# RCA Forum
# Stormwater Group

## Stormwater Risk Assessment

## Guide for Road Engineers

**March 2009**

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# Road Controlling Authority Forum - Stormwater Group

# Stormwater Risk Assessment Guide for Road Engineers

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# 1 Introduction

The RCA Forum Stormwater Group (SWG) identified the need to provide road engineers with practical guidance on the relationship of road runoff on receiving waters so as to assist their decision-making on stormwater management.

The RCA Stormwater Group invited MWH New Zealand Ltd (MWH) to review the various research findings that relate road runoff to effects on receiving water bodies and synthesise these findings into a simple risk assessment guide. The aim was to develop practical guidance with appropriate directions to steer the user.

MWH prepared a draft flowchart "Stormwater Environmental Risk Assessment Guide for Road Engineers" that was presented to the SWG at its meeting on 3rd April 2008. The guide is intended to help road engineers consider the potential for harmful environmental effects from road runoff as part of road design and road network management.

Initial response from SWG members was that the risk approach and draft flowchart looked promising and should be further evaluated by members in a trial period in different situations, in order to provide feedback on its value as a decision tool for managing road runoff.

At the SWG meeting in February 2009, members reported that the flowchart had had limited testing amongst stormwater management peers and there was a need to put it on the RCA Forum SWG website for more widespread dissemination and evaluation by practitioners.

In furtherance of this, MWH has prepared this report which summarises the research that led to the development of the flowchart guide and presents the current version (see Appendix A).

## 1.1 Background and objective

Relationships between vehicle contaminants, road runoff and effects on waterways are complex and site specific. For example:

- A wide range of pollutants (such as heavy metals and hydrocarbons) is released from vehicles
- Contaminant load in runoff varies according to traffic and road characteristics
- Movement of contaminants from vehicles to road corridors to aquatic environments is highly variable
- The resiliency of waterways and aquatic biota to the effect of vehicle and road contaminants varies according to the physical and biological characteristics of the waterway itself, other sources of contamination and existing levels of disturbance

While much research has been conducted into the nature of road runoff, its effects on the receiving environment and the performance of stormwater treatment devices, there was no practical guidance for road engineers on how to assess the risk of road runoff on receiving waters so as to assist their decision-making on stormwater management.

The genesis for the flowchart guidance came from the RCA Forum SWG. The Group identified a need to draw together research findings from road runoff contaminants and their environmental effects. The Group wished to portray research findings in a graphical format to assist road engineers with their stormwater management decision-making.

The original concept developed by the SWG (termed the `Tong Graph') sought to relate the sensitivity of receiving environments with traffic volume/road type. The objective was to help practitioners identify when they need to take action on contaminants in road runoff under a range of road/traffic conditions. While the Tong Graph provided a conceptual tool, the underlying variables and data that define the relationships needed further definition and evaluation in order to provide a qualitative relationship.

The main objective of this project was to provide road engineers with a simple flowchart to assist their understanding and assessment of the effects of road runoff on receiving water bodies by:

- Clarifying the factors that could contribute to a harmful environmental effect from road runoff
- Assist screen networks for potentially adverse environmental effects in preparation for discharge or activity consent applications, as required by the Resource Management Act 1991 (RMA)
- Enabling road managers to target limited resources at mitigating highest risk sites

The flowchart development is also intended to assist meeting the RCA SWG objectives by:

- Summarising relevant research and transposing it into practical advice for road engineers
- Identifying gaps in knowledge and research required to close them.

## 1.2 Scope and methodology

The proposal for this work referred to the development of a stormwater risk assessment tool. We considered it important to clarify the focus of the research on natural environmental and community health values and therefore refer to the output as an *environmental* risk assessment guide. Due to the considerable uncertainties and gaps in data and guidance on how to refine and relate risk factors we also refer to the flowchart as a guide rather than a tool.

The project comprised three stages, as summarised below:

*Stage 1 – Reviewing parameters contributing to adverse environmental effects of road runoff*

A brief review of recent New Zealand literature was conducted to identify the parameters that influence the potential environmental risk to aquatic environments from road runoff. Several parameters were identified at the outset of the project as focus areas for the review:

- Sensitivity of water bodies to road and vehicle contaminants
- Relationship between traffic volumes and contaminant concentrations
- Effectiveness of drainage pathways in attenuating contaminant loads

The literature review sought to identify quantitative thresholds of influencing factors.

*Stage 2 – Development of flowchart*

A flowchart was developed to illustrate the link between key parameters identified in Stage 1:

- The nature of the pathway that conveys road runoff to a water body
- The sensitivity of the receiving environment
- The operating characteristics of contributing road/s

The flowchart takes users through a series of questions. Thresholds are incorporated into each question to rank the risk potential. The user is guided to either proceed to another step to consider additional site parameters or to take action based on the potential risk.

*Stage 3 – Prepare summary report*

The outputs from Stages 1 and 2 are presented in this report. It contains guidance to aid the interpretation and application of the flowchart (and, where appropriate, further information required to be obtained by the user). Gaps in research are identified and are outlined in suggestions for further research.

## 1.3 Limitations

The purpose of the flowchart is to provide guidance on managing the adverse chronic effects of surface water runoff from roads on sensitive water bodies. The flowchart does not address other associated risks from contaminated runoff such as increased pollutant loads from erosion or accidental spills.

Runoff from roads has the potential to cause a range of secondary effects to property and road operations, such as flooding of adjacent properties, failure of road surface and pavement layers or the disruption of traffic due to surface flooding. This report does not address these operational and technical concerns.

The scope of the project focuses on general risk characteristics from road runoff on a relative basis rather than identifying absolute environmental effects. The scope of the project has not allowed for a detailed analysis of potential environmental risks for all permutations of roads, drainage and stormwater treatment systems and receiving environments.

# 2 Key variables influencing effects of road runoff

Published literature confirms the potential for adverse environmental effects to occur when runoff containing vehicle contaminants are conveyed by drainage pathways to water bodies sensitive to these effects due to physical and ecological effects, loss in human-use values and existing levels of disturbance.

The available research identifies potentially adverse environmental effects of zinc, copper and polycyclic aromatic hydrocarbons from road runoff. Kennedy (2005) notes the environmental significance of elevated concentrations is dependent on the phase of each element and sensitivity of each receiving environment. Gardiner and Armstrong (2007) report the change in composition of benthic fauna surrounding marine outfalls receiving road runoff. These authors note the primary concern, from scientific and road management perspectives, of potential contaminant build-up in sediments to levels that may have adverse ecological effects if no steps are taken to limit contaminant loads in road runoff.

From the literature search we have identified three interlinked parameters for road managers to consider as part of a broad assessment of receiving environment sensitivity to road runoff:

- Road-related factors affecting the quality of runoff such as the relationship between traffic flows, congestion and road characteristics (source risks)
- The effectiveness of treatment devices and drainage routes in reducing contaminant loads (pathway considerations)
- Water body characteristics (receptor or receiving environment).

From the available literature we were not able to identify quantitative thresholds of vehicle contaminant emissions for different road and driving conditions, nor the severity of consequential environmental effects in aquatic receiving environments. We conclude that no simple set of proxy indicators can account for the complex interactions between source, pathway and receiving environment parameters.

Therefore road engineers are encouraged to adopt a risk management approach and consider the site-specific risk factors under each of these parameters to determine if road conditions pose a threat to the health of receiving environments.

These risk factors are briefly discussed below and form the basis of the flowchart described in Section 3. A fuller discussion is given in the sensitive receiving environment risk methodology described in Gardiner and Armstrong (2007).

## 2.1 Source factors affecting the quality of road runoff

The primary risk factor to road runoff is the density of traffic as this is the main driver of vehicle-derived contaminants. Source (i.e. road-related) factors that influence the emission load of contaminants from vehicles are:

- Traffic flows: numbers of vehicles, travel speed, traffic flow conditions
- Traffic composition: age and types of vehicles
- Road terrain: vertical topography and horizontal alignment

Traffic is the main source of road runoff pollution with the main contaminants of concern being heavy metals (notably copper and zinc) and PAH. The literature indicates that pollution from road runoff is very variable in nature and has a complex relationship with runoff quality. Caltrans (2003) and Kayhanian et al. (2003) report on the results of a substantial state-wide monitoring programme in California. Sites with higher AADTs had higher concentrations of nearly every contaminant evaluated.

While traffic volumes are a key attribute, the degree of traffic congestion and road characteristics have a strong influence on vehicle emission rates, and hence contaminant loads in runoff. Roads with the same traffic flows but markedly different road characteristics are found to generate different contaminant loads in runoff.

The use of AADT as a traffic threshold screening indicator for road runoff quality is reviewed in Gardiner and Armstrong (2007). In the UK, runoff from roads with traffic flows between 5,000-15,000 (AADT) are deemed low risk to surface waters and are not required to undergo further risk assessment (CIRIA, 1994). The US EPA found significant effects from highways only when traffic volumes exceeded about 30,000 VPD.

However, traffic levels measured as AADT are found to be a poor proxy for runoff quality. Thus, for example, Drapper et al. (2000) found that traffic density and runoff quality from highways were only weakly correlated and not sufficiently robust to propose traffic volume as the best indicator for roads requiring runoff treatment.

A further limitation with AADT as a screening tool is that depositional water bodies are potentially affected by runoff contributions from both direct and indirect pathways. While an AADT threshold may be set for a road section that discharges directly to a water body, this will take no account of the effects of indirect runoff that may be discharged from the same road further up the catchment. A related issue with an AADT threshold is that a series of road sections that discharge directly to an adjacent water body may each fall below the threshold but together exert an adverse cumulative effect on the water body.

Current field research by NIWA that seeks to establish the vehicle emission factors of various pollutants in road runoff under different traffic/road conditions (Moores, 2008) may provide a better quantitative basis for determining contaminant loads from New Zealand road networks.

Contaminants from other sources such as industrial sites, residential properties and roof runoff may be conveyed by road drainage pathways to receiving environments. Kennedy (2003) noted the difficulties associated with distinguishing the effects of contaminant runoff from roads and highways on streams from the effects of contaminants derived from other sources of urban runoff such as industrial sites, residential properties and roof runoff.

## 2.2 Pathway

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.

The substrate, treatment mechanism and distance travelled by road runoff once it leaves the carriageway determine the effectiveness of drainage pathways in either filtering the contaminant load from road runoff or conveying it to a receiving water body.

In the context of particulate matter in road runoff, Gardiner and Armstrong (2007) distinguish three pathway categories depending on their `connectivity' to the receiving environment:

- Direct - provide non-permeable conveyance surfaces e.g. runoff into stormwater pipes discharging directly into a water body
- Indirect - where runoff first enters a stream or river which may temporarily detain contaminated sediment before this reaches the final receiving water body
- Diffuse - impede flow of runoff contaminants e.g. vegetative strips along a road verge.

Diffuse pathways result in almost complete attenuation of suspended load. Thus when avoidance or reduction of adverse environmental effects from road runoff is the objective, a diffuse pathway offers the lowest environmental risk. The type of road drainage infrastructure (e.g. catchpit, swale) may also act as stormwater control devices and therefore influence the risk to downstream receptors.

## 2.3 Sensitivity of water bodies to road and vehicle contaminants

A literature review by Gardiner and Armstrong (2007) identified the following key considerations that may make a water body sensitive or vulnerable to adverse effects of road runoff:

- The physical characteristics of the water body:
  - the size of the water body (dispersal and dilution characteristics),
  - water movement (determines rates of mixing, dispersion and sediment deposition).

Low energy 'depositional' or 'sink' environments, with little water movement, are at greatest risk of build-up of contaminants in fine sediments to levels representing a threat to benthic organisms.

- The natural/ecological values associated with the water body, such as:
  - rare/endangered species

- communities with high species diversity
- habitats/communities particularly sensitive to stormwater-related effects
- high conservation status (e.g. a water body of national significance).

MWH (2003) records a build-up of contaminants (mainly zinc and copper), decreased species diversity and dominance of optimistic species in the vicinity of stormwater outfalls in the inner Wellington Harbour. Kouvelis and Armstrong (2004) identify the removal of overhanging vegetation, modifications to stream banks and bed, and the installation of poorly designed drainage and treatment devices can have significant adverse effects on aquatic ecosystems, including impeding fish passage.

- Human uses and values associated with the water body, for example:
  - aesthetic/recreation/tourism values
  - cultural values
  - drinking water source.

There is little information to indicate that any freshwater species (e.g. eel, watercress) exposed to metals or PAHs derived from road runoff would bio-accumulate these contaminants to a point that would result in them being unsuitable for human consumption from a health risk perspective (Kennedy, 2003).

- The existing degree of contamination or disturbance: ANZECC (2000) recommends the use of three ecosystem condition ratings to determine the appropriate level of protection:

  - High conservation/ecological value systems
  - Slightly-to-moderately disturbed systems
  - Highly disturbed systems.

The philosophy behind selecting a level of protection is either (i) maintain the existing condition or (ii) enhance a modified ecosystem by targeting the most appropriate level.

Based on the above criteria, water bodies need to be assessed individually by road managers, in consultation with the relevant regional plan and regional council, to identify the risk of road runoff causing adverse environmental effects either as a result of current and projected operational runoff, or in the location and design of a new section of road.

# 3 Environmental risk assessment flowchart

## 3.1 Flowchart overview

The key variables influencing the adverse environmental effects of road runoff on receiving environments, as discussed in Section 2, have been combined into a flowchart (Appendix A). The flowchart maps the nature and interrelationship of each factor (source, pathway and receiving environment) at a high level.

The user is taken through a series of steps, in respect of their specific network, with questions about the nature of the drainage pathway, receiving water body site characteristics and traffic conditions. The flowchart maps the decision points that determine potential risk and identifies potential courses of action.

The flowchart distinguishes scenarios that potentially pose a high risk of adverse environmental effects from road runoff on receiving environments (e.g. direct discharge from a road with congested traffic discharging directly to a sensitive water body where no existing stormwater treatment is in place.

The decision making framework flowchart is staged to identify low risk scenarios first:

- Step 1 considers the nature of the pathway. If no pathway exists, then there is no risk to the receiving water body, irrespective of how much traffic the road network carries, and no further assessment is needed.

- Step 2 considers the receiving environment. If this water body is dispersive then there is a likely to be a low risk of adverse environmental effects and no further assessment is needed.

- Step 3 may be invoked, when both a pathway and a sensitive (depositional) receiving environment are identified, in which case the likely risk is based on a qualitative consideration of traffic flow, degree of congestion and road terrain.

Advice about potential actions is necessarily general, particularly in reference to regional plans prepared under the RMA, to allow for regional differences in environmental conditions and management approaches.

The approach focuses on the likelihood of road runoff causing adverse environmental effects. The other component of a risk analysis (consequences) is not considered in detail in the flowchart. The consequences of road runoff on aquatic receiving environments are determined by site-specific factors. In the absence of site-specific details, flowchart users are encouraged to take a precautionary approach in estimating possible consequences.

Guidance on stepwise application of the flowchart is described below.

## 3.2 Application of flowchart

*Step 1* - the user considers the nature of the pathway connecting the road discharge to the receiving water body, including the presence of any treatment systems (natural or installed). If no pathway exists, i.e. if stormwater treatment is in place or if runoff is not conveyed to an aquatic receiving environment, it is highly unlikely that adverse environmental effects would occur due to contaminants in road runoff. Alternatively if some road runoff is discharged to a water body in an untreated state (directly or indirectly), there could be an environmental risk and further analysis of the network is recommended (i.e. proceed to Step 2).

*Step 2* - the second step in the flowchart inquires about the physical nature of water flow within the ultimate receiving environment. Dispersive environments with rapid water flows and mixing present a low likelihood of being susceptible to contaminants in road runoff. Alternatively, aquatic biota in a depositional environment (e.g. head of estuary) are more likely to be exposed to sediments containing road runoff contaminants due to low dilution and dispersal factors. In the latter case there could be an environmental risk and consultation with the regional council is recommended as well as further analysis of the network (i.e. proceed to Step 3).

*Step 3* - the third step in the flowchart invites consideration of traffic behaviour and road conditions where flowchart users have passed through Steps 1 and 2 and identified sections of road network with direct or indirect road runoff discharges into depositional receiving environments.

The flowchart distinguishes between vehicle travel in uncongested conditions and travel in congested conditions (or hilly terrain) where there is greater frequency in braking/acceleration, and hence increased generation of vehicle contaminants such as copper, zinc and PAHs.

Uncongested traffic conditions are classified in the flowchart as generating a low to moderate risk of adverse effects. In consultation with the relevant regional plan and regional council, road managers are prompted to consider receiving environment values and installation or retrofit of stormwater treatment devices. Users are referred to the Tier 1 screening methodology (see example in Figure 3-1) for identifying and prioritising potential `hot spots' on receiving water bodies affected by road runoff (Gardiner and Armstrong, 2007).

Under interrupted or congested traffic conditions (or where the network terrain necessitates frequent braking and acceleration, the flowchart suggests a moderate to high risk of adverse environmental effects. In addition to advice provided to manage uncongested conditions, the guide suggests a more detailed review of the cumulative effects of traffic flow, congestion and terrain on the relative contaminant load at discharge points on the road network. Users are referred to the Tier 2 assessment methodology (see example in Figure 3-2) for contaminant load modelling of road networks (Gardiner and Armstrong, 2007). Sediment and water testing at the discharge to the receiving water body is also recommended to assist in determining the need for/prioritising treatment options.

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| **3. Traffic flow (including effects of congestion and terrain)**<br><br>Where runoff is not intercepted by some form of treatment and is discharged directly or indirectly [4] into a waterbody with depositional characteristics, are traffic conditions predominantly uncongested (free-flow) with mostly flat terrain? | **Yes** ⇨<br>Vehicles travel in predominantly uncongested conditions in mostly flat terrain resulting in minimal braking and acceleration. | **Low to Moderate**<br>There is low to moderate potential for contaminants in road runoff to cause an adverse environmental effect; risk increases with traffic volume. | Flat, straight, sections of road with free-flow traffic conditions generate less copper, zinc and particulate matter due to low braking and acceleration. | Sustained high traffic volumes may generate contaminant loads that could cause moderate to high adverse environmental effects.<br><br>Current research by NIWA into vehicle emission factors [3] may provide some guidance on how contaminant loads in runoff vary with road type, traffic congestion and terrain.<br><br>Existing discharge consents may permit discharges in these conditions. | New applications or discharge consent renewals should review the operative regional plan and consult the regional council to determine potential biophysical characteristics, human uses and values that may be sensitive to the contaminants in road runoff.<br><br>Proactively installing or retrofitting stormwater treatment measures may provide cost effective environmental improvements before potentially rigorous regulatory standards are enforced.<br><br>Consider "Tier 1 screening" [5] of the network to identify areas of high traffic activity, drainage pathways and discharge locations to receiving environments potentially at risk from road runoff.<br><br>Sediment and water testing at identified locations and site visits may assist in prioritising treatment options and designs. |
| | **No** ⇨<br>Vehicles are required to brake and accelerate due to interrupted or congested traffic conditions, intersections/signals, and/or the network is predominantly in hilly terrain. | **Moderate to High**<br>There is moderate to high potential for contaminants in road runoff to cause an adverse environmental effect; risk increases with traffic volume. | Congested traffic conditions and hilly terrain that require frequent braking and acceleration generate more copper, zinc and particulate matter. | Current research by NIWA into vehicle emission factors [3] may provide some guidance on how contaminant loads in runoff vary with road type, traffic congestion and terrain.<br><br>Existing discharge consents may permit discharges in these conditions. | Review the network to identify areas of congestion and untreated drainage pathways to potentially sensitive receiving environments.<br><br>Consider more detailed appraisal(e.g. "Tier 2 assessment" [5] ) to model cumulative effects of traffic flow, congestion and terrain on vehicle-derived contaminant loads for comparing relative risk to each sensitive receiving environment and to prioritise future responses.<br><br>Sediment and water testing at identified locations and site visits may assist in prioritising treatment options and designs. |

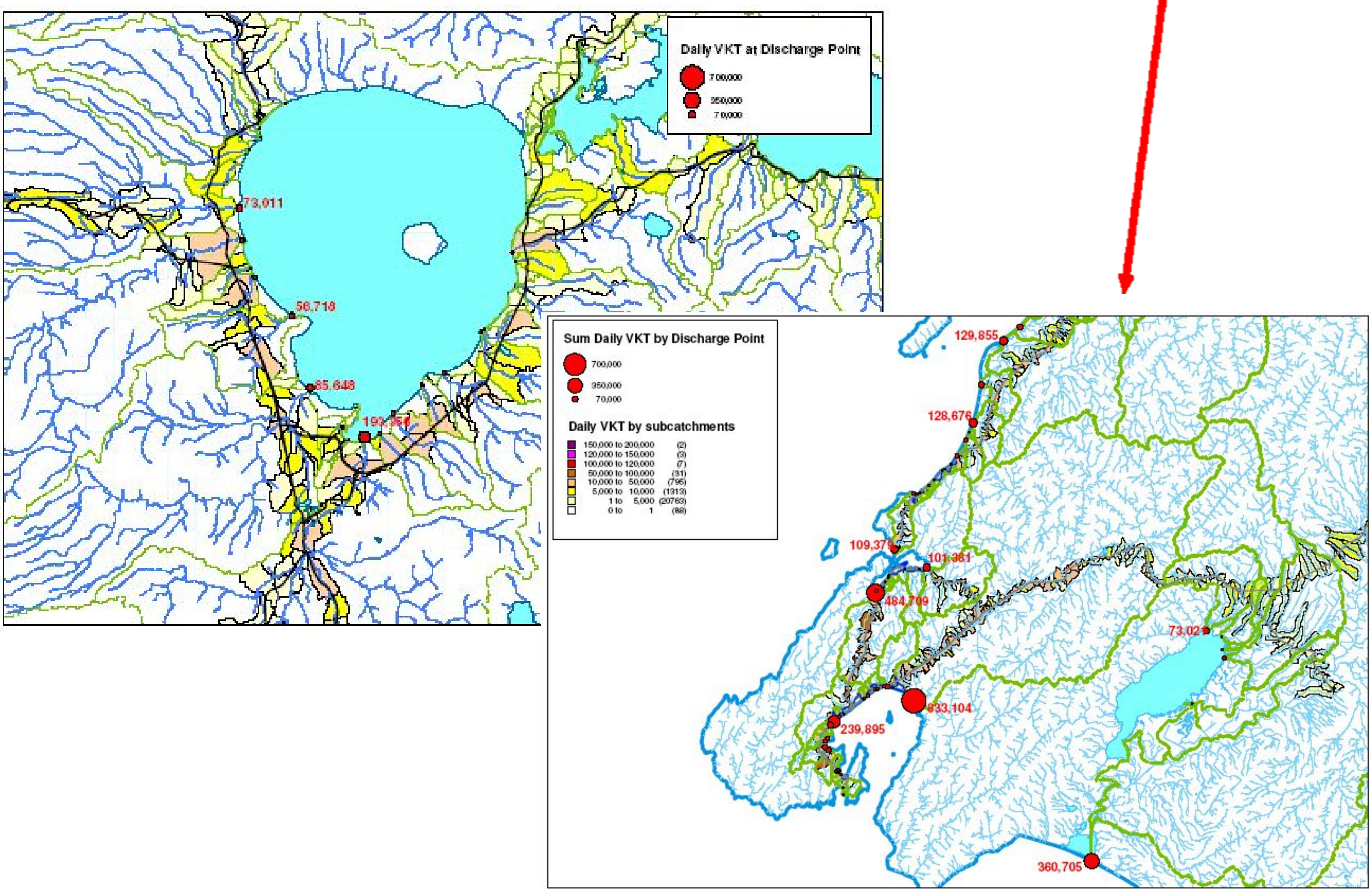


Figure 3-1 Example Tier 1 screening of state highway networks (Gardiner & Armstrong, 2007)

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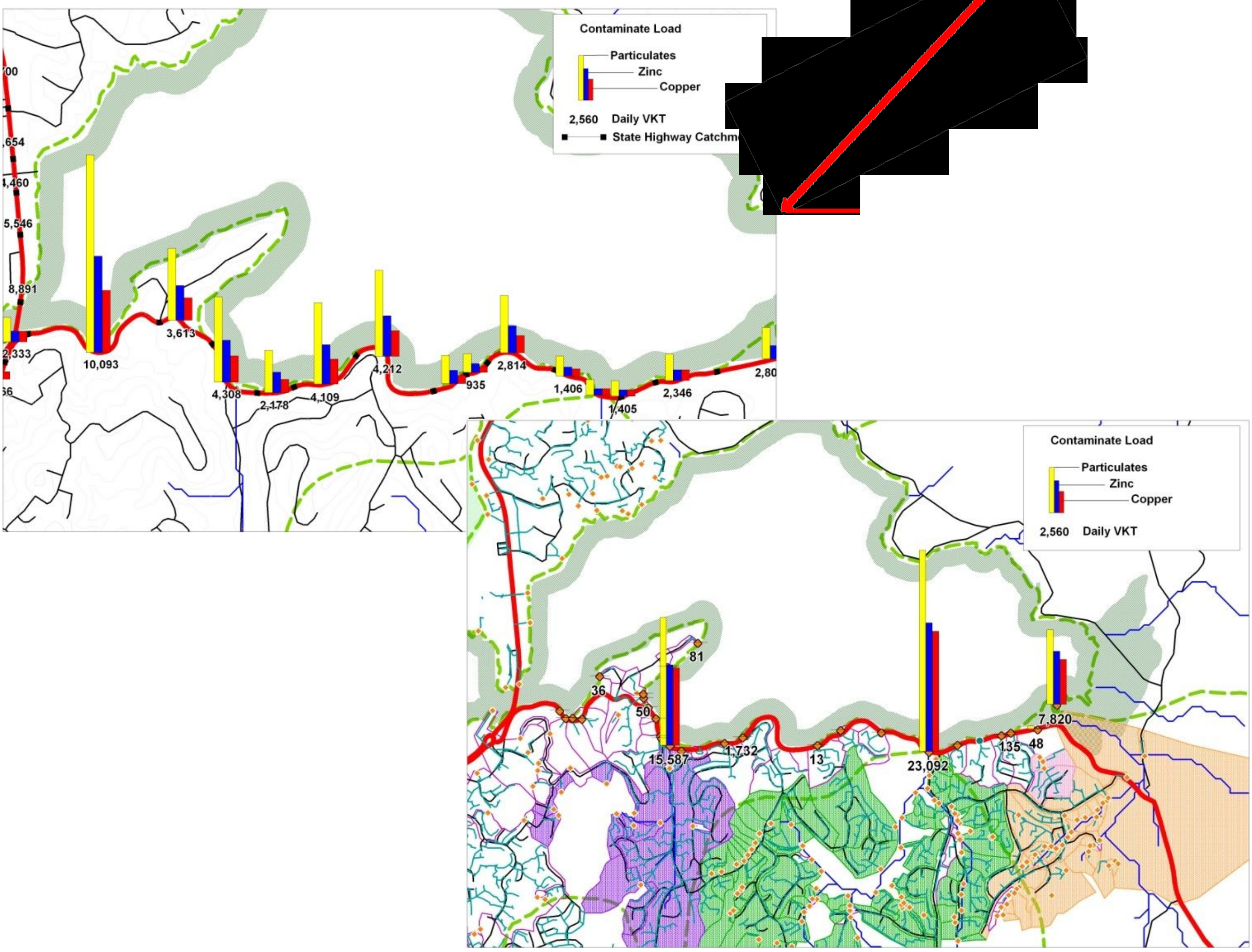


Figure 3-2 Example Tier 2 assessment of road networks (Gardiner & Armstrong, 2007)

# 4 Gaps in current knowledge

The literature review and development of the flowchart guide has highlighted a number of gaps in information that could otherwise assist road and water managers to ensure adverse environmental effects of road runoff are addressed, where these are a priority. These are briefly discussed below.

**Traffic volume thresholds and linkage to runoff quality**

A limitation with the existing flowchart is that it is based on a qualitative assessment of risk factors, and in particular does not set a threshold traffic flow under Step 3. No guidance was found in the New Zealand literature to quantify what level of traffic may generate an adverse environmental impact on a water body. There is, in particular, a desire by road managers to be able to work off quantitative thresholds of traffic volumes (e.g. measured as AADT) as indicators of potential adverse effects.

The limitations of using AADT as a proxy for runoff quality are discussed in Section 2.1. A better measure of risk from traffic intensity is VKT (vehicle kilometres travelled, where VKT = AADT x road length) and applying this measure to all roads within the catchment of the affected water body. This approach is included in the `Next Steps' section of Step 3 of the flowchart in relation to Tier 1 screening/Tier 2 assessment (Gardiner and Armstrong, 2007).

VKT is related to the pollution load by the Vehicle Emission Factor (VEF), typically expressed in units of g/day. The current NZTA-funded field research study underway by NIWA (Moores, 2008) will derive different values of VEF for a range of contaminants and road types/ operating environments.

A future goal would therefore be to incorporate the VEFs from the NIWA study into the Tier 1 screening method to provide a better estimate of the total vehicle pollutant load in a road network. This would be of value in providing a quantitative measure of the risk from different traffic/road characteristics under Step 3 of the flowchart.

**Linkage of contaminant load to adverse environmental effects of road runoff**

A second significant shortcoming of the flowchart is that the scale of effects on the water body is couched in relative terms (i.e. low, moderate, high). A crucial issue is therefore quantifying the relationship between the contaminant load in runoff to a measurable threshold effect in the water body affected by the runoff. This relationship will depend both on the nature of the contaminant and the capacity of the receiving environment to assimilate a contaminant load, and will therefore effectively vary with each water body.

Such thresholds are normally expressed in terms of threshold effects levels and probable effects levels (TELs and PELs, respectively). Examples have been determined for estuaries in Auckland e.g. effects threshold for zinc in Pakuranga Estuary) that are subject to heavy urban stormwater pollution (ARC, 2004).

In terms of the flowchart, determination of an indicative threshold provides a basis for quantifying the sensitivity of the receiving environment in terms of permissible pollutant load. Determination of the current accumulation rate of contaminant load (from network modelling at the catchment level) in combination with the current level of contaminant in sediment (see below) at the discharge point from the road network would provide the basis for determining whether the water body was at risk of exceeding the TEL or PEL.

Further research at the catchment level is needed to shed more light on the relationship between traffic intensity in a catchment, the resultant sediment quality in the receiving water body and the onset of deleterious effects. This research will provide the quantitative basis for relating traffic intensity to risk of adverse environmental effects in water bodies and therefore assist decision makers in determining the need or otherwise for stormwater treatment.

**Sediment quality at receiving environment**

Road managers would benefit from having access to site-specific information about the sensitivity of water bodies to the contaminants in road runoff. If sediment and water testing was used by regional councils to set threshold effect levels (TELs) for road contaminants for vulnerable water bodies, road and water managers would be able to model sediment concentration distributions on a time horizon based on vehicle emission factors and projected vehicle flows. Other contaminant sources could also be factored in to a cumulative picture of sediment and contaminant build-up over time. Treatment requirements could be targeted at those contributing sources to ensure contaminant levels are maintained within appropriate levels.

In the medium to longer term, and as current and planned NZ research programmes collect more field data, it is likely that the empirical relationships between the source-pathway-receptor variables will be better understood and quantitatively defined for a variety of different New Zealand road/traffic conditions.

# 5 Conclusions and recommendations

An Environmental Risk Assessment Flowchart for Road Runoff has been developed using available literature to provide road managers with a simple high level methodology to screen their network and identify risk factors that could contribute to adverse environmental effects from road runoff.

The flowchart comprises a stepwise framework to allow the user to decide whether or not their road network presents a potential risk to sensitive receiving environments from vehicle-derived contaminants in road runoff, based on qualitative indicators, and using the source-pathway-receptor concept. It helps steer practitioners to identify when they may need to take action on contaminants in road runoff under a broad range of road/traffic conditions, receiving environments and existing natural/engineered treatment systems.

The relationship between variables linking road traffic to stormwater quality, and thence to possible adverse effects on receiving waters, is complex and site-specific. It is recognised that in providing such a tool for road engineers, there is a risk of oversimplification of these relationships. Against this proviso, the flowchart is intended to be a guide to assist road manager with decision-making and provide a pointer to more detailed modelling techniques.

A limitation of the flowchart is that it is qualitative and therefore application is very dependent on user judgement. For example, it was not possible to determine an indicative threshold of traffic flow/intensity that relates to the onset of potentially adverse environmental effects in water bodies. Findings from current and future research on the relationship between vehicle emission factors, traffic and road characteristics and contaminant levels in sediment within receiving water bodies is likely to shed more light on this aspect.

The flowchart is intended to be a `work in progress' that could be refined as findings from current research programmes are made available. In its present form, the guide may be of use, for example, to TLAs in presenting a risk management approach to road runoff during their initial discussions with regional councils on consent renewal.

It is recommended that the flowchart be made available for comment and field evaluation by TLAs to evaluate its practical benefits under a range of road runoff management scenarios.

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