Figure 6.1).

Figure 6.1 Base map of study area.

The study area extends from Titahi Bay in the west to the eastern end of the Pauatahanui Inlet to the east, and from around Plimmerton in the north to Porirua in the south. The area was chosen as it has a suitable mix of local roads, state highways and SREs, and GIS data for the road networks and traffic flows was readily available.

The road networks and principal SREs in the study area are shown in Figure 6.2. State highways (SH1 and SH58) are marked by a thick black line and the main SREs are shaded.

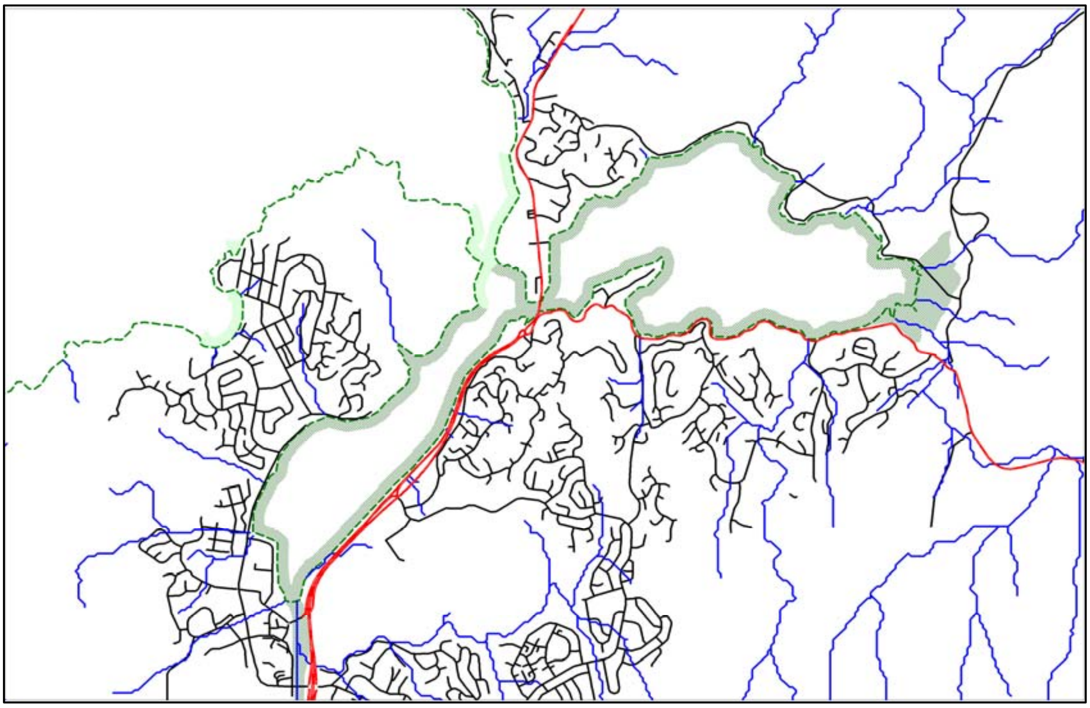

Figure 6.2 Road networks and main SREs in study area.

High sensitivity (type `H') waterbodies include the western arm of Porirua Harbour (known as the Onepoto Arm); the eastern arm (known as the Pauatahanui Inlet); a wetland at the east end of the Pautahanui Inlet (that includes the lower reaches of the Pauatahanui stream); and the lower reaches of Porirua Stream adjacent to the estuary. Type `M' SREs include the northern reach of Porirua Harbour (near Plimmerton) and Titahi Bay on the west coast facing the sea.

(Note: other smaller waterbodies are not marked at this scale; identification of all SREs was not attempted as the purpose was to evaluate the methodology rather than apply this to all SREs in the study area).

6.3 Tier 1 screening

The Tier 1 screening process was applied separately to local roads and state highways in the study area shown in Figure 6.1, as described below.

6.3.1 Local Roads

The plot of daily VKT by sub-catchment for local roads is shown in Figure 6.3. The plot represents the spatial traffic intensity and may be used (to a first approximation) as a surrogate measure of the pollutant load from vehicle-derived road runoff.

The `white' areas contain no roads and therefore no VKT. Areas with few roads are lightly shaded while areas with high traffic density are dark. Highest VKT values are found in the industrialised area of Porirua City at the southern end of Porirua Harbour.

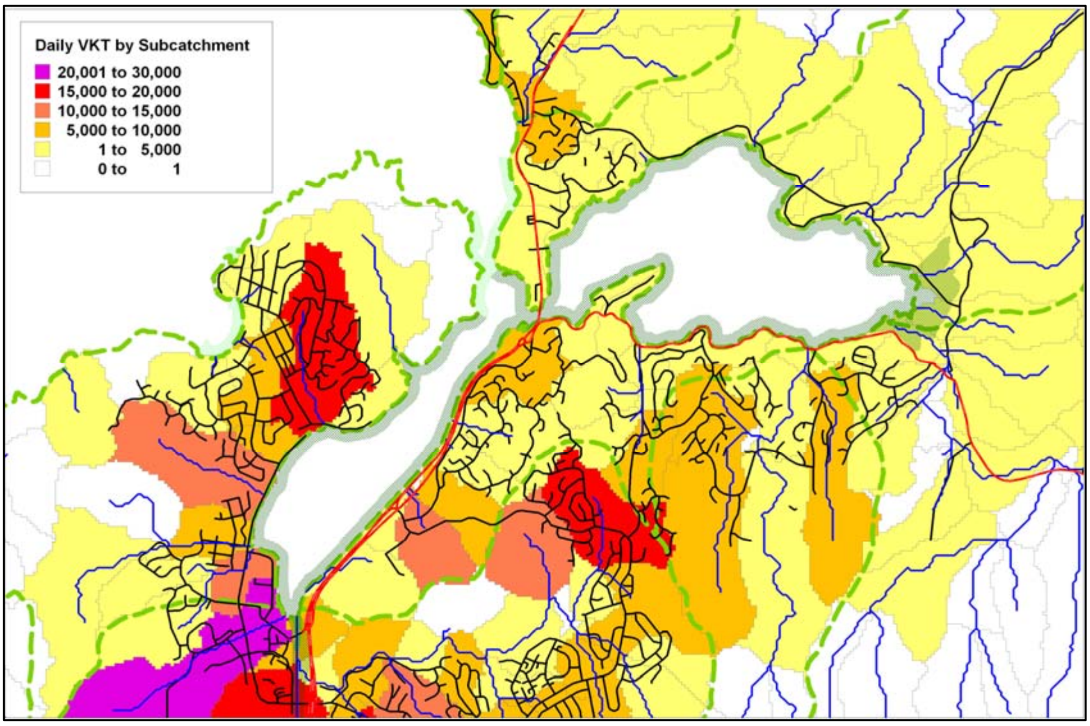

Figure 6.3 Daily VKT by sub-catchment for local roads in the study area.

The spatial distribution of VKT in relation to the two largest SREs (west and east arms of the Porirua Harbour) was then analysed by considering the stormwater drainage pathways in the study area. The group of sub-catchments that drain to common discharge locations on the two SREs were identified. The VKTs from each group were summed and the values labelled on the plot (Figure 6.4).

The largest VKT (139,320) occurs at the southern (Porirua) end of the Onepoto Arm. This represents a significant `hot-spot' and is due to the cumulative effect of 5 sub-catchments with moderate to high traffic density (starting from Cannon's Creek in the centre of the figure) that discharge in a westerly direction towards the Porirua Stream.

The contaminant load represented by the VKT value at the Porirua hot-spot is about a factor of 5 greater than the next largest values (VKT around 25,000). These were found at two locations: on the western coastline of the Onepoto Arm representing discharge from the suburb of Titahi Bay; and at Ducks' Creek at the southeastern end of

Pauatahanui Inlet which is the discharge point for a large fraction of road runoff from the Whitby area.

The above case study illustrates how Tier 1 screening using spatial analysis of VKT by catchment may be used to identify and rank those parts of an SRE potentially most at risk from road runoff, and which parts of the road network are contributing to this risk.

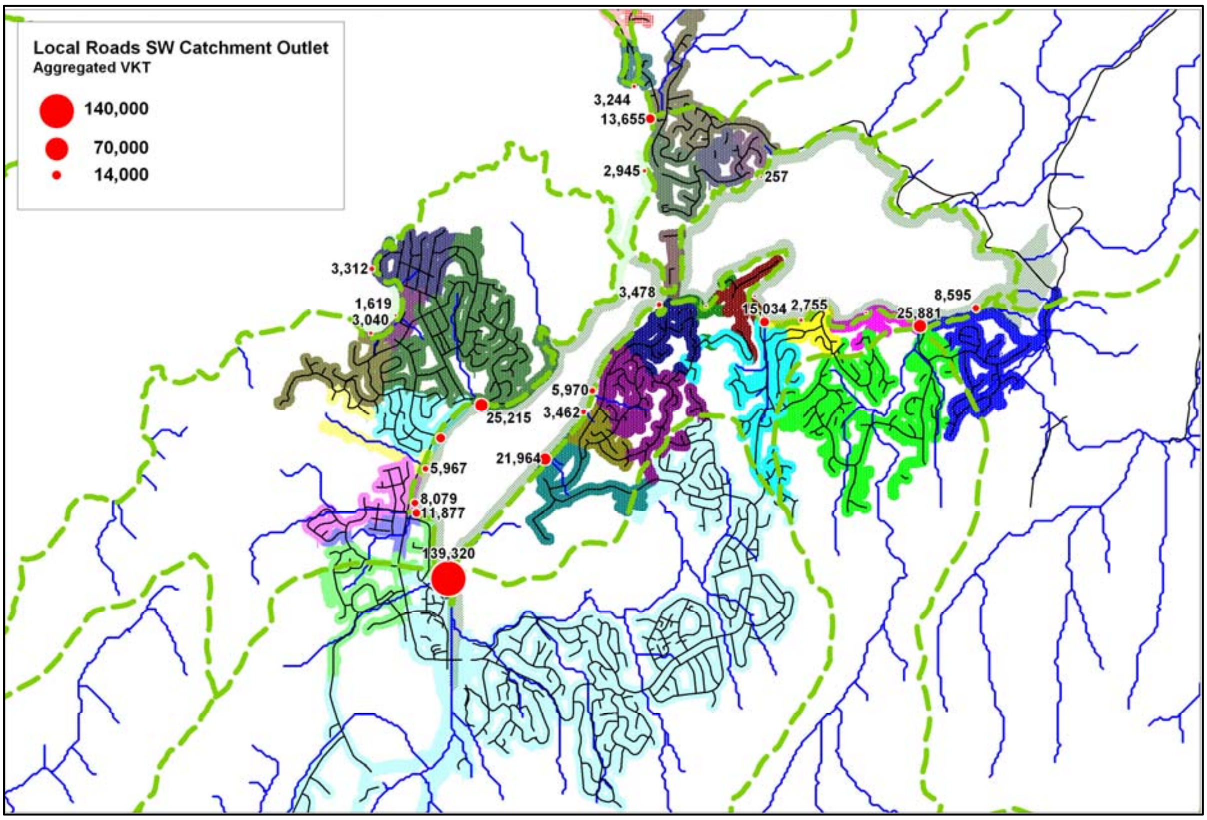

Figure 6.4 Tier 1 screening of local road network showing relative pollution potential (sum of daily VKT) at discharge to SREs.

6.3.2 State highways

Tier 1 screening was applied to the sections of state highway (SH1 and SH58) in the study area. The VKT plot for state highways is shown in Figure 6.5.

The state highway VKT distribution reflects the high traffic flows along the dual 2-lane SH1 running adjacent to Porirua Harbour (around 24,000 AADT). Markedly lower flows are found on the two-lane rural highway (SH58) that skirts the southern side of Pautahanui Inlet (around 13,000 AADT at the western end by the bridge, reducing to about 8,000 further to the east). Highest traffic densities are found in the sub-catchment just south of the Porirua Harbour bridge where the two state highways converge.

6.3.3 Combined road networks

Adding the VKT data in Figures 6.2 (for local roads) and Figure 6.5 (for state highways) provides an overall indication of traffic activity in the study area (Figure 6.6).

The combined VKT plot allows a qualitative appraisal of the pollution potential of the different road networks and where cumulative impacts on SREs may arise from discharges of road runoff that warrant further appraisal under Tier 2.

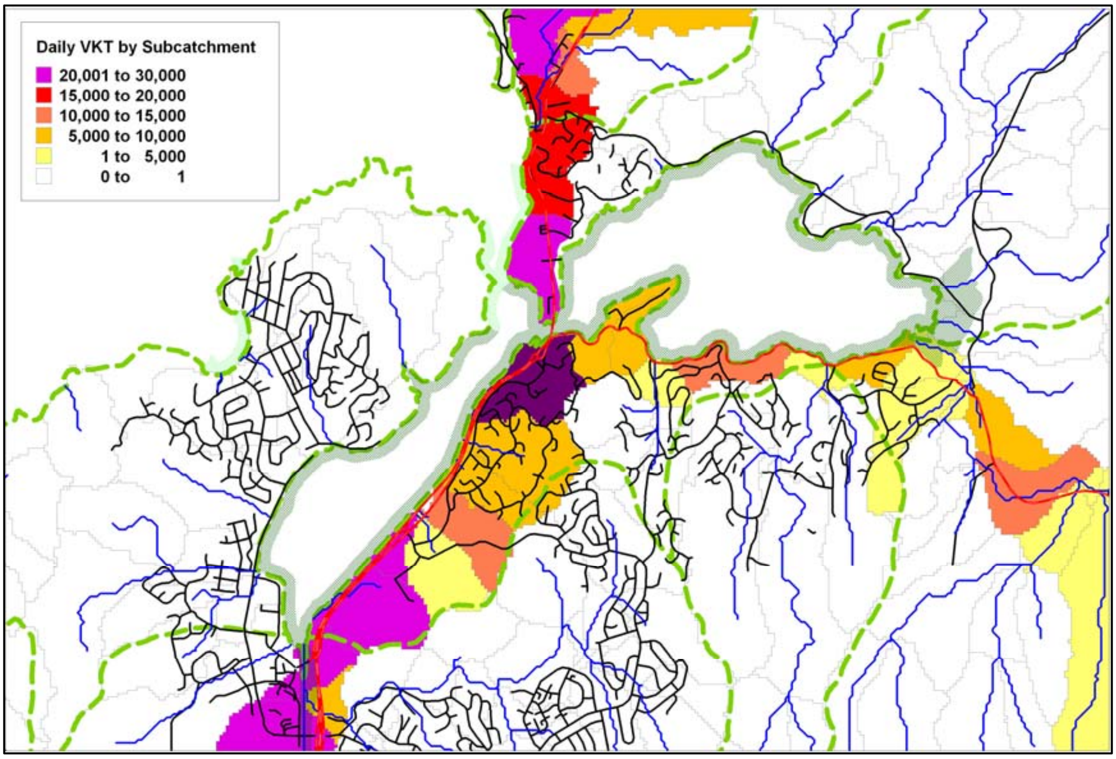

Figure 6.5 Daily VKT by sub-catchment for state highways in study area.

6.4 Tier 2 assessment

A full Tier 2 assessment was not attempted under the Pilot Study as the objective of the project was to develop and test the methodology rather than appraise all the road networks in the study area.

The Tier 2 assessment process was tested on a small part of the study area comprising the local roads and state highway that discharge runoff along the southern coastline of Pauatahanui Inlet. This stretch of coastline runs from Paramata Bridge in the west to the residential area near the eastern end of Pauatahanui Inlet. The SH58 runs close to this waterbody while the local road networks that discharge runoff to this coastline are situated in a number of catchments above and to the south of the Inlet (see Figure 6.6).

The analysis excluded contributions to the Inlet pollutant load at its eastern end from runoff discharged into the Pauatahanui Stream by local roads and the SH58 that lie further up the catchment to the east and south-east. Although these parts of the road network lie outside the study area they make a significant indirect contribution to pollutant load at the discharge point to the Inlet.

6.4.1 State highway

Transit New Zealand hold GIS data on drainage features for state highways but do not have GIS data for the connecting drainage and point of discharge to the receiving environment. Therefore it was not possible to assign source-pathway-receptor configurations to sections of the highway.

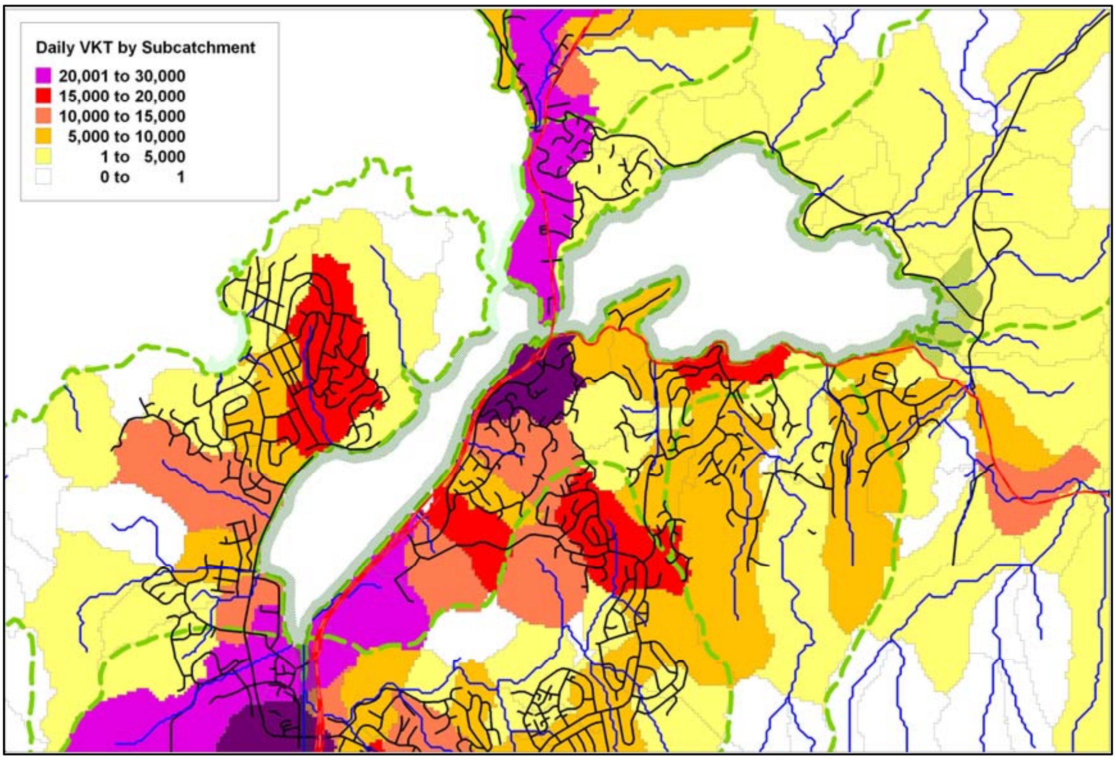

Figure 6.6 Daily VKT by sub-catchment for combined road networks.

The highway section under study was therefore divided into `highway catchments', each representing approximate areas of common drainage which were assumed to discharge directly to the nearest waterbody. The start and end-point of each highway catchment was estimated as sequential inflections (locations of zero or near zero road gradient) determined from the vertical alignment plotted as a longitudinal section of the highway.

A nominal discharge point to the SRE was assigned midway along each highway catchment. This process resulted in about 30 highway catchments along the 5.7 km section of SH58 that varied from 9m to 680m in length.

Traffic flows (AADT) on the section of SH58 under study vary from around 13,000 near the Paramata Bridge to about 8400 at the eastern end. The road is characterised as generally rolling with tight bends in the western half. The level of service (degree of traffic congestion) was estimated to vary between `free flow' and `interrupted' for the sections under study. A value of 3% HCV was assumed for running the vehicle contaminant load model. No sump attenuation was allocated for highway drainage and the discharge was assumed to have a direct pathway to the adjacent Inlet.

A distribution map of the relative daily contaminant load (particulates, zinc and copper) in runoff for the road sections (represented by highway catchments) is shown in Figure 6.7.

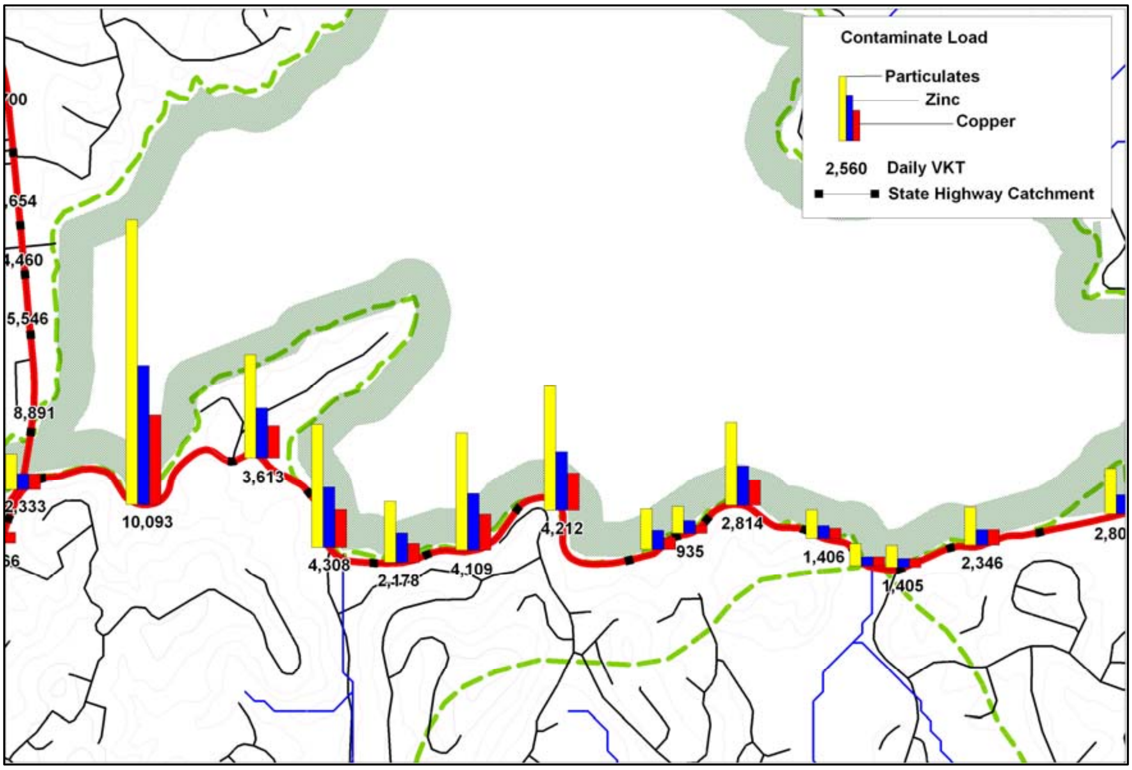

Figure 6.7 Tier 2 assessment of SH58 runoff to Pauatahanui Inlet southern coastline showing variation in daily contaminant load by highway catchment.

(Note: the bars are arbitrary and have been scaled to show the three contaminants; thus comparisons of load can be made within but not between contaminants).

Figure 6.7 indicates a `hot-spot' in runoff contaminant load at the western end near the Paramata Bridge. The distribution of higher loads in the western half of the SH58 reflects the higher traffic flows as well as the bends and hills on this section. The flatter more open and less trafficked eastern section has a lower runoff contaminant load profile.

Figure 6.7 includes the daily VKT figures for each highway catchment road section, shown for comparison purposes next to each of the bar graphs. There is good correlation between the values for daily VKT (determined from Tier 1) and their respective contaminant loads (from Tier 2), validating the use of Tier 1 as a screening process.

6.4.2 Local roads

Findings from the Tier 2 assessment of local roads that discharge runoff to the abovementioned section of coastline (along the southern side of the Pauatahanui Inlet) are shown in Figure 6.8.

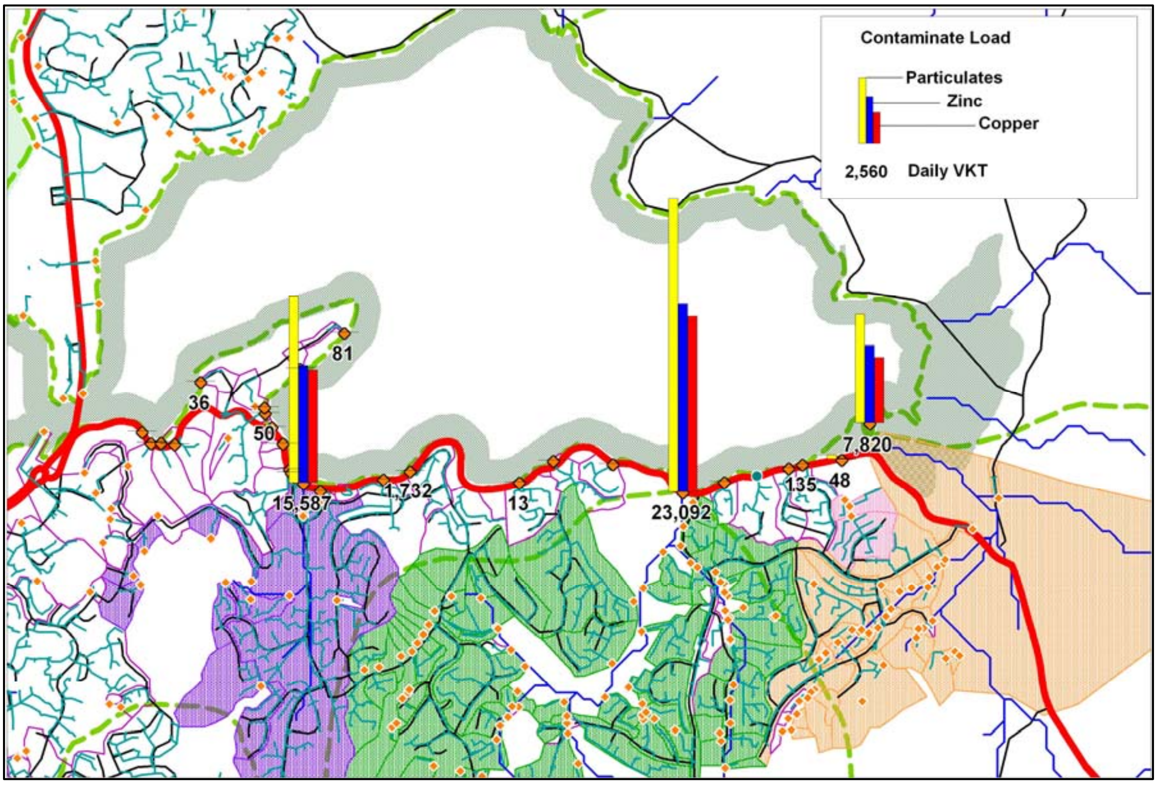

Figure 6.8 Tier 2 assessment showing relative contaminant loads in runoff from local road catchments draining to the southern coastline of Pauatahanui Inlet.

As for the state highway analysis, the contaminant loads are given in arbitrary units (i.e. bars representing particulate, zinc and copper) and may be compared for each contaminant, but not between contaminants, as they have been scaled to fit the graph for ease of viewing.

The final runoff discharge points to the SRE are depicted by 'diamond' symbols along the coastline. The smaller diamonds (located inland) are the points where road runoff discharges to local streams.

The graph shows that pollutant loads in runoff from local roads that discharge to this stretch of Inlet coastline are concentrated at three locations:

i) Browns Bay (centre left of Figure 6.8),
ii) Duck Creek (centre right), and
iii) Pauatahanui Stream (discharge to estuary).

The relative contaminant load in runoff at these three discharge locations reflects the amount of vehicle activity in the respective stormwater catchments that drain to these locations. This pattern is also evident from the daily VKT figures shown under each bar graph. (Note: some numbers are not shown as they are very small.)

As for the Tier 2 state highway analysis, the VKT figures (from Tier 1) correlate well with the relative pollutant loads estimated under Tier 2.

6.4.3 Comparison of highway and local road contributions

Data from the Tier 2 assessments described above have been used to compare vehicle-derived contaminant loads (relative magnitude and spatial distribution) for the SH58 (Figure 6.7) and local roads (Figure 6.8) along the southern coastline of the Inlet.

To a first approximation, the overall contaminant load (sum of discharges along the section of coastline) is split roughly 50:50 between local roads and the SH58, however there are major differences in the localised distribution:

- i) Section east of Paramata Bridge - this is almost entirely dominated by the SH58 component, given the absence of local roads in this location.
- ii) Browns Bay (stream discharge to estuary) - based on VKT, the distribution is approximately 22% SH58 and 78% local roads; for the whole Bay area the contributions are similar.
- iii) Duck Creek (stream discharge to estuary) - this is almost entirely dominated by the local road component (95%).
- iv) Pauatahanui Stream (discharge to estuary) - the VKT at this location gives a split of about 25% SH58 and 75% local roads[1].

The above analysis demonstrates that steps to reduce vehicle-derived contaminants to this part of the estuary will need to take cognisance of relative contributions from the highway and local roads, and be focussed on the locations at greatest risk.

6.5 Implications from Tier 2 risk assessment

6.5.1 Sediment quality data in study area

Since 2004, Greater Wellington Regional Council (GWRC) has been studying the quality of marine sediments in Porirua Harbour to establish the present-day levels of urban-derived contaminants and the trends in their concentrations (Milne et al. 2006).

Five sub-tidal sites were selected for assessment, two in the Onepoto Arm (POR1, POR2) and two in the Pauatahanui Arm (PAH1, PAH2) – see Figure 6.9. A third sub-tidal site was recently added in the Pautahanui Arm (PAH3).

The results from samples taken in 2004 showed copper, zinc and lead concentrations above the Auckland Regional Council's Environmental Response Criteria (ARC ERC) in surface sediments of the Onepoto Arm, but not those of the Pauatahanui Arm (Sherriff 2005). The report noted that copper is approaching ecologically significant concentrations in the sub-tidal sediments of Browns Bay in the Pauatahanui Arm.

[1] Both the SH58 and local road contributions discharged at this location will in reality be larger as the analysis excludes runoff from these roads to streams further up the catchment (as they are situated outside the study area).

Figure 6.9 Map of Porirua Harbour showing the positions of the sites for GWRC's investigation of marine sediment quality (From Sherriff 2005).

Concentrations of total copper and zinc in sediments from the four sub-tidal sampling locations are shown in Figure 6.10. These two metals are of particular interest in the context of this research report as they have a potential contribution from vehicles.

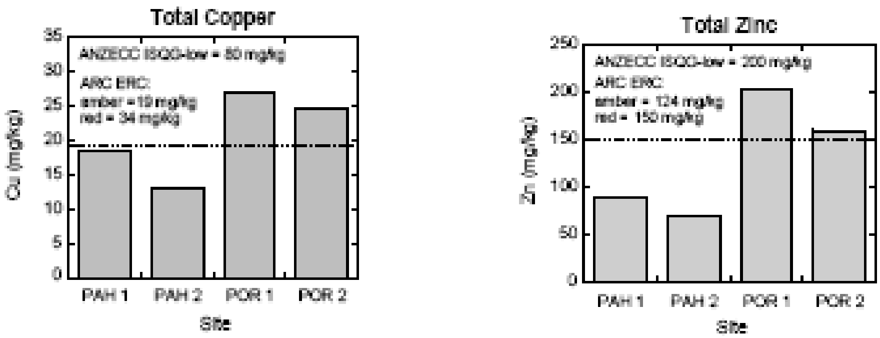

Figure 6.10 Concentrations of total copper and zinc (mg/kg) in Porirua Harbour sediments (from Sherriff 2005).

Concentrations of total copper and zinc in the two samples taken from the Porirua Arm exceed the ARC ERC amber threshold. Zinc also exceeded the red threshold at both of these locations. In contrast, concentrations for the two locations in the Pauatahanui Arm are below these thresholds. However, of note is the copper value for PAH1 (Browns Bay) which is marginally below the ARC ERC amber threshold of 19 mg/kg.

6.5.2 Comparison with Tier 2 risk assessment

The sediment data described above have been interpreted in the context of findings from the Tier 2 risk assessment conducted for roads discharging into the southern coastline of the Pautahanui Arm.

Direct comparison of the two sets of data is not possible as the Tier 2 data are expressed in pollutant load (mass of pollutant per day in arbitrary units) while the GWRC data are concentrations of metals in surface sediments.

The Tier 2 data also reflect only vehicle contributions while the GWRC data reflect all other sources that may be present e.g. zinc from roof runoff. Both GWRC sampling locations in the Pautahanui Arm (PAH1 - Browns Bay; and PAH2 - Duck Creek) are expected to contain sediments containing contaminants that have contributions from stormwater discharges from the urban catchments.

In this context, the significant contribution to zinc levels in stormwater from roof runoff may obscure the smaller contribution from vehicles. On the other hand, copper levels in sediment at these two locations may be a better indicator of the contaminant contribution from vehicles in the catchment, given the absence of other major sources in urban runoff. For this reason the discussion below is restricted to a comparison of copper data.

6.5.2.1 Duck Creek

The Tier 2 assessment predicted a comparatively high vehicle-derived copper load at Duck Creek (confluence of stream with the estuary) that is almost entirely dominated by the local road component. In contrast, GWRC data for the subtidal sampling location off Duck Creek (PAH2) returned the lowest values of the four sampling locations, with total copper in sediments well below the applicable guidelines.

Caution is needed in comparing pollutant loads discharged at a point to the consequent build-up of contaminants in nearby sediments. The mouth of Duck Creek is exposed to a combination of high winds and strong waves which are likely to result in dispersal of sediment at the estuary mouth, as evidenced by its low mud content. This was the reason GWRC’s chosen long term sediment sampling location for Duck Creek was moved further offshore in a sub-tidal zone (NIWA 2005).

The above analysis suggests that natural processes are effective at dispersing stormwater discharges to the mouth of Duck Creek. The difference between the predicted Tier 2 output and GWRC sediment quality data may simply reflect the fact that while the relative vehicle-derived copper loads from local roads (Tier 2) are highest at the mouth of Duck Creek along this stretch of coastline, the levels that build up in sediments are not significant in absolute terms.

6.5.2.2 Browns Bay

The Tier 2 assessment also predicted a comparatively high vehicle-derived copper load at Browns Bay (stream discharge to estuary) that has a dominant local road component. The GWRC data for the sub-tidal sampling location off Browns Bay (PAH1) returned a comparatively high level of total copper in sediments, marginally below the ARC EC amber level.

The situation with Browns Bay is very different from Duck Creek. The Bay lies in the lee of the Golden Gate peninsula and, as a result, is a depositional environment that is protected to some degree from wind and wave effects. The sediments in Browns Bay were found to be higher in silt than most other locations along the southern shore. For this reason, the Bay was chosen as a suitable sampling location for the GWRC long-term sediment monitoring programme (NIWA 2005).

The above analysis suggests that natural processes are not so effective at dispersing stormwater discharges within Browns Bay. The predicted (Tier 2) peak copper load in road runoff discharged to the Bay appears to manifest itself as elevated levels of copper in sediment within the Bay. While the relative pollutant load of vehicle-derived copper from local roads (Tier 2) is lower than at the mouth of Duck Creek, the depositional environment at Browns Bay results in the build-up of significant levels in sediments.

The above findings emphasise that local knowledge and professional judgement must be used in applying the Tier 2 assessment to road networks in order to interpret relative pollutant loads at the point of discharge in terms of the significance of their impacts on a local waterbody.

7. Conclusions

A GIS-based method has been successfully developed for identifying and ranking sensitive receiving environments (SREs) at risk from road runoff.

The methodology incorporates the source-pathway-receptor risk concept to spatially link areas of high traffic intensity, runoff discharge routes and sensitive downstream environments potentially at risk. Both local roads and state highways can be accommodated. Use of GIS is an essential requirement for application at the regional/national level.

The methodology has been tested in a pilot study in the Porirua area of Wellington. Tier 1 screening is capable of identifying SREs that are potential hotspots from road runoff. Tier 2 allows a more detailed assessment of the distribution of contaminant loads from individual section of the road network, and derivation of a risk rating that allows prioritisation of areas for consideration of runoff treatment. The tool can also determine the relative contributions of pollution in road runoff from state highways and local roads.

The pilot study has demonstrated that the Tier1/Tier 2 process provides meaningful spatial analysis of relative pollutant loads by catchment that can be used to identify and rank areas of a sensitive waterbody potentially most at risk from road runoff, and which parts of the road network are contributing to this risk.

The tool has application both for existing roads (e.g. identifying potential need for retrofitting stormwater treatment) and for new roads (e.g. corridor studies to identify any SREs close to proposed alignments). It may also be used as a planning tool for predicting the distribution of contaminant loads based on future traffic forecasts.

The tool should be of assistance to Land Transport New Zealand and territorial local authorities in their efforts to improve the management of road runoff. The concept of using a risk-based approach to classify receiving environments may also assist regional councils in the development of an improved regime for the regulation of stormwater discharges.

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Volume II

Appendix A: Literature review of receiving environment sensitivity

Appendix B: Development of SRE sensitivity rating system

Appendix C: Rating the sensitivity of receiving environments to road runoff

Appendix D: Literature review of factors affecting quality of road runoff

Appendix E: Vehicle contaminant load model

Appendix F: Glossary