SENSITIVE RECEIVING ENVIRONMENTS AT RISK FROM STATE HIGHWAY RUNOFF

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ABSTRACT

Runoff from roads contains pollutants that potentially may have an adverse effect on sensitive receiving environments (SREs e.g. lakes, estuaries) situated downstream of the road corridor. This paper describes initial results of a GIS-based assessment of the national state highway network to determine SREs potentially at risk from road runoff. The project is part of a programme supporting Transit's policy and objectives for the sustainable management of state highway runoff. The screening method uses a source-pathway-receptor approach with traffic intensity (VKT: vehicle-km travelled) as a measure of relative pollution risk. Thematic maps are used to identify areas of regional waterbodies at most risk (`hot spots') ranked on the basis of VKT. Sections of carriageway with higher risk (e.g. heavy traffic with impermeable kerb & channel drainage into a SRE) identified from the hot spots are prioritized as candidate sites for ground-based evaluation and potential stormwater retrofit. Example `hot spots' are described for river crossings, discharge points to estuaries and lakes from runoff within the road catchment., and risks to groundwater from discharges to soak pits alongside the highway. Wetlands were excluded for lack of a national data set. The paper concludes with a brief overview of other stormwater management initiatives being implemented by Transit.

KEYWORDS

Road runoff, GIS, contaminant, pathway, sensitive receiving environment, state highway, stormwater, risk assessment, Transit New Zealand

1 INTRODUCTION

Stormwater management is a fundamental aspect of a sustainable land transport system and is a significant environmental responsibility for territorial road authorities. Control of stormwater quality, in particular, is an aspect that is attracting increasing regulatory attention in New Zealand in terms of compliance with Regional Plans and the regulation of discharges from road infrastructure through consent conditions.

In line with their Strategic Plan and Environmental Plan objectives for the sustainable management of state highway runoff, and in response to these regulatory concerns, Transit New Zealand is implementing a stormwater management retrofit programme. The objective is to achieve tangible improvements to the quality of stormwater discharged from critical parts of the state highway network that may be affecting sensitive waterbodies. In support of this programme, Transit is developing a stormwater treatment standard that will reflect best practice throughout the national state highway network.

The strategy being followed is to identify sensitive receiving environments that may be at risk from the state highway runoff and implement a programme of retrofit treatment for identified critical parts of the network. The use of risk management techniques is in line with Transit's requirement to demonstrate best value investment to focus resources where they will have most benefit.

The retrofit programme comprises a number of interlinked stages:

- i) Screening of the network for waterbodies potentially at risk
- ii) Identifying candidate sites on the priority sections of highway for potential stormwater retrofit
- iii) Evaluating stormwater treatment options for short-listed candidate sites
- iv) Detailed design and obtaining consent for the preferred treatment option
- v) Implementing and monitoring stormwater treatment systems.

This paper presents findings from the initial network screening stage. The screening process highlights `high risk' sections of highway in which to focus the search for candidate sites for retrofit treatment, using field assessments under the following stage. The paper describes how the screening process feeds into the second stage by highlighting the most appropriate sections of highway in which to search for candidate sites for retrofit treatment, by subsequent field assessments under the following stage.

Included is a description of the GIS-based methodology used to screening the network and a preliminary analysis of those parts of regional waterbodies that are potentially at most risk (`hot spots'). Examples are described for estuaries in Auckland, lakes in Wellington and Rotorua, state highway crossing points of major waterbodies and a preliminary assessment of risk to groundwater in the Christchurch area from soak pits servicing the highway. The paper concludes with a brief overview of other stormwater management initiatives being implemented by Transit.

2 APPROACH

The approach taken to assess risk to waterbodies from state highway road runoff is based on the Tier 1 screening approach described by Gardiner and Armstrong (2006, 2007). Tier 1 is used to screen SREs that may be at risk and identify road sections in the catchment which are the source of the risk.

The SRE screening tool is built around the source – pathway – receptor concept. For a risk to be present there must be a source of traffic to generate a contaminant load in runoff, a pathway for transporting the runoff and a sensitive receiving environment (waterbody receptor). The key GIS data files required are SREs, sub-catchments, traffic flow data (AADT) for the road network and data on waterbodies in the area under study.

The method uses traffic intensity as the proxy for pollution risk of runoff from the state highway. Pollution risk is represented quantitatively in terms of VKT (vehicle-km travelled) which is determined as the product of traffic volume (AADT) and road length (km). The distribution of VKT represents the spatial traffic intensity and to a first approximation is a surrogate measure of the pollutant load from vehicle-derived road runoff. While the use of VKT as a proxy for pollutant load is a simplifying assumption, it may be used on a comparative basis as a pointer to areas of potential concern.

The outputs from Tier 1 are areas of a regional waterbody (`hot spots') that are potentially at most risk from runoff. Impacts of direct discharges (e.g. bridge crossing points) are ranked by VKT. Impacts of indirect discharges (e.g. runoff via a stream/river to the final receiving environment) are ranked by cumulative VKT in the catchment traversed by the highway.

The Tier 1 approach required modification before it could be applied to screening the national state highway network. This included automating the process of aggregating VKT at the catchment level and the inclusion of a filter for characterising the type of carriageway stormwater channel (SWC) to assist identification of candidate sites on the road network for potential retrofit.

The screening framework developed under this project for the state highway network is described below (see also Section 3 – Methodology). The method was applied to selected regions and applied to estuaries, lakes, river crossing points and groundwater. Wetlands were excluded for lack of a national dataset.

2.1 APPLICATION OF SPR MODEL TO STATE HIGHWAYS

2.1.1 TREATMENT OF HIGHWAY DRAINAGE TYPE

The type of highway drainage plays a key role in controlling the contaminant load in runoff leaving the road, and therefore the risk to downstream receptors. 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 downstream waterbodies.

On the other hand, many sections of rural state highways have either earth drains (which permit some infiltration of runoff) or allow runoff to simply infiltrate the highway verge along the length of the carriageway. In these cases, the runoff takes a more diffuse pathway and the quantity and impact of pollutant load entering nearby waterbodies is reduced.

A stormwater channel (SWC) layer was therefore introduced into the Tier 1 screening process to distinguish highway sections with different drainage characteristics in order to highlight `higher risk' sections of carriageway to aid the selection of candidate sites for potential treatment. The stormwater channel code in Transit's Road Assessment and Maintenance Manual (RAMM) database was used for this purpose (see Section 3).

2.1.2 TREATMENT OF PATHWAY AND RECEPTOR

A difficulty in applying the source-pathway-receptor (SPR) risk model to the state highway network is the lack of specific information on the pathway (discharge route) taken by runoff after it leaves the highway corridor and the point of discharge to the final receiving environment (e.g. outfall to lake).

While the general pathway and receptor for state highways may be surmised in simple cases (e.g. in rural areas) by local inspection, the drainage configuration in urban environments is complicated by a network of sumps/catchpits, culverts and pipes, some of which may be disused, sealed off or inter-connected to the local stormwater network. This is the situation in Auckland where, as part of a global consent programme, Transit is undertaking a major mapping exercise of the state highway drainage network in designated stormwater catchments using CCTV and GPS techniques.

In the absence of detailed pathway/receptor information, some conservative assumptions have been made in applying the SPR risk model to the state highway network:

i) For discharges to surface waterbodies, all runoff is assumed to be discharged to the SRE irrespective of any treatment device (e.g. sumps/catchpits) on the SH drainage network.

ii) For indirect discharges to surface waterbodies (e.g. those routed via a stream/river or which traverse overland by sheet flow prior to entering the final receiving environment), the pollutant load in runoff is assumed to enter the local sub-catchment through which the SH passes and be transported by streams/rivers/culverts to the final receiving environment at the bottom of the catchment.

iii) The risk to SREs from direct discharges (e.g. outfall, bridge crossing) is proportional to VKT on the section(s) of SH that discharges to the SRE. For indirect discharges, the risk is proportional to the sum of VKT on the section(s) of SH within the catchment that drains to the SRE (measured as `aggregated VKT' at the final discharge point).

The aggregated VKT values represent traffic intensity at source and have not been adjusted to take account of the type of highway drainage (see below) or pathway. For indirect discharges, it is possible that a fraction of the pollution load in runoff represented by the VKT at source never reaches the final receiving environment. For example, after leaving the highway, runoff may be discharged to ground, diverted into the local stormwater network or be treated at some point. The VKT values therefore represent a conservative risk profile with the benefit of a standardized approach for comparing risks across the national state highway network.

2.2 SCREENING FRAMEWORK FOR STATE HIGHWAY RUNOFF

Based on the above considerations, the screening framework developed for assessing the risk of runoff from the state highway network on SREs in given in Table 1. Under the framework, SREs are divided into surface waterbodies and groundwater resources with the following assumed pollution mechanism from road runoff:

- *Surface waterbodies* – depositional environments with a risk of build-up of heavy metals (Cu, Zn) and PAH due to long-term transport and deposition of suspended sediment in road runoff from sections of SH that lie within the SRE catchment, either directly (e.g. outfall or bridge over SRE) or indirectly via a stream/river draining to the SRE.

- *Groundwater* – Infiltration of polluted runoff (with or without pre-treatment) from sections of SH that overlie the groundwater recharge zone, either directly (e.g. sump/pipe to soak pit) or indirectly.

Table 1 lists the source and pathway risk factors that are considered in the screening framework. The main source risk factors are traffic intensity (expressed as VKT) and presence of impermeable highway drainage (e.g. kerb and channel) along carriageways.

Table 1: Screening framework for assessing SREs at risk from state highway runoff

SRE at risk	Source risk factors	Pathway risk factors	Target state highway asset
Surface waterbodies[a]	VKT[b] in catchment of SRE; impermeable drainage (kerb and channel).	Direct - piped discharge	*Outfall* to SRE with high VKT
		Direct - runoff to SRE	*Bridge crossing* over SRE with high VKT
	VKT in sub-catchment traversed by SH; impermeable drainage (kerb and channel); length of SH in catchment draining to SRE.	Indirect – runoff to SRE via stream/river or overland flow through catchment	*Carriageways* with both high VKT and kerb & channel drainage
Groundwater	VKT on SH overlying recharge zone; impermeable drainage (kerb and channel); presence of soak pits (with or without pre-treatment).	Direct or indirect discharge route to subsurface; hydraulic connection to aquifer	*Soak pits* receiving discharge from high VKT, kerb & channel carriageways

a) waterbodies with `depositional' characteristics such as estuaries, lakes, wetlands b) vehicle-km travelled on state highway

Table 1 also shows the target state highway assets under each category that require risk assessment in order to identify candidate sites on the network for further consideration of stormwater retrofit treatment options. Outfalls were not considered as their locations are not mapped and are generally only known from local site inspection. The asset classes that were screened in this study were bridge crossings, high traffic carriageways and soak pits.

3 METHODOLOGY

3.1 TIER 1 SCREENING PROCESS

Figure 1 is a flowchart of the Tier 1 screening process for identifying SREs at risk from stormwater originating from road networks (Gardiner and Armstrong, 2006, 2007). The steps shown on the right hand side of the flowchart refer to the methodology applied to the national state highways, and are described below.

Step 1 – Data collection

Road and traffic data sourced from Transit's RAMM database that was used to prepare a GIS base map are given in Table 2.

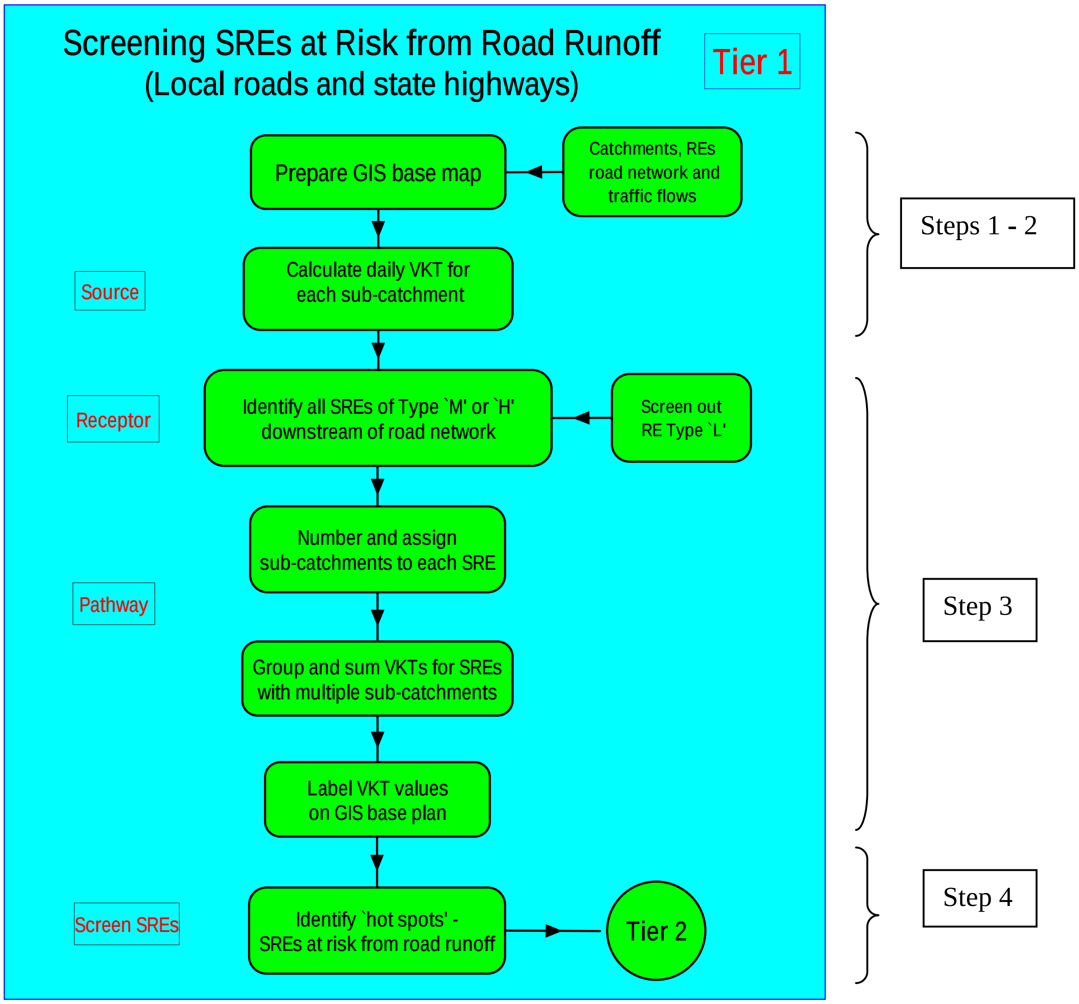


Figure 1: Tier 1 flowchart for screening SREs at risk from road runoff

Table 2: Data sourced from the Transit RAMM database

Data set	Description
Carriageways	The section of road on either side of the highway centreline that carries the traffic and which is divided into one or more lanes.
Surface water channels	These represent the type of drainage channels present along the side of the state highways. There are a number of types of drainages channels and these have been further classified into three groups for the purpose of this study: impermeable, permeable and unclassified (see Table 4).
Drainage	The drainage data relates to the types of drainage features along the state highways. These include sumps, catchpits and culverts, and are located at specific points along the state highways rather that along carriageways (as is the case for the surface water channel data).
Bridges	Within the RAMM database, bridge sections of the state highways are separated from the carriageways, so have been brought in separately as an individual GIS layer. Bridges that cross waterbodies represent points of assumed direct discharge of stormwater from the state highway to an SRE.
AADT	Annual Average Daily Traffic (AADT) provides an indicator of the amount of traffic flow on each section of state highway. Each carriageway and bridge has a given AADT value which, in combination with the carriageway or bridge length (in km), is used to calculate daily VKT.

The environmental data used in the risk assessment is given in Table 3.

Table 3: Environmental data used to assess state highway risk to waterbodies

Data set	Description	Source
Sub-catchments	These are sub-catchments as defined by the NIWA REC database. They relate to sections of streams and rivers.	NIWA
Rivers and streams	These are rivers and streams defined by NIWA in the REC database. Each section of stream contains multiple attributes including stream order and length.	NIWA
Lakes	This data only provides the position and outline of each lake in New Zealand; no attributes for the lakes are present and a more detailed data set was not available.	LINZ
Estuaries	No national data set was available therefore the coastline in the LINZ database was used to identify the location of estuaries.	LINZ
Wetlands	No national data set was available therefore wetlands were excluded from this initial analysis.	-

Step 2 – Daily VKT by sub-catchment

The calculation of daily VKT by sub-catchment initially requires the identification of all sub-catchments that contain a section of a state highway. The carriageways of each state highway are grouped by the sub-catchments they fell within. Carriageways that cross a catchment boundary are apportioned into adjacent sub-catchments. The daily VKT of each carriageway is calculated from the AADT value and length of state highway. The sum of all the carriageway VKTs within each sub-catchment is then calculated to provide the daily VKT by sub-catchment. This value is mapped thematically using gradational colours to represent ranges of daily VKT. A typical VKT output map is shown in Figure 6.

Step 3 – Identifying SREs and assigning sub-catchments

The model for assessing the risk from stormwater runoff on an SRE is catchment-based, that is, it is assumed a given SRE will be impacted by, and only by, stormwater runoff within its catchment. A key step, therefore, in defining the magnitude of potential impact on an SRE is defining its catchment boundary. Unfortunately, no national catchment data was available for New Zealand lakes, estuaries or wetlands. As a result, an alternative approach was developed in this study. Using the stream and river data provided in the REC database, discharge points to the coast were identified. The drainage catchment for each discharge point was then defined. By overlaying the sub-catchments containing a section of state highway and the drainage catchments, the sub-catchments were grouped by their respective drainage catchment.

Step 4 – Identification of hotspots

The VKTs of each sub-catchment traversed by the state highway are added together to derive the total daily VKT value assigned to each discharge point on the SRE (termed the `aggregated VKT'). The aggregated VKT is plotted as a red circle at the final discharge point with the diameter of the circle proportional to the value. Hot spots (SREs with potentially high risk from runoff) are ranked by their aggregate VKT.

While generation of a VKT sub-catchment map covering the national state highway network was achieved, it was not possible to complete the aggregated VKT process at a national level due to the extensive processing time required. Instead, the process was completed at a regional level (including Auckland, Taupo, Rotorua, Wellington and Canterbury) based on the national VKT fingerprint and distribution of a selection of SREs (estuaries, large lakes and groundwater). This provided an overview of the likely risks of the network on representative waterbodies across the country.

Surface water channel (SWC) layer

The SWC layer distinguishes higher risk (`Type A') non-permeable stormwater channels (e.g. kerb & channel) from lower risk (`Type B') permeable discharge pathways (e.g. earth lined channels). Carriageways with no SWC code in RAMM are designated Type C and are assumed to represent carriageways where storm runoff infiltrates the highway verge (lowest risk to SREs). Table 4 lists characteristics for the three SWC types.

Table 4: State highway surface water channel (SWC) characteristics

SWC	RAMM SWC lookup codes	Description	Risk to SRE	Colour[a]
Type A	DA, DC, DP, DS, KC, KCC, KCS, KDS, KS, MKC, MKCC, OTHER, SLTC, UKN	Hard surface, non-permeable e.g. kerb & channel	High	Red
Type B	SWCD, SWCDS, SWCS, SWCSS	Permeable earth channels	Medium	Green
Type C	No code (all other non-coded carriageways)	No SWC on highway verge	Low	None[b]

a) Colour of offset on GIS plot representing SWC type on carriageway either side of SG centerline; b) Non-spatialised so appear on GIS plot as blank offset sections of carriageway

3.2 METRICS FOR RANKING SRE RISK AND CANDIDATE SITES

The Tier 1 metrics used ranking SRE hot spots and identifying potential candidate sites on the highway for stormwater retrofit are given in Table 5.

Table 5: Metrics for ranking SRE hot spots and identifying candidate sites on state highway

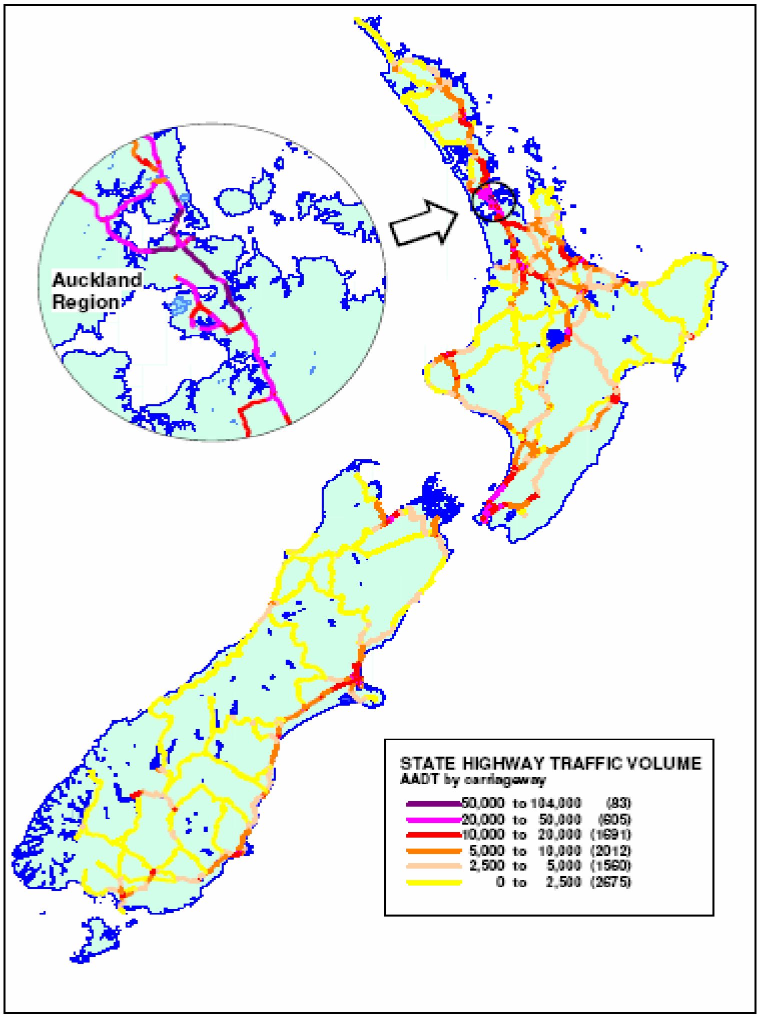
SRE at risk	Target candidate site[c]	Metric for ranking SRE `hot spots'	Metric for ranking candidate site[c]
Surface waterbody[a] - direct	Bridge over waterbody	Daily VKT for bridge section of SH	As per SRE
Surface waterbody[b] - indirect	Carriageway (high risk)	Aggregated VKTb[d] in catchment at discharge to SRE (e.g. head of estuary, lake)	SH sections in catchment of SRE with Type A SWC, ranked by VKT
Groundwater (aquifer)	Soak pit over aquifer recharge zone	Number of soak pits per SH section or ranked by VKT/pit	As per SRE (priority to pits without pretreatment device)

a) Typically river or harbour crossing; b) Typically estuaries, lakes, wetlands; c) Sections of highway for potential retrofit stormwater treatment d) Sum of VKT for each sub-catchment traversed by the state highway in a given catchment

4 RISK PROFILE OF RUNOFF FROM NATIONAL SH NETWORK

4.1 REGIONAL TRAFFIC DISTRIBUTION BY SUB-CATCHMENT

The state highway comprises about 11,000 km of roads split into 8,626 carriageways. Figure 2 shows the national highway network and distribution of traffic volume by carriageway (expressed in terms of AADT - annual average daily traffic measured in vehicles per day). The inset shows the distribution in Auckland, the region with the highest traffic density.



Traffic levels vary widely across the country with busier state highways coinciding with the main urban centres and the major inter-urban transport corridors.

Highest traffic flows (AADT >20,000) are represented by only about 3.5% of the length of the network (red and purple sections in Figure 2). Conversely, about 55% of the network has low traffic flows (AADT<2500) reflecting the preponderance of rural highways in the country (sections coloured yellow).

Waterbodies are potentially at risk from road runoff only from sources of waterborne pollution within their catchment, hence the risk from road runoff needs to be determined on a catchment basis.

The proxy used in this study for the pollution potential of stormwater runoff is total VKT (vehicle-km travelled) in the sub-catchments traversed by the highway.

Figure 2: National distribution of state highway traffic volume (AADT by carriageway)

Table 6 shows the distribution of daily VKT in the sub-catchments traversed by the national SH network. The values span 5 orders of magnitude and reflect the wide range in traffic intensity from catchments containing high capacity urban motorways (e.g. central Auckland exceeding 150,000 VKT per day) to single lane rural highways, many of which experience less than 10,000 VKT per day.

Table 6: Distribution of VKT in sub-catchments traversed by the national SH network

Range (daily VKT)	Sub-catchments in range	
	Number	%
150,000 – 200,000	2	<0.01
120,000 – 150,000	3	0.01
100,000 – 120,000	7	0.03
50,000 – 100,000	31	0.13
10,000 – 50,000	795	3.46
5,000 – 10,000	1313	5.71
0 – 5000	20,851	90.65
Total	**23,002**	**100**

The VKT statistics show that only 3.6% (838) of the total of about 23,000 sub-catchments intersected by the state highway network have a daily traffic burden exceeding 10,000 VKT. The implication is that many waterbodies that could potentially be affected by highway runoff due to their location within a catchment traversed by the road network are unlikely to be subject to major risk. In other words, the search for SREs at most risk should be directed at the comparatively small number of sub-catchments with high traffic activity.

The regional distribution of the 838 `higher risk' sub-catchments with >10,000 daily VKT is shown in Figure 3.

By far the majority occur in the Auckland region (43% - includes Waikato) with 15% in Wellington, 13% in Canterbury and the remainder spread across other regions.

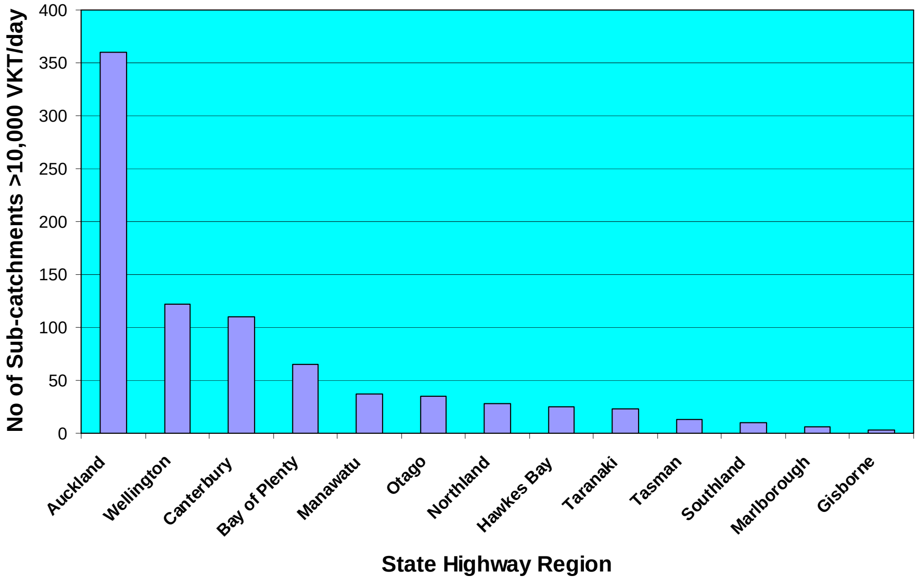


Figure 3: Regional distribution of state highway VKT by sub-catchment

For this reason the initial search for SREs at risk has been focused in the Auckland, Wellington and Canterbury regions as well as specific major waterbodies in close proximity to major state highway networks highways (e.g. Rotorua, Taupo), as discussed in Section 5.

Findings from the risk profile of highway -waterbody crossings are discussed below.

4.2 RANKING STATE HIGHWAY WATERBODY CROSSINGS

The national distribution of the top 30 waterbody crossings for the state highway network is shown in Figure 4.

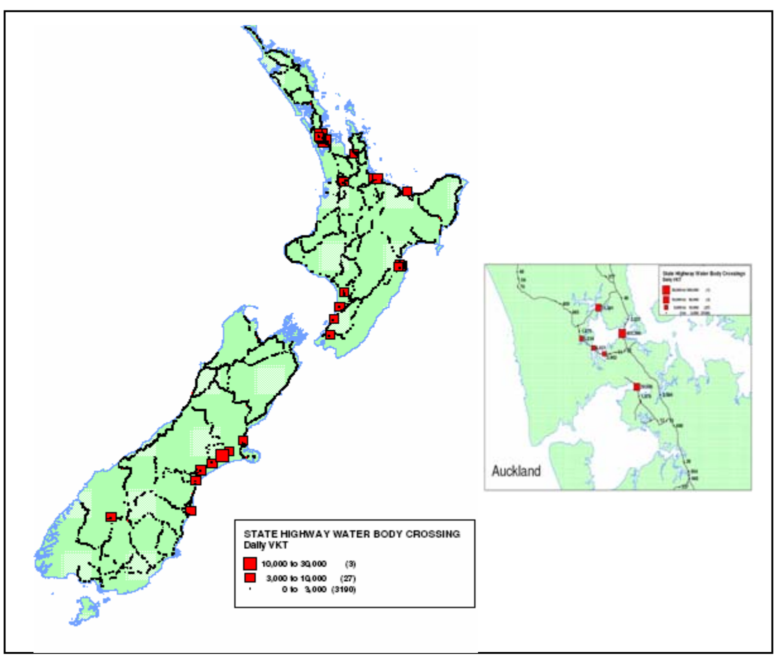


Figure 4: National distribution of state highway waterbody crossings ranked by VKT

The RAMM database contains a total of 3220 crossing points which range from small stream culverts to major bridge structures. The top 30 state highway waterbody crossings (red squares) are ranked by their traffic usage with values ranging from 3,000 to 30,000 VKT/day. Clusters of bridges with heavy traffic, and therefore potentially high pollutant loads in runoff, are to be found in Auckland, Wellington and Canterbury. The insert in Figure 4 shows the regional distribution of the top 6 crossing points in Auckland.

The top 15 state highway waterbody crossings ranked by daily VKT are listed in Table 7. The Auckland Harbour Bridge has by far the largest traffic load (around 400,000 VKT/day) and is an order of magnitude larger than the second highest crossing (Mangere Bridge at 29,080 VKT/day). The majority of major highway crossings in Auckland traverse inner estuaries that will be susceptible to direct discharges of highway runoff.

Table 7: Top 15 state highway waterbody crossings (bridges) ranked by VKT

Bridge ID	Name	State Highway	Length (m)	AADT	Daily VKT
n/a	AUCKLAND HARBOUR BRIDGE	1	n/a	n/a	403,380
1687	MANGERE BRIDGE WEST (N'BOUND)	20	644	45,156	29,080
990	RAKAIA RIVER BRIDGE	1S	1,757	10,224	17,964
1337	UPPER HARBOUR BRIDGE	18	457	24,914	11,391
814	WHIROKINO TRESTLE BRIDGE	1N	1,098	8,514	9,348
1294	WHAU BRIDGE NO2	16	183	47,031	8,621
985	WAIMAKARIRI RIVER BRIDGE (S'BOUND)	1S	422	17,895	7,555
986	WAIMAKARIRI RIVER BRIDGE (N'BOUND)	1S	422	17,895	7,555
1395	MAUNGATAPU BRIDGE	2	310	22,200	6,882
992	ASHBURTON RIVER BRIDGE	1S	342	19,612	6,715
2560	TUTAEKURI RIVER BRIDGE	50	273	20,069	5,479
807	RANGITIKEI RIVER BRIDGE BULLS	1N	420	12,965	5,447
1295	WHAU BRIDGE NO1	16	183	28,552	5,234
1657	MOONSHINE BRIDGE	2	179	24,405	4,378
1715	WAIHOU RIVER BRIDGE (KOPU)	25	465	8,600	4,002

Bridges represent the aspect of a highway where stormwater runoff is most clearly identified. Canadian research has found stormwater sediments near road bridges “grossly polluted” with zinc, copper and lead, thus suggesting uncontrolled discharge from highway crossing points could significantly impact receiving water quality (Maraslek et al., 1997).

Remedial measures are being taken to treat road runoff from the Auckland Harbour Bridge. However, the results of this study indicate that there are other highway crossing points where a review of drainage arrangements for the bridge could potentially reduce the risk of pollution. The focus should be on bridges that cross waterbodies that are sensitive to the effects of sediment accumulation and contaminated road runoff, and with high ecological value. Thus, for example, effort could be directed at some of the heavily trafficked crossings in Auckland that span sheltered inner estuaries containing mangrove swamps.

5 REGIONAL `HOT SPOTS’ AT RISK FROM HIGHWAY RUNOFF

This section illustrates a selection of hot spots for SREs that may potentially be at risk from state highway runoff as identified by the VKT risk assessment. These include surface waterbodies represented by estuaries in Auckland, Rotorua Lake, and Pauatahanui Inlet in Wellington. Also included is a preliminary assessment of risk to groundwater in the Christchurch area from soak pits on the state highway. Apart from major lakes such as Taupo and Rotorua, the lack of detailed national GIS datasets for lakes and wetlands meant that the risk posed to these waterbodies from state highway runoff could not be assessed.

5.1 AUCKLAND ESTUARIES

Figure 5 shows the location of SRE `hot spots’ (red circles at the base of catchments) identified in the Auckland region using the Tier 1 screening process. The aggregated value of VKT at the discharge point to the SRE is a relative measure of the pollution risk to the waterbody from runoff discharged by the state highway that traverses the catchment.

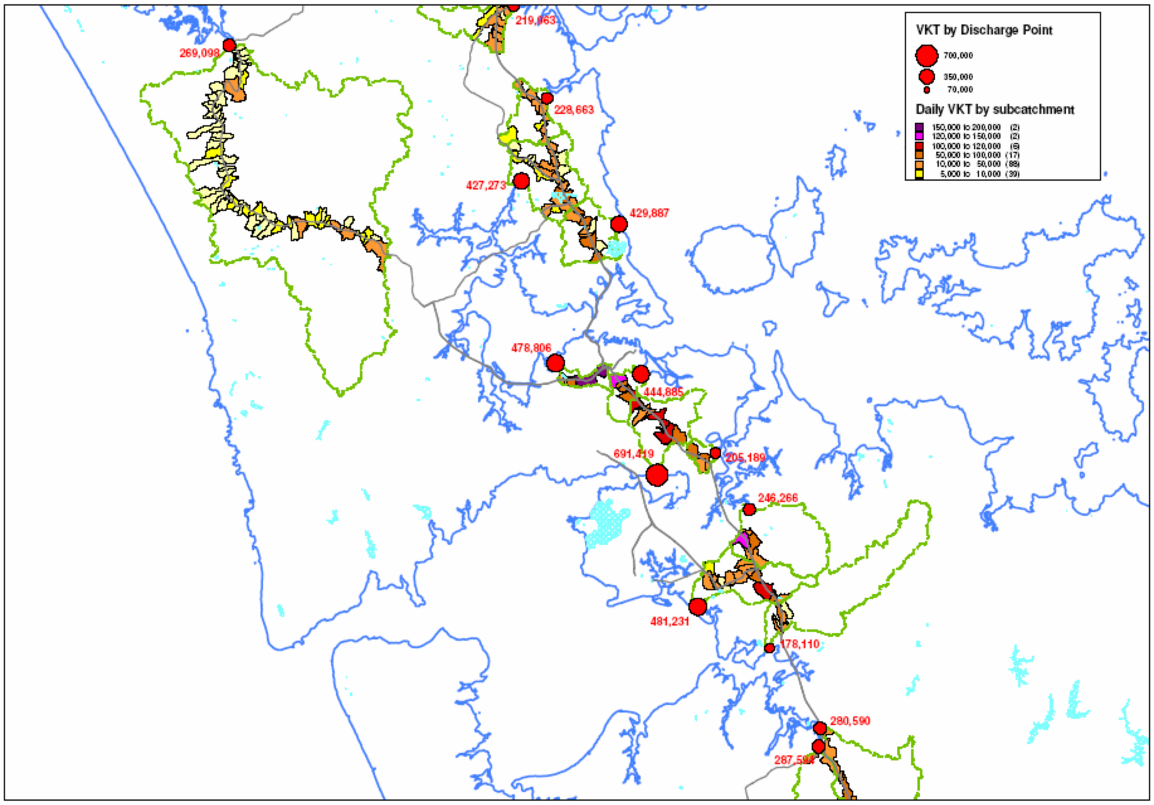


Figure 5: Auckland estuary hot spots in receipt of discharge from state highway

Table 8 lists the top 15 hot spots in Auckland ranked by aggregated VKT at the discharge point to the SRE. The SREs are typically upper estuaries of tidal creeks or rivers and therefore particularly susceptible to pollution from road runoff. The aggregated VKT at the discharge to these waterbodies ranges from a low of 178,110 (Pakakura Stream, Takanini) to a high of 691,419 for Mangere Inlet. These values are high compared with SREs at risk from highway runoff in other urban areas of the country and reflect the very high traffic densities within the Auckland catchments.

Table 8: Tier 1 listing of top 15 Auckland SRE hot spots ranked by VKT

Rank	Catchment ID	Catchment area (km^2)	Aggregated Daily VKT	SRE Name / Location
1	472	18.4	691,419	Mangere Inlet / Onehunga
2	345	21.4	481,231	Puhinui Creek / Manukau
3	636	4.8	478,806	Motions Creek / Grey Lynn
4	543	7.2	444,885	Hobson Bay / New Market
5	592	15.1	429,887	Wairau Creek / Milford
6	675	23.8	427,273	Lucas Creek / Albany
7	320	39.8	287,594	Ngakoroa Stream / Drury
8	294	54.0	280,590	Drury Creek / Drury
9	940	267.0	269,098	Kaipara River / Helensville
10	334	28.3	246,266	Otara Creek / Otara
11	728	12.4	228,663	Okura River / Okura
12	800	15.4	219,963	Weiti River / Silverdale
13	755	97.3	219,681	Mahurangi River / Warkworth
14	449	3.3	205,189	Tamaki River* / Panmure
15	300	41.1	178,110	Papakura Stream / Takanini

Figure 6 is a detailed Tier 1 map illustrating the highway/sub-catchment configuration for one of the Auckland hot spots (Puhinui Creek, Manukau). The Puhinui Creek catchment is defined by the dashed green line. The numerical values of daily VKT are plotted in the centre of each sub-catchment. The aggregated VKT at this location is 481,231 and it is No 2 on the list ranked by VKT.

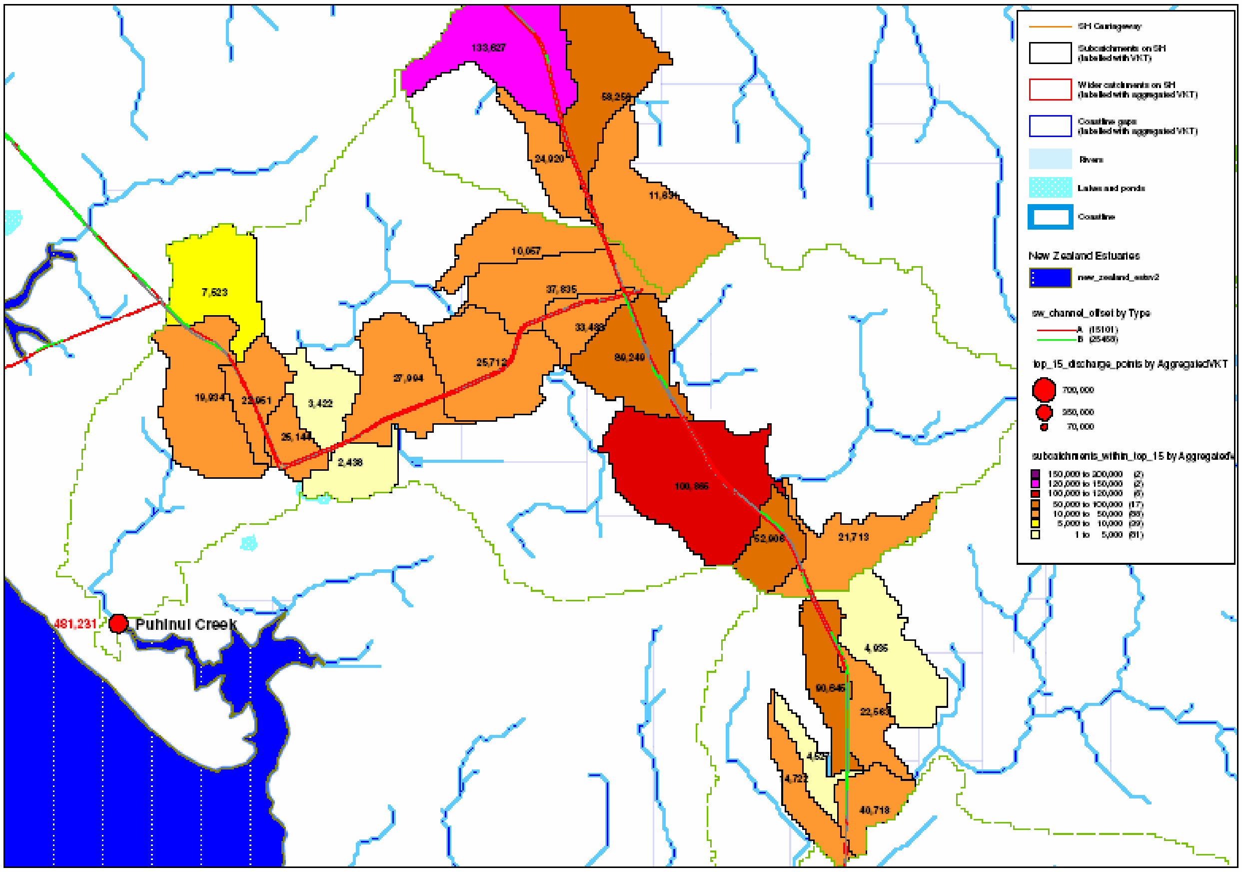


Figure 6: Example Tier 1 detail for Auckland hot spot - Puhinui Creek, Manakau

The SH has coloured `tramlines' offset either side of the centreline denoting the type of stormwater channel (SWC) coded in RAMM for each carriageway. The high risk sections of carriageway with kerb and channel (Type A) SWC are shown in red. The road sections where there is coincidence of Type A SWC and high traffic density (high VKT) are those which could be further investigated on the ground for potential stormwater treatment. In the case of Puhinui Inlet, the Tier 1 screen points to the need for further investigation of kerb and channel sections within Manukau City centre (sub-catchment with VKT 100,865) as well as the section of SH 20 immediately west of the intersection with SH1.

It is recognized that this is a simplistic analysis of a highly urbanised area with a complex stormwater reticulation network. Any measures to improve stormwater quality discharge to the Inlet would, of course, need to take account of discharges from both the state highway and local roads, as well as well as other stormwater pollution not attributed to road traffic.

5.2 LAKE ROTORUA

Lake Rotorua is a large and sensitive waterbody that is at risk of pollution from surrounding land use due to the radial configuration of surrounding catchments that drain towards the lake (Figure 7). The figure shows an extensive network of highways (SH5 and SH36 to the west; SH30 and SH33 to the east) that encircle about 75% of the lake perimeter and which converge in Rotorua town situated at the south-western end of the waterbody. The Lake was therefore included as a prime target for Tier 1 risk assessment of state highway runoff.

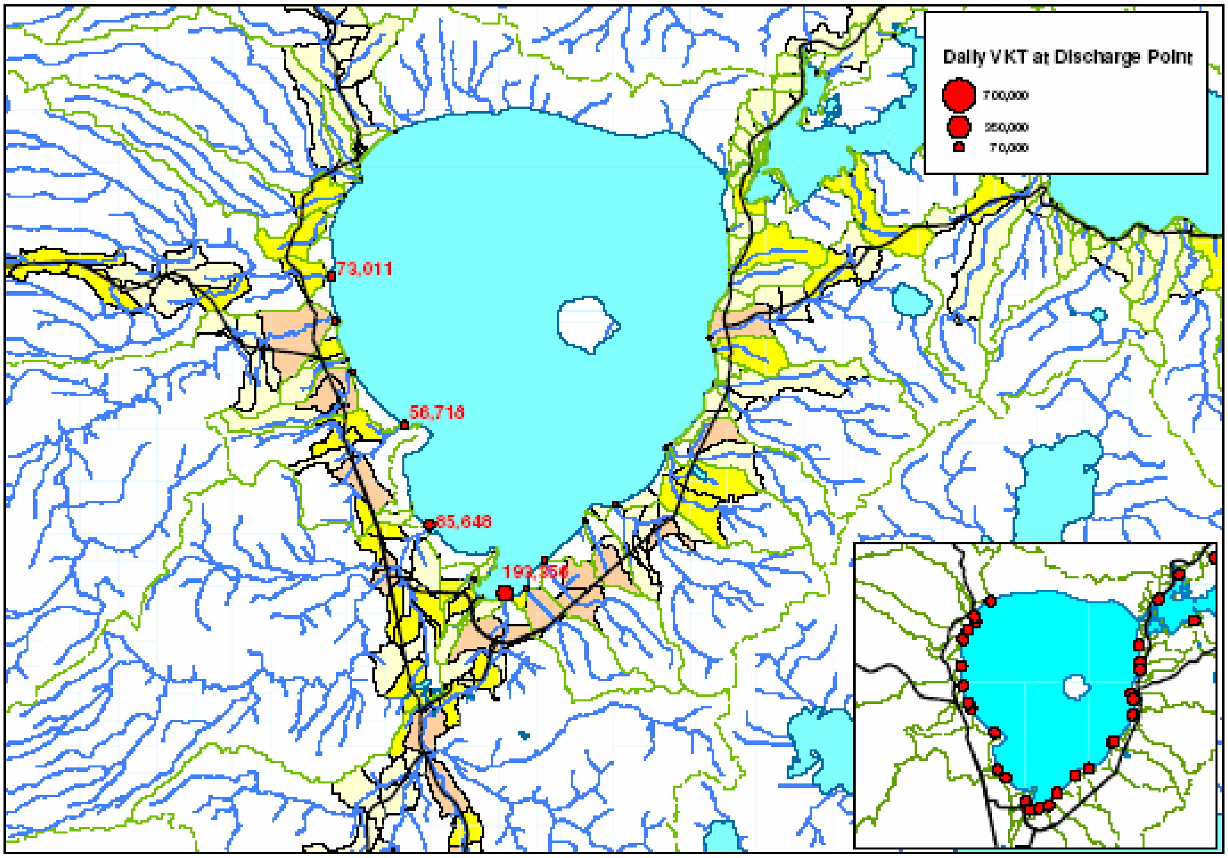


Figure 7: Regional map of Lake Rotorua showing top 4 hot spots from highway runoff

Results of the Tier 1 screening process are also shown in Figure 7 with hot spots located at the stream discharge point to the Lake identified as red circles with their aggregated values of VKT. The relative pollution potential of the SH network is greatest at the southern end of the Lake in Rotorua where the density of state highways is greatest (daily VKT of 193,356). Three smaller hot spots are found along the western coast (daily VKTs ranging from 56,718 to 85,638).

The insert in Figure 7 shows all the discharge points to the Lake from catchments that carry highway traffic. While many of these represent comparatively small pollutant loads (<10,000 VKT/day), the waterbody is enclosed and susceptible to cumulative effects, therefore it may be more appropriate to consider the overall impact of highway runoff in terms of the discharge to the Lake as a whole. This value is in the order of 700,000 VKT/day and, on a purely relative basis, is similar to the top estuary hot spot identified in Auckland (see Section 5.1).

Figure 8 is a detailed plan of the section of SH5 that traverses the catchment of the Waiowhiro Stream situated towards the southern end of the Lake's western shore (refer to hot spot in Figure 7 with 56,718 VKT/day at discharge). Figure 8 shows that the highway crosses the stream at three locations in this catchment with over 20 sumps/catchpits servicing the mostly Type A (kerb and channel) surface water channels along each carriageway.

Transit is working with Rotorua District Council to reduce the impact of highway runoff in this location (see Section 6.3).

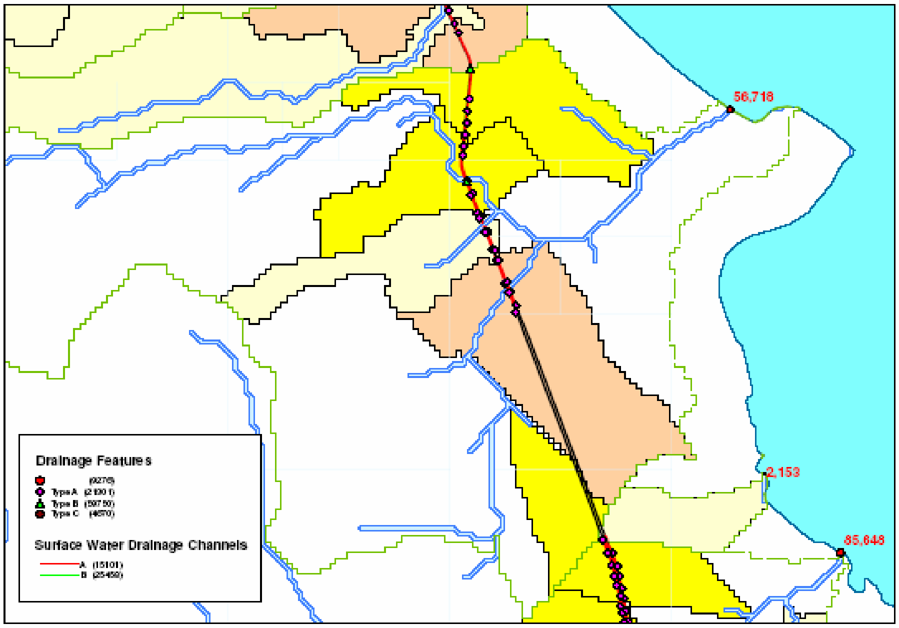


Figure 8: Hot spot in the Waiowhiro Stream catchment from SH5 runoff

Based on the risk assessment, further field investigation of the hot spots identified in this risk assessment are planned to determine whether the stormwater management initiative should be extended to other sections of the state highway around the Lake.

5.3 WELLINGTON

Figure 9 shows the location of SRE `hot spots' in the Wellington region using Tier 1 screening. Only the southern part of the region is shown as the northern half does not have any significant hot spots.

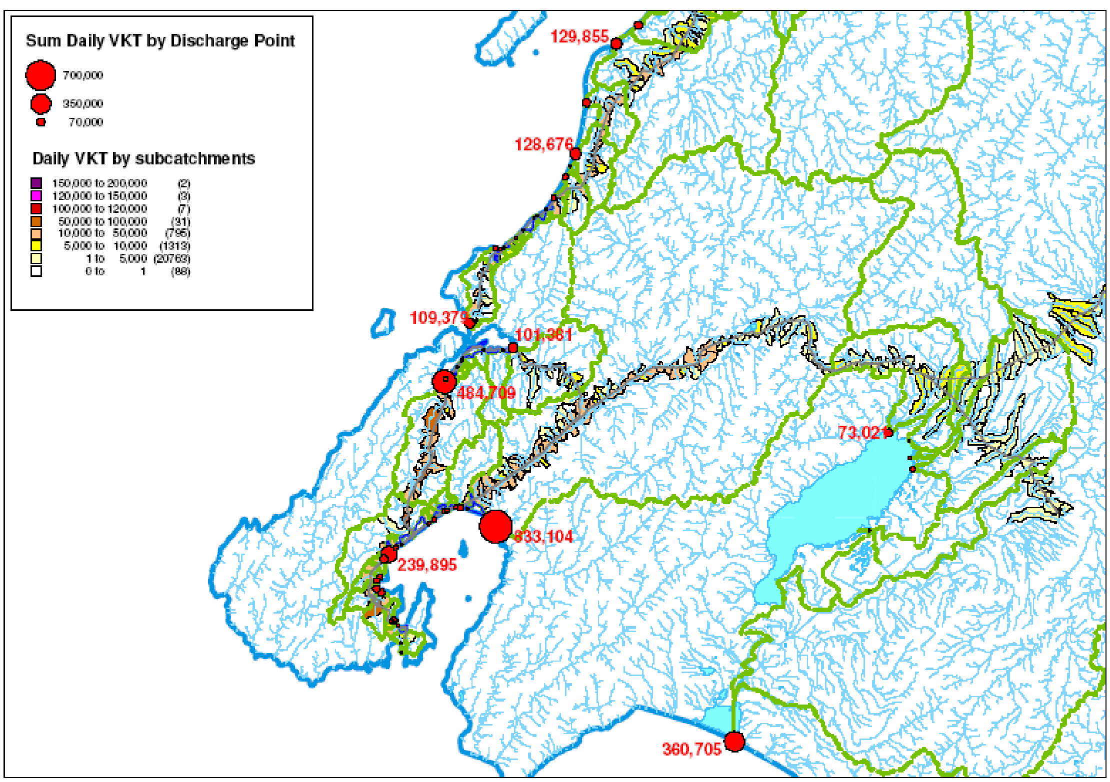


Figure 9: Regional map of southern Wellington showing hot spots from highway runoff

Attention is drawn to two hot spots in Figure 9:

i) The Porirua hot spot has a high aggregated VKT (around 485,000) from highway runoff. A previous study (Gardiner and Armstrong, 2006) identified that this area is also potentially subject to high pollution from the local road network (daily VKT about 139,000). State highway SH1 therefore contributes about 78% of the total traffic-generated runoff pollution in this catchment. However sediments near the discharge point of Porirua Stream with the estuary are polluted by heavy metals from industrial discharges (Sherriff, 2005) so any measures to improve stormwater quality in this area would need to take account of these sources.

ii) The Pauatahanui Inlet hot spot at the eastern end of the Pauatahanui Arm (centre of plot). The Inlet at this location is a particularly sensitive waterbody with a wetland area and the aggregated VKT value at the Inlet from the SH58 is relatively high (around 101,381). Sections of the SH58 with kerb and channel in this catchment would be worth investigating for potential stormwater treatment options. It will be also important to consider the future effect of road runoff from the Transmission Gully interchange in this area.

5.4 RISK TO GROUNDWATER

Figure 10 is a regional VKT plot for the Christchurch area showing the distribution of highways and the traffic intensity by sub-catchment. The plot shows the aquifer protection zone which defines the area of groundwater vulnerable to surface pollution (Source: ECan).

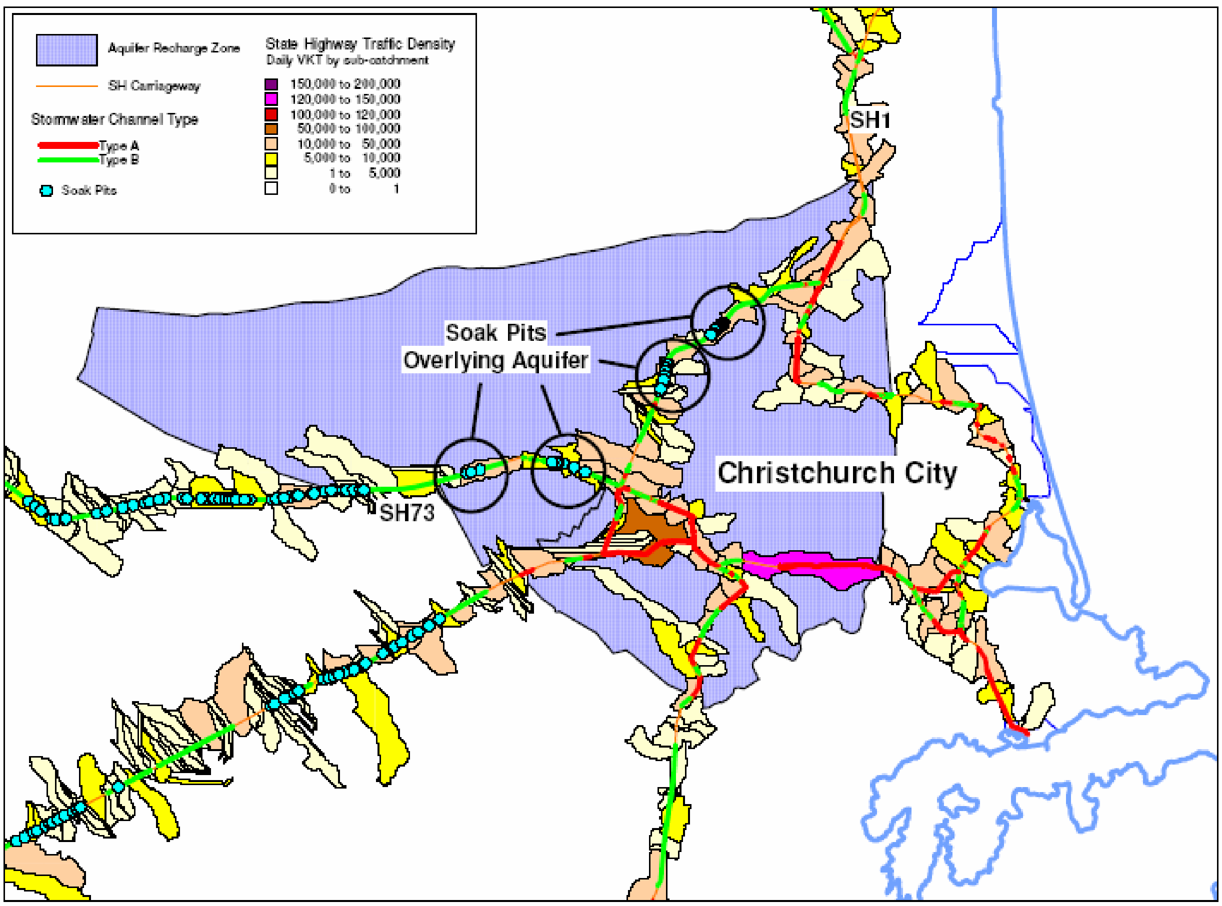


Figure 10: Hot spot soak pits alongside SH1 and SH73 that overlie the Christchurch aquifer

Soak pits servicing runoff on the highway are indicated by green circles. The pits are mainly located in low lying areas alongside highways to the west and south-west of the city (SH73 and SH1). Most of the soak pits in these areas are situated outside the aquifer recharge zone. However, several clusters of pits alongside these highways overlie the aquifer, as highlighted in the figure.

Traffic flows alongside these pits on SH1 are high (AADT in range 20,000- 25,000) as this highway functions as a bypass for Christchurch city. Although runoff is discharged along the length of the carriageways via a diffuse pathway to earth (Type B) stormwater drainage channels, which is likely to provide some attenuation of pollutant load, the pits pose a potential risk to groundwater from point source infiltration of runoff. Further investigation is planned by Transit to evaluate the risks from these soak pits and the adequacy of current stormwater management measures e.g. presence of pre-treatment devices and maintenance regimes.

6 TRANSIT'S APPROACH TO STORMWATER MANAGEMENT

6.1 REGULATORY FRAMEWORK

The Land Transport Management Act (2003) s77 makes clear Transit's obligations:

(1) The objective of Transit is to operate the state highway system in a way that contributes to an integrated, safe, responsive, and *sustainable land transport system*.

(2) In meeting its objective, Transit must exhibit a sense of *social and environmental responsibility*, which includes—

"*avoiding, to the extent reasonable in the circumstances, adverse effects on the environment*;"

Transit's Environmental Plan describes how this is accomplished by means of policies, objectives, and performance indicators. Nevertheless, the absence of water quality standards and criteria present a significant difficulty in identifying water quality problems and in defining and achieving goals in New Zealand (Caruso, 2000). New Zealand is the least environmentally regulated country in the world (Logan, 2007.)

Consequently, Transit is faced with the dilemma of a willingness to be environmentally, socially and fiscally responsible without measurable parameters to judge our actions or predict the need for mitigation. A recent review identified stormwater treatment as a major contributor to unanticipated increases in state highway construction costs (Ministerial Advisory Group, 2006).

6.2 TRANSIT'S APPROACH TO STORMWATER MANAGEMENT

Transit is aware of increasing concerns on stormwater quality from the regulatory viewpoint and the need to identify and retrofit treatment systems for critical parts of the state highway network

Transit currently manages its effects on stormwater in three ways: controlling sediment and erosion from earthworks during construction, establishing stormwater quality treatment approaches as required by RMA consent conditions when building new state highways, and a voluntary retrofit program of existing state highways.

Internally, there is a need to demonstrate best value investment on retrofit programmes. A need has also been identified to develop a definitive stormwater treatment standard that will reflect best practice, be practical and acceptable to regulators and which may be rolled out to all Transit regions.

Given the absence of clear regulatory environmental standards, Transit has adopted the international practice of Best Management Practices (BMP) in managing stormwater issues. Table 10 sets out Transit's approach for managing stormwater retrofit on state highways.

Table 10: Transit's approach to managing stormwater retrofit on state highways

Issue	Aspect	Transit Approach
A. What is at risk?	Waterbodies at risk and potential candidate sites.	Use the source-pathway-receptor approach to identify waterbodies at risk from highway runoff and identify sections of highway for potential stormwater retrofit (`candidate sites').
B. Where to retrofit?	Establish need for treatment, short list candidate sites and treatment options.	Review environmental data for waterbodies at risk (stormwater and sediment quality) against regional guidelines to establish environmental baseline and need for stormwater treatment; perform field evaluation of candidate sites to `ground truth' local runoff drainage, outfalls, existing natural capability for s/w treatment and engineering constraints; develop short list of candidate sites and options for s/w treatment.
C. When to treat?	Trigger criteria	Develop policy, criteria and thresholds for triggering need for stormwater treatment.
D. How to treat?	Treatment standards	Develop Transit's Stormwater Treatment Standard
E. Implement	Design, install and monitor treatment systems	Using outputs from A-D, design stormwater treatment systems for identified candidate sites, obtain consents, install treatment devices and implement a management plan to ensure effective maintenance and monitoring over system lifetime.

Further details of stormwater management initiatives currently being implemented by Transit are discussed below.

6.3 TRANSIT STORMWATER INITIATIVES

Stormwater retrofit programme

The retrofit program is designed to improve conditions on the existing network. Environmental effects from stormwater (as well as noise and visual quality) are prioritised against criteria and funding is allocated accordingly. In addition, we work with local authorities to protect significant waterbodies.

For example, runoff from the SH5 discharges into the Waiowhiro Stream near Rotorua and then into Lake Rotorua. The highway AADT is 20,000, which is composed of 10% heavy commercial vehicles (HCV), and a speed limit of 70 km/hr in present. In partnership with the Rotorua District Council, and as part of the Crown lakes restoration project, Transit installed a catch pit and litter basket.

In a contemporaneous project on the SH58 near the western end of Pauatahanui Inlet, a particularly sensitive tidal waterbody near Wellington, funding has been allocated to the field trial of proprietary catchpit filter systems whose performance is being monitored for effectiveness over a 6-month period. The highway AADT is 14,000 with 10% HCV and a speed limit of 50 km/hr. Given space limitations on the narrow sections of highway that back on cliffs, use of catchpits filter socks is the only practical means for stormwater retrofit in this area. Approximately half of the pollutant loading along the southern coastline of the Inlet coastline comes from the SH58 with the other half from local roads.

Consents database

Currently, Transit has an initiative intended to improve our approach to the consenting process. We are developing a national database on all consents, including stormwater discharges, with an objective to find the best examples, which will be developed into pro forma consent guides for our staff and suppliers.

Preliminary results indicate that, all too often, demonstrating compliance with consent conditions is difficult to achieve. The development of a consent condition library in cooperation with regional authorities should improve the application, approval, monitoring and compliance processes.

Transit holds over 300 stormwater discharge consents in the Auckland region. As they become subject to renewal we are collecting more detailed information as to their location and condition using GPS and CCTV assessment.

Stormwater treatment standard

In order to provide more certainty and clarity, Transit is developing a *Stormwater Treatment Standard* that will be specific for New Zealand state highways. The standard will be based on international best practice and will identify the most appropriate and cost effective type of stormwater treatment depending on factors such as slope, soils, available land, and the sensitivity of the receiving environment. The standard will provide worked examples, calculations, decision trees and treatment options.

A key goal is to encourage low impact design (LID), which maximises sustainable maintenance practices. Swales, an example of LID, have been found to be an effective means of removing contaminants, in particular both zinc and copper (Berret et al., 1998; Dierkes & Beiger, 1998.), and are also effective as traps or sinks due to their high organic carbon content. Seepage from swales into groundwater found neither zinc nor copper exceeded European permissible limits for drinking water (Dierkes & Beiger, 1998). Within the sediments, leachable zinc and copper were found at levels up to 120 and 210 μg/L respectively. These values are far below the limits which would classify them as hazardous waste (TCLP $250{,}000_{Zn}$ and $25{,}000_{Cu}$).

Stormwater metrics

Stormwater management is a significant environmental responsibility for Transit. Our key performance indicator for water resources is:

'cumulative vehicle-kilometre-travelled where highway runoff is treated by designed solutions, such as both natural and engineered water-filtering systems, before being discharged into sensitive waterbodies'.

Information management systems are under development that will allow us to annually report on this indicator. The SPR methodology and improved recording of stormwater treatment devices in RAMM will assist us in this task.

7 CONCLUSIONS

The following conclusions are drawn from the preliminary Tier 1 screening of risks to waterbodies from state highway runoff:

National perspective of highway runoff

- Traffic levels on state highways vary widely across the country. Highest traffic flows (AADT >20,000) are represented by only about 3.5% of the network and are to be found in the main regional cities and interurban corridors. Conversely, about 55% of the network has low traffic flows (AADT<2500) reflecting the preponderance of rural highways.

- A measure of the polluting potential of state highways on waterbodies is given by the sub-catchment traffic intensity measures in VKT. Only 3.6% (838) of the total 23,000 sub-catchments intersected by the state highway network have a daily traffic burden exceeding 10,000 VKT. The implication is that many waterbodies that could potentially be affected by highway runoff due to their location within a catchment traversed by the road network are unlikely to be subject to major risk.

Bridge crossings

- Auckland Harbour Bridge has the highest pollutant load from runoff (over 400,000 VKT/day) based on ranking of highway/waterbody crossing points in terms of traffic usage. The next top 14 state highway waterbody crossings have an order of magnitude lower impact in the range 29,000 to 4,000 VKT/day.

- Uncontrolled discharge from highway bridges may significantly impact receiving water quality. Clusters of highway bridges with heavy traffic, and potentially high pollutant loads in runoff, are found regionally in Auckland, Wellington and Canterbury. The majority of major highway crossings in Auckland traverse inner estuaries that will be susceptible to direct discharges of highway runoff.

Regional hot spots

- Tier 1 screening assessment of the state highway network has identified a number of hot spots at regional waterbodies where high VKT indicate an elevated risk of vehicle-related pollution from road runoff. Estuaries in and around Auckland are the waterbodies with highest risk as a result of indirect discharges of runoff from heavily trafficked sections of highway that traverse their catchments. The top 10 hot spots have daily VKTs of between 178,000 and 691,000.

- Lake Rotorua has a number of hot spots at stream discharge points due to the network of highways around the waterbody. VKTs for the top four hot spots lie in the range 57,000 to 193,000 with three located on the western side of the lake and the highest value at the southern end associated with highways in and around Rotorua town.

Risk to groundwater

- Tier 1 screening of the state highway network in Christchurch has identified several clusters of soak pits alongside SH1 and SH73 that overlie the aquifer protection zone, and which are potentially a risk to groundwater from point source infiltration of runoff. Further investigation is planned by Transit to evaluate the risks from these soak pits and the adequacy of current stormwater management measures.

Further developments

- Limited availability of national GIS datasets precluded a thorough investigation of the risks to all significant waterbodies in the country. It is intended that further screening be undertaken when the national datasets being prepared for estuaries, lakes and wetlands under the Government's Sustainable Water Programme of Action are available.

- The drainage mapping programme of the highway network in Auckland, currently being prepared on behalf of Transit as part of their global consents programme, will provide the opportunity to complete a more detailed risk assessment of the effects of stormwater runoff using Tier 2 pollutant load modeling.

Concluding comments

The screening tool is intended to be used on a comparative rather than absolute basis for assessing road networks and their effects on receiving environments. The values of VKT derived for hot spots are a relative measure of the pollution potential of highway runoff. While Tier 1 screening provides a valuable pointer to SREs at risk and a focus on areas of the road network for further consideration, it does not provide information on whether a waterbody is actually polluted by road runoff, nor does it provide data to permit comparison with environmental standards e.g. sediment quality.

Risks to receiving environments identified by the tool, and the potential need for stormwater treatment, require follow-up field investigations before decisions can be made on suitability of specific locations for potential retrofit treatment. This is particularly the case with the state highway stormwater system given the lack of information on the actual pathway and destination of runoff.

Notwithstanding these limitations, the screening tool provides Transit with the means to take a national perspective of risks to receiving environments from runoff across the state highway network. The study findings reported here are preliminary but highlight a number of sensitive waterbodies that are potentially at risk from runoff and the sections of highway where remedial action may be warranted. Field investigations are underway by Transit to further evaluate these higher risk areas and develop an appropriate response in line with their stormwater management programme.

ACKNOWLEDGEMENTS

This report represents the opinions of the authors and does not necessarily represent the views or policies of Transit New Zealand.

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