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# A RISK BASED APPROACH TO WATER SENSITIVE HIGHWAY DESIGN

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**ABSTRACT**

The original project brief for the upgrade of a major motorway in Ipswich, incorporated stringent water quality design objectives. This would have ultimately resulted in oversized infrastructure and an excessive number of water quality treatment devices on the project. The requirements listed in the brief included treatment of all runoff to comply with the Queensland Environmental Protection Policy (Water) (EPP) requirements as well as provision of 40kL spill capture at every discharge point.

The motorway runs through a predominantly urban area and the available corridor is highly constrained, restricting the land available for water quality treatment. The construction and operation of the motorway has the potential to affect the quality of a number of waterways located in close proximity to the project. Spatial constraints associated with the motorway upgrade in combination with the stringent water quality design criteria served as a catalyst for an innovative risk-based approach to stormwater quality and spill management.

Careful consideration of the water quality objectives' (WQOs) intent within the project constraints resulted in the development of a new water quality design framework that included a risk assessment to identify the likelihood and expected impact on each receiving environment.

The water quality assessment was based on major sources of pollutants including heavy metals from vehicle movements. The likelihood of pollution was estimated based on expected traffic movements, the number of turning/ braking movements, volume of runoff and potential for litter-generation. The anticipated impact was quantified based on the proximity to a sensitive waterway. Road catchments associated with high risks were provided with major treatment measures such as basins and wetlands; road catchments associated with low risk were deemed less critical and incorporated minor treatment measures such as swales and extended flow paths, wherever practicably possible.

The petrochemical spill assessment adopted a similar methodology and included an assessment on the probability of a spill (including the risk of ignition) and its relative impacts. Detailed crash statistics were collated and reviewed from local and overseas sources to identify the potential risks, volumes and expected impacts of a spill. An event tree, created using Palisade Decision Tree software, was used to estimate the probability of a spill and the probability of fire from a spill based on the collated information. Designated spill capture devices were provided in high-risk locations, while road catchments associated with low risk were deemed less critical and where practicable incorporated secondary spill capture aids such as extended flow paths or swales.

The adopted risk management approach resulted in less water quality infrastructure targeted at high risk sites to provide a tailor-made solution for the Ipswich Motorway Upgrade.

**PROJECT DESCRIPTION**

The Ipswich Motorway Upgrade (IMU) – Dinmore to Goodna involves the upgrade of 8km of extremely constrained urban motorway from four lanes to a minimum of six lanes and also includes four motorway interchanges. The project is being undertaken to provide reliable travel flow on the motorway, increase motorway capacity and traffic flow by reducing congestion for the future, and provide a safer motorway by providing new and upgraded service roads that will separate local and regional traffic. It is exected that the motorway will convey up to 168,000 vehicles per day by 2032.

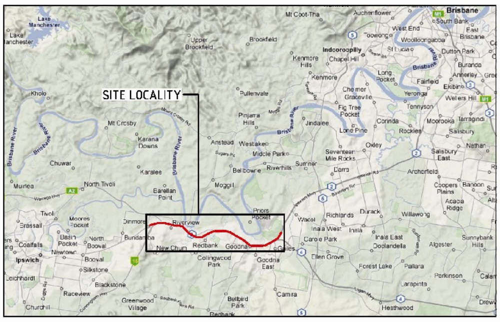


***Figure 1: Site Locality***

An alignment for the Ipswich Motorway Upgrade is provided as Figure 2.

The Queensland Department of Transport and Main Roads (DTMR) established the Origin Alliance project to deliver the project. The Origin Alliance team includes DTMR, Abigroup Contractors, Fulton Hogan, Seymour Whyte, Parsons Brinckerhoff and SMEC

**KEY ISSUES**

The upgraded motorway is a vital piece of infrastructure that is required to link Ipswich with Brisbane and allow goods and materials to be conveniently transferred. The goods vary from people to freight that can include hazardous chemicals such as hydrocarbons. Unfortunately, vehicles can lead to pollution of waterways through vehicle emissions and wear, or at worst can lead to accidents where large volumes of hazardous material may be spilt into sensitive environments. The IMU project dealt with this by stipulating requirements in the design brief for stormwater discharges and the need for some form of spill capture to protect the receiving environment as listed below:

- The part(s) of the drainage system that deal(s) with general pavement drainage must incorporate methods for retention of 40,000 litres of polluted run-off (including oil and chemical pollutants/spills) at each point of discharge from the Project Site; and
- Stormwater discharges must meet the EPP (Water) requirements as well as Australian and New Zealand Environment and Conservation Council (ANZECC) and/or locally relevant water quality guidelines.

The water quality objectives (WQOs) are detailed in the EPP (Water) and set pollutant concentration targets for various water quality indicators.

Adopting the above brief would require greater than 50 spill capture devices to intercept runoff at each outlet and greater than 20 high performance treatment measures such as wetlands and bioretention basins that require regular maintenance to operate effectively. The motorway runs through a predominantly urban area of Ipswich City and the available corridor is constrained, restricting land available for water quality treatment measures.

Although the brief prepared by DTMR aimed to provide the best outcome for the adjacent environment, the brief was written by a section of DTMR who are solely focussed on water quality. Other sections of DTMR have to monitor, operate and maintain the infrastructure and have a different understanding of the impact of the original design brief.

Given the stringent water quality objectives, lack of available land for treatment measures, the large number of "required" treatment measures, the expected maintenance burden and the question as to whether all of the nominated treatment measures provide value for money, it was decided to challenge the original brief and investigate a risk-based approach to both water quality and spill capture requirements.

The key issues for the risk based approach was to provide a transparent methodology for selecting appropriate treament measures at key locations that will provide the maximum "bang for buck" in terms of construction and operating costs as well as protecting sensitive environmetal areas

## RISK ASSESSMENT PRINCIPLES

### Risk and the effect of uncertainty

Risk is defined as the effect of uncertainty on objectives (AS/NZS ISO 31000). In the context of Water Sensitive Highway Design (WSHD), the objectives of a risk management framework may be expressed as the protection of the environment and/or human health from the adverse effects arising from the discharge of pollutants or contaminants through the stormwater system. Uncertainty arises from the difficulty of accurately predicting and adequately controlling the discharge of contaminants to meet those objectives. Predicting discharge results is difficult due to the variability in the type, quantity and concentration of pollutants being discharged to stormwater systems.

The majority of uncertainties in the analysis is due to the difficulty in obtaining relevant data that adequately describes aspects such as the generation of contaminants, actual rainfall data (not design storms), real traffic volumes and vehicle types, accident rates and locations, the type and volumes of goods carried on the road network, and the quantities that might be spilled in the event of an accident.

The provision of control systems to mitigate any impacts will in all cases be constrained to some extent by resources, including cost, and the objective must therefore be to reduce the risk remaining after the provision of such controls to an acceptable level.

### The measurement of risk

Risk is commonly measured as a combination of the consequences of an event that can affect objectives and its likelihood or the frequency with which it occurs. Generally across a range of events risk can be described as:

$$Risk = \sum_i Consequence_i * Frequency_i$$

or more generally:

$$Risk = \sum_i f(Consequence_i, Frequency_i)$$

The function *f* may be non-linear and include additional factors that allow, for example, for biases in the way a single serious event or more frequent but less serious events are perceived and rated; or to allow for different types of risk (such as environmental and safety) to be summed by giving each an agreed weighting (The resulting risk value might not be physically meaningful, but the numerical value will provide a means of comparing different scenarios).

Risk may be assessed in a number of ways ranging from qualitative assessments that use descriptive terms rather than numerical values, through semi-quantitative methods, to fully quantitative assessments that give numerical estimates of risk. The methods used will depend on many factors, including the purpose of the assessment, the nature of the events and consequences being assessed, and the availability of data or a model to predict the consequences of an event in numerical terms.

A common method of completing a risk assessment that is described in *IEC/ISO 31010: Risk management – Risk assessment techniques*, uses a risk ranking matrix to combine qualitative or semi-quantitative measures of consequence and frequency or probability to generate a risk rating that can then be compared to objectives and used to guide risk mitigation actions. This tool requires that users and/or stakeholders have agreed how consequences will be described (e.g. what might constitute an insignificant or a serious consequence); how frequencies or probabilities will be described (e.g. what does infrequent or almost certain mean); how does the organisation view the risk that results from all possible combinations of each of these factors (e.g. low, medium, high); and what action is required for each of these risk ratings (e.g. accept risk, manage risk, mitigate unacceptable risk).

The measure of the risk affecting these objectives might typically be expressed in terms such as probability of exceeding a discharge standard, cleanup dollars per annum, or fatalities per annum.

The assessed risk for any WSHD system would ideally be described as a single number combining environmental and human impacts. Calculation of such a number requires suitable biasing factors that allow the consequences of a particular discharge or spill on the environment and on human health to be compared, so that risk terms such as dollars per annum and fatalities per annum can be summed. Agreeing such factors is likely to be difficult, and the calculation of the actual environmental, health and safety consequences is in any case likely to be complex for any real system. In the case of the IMU, it is likely that different factors would be needed for each catchment depending on the environmental values of the receiving environment and the human population potentially affected.

## WATER QUALITY RISK ASSESSMENT

### Pollutants of Concern

The pollutants present in the operation of typical motorway environments are generated from vehicle movement and wear, and range from gross pollutants to particulate and soluble contaminants. These pollutants and the potential sources of these pollutants in road runoff are provided in Table 1.

***Table 1: Sources of pollutants in road runoff***
***f***

| Pollutant | Source of pollutant |
|---|---|
| Gross pollutants and litter | Overflows of rubbish containers; dropping of rubbish; material blown from rubbish sources, material thrown from vehicles |
| Sediment and suspended solids | Natural erosion of batters; erosion of road pavement; tyre rubber particles; bearings, engine and brake wear residues |
| Nutrients – primarily phosphorous and nitrogen | Roadside fertilizers; leaching of organic matter (i.e. Twigs, leaves, grass clippings), ash from bush fires |
| Biological oxygen demand and chemical oxygen demand | Decay of organic matter (i.e. twigs, leaves, grass clippings) |
| Pesticides and herbicides | Roadside pesticides and herbicides |

| | |
|---|---|
| Heavy metals (Pb, Zn, Cu, Cd, Ni, Cr, Fe, Mn) | Vehicle oil, grease and petrol; fuel combustion; tyre, bearing and brake wear; corrosion of engine; roadside phosphate fertilizers; corrosion of road signs and barriers; leaching of bitumen and pavement materials |
| Platinum-group elements (Pt, Pd, Rh) | Release from autocatalysts |
| Hydrocarbons including oil, grease and surfactants | Vehicle leaks and emissions; spills |

(Lottermoser B, 2005)

**Environmental Framework**

The Alliance not only challenged the "value for money" impact of the brief, but also reviewed the nominated water quality objectives. The Water Quality Objectives (WQOs) defined by the Queensland Department of Environment and Resource Management (DERM) include numerous physico-chemical parameters, toxicants, litter/gross pollutants, riparian vegetation and habitat parameters. Not all parameters can be easily modelled and typically only Total Suspended Solids (TSS), Total Phosphorus (TP), Total Nitrogen (TN) and Gross Pollutants are modelled and evaluated during the conceptual design stages. Toxins such as heavy metals tend to "utilise sediment as the medium for transportation in runoff" (Wong et al, 2000). It is therefore expected that the majority of pollutants will be reduced if TSS, TP, TN and gross pollutants are reduced to acceptable levels. It is noted that particles and pollutants from vehicles and vehicle movements are expected to be fine. Wong et al quotes work undertaken by Colandini and Legret (1996) that found that that the association between heavy metals and particulates is distributed bi-modally with the highest concentrations of Cd, Cu, Pb and Zn being associated with sediment particles of less than 40 µm in size (Wong et al 2000). Specific treatment measures that target fine particles with a low hydraulic loading rate such as bioretention will be required within the adopted treatment train to ensure a reduction of targeted pollutants.

The Queensland Water Quality Guidelines (QWQG) – a document which "should be seen as an extension of the ANZECC 2000 Guidelines" and thus an extension of the EPP (Water) – advise that the WQOs presented under the EPP (Water) generally apply to flowing creeks and are "representative of waterway conditions under normal base flow regimes" (Environmental Science Division, 2006). Furthermore the QWQG states that the concentration targets "should generally be applied under normal base flow conditions" and that "under extreme high or low-flow conditions, guideline application requires careful consideration". It is therefore not appropriate to compare stormwater runoff from a development/motorway upgrade with the concentration objectives, which are more applicable to the baseline monitoring of a waterway. QWQG (2006) in conjunction with ANZECC (2000) advise that "this type of issue is best dealt with using load-based guidelines". Indeed, the adoption and compliance with concentration-based WQOs as identified by the EPP (Water) proved problematic and conservative when modelling stormwater run-off from the project site. The QWQG recommend the use of load-based reduction targets for reviewing stormwater discharges. The load-based pollutant reduction targets were adopted on the project as recommended in the South East Queensland Regional Plan 2005–2026 Implementation Guideline No. 7.

**Adopted Water Quality Targets**

DTMR confirmed that a risk-based approach to the selection of water quality treatment measures was required for the project in order to provide protection to receiving water bodies within the spatial constraints. The load-based pollutant reduction targets obtained from the SEQ Regional Plan 2008 were adopted for the project as follows:

- 90% reduction in Gross Pollutants (GP)
- 80% reduction in Total Suspended Solids (TSS)
- 60% reduction in Total Phosphorous (TP)
- 45% reduction in Total Nitrogen (TN)

**Water Quality Risk Assessment**

A water quality risk assessment was carried out to identify the expected type, load and potential impact of stormwater pollutants at the various discharge points.

The risk assessment was based on Australian Standard AS/NZ ISO 31000:2009 which highlights the need to identify and clarify the potential likelihood of the risk (i.e. how probable is the event) and the consequence of that event. By tabulating both of these parameters a risk matrix was formed that highlights key risks based on likelihood and the consequence.

The major source of pollutants including heavy metals is from vehicle movements. It is expected that road segments with lower predicted traffic volumes, as well as fewer turning/braking movements, lower runoff flows, and lower potential for litter-generation (away from public areas, industrial/commercial lots and car-parks), are likely to produce less pollutants. The water quality risk assessment was therefore based on these considerations.

The motorway was split up into water quality catchments based on the points of discharge. The need to treat runoff and the choice of device for any given catchment was determined through a risk matrix presented in Table 2.

It was expected that road catchments associated with 'Extreme' and 'High' risks required major treatment measures within an appropriate treatment train. Trash racks (used to collect gross pollutants) and vegetated swales (adopted to reduce coarse sediment) are the pre-treatment devices for the bioretention basins or wetlands that were used to reduce fine particulates. Road catchments associated with 'Low' risk were less critical and incorporated minor treatment measures such as swales and extended flow paths, wherever practicable. Catchments associated with 'Medium' risk were assessed on a case-by-case basis to determine the most appropriate type of treatment.

**SPILL CAPTURE RISK ASSESSMENT**

**Background**

The preceding section describes the assessment undertaken to determine the most effective and efficient means of protecting water quality from the diffuse (non-point) sources of pollutants that are generated from the operation of any highway. Another source of water quality impacts arises from discrete and relatively infrequent events such as vehicle accidents, whose timing and effects cannot be accurately determined, but must generally be evaluated by a stochastic (statistical) modelling process. For the IMU, an assessment was carried out to identify locations where the risks of hazardous material (HAZMAT) spills, particularly flammable hydrocarbons, were likely to be unacceptable and where spill capture devices would therefore be required to mitigate the risk.

As described in the previous section, designing the IMU stormwater system to be able to capture every possible spill type and size is not feasible within the space-constrained footprint available, and is not likely to be a cost effective approach. A more strategic approach to determine the type, size and placement of treatment systems needed to address spills was therefore required. The risk-based approach used is described in this section.

The main concerns associated with HAZMAT spills include contamination of the local watercourses and the risk of fire from flammable and combustible materials flowing down creeks and other drainage lines through residential and industrial areas.

In order to determine where spill capture devices were needed, the motorway was divided into a series of catchments, each comprising all the sections of road discharging to a single location.

In cases where it is not practical to undertake the additional modelling and calculations needed to estimate values for the environmental harm or the number of injuries or fatalities that might occur, or when the accuracy of the models and data available makes it unlikely that the additional effort would be justified, it is proposed that an estimate of the type of material involved and the size and frequency of spills may be used as a suitable and more readily calculated proxy in describing the likely magnitude of the consequences for any event. Whilst it is not possible from this measure of risk to infer directly the actual risk that might arise in terms of environmental harm (such as cleanup costs) or human impacts (such as fatalities), it does enable a comparison of risk scenarios, and in the context of water quality protection is particularly useful because the size of spills is relevant in deciding on the design and sizing of treatment or detention structures.

The risk assessment for each catchment therefore included an evaluation of:

- the frequency of spills, and
- the relative size and impacts of each spill (including the probability of ignition)

**Methodology**

The evaluation of frequencies and outcomes was completed using an event tree model that described the sequence of events leading from a vehicle accident to a spill of HAZMAT or fire. The model included factors describing the probability of various outcomes from each initiating event calculated from predicted traffic volumes, the types of vehicles and accident rates which were based on statistical data gathered for the Ipswich Motorway, and from various Australian and international sources. Where possible, these factors were specific to each section of road in the network. The results for all sections of road reporting to a particular discharge point were summed to calculate the overall risk for that catchment. It must still be remembered that because of the non-linear relationships between spill size and impact, many events with a minor consequence are unlikely to result in the same level of risk as a few events with a much greater consequence, even if the aggregate size of the spills is similar over any time frame. For WSHD, the frequency of spills exceeding a particular size is especially relevant to the sizing of detention systems.

There are no generally accepted criteria known that prescribe a level of protection that is suitable or necessary for any particular size and frequency of HAZMAT spills for a road such as the IMU. However, the method described here does provide the ability to rank each catchment area in terms of spill risk, and thus to prioritise catchments that are most at risk. It also allows design teams to make an informed decision, in collaboration with stakeholders, on what level of protection will normally be provided at any given level of risk. In addition to the predicted size and frequency of spills, these decisions need to consider the impacted community and environmental values.

The assumption was made early in the project (based on experience and empirical observation) that fuel spills would probably pose the highest risk to the environment and also in causing fires. It was expected that the HAZMATS transported in the largest quantities would be Class 3 Dangerous Goods (DG) (i.e. flammable liquid, typically petrol) and combustible liquids (typically diesel) and that these materials would therefore be involved in the majority of accidents involving a significant quantity of dangerous goods. If the assumption is correct, some simplification of the modelling is possible.

The approach taken to the assessment was as follows:

- Estimate what proportion of all dangerous goods likely to be transported on the motorway falls within each class of interest (flammable, combustible, corrosive etc).
- Verify that Class 3 flammable liquids and combustible liquids are likely to form the largest class of materials of interest to the study.
- Make an estimate of the total number of dangerous goods vehicles currently travelling on the motorway
- Forecast the total number of dangerous goods vehicles that will travel in the future on the motorway
- Estimate the current and likely future accident rates for dangerous goods vehicles following the motorway upgrade.
- Estimate the number of dangerous goods vehicles likely to be involved in accidents in the future
- Estimate the number of accidents that result in spills of dangerous goods of relevant classes, the size of each spill, and the number of spills that are likely to ignite.
- Total the number of accidents of each type, in various size ranges, for each drainage catchment along the upgraded motorway.

In order to estimate the size and frequency of each type of spill, an event tree model was created using the Palisade PrecisionTree® software add-in for Excel. Example sections of the tree are shown in Figures 3 and 4. The steps involved in the event tree model are as follows.

- Consider only accidents involving commercial vehicles (CVs).
- Is the CV a goods CV or non-goods CV (e.g. bus, taxi, service vehicle)?
- If a goods CV, is it a light CV, rigid truck or articulated truck?
- For each class of vehicle, is it carrying HAZMATs?
- If it is carrying HAZMATS, does the accident result in a leak or spill?
- If it leaks or spills, is the spilled material petrol, diesel or some other HAZMAT?
- For each type of material spilled, what is the likely size of the spill, based on the size/type of CV involved?

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An extended model also asked the questions:

- For each size of spill of a relevant hazmat (flammable and combustible), does the spill ignite immediately (generally near the accident site)?
- If ignition is not immediate, is there delayed ignition (which may be at a distance from the accident site)?

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The result produced by the event tree is a series of probabilities that any accident involving a CV results in a spill of a hazmat of interest of a particular size, and also that the spill ignites (either immediately or after some delay). Summing the probabilities of all the spills of a particular material and size across all vehicle types, and of all fires resulting from spills of a particular size across all materials and vehicle types, provides an overall probability of particular sized spills and fires resulting from any accident involving a CV. Multiplying by the estimated frequency of CV accidents for any section of road gives an estimate of the number and size of spills and fires.

For the IMU project, vehicles were considered in three classes: light CV, rigid truck and articulated truck (including B-doubles), with an assumed maximum load capacity for each class. Based on the maximum load size, up to four spill size categories were considered for each vehicle type: minor (< 100 L); moderate (100-1000 L); large (1,000-10,000 L); and very large (>10,000 L).

A significant problem with many risk assessments is access to current, relevant, reliable data from which to derive appropriate estimates of probabilities, frequencies and consequences to input to any model. For this assessment, data was drawn from:

- United States (US) Pipeline and Hazardous Materials Safety Administration- Hazardous Materials Incident Reporting System (HMIRS). (https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/)
- American Bureau of Statistics (ABS) Survey of Motor Vehicle Use (Catalogue No. 9208.0, October 2004) showing total km travelled and total tonne-km travelled by various types of vehicle)
- ABS Survey of Motor Vehicle Use (Catalogue No. 9210.0.55.001) Table 20, showing total tonnes carried by State/territory of registration, by type of vehicle, by commodity carried (2002)
- Queensland Department of Transport and Main Roads accident statistics for the Ipswich Motorway 2001-2006, by heavy vehicle type.
- Traffic counts for the Ipswich motorway 2001-2006
- Annual Average Daily Traffic (AADT) traffic forecast calculations for design year 2021 for all IMU links, including on- and off-ramps, with estimated AM and PM peaks.

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The HMIRS database provides extensive data on real crashes involving HAZMATS from the USA. It is assumed that transport of HAZMATS in the USA and Australia are generally similar. Data was analysed for the 10 years to 2008 to determine the typical sizes of loads and resulting spills (if any), the types of hazmat carried, types of crash, and the consequences of the accident, i.e. environmental harm, fire, explosion, injuries, fatalities etc.

An analysis of the top 85% (2373) of the 2806 incidents classed by United Nations (UN) dangerous goods number shows that:

- 827 (35%) were classed as flammable (Class 3, e.g. petrol)
- 807 (34%) were classed as combustible (e.g. diesel)
- 512 (22%) were corrosives (e.g. acid)
- 61 (3%) were class 2 flammable gases (e.g. Liquefied Petroleum Gas (LPG))
- 39 (2%) were oxidising substances (e.g. peroxides, ammonium nitrate).
- 126 (5%) were for “miscellaneous risk” substances, including environmentally hazardous substances (56).

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These results confirmed the assumption that flammable and combustible goods are likely to be the principal source of risk from HAZMAT spills.

Based on this data, the breakdown of HAZMATS used in the model was 35% for both flammable and combustible liquids, and 30% for other classes.

Traffic counts for various road links in the existing Ipswich Motorway provided a breakdown of the number of vehicles in each vehicle class (light CVs, rigid trucks and articulated trucks), and the fraction of each class that are goods vehicles. These data allow the calculation of the fraction of all commercial vehicles that are goods vehicles. ABS figures suggest that on average, 24% of CVs are goods vehicles. The calculated numbers for the motorway are consistent with this value. The percentage of each class of goods vehicle carrying HAZMATS was taken from ABS statistics for Queensland: 2% of light CVs, 7% of rigid trucks, and 16% of articulated trucks.

Two other pieces of data are needed to evaluate the event tree model. The probability of a spill being in each spill size category was estimated from vehicle size and an analysis of the HMIRS data. The probability of immediate or delayed ignition of a flammable materials spill has been estimated using correlations developed by Ronza et al (2007), who have undertaken an extensive analysis of the HMIRS and other spill data.

Finally, the probabilities of spills and fires generated by the event tree model were multiplied by the length of the road section, the predicted traffic count (AADT), and the predicted accident rate per kilometer travelled for the upgraded motorway to obtain the predicted number of accidents of CVs, and the number of spills and fires in each size range as a frequency.

An accident rate of 18 accidents per hundred million vehicle km travelled (18 per 100MVKT), was assumed as a typical accident rate for a modern urban motorway designed to good standards.

**Results**

An example of the results of running the model for a section of motorway (IMU Road zone E9, Catchment ID 108A) is provided in the following Table 3:

***Table 3: Example of spill probability***

| Parameter | Value | Units |
|---|---|---|
| Road length | 480 | M |
| Forecast AADT | 56719 | Vehicles/d |
| Forecast CVs | 15889 | Vehicles/d |
| Forecast DG vehicles | 986 | Vehicles/d |
| Total accidents | 1.79 | Accidents/annum |
| **Precicted recurrence of:** | | |
| HAZMAT spills (all classes) | 245 | Years |
| Very large HAZMAT spills (all classes) | 545 | Years |
| Flammable spills | 351 | Years |
| Very large spill fires | 2562 | Years |

These results were aggregated with other sections of road within the same catchment to determine the total number of spills and fires of various sizes.

To assess the relative impacts of a spill, the following factors were considered:

- The proximity of discharge to natural waterways/ public areas/ properties and the time available to respond
- The sensitivity of the receiving environment (i.e. proximity to a natural waterway or habitat downstream)
- The size of the spill

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In practice, there was little significant variation in the relative proportions of the three vehicle size classes across the whole road network. The distribution of spill sizes was therefore relatively constant, and the total number of spills could be used as a reasonable representation of the frequency of events, with the proximity of the stormwater discharge point to sensitive waterways as the principal measure of the consequence.
The risk ranking matrix used to assess spill risk for any given catchment is shown in Table 3. It was expected that road catchments associated with 'Extreme' and 'High' risks required dedicated spill capture, road catchments associated with 'Low' risk were deemed less critical and where practical incorporated secondary spill capture aids such as extended flow paths or valves allowing for spill containment in the

longitudinal pipe network. Catchments associated with 'Medium' risk were assessed on a case-by-case basis to determine the most appropriate and feasible type of treatment.

**DISCUSSION**

The adopted risk based approach to water quality and spill capture was based on current best practices as outlined in AS/NZ 31000-2009. The approach reviewed the expected pollutants for each component, and then estimated the likelihood and the consequence of polluted discharge. The likelihood and consequence for both approaches were different, however both could be plotted in a matrix to quantify the risk from Extreme to Low to rank each catchment and highlight those road segments and receiving catchments that required a high level of treatment.

The water quality assessment utilised easily available data to identify the likelihood of pollution such as vehicle numbers, turning movements etc for water quality based on guidance from references such as Wong et al that highlighted that pollutants can be linked to traffic volumes. Although the relative values are subjective and can be changed on a project by project basis, the idea that water quality is linked to vehicle numbers seems appear sound.

The catchments were broken up into defined road segments with expected traffic volumes based on detailed transport modelling to highlight key risk areas. This was ground truthed with discussions with DTMR water quality and maintenance staff to confirm that the results seemed realistic. The choices of numeric cut-off values for vehicle numbers was arbitrary and as such is subjective, however the assumed values fall within the ranges of volumes for the site and are deemed to be appropriate for this study

Other key criteria to determine likelihood or poor water quality included land use such as car parks and industrial/commercial areas where litter and gross pollutants might be expected to collect. The size of the catchment is also expected to be significant with smaller areas having less of an ability to generate pollutants compared to larger catchments.

The impact of the expected pollution was based on proximity to a water course and the relative environmental significance of the receiving environment. If the receiving area was a natural wetland or received flow directly from the motorway, then it automatically received an extreme ratting. In areas where the discharge had a relatively long overland flow path, the weighting was reduced as it was expected that additional measures could be implemented in the time it took the flow to reach the waterway, or that the natural processes of the creek and channel systems would assist in reducing pollutants prior to discharge. Although this is not ideal, it was recognised that the local gullies and flow paths had much lower environmental values compared with the major flow paths. Once the selection of treatment measures was completed a MUSIC analysis of the adopted treatment measures was undertaken to determine if the load based objectives were met. In catchments with an Extreme Risk, the adopted treatment measures were found to meet the required reduction targets. In catchments with a low risk it was not uncommon that not all parameters were met. This was deemed acceptable as the risk management process highlighted the areas that required a high level of treatment, and it was provided for these areas.

The spill capture process was more deterministic adopting "typical" crash statistic data and looking for trends that could be modelled with the decision based software. Again, the modelled data was based on information of key parameters that are well known – traffic volumes and expected break down of heavy vehicles. Excellent data from the US Department of Transport (DOT) enabled an analysis of spill types to get a feel for expected spills and the risk of additional consequences such as fire and explosion. This data is not available for Australian mtorways, however the relative breakdown of spills is expected to be similar to the US.

The use of a this management approach to identify risks and appropriate mitigation measures is not new, however the adoption of such a procedure to provide "value for money" and reduce capital, operation and maintenance costs in this context may be. Coupled with the rigorous analysis of expected spills based on known local traffic data and collected information from the US, the adopted methodology for water quality is a first for DTMR in Queensland.

The results of the analysis were scrutinised by Alliance reviewers, verifiers and DTMR. Although all parties agreed with the model inputs and each step was transparent, additional treatment measures were incorporated in some areas to ensure the protection of downstream environments. Although this may seem to be a rejection of the adopted methodology, it highlights that "groundtruthing" model outputs is advisable, and that decisions can be made after the analysis to cater for individual perceptions or politically sensitive areas, and ensure that key design parameters such as manitenance access are considered.

## CONCLUSION

The following conclusions were reached during the water quality assessment for the project.

1. **Original brief** – The original brief was extremely conservative and would have resulted in an effective stormwater management treatment strategy, however, it would not have been effcient and the capital, operation and maintenance costs would have been high.
2. **Risk based approach** – A risk based approach utilising a recognised framework can "rank" catchments and indicate where the greatest impact can occur. Focusing on these areas is expected to limit costs and focus funds where the greatest benefit can be realised.
3. **Groundtruthing** – Although the framework is based on best practice, the results of the assesment should be reviewed to ensure they appear sensible.
4. **Consultation** – Consultation with key stakeholders such as operators and maintenance staff highlights the need to fully understand the system and the impacts that redundant treatment measures may have.

This investigation has shown that significant savings can be achieved through the implementation of a risk based approach to water quality. Successful implementation of the adopted approach requires a good understanding of the poential impacts on downstream users and and the key contributers to risk.

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***Figure 2: Project Alignment***

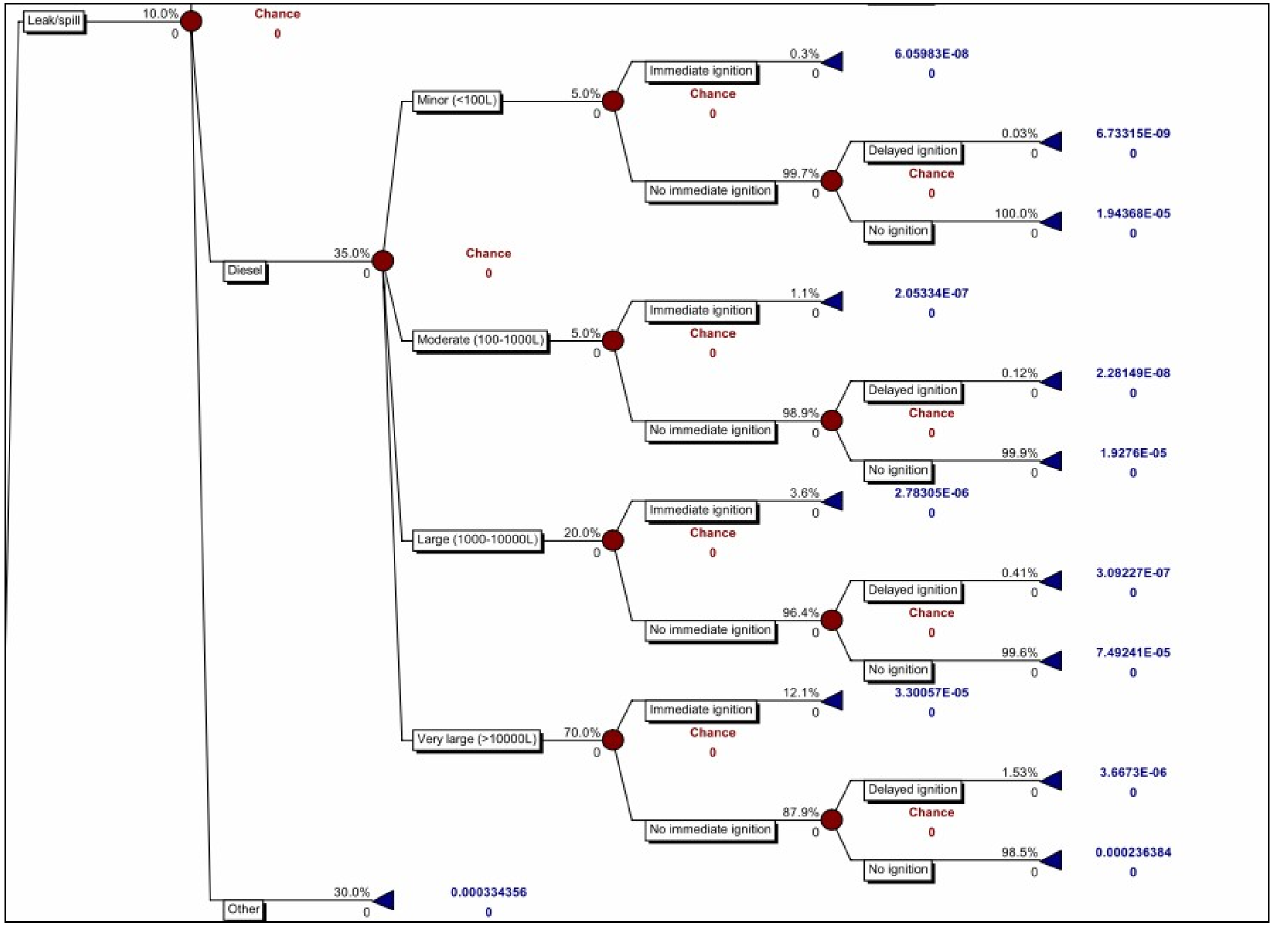


***Figure 3: Example of part of the event tree (Articulated truck, ignition of diesel)***

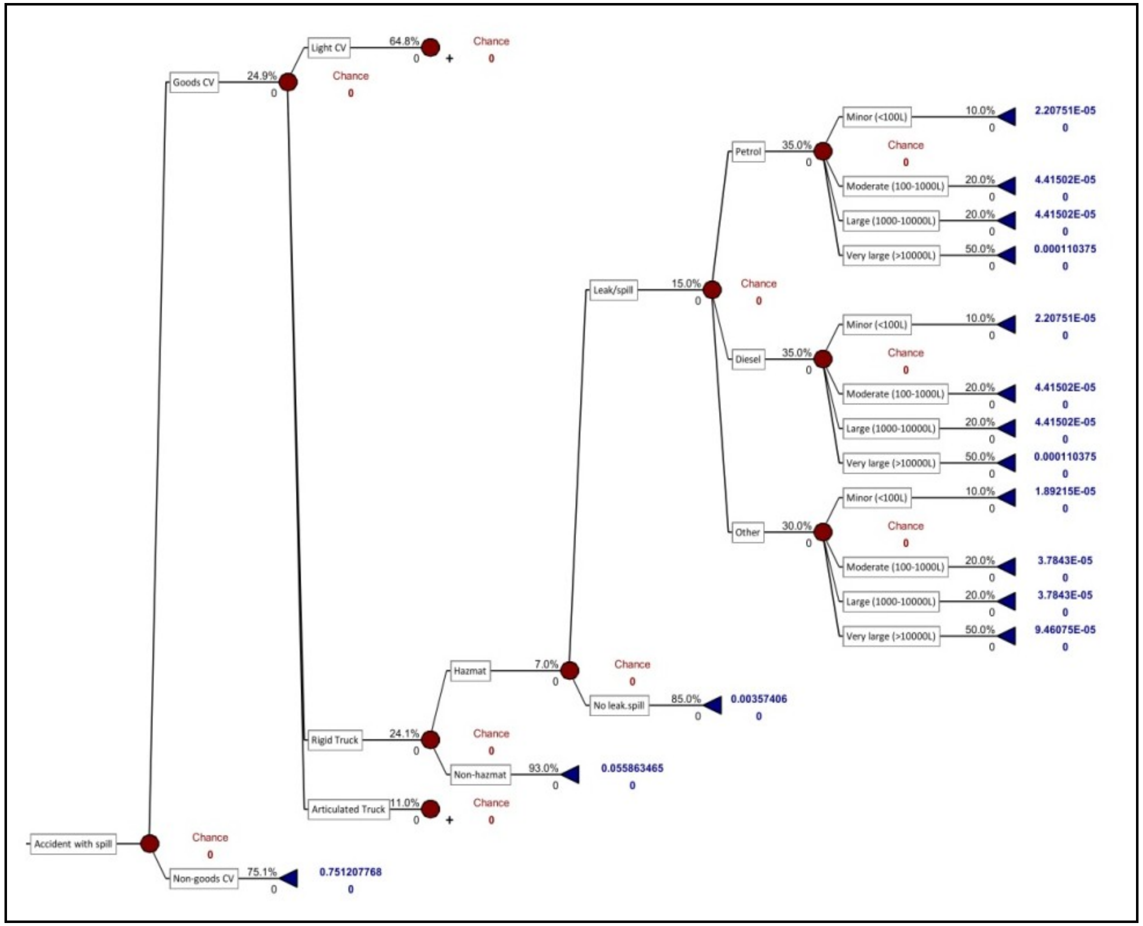


***Figure 4: Example of part of the event tree (Rigid truck, spill of HAZMAT)***

***Table 2: Water Quality Risk Assessment Matrix***

| LIKELIHOOD of pollution | Criteria* | RATING | **IMPACT** (Discharge Proximity to a Waterway) | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Insignificant** (2km+) | **Minor** (500m-2km) | **Moderate** (200m-500m) | **Major** (0-200m) | **Extreme** (Directly into a waterway) |
| | • Traffic Volume (AADT): 60,000+ | **Extreme** | M | H | H | E | E |
| | • Traffic Volume (AADT): 30,000-60,000<br>• Adjacent to a significant car park, industrial/ commercial area<br>• Catchment >2ha | **High** | M | M | H | H | E |
| | • Traffic Volume (AADT): 5,000- 30,000<br>• Adjacent to a public area<br>• Catchment >1ha & ≤2ha<br>• Intersection/ Lights | **Med** | M | M | M | H | H |
| | • Traffic Volume (AADT): 1,000- 5,000<br>• Catchment >0.5ha & ≤1ha | **Low** | L | M | M | M | H |
| | • Traffic Volume (AADT): <1,000<br>• Catchment ≤ 0.5ha | **Very Low** | L | L | M | M | M |

*Note: In order to determine the Likelihood rating for any given catchment select the highest rating with at least one criterion matched by the subject catchment.

Legend

| | |
|---|---|
| E | Extreme |
| H | High |
| M | Medium |
| L | Low |

***Table 3 Spill Risk Assessment Matrix***

| | | | **IMPACT** | | | |
|---|---|---|---|---|---|---|
| | **CRITERIA** | | REMOTE<br><br>(Discharge point >1km from a waterway) | INTERMEDIATE<br><br>(Discharge point 200m-1km from a waterway) | CLOSE PROXIMITY<br><br>(Discharge point <200m from a waterway) | MAJOR CONCERN<br><br>(Discharging into an environmentally sensitive habitat/ waterway or directly to private property) |
| | | **RATING** | **MINOR** | **MODERATE** | **MAJOR** | **EXTREME** |
| **LIKELIHOOD of spill** | More frequent than 1 in 200yrs | **HIGH** | MED | HIGH | HIGH | EXTREME |
| | More frequent than 1 in 1000yrs | **MED** | LOW | MED | MED | HIGH |
| | Less frequent than 1 in 1000yrs | **LOW** | LOW | LOW | LOW | MED |