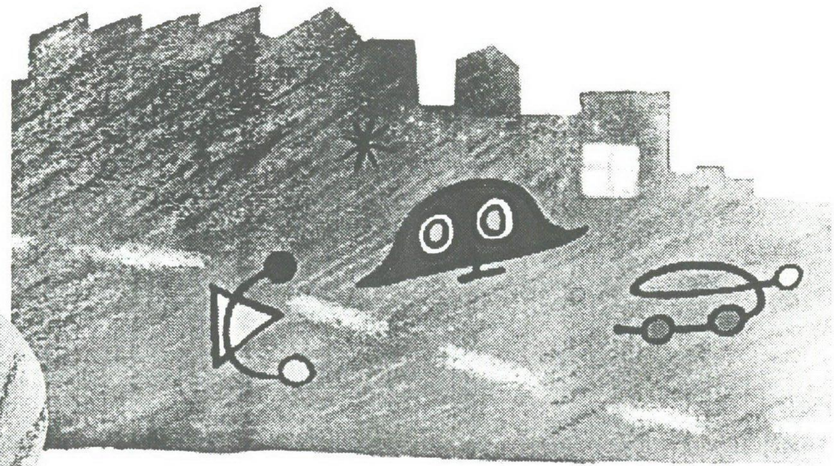

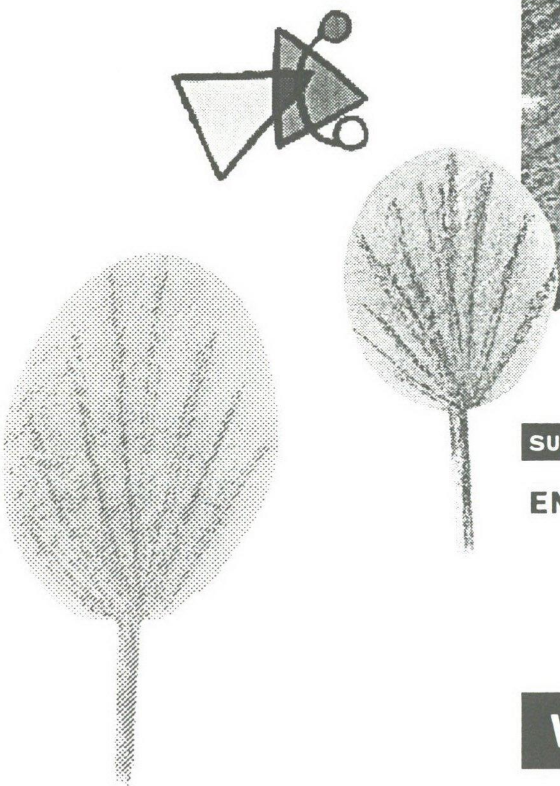

SUPPLEMENT TO M5 EAST MOTORWAY

ENVIRONMENTAL IMPACT STATEMENT

WORKING PAPERS

VOLUME 2 OF 3

1996

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Better Roads.Safer Roads.
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Note: The proposal assessed in the Supplement to the 1994 M5 East EIS is referred to in these working papers variously as: Alternative H, the Southern Variation, the proposal, the preferred alternative (or option).

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M5 MOTORWAY EAST: TRANSPORT OF DANGEROUS GOODS

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Prepared for the Roads and Traffic Authority Sydney Region

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ROADS AND TRAFFIC AUTHORITY
SYDNEY REGION

M5 MOTORWAY EAST
TRANSPORT OF DANGEROUS GOODS

AUGUST 1995

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CONTENTS

EXECUTIVE SUMMARY

S1. INTRODUCTION

S1.1 Background

The M5 East EIS (Manidis, 1994) addressed conceptually the issue of dangerous goods transport through tunnels. The M5 East has been developed as a truck route consistent with the Integrated Transport Strategy, and, as a general principle, should provide facilities for all trucks in order to relieve surrounding suburbs of unnecessary intrusion by heavy vehicles.

There are substantial volumes of Dangerous Goods (DG) transported by road from the Central Industrial Area (CIA) and Port Botany to areas of Sydney and more distant destinations, which could use the new section of the M5 Motorway. Currently these vehicles use a number of routes which travel through industrial, commercial and residential areas. There is a level of risk associated with this transportation. There is risk to people who live, work, attend school, visit shopping centres etc. along these routes and to other road users. There is also some level of risk to the biophysical environment and to property including the transport infrastructure.

The construction of the eastern section of the M5 Motorway creates an opportunity to change the routes used by the Dangerous Goods (DG) traffic. The point at issue is whether permitting the use of the M5 between Mascot and Beverly Hills for DG transportation, with or without partial restriction of load type, time etc, would result in a lower level of risk overall and whether the resultant risk levels would satisfy any risk acceptability criteria which may be relevant.

The principal concern in this regard is risk to road users and adjacent residents arising from possible incidents along the M5 East Motorway, including the Tunnels, and along the alternative routes.

S1.2 Objectives of the Study

The aim of this study was to provide information which will form the basis for a firm decision as to whether or not dangerous goods (DG) should be permitted to pass through the M5 Tunnels.

The evaluation and analysis included the assessment of the route along Stoney Creek Road, to the south of the M5 East Motorway, and a route through Marrickville and along Canterbury road to the north (**Figure 1.1**).

S1.3 Study Approach

The work undertaken for study included:

- A quantitative description, analysis and evaluation of the current and likely future cumulative traffic situation in relation to the movements of tankers and flat top trucks carrying dangerous goods likely to use the relevant routes.

- Identification of the hazardous incident potential for different loads on each of the routes.

- Analysis of the consequences of such incidents in terms of human fatality and injury for other road users and people in surrounding land uses. The potential for damage to the transport infrastructure (principally the tunnel) and consequential traffic disruption during the repair period were covered. The comparative potential for harm to the biophysical environment was also assessed.

- Analysis of the frequencies of incidents and of the presence of potentially exposed populations.

- Estimation of societal and individual risk as appropriate.

- Consideration of the frequency of hazardous materials incidents resulting in major damage to infrastructure and likely consequences and time taken to repair or reinstate.

- Identification of opportunities for risk reduction (including physical design features of tunnel and operational controls).

- Formulation of recommendations on what DG loads should be permitted to use the M5 East with the existing design, what controls and design features should apply, and what further. work should be undertaken.

S2 BASIS FOR EVALUATION

The Department of Urban Affairs and Planning has developed and implemented a comprehensive approach to land use safety planning based on the assessment and management of risk. This approach involves systematic hazard analysis and risk quantification. It is applied to transportation as well as fixed sites and is particularly useful for the identification of least risk options and cost effective risk reduction measures. In the transport case, it is particularly effective in identifying least risk routes. The principles and criteria included in the latest DoP Draft Guidelines (issued early in 1994) for Route Selection formed the basis of the assessment of the routes in terms of the estimated risks and other relevant factors.

The emphasis in this Study was on a comparative risk assessment, rather than on absolute levels of risk along the routes. While individual risk calculations may be appropriate in some circumstances, a societal risk approach is generally more appropriate in the transport risk assessment. It is appropriate and essential in this case to include the population of other road users in the societal risk calculation.

The road classification for each of the routes is shown on **Figure 2.1**. Each route was divided into sections to enable their detailed analysis. The sections for the three routes are also illustrated in **Figure 2.1**. The number of lanes and traffic signal locations along the three routes are illustrated in **Figure 2.2**.

S3. DATA COLLECTION AND SURVEYS

S3.1 Review of Previous Reports

Previous reports and studies relevant to the DG transport in the area and the M5 were reviewed. The review highlighted the limitations of the available data and limited extent of previous work undertaken in quantified risk assessment of hazardous materials transport through tunnels - particularly work attempting to deal with the real design features tunnels instead of simplified models.

The information included in the M5 Motorway East Environmental Impact Statement (Manidis, 1994).and supporting documents was used as the basis for this study.

S3.2 Routes and Traffic Information

The available daily volumes along the Northern and Southern routes are shown on **Figure 3.1**. Existing AM and PM peak hour traffic flows shown on **Figure 3.2.**

All vehicles carrying dangerous goods along Canterbury Road, and Stoney Creek Road were recorded by type of vehicle and class of dangerous goods. About 70 percent of all movements take place during the day between 6.0am and 6.0pm. The largest concentration of Dangerous Goods vehicles, along the corridor, appear to occur between 1.00pm and 3.00pm.

The existing AM and PM peak travel speeds are also shown in **Figures 3.3a and 3.3b** respectively. These speeds are for the peak direction.

Land use along the alternate routes is shown in **Figure 3.4.**

S3.3 Road Crashes

The Northern route has about twice the number of crashes (491) as the Southern route (232). Truck crashes represent about 7% of crashes on the Northern route and 10% of crashes on the Southern route. The data on crashes on the M5 Motorway West was used to determine the probable crash rates on the M5 Motorway East. Truck crashes accounted for about 6% of the total crashes. along this route.

S4. TRAFFIC PATTERNS OF DANGEROUS GOODS

On a typical weekday vehicles carrying dangerous goods accounts for about 0.30% of all vehicles. It was then found that for an average day over a full week, vehicles carrying dangerous goods accounts for about 0.24% of all vehicles.

AM peak hourly traffic volumes projections, for the years 1996, 2001 and 2011, included in the EIS were used. This information was then factorised to determine the AADT Volumes for each section of the three routes.

The annual potential number of Dangerous Goods are summarised in Table S1 for the years 1996, 2001 and 2011.

TABLE S1
PROJECTED VOLUMES OF DANGEROUS GOODS VEHICLES
Yearly

SCREENLINE *	1996	2001	2011
East of Bexley rd & Preddys Rd			
Canterbury Rd (N1 to N20)	15632	16597	19663
Stoney Creek Rd (S1 to S9)	68965	73222	86753
TOTAL	**84597**	**89819**	**106416**
M5 Motorway (M1 to M7)	84597	89819	106416
West of Bexley rd & Preddys Rd			
Canterbury Rd (N21 to N25)	16941	18170	20513
Stoney Creek Rd (S11 to S13)	58863	63136	71275
TOTAL	**75804**	**81306**	**91788**
M5 Motorway (M8 & M9)	75804	81306	91788

* refer to Figure 2.1 for route sections

S5. OVERALL EVALUATION OF ALTERNATIVE ROUTES

S5.1 Road and Traffic Factors

The road and traffic factors along the three routes are summarised in **Table S2.** From a traffic perspective that the M5 East Motorway route is the most preferred route between the M5 West Motorway, at King Georges Road, and the Qantas Drive /O'Riordan Street /Joyce Drive intersection. The M5 East Motorway route has shorter route length and higher average travel speeds, and thus shorter travel times than either the Southern or Northern routes.

The M5 East Motorway will also provide the best Level of Service. Whilst the Southern Route will experienced the lowest M.Veh.kms of travel. This is largely due to the availability of the faster route along the M5 East Motorway which will thus attract more traffic.

S5.2 Road Safety Factors

The road safety factors along the three routes are summarised in **Table S3.** On all account the M5 East Motorway will provide the safest route by far in terms of potential crashes.

TABLE S2
TRAFFIC SERVICE FACTORS

	M5 East Motorway		Southern Route		Northern Route	
Route Length km	12.03	✔✔	12.62	✔	16.77	-
Travel Time & Speeds						
Average Speed km/h AM peak	48	✔✔	22	✔	22	✔
km/h PM peak	50	✔✔	29	✔	23	-
% of Route with Speeds < 25 km/h AM	2	✔✔	28	✔	53	-
PM	2	✔✔	21	✔	43	-
Average Travel Time mins AM peak	15	✔✔	34	✔	47	-
mins PM peak	14	✔✔	26	✔	45	-
Travel Parameter						
Yearly M Veh km travel 1996	203.94	✔	166.65	✔✔	257.91	-
2001	226.09	✔	200.43	✔✔	269.44	-
2011	280.74	✔	263.42	✔✔	302.53	-
Level of Service						
% of Route with LoS F East/b 1996	32%	✔✔	40%	✔	72%	-
West/b 1996	0	✔✔	0	✔✔	4%	-
% of Route with LoS F East/b 2001	34%	✔✔	47%	✔	72%	-
West/b 2001	0	✔✔	0	✔✔	4%	-
% of Route with LoS F East/b 2011	34%	✔✔	59%	✔	83%	-
West/b 2011	0	✔✔	10	✔	9%	-
Number of Traffic Signals	7	✔✔	27	✔	48	-

✔✔ = Preferred *✔ = Alternative*

TABLE S3
ROAD SAFETY FACTORS

	M5 East Motorway		Southern Route		Northern Route	
Crash Rates						
All Crashes/M.veh kms	0.58	✔✔	1.36	✔	2.1	
Truck Crashes/M.veh.kms	0.06	✔✔	0.14	✔	0.15	
Truck Crashes/M.trucks.kms	0.87	✔✔	2.65	✔	2.94	
Predicted Crashes						
all Vehicles 1996	117	✔✔	198	✔	539	-
Trucks 1996	12	✔✔	17	✔	34	-
all Vehicles 2001	133	✔✔	238	✔	561	-
Trucks 2001	13	✔✔	22	✔	37	-
all Vehicles 2011	171	✔✔	306	✔	631	-
Trucks 2011	16	✔✔	29	✔	41	-

✔✔ = Preferred *✔ = Alternative*

S5.3 Environmental and Land Use Factors

The M5 East Motorway route has the least effect on residential and commercial/industrial frontage as noted in **Table S4**.

TABLE S4
LAND USE FACTORS

	M5 East Motorway		Southern Route		Northern Route	
Population						
Land Use Population Density	1,445	✔✔	2,943	✔	3,276	-
Number School Pupils	0	✔✔	4,161	-	3,919	✔
Number Hospital Beds	0	✔✔	0	✔✔	156	
Land Use						
% of Route Residential	19.6%	✔✔	52.6%	-	43.1%	✔
length of route Residential	2.36	✔✔	6.64	✔	7.23	-
% of Route Schools	0.0%	✔✔	4.5%	-	2.8%	✔
% of Route Hospitals	0.0%	✔✔	0.0%	✔✔	0.3%	-
% of Route Commercial/Industrial	14.4%	✔	8.4%	✔✔	51.7%	-
length of route Commercial/Industrial	1.73	✔	1.06	✔✔	8.67	
% of Route Open Space	38.9	✔✔	8.6	✔	2.1	-
Works and Developments Factors		✔✔		✔		-

✔✔ = Preferred *✔ = Alternative*

S5.4 Hazards and Risk Factors

The methodology for the hazard analysis and risk assessment component of the study is described in **Section 6.1**. The analysis, described in **Section 6.2,** was undertaken by Dangerous Goods Class, taking account of load types (bulk or packaged) and of the specific open air and tunnel conditions applying. For the analysis of the cases in the tunnel, it was necessary to adopt an assumed tunnel design following as closely as possible the design characteristics outlined in EIS but supplementing them as necessary where they were not specific.

The first step in the analysis, hazard identification process, involved examining the potential for loads of the types known or likely to be carried along the subject routes to be involved in incidents which result in human fatality or injury, damage to transport infrastructure or harm to the biophysical environment. This analysis eliminated Class 6.2, Class 7 and Class 9 from further consideration. For the other classes, representative materials were selected and incident scenarios developed using event trees.

The consequences of these incidents were then analysed and consequence distances and footprints estimated. The consequence analysis showed that incidents involving Class 6 and Class 8 loads would not result in relevant fatality outcomes and would therefore not contribute to fatality risk. The remaining DG classes were carried forward for the frequency analysis. Property damage consequences were also analysed and for a number of classes a significant potential for major damage to the tunnel structure or systems was found.

The frequency analysis drew on local, NSW, Australian and overseas data sources as appropriate supplemented by judgement where necessary. Both the frequency analysis and the consequence analysis used conservative numbers and analytical approaches with due regard to the sensitivity of the analysis to values and assumptions which might tend to favour the open air or the tunnel cases.

The population densities and presence for both road users and people on surrounding lands were factored into the analysis and the consequence and frequency results combined to generate societal risk F-N (frequency and fatality number) pairs. These F-N pairs were plotted as curves enabling comparison of the societal risk profile for each of the remaining DG classes and the DG movements overall for each of the three routes and for the alternative routes combined against the M5 East.

The differences in the risk levels were found to be principally driven by the tunnel section of the M5. For the open air sections, the M5 would clearly be the preferred route as it is better separated from other land uses and is expected to have a significantly lower crash rate than the other urban arterial roads.

The effect of the tunnel environment on hazardous incident frequency and severity is not consistent across classes. Accordingly the results do not show a consistent pattern which might justify a blanket decision to permit or to prohibit DG's. The following conclusions can however be reached on a class by class basis.

(i) Risk to People

For the assumed tunnel design, the outcomes of the study indicate that in terms of people:

- It would be preferable to transport Class 1 DG's via the M5. If they were to be moved only at night then this conclusion would be more strongly supported.
- The M5 would not be the least risk route for Class 2.1's having due regard to the likely effects of changes in assumptions on heat radiation consequence modelling.
- For Class 2.2 and 2.3 materials neither the M5 nor alternative routes can be identified as clearly preferable on risk grounds.
- For Class 3, the M5 is not the least risk route once the revised heat radiation fatality assumption is used.
- The M5 would not be the least risk route for Class 4's, particularly once the revised heat radiation fatality assumption is used .
- The M5 would not be the least risk route for Class 5's once the revised heat radiation fatality assumption is used.
- There would appear to be no impediment on fatality risk grounds to Class 6 loads using the M5/tunnel. (This may not be the case if injury risk were to be taken into account.)

- There would be no impediment on fatality or injury risk grounds to Class 7 loads using the tunnel (subject to route specific assessment for any major loads in line with regulations.)

- There would be no impediment on fatality risk grounds to Class 8 loads using the M5/tunnel. If injury risk were to be taken into account, however, it is considered likely that the open air routes would prove to be preferable.

- No conclusions can be reached on Class 9 materials or mixed loads as the findings for the separate classes are not uniform.

- For DG's taken as a whole the M5 route is the least risk route for parts of the N range only and is substantially higher in risk for other parts. Neither the M5 nor the alternative routes could therefore be clearly said to be preferable on risk grounds.

- If DG loads are permitted to use the tunnel there would be credible scenarios with potential for substantial damage which would require prolonged closure.

The preliminary investigation of possible design modifications to the tunnel indicates that such changes should be able to change the risk profile for all DG Classes such that the M5 would become the least risk route. It would be expected that the measures put forward in **Section 8** of the report would achieve this end. It would however be appropriate for the effect of these measures on risk levels to be assessed once design concepts have been worked up and again on the final design.

These conclusions are specific to this case with its specific DG traffic volumes , DG load mix, tunnel length and drainage and ventilation system, traffic density, crash rates etc. and to the population density, crash rates etc. of the alternative routes. They should not be applied to any other tunnel case.

(ii) Property Damage

The analysis of property damage was essentially limited to consideration of damage to the tunnel structure and systems as this was seen as the area most relevant. In the tunnel the extent of direct fire involvement and the heat fluxes received would be such that more extensive involvement of cars and trucks could be expected. The contribution of these secondary fires to the duration of the event and consequently to the extent and severity of structural damage could well be significant and has been considered in developing the conclusions on tunnel damage below.

The consequences in terms of losses of motor vehicles and their loads has not been quantified or analysed as it was not considered central to the objectives of the study. It should however be noted that this effect could add substantially to the overall cost of incidents in the tunnel and would be expected to be much more significant for the tunnel than for the open air sections. If it were to be determined that such potential losses should be factored in to the equation, the risk and dollar cost consequences could be readily estimated in a separate analysis.

For the assumed tunnel design, the outcomes of the study indicate that several incident outcomes would have significant potential to damage the tunnel structure, fittings and operating systems:

These events could result in tunnel closures for repairs for periods of up to 9 months. Fire events involving flammable liquids, the largest class, could involve closures of up to 6 months. Detailed consideration of this aspect was beyond the scope of this study but could be incorporated in the second phase of the work.

S5.5 Operating Cost Factors

Based on route length and travel time the comparative cost of using the routes has been calculated based on $60 per hour, being a representative average vehicle operating cost. For the M5 East Motorway route an option of $4 toll per truck has also been assumed. The comparative costs of using the routes is shown in **Table S5.** Including a Toll, the M5 East Motorway provides the most economical route between Port Botany and the M5 west Motorway.

TABLE S5
OPERATING COSTS FACTORS

	M5 East Motorway		Southern Route		Northern Route	
Operating Cost Factors AM peak	$15	✔✔	$34	✔	$47	-
PM peak	$14	✔✔	$26	✔	$45	-
AM peak + $4 t	$19	✔✔	$34	✔	$47	-
PM peak + $4 t	$18	✔✔	$26	✔	$45	-

✔✔ = Preferred *✔ = Alternative*

S6 CONCLUSIONS

The overall assessment of the alternative DG transport route has found that on all grounds other than risk the M5 route is superior. The risk assessment also found that the open air section of the M5 route would pose a lower risk than the alternative routes. With the assumed design however the risk attributable to the tunnel section of the M5 East route was sufficient for some classes to bring it to a level greater than that applying to the alternative routes.

In the course of the risk assessment a number of aspects of tunnel design and operating and emergency systems were identified which if amended or attended to in the light of DG use should be capable of ensuring that the M5 would be the least risk route. The identified measures need, however, further development and refinement in the context of careful consideration of their technical and economic feasibility. This assessment should be carried out in conjunction with the preliminary and/or final design of the Tunnel . Following such further development it will be possible to quantify the extent of the effect of the measures on risk levels.

It is important to recognise however that the focus, in developing the appropriate set of measures, has been as much on eliminating potential incident outcomes and reducing their consequences as on reducing likelihood. Furthermore, the principle of "avoiding avoidable risk" has been applied to help ensure that if DG's are to be permitted to use the tunnel then it will be as safe as practicable.

Tunnel features identified as warranting attention include:

- the ventilation system
- the capacity of drainage systems and sumps
- the cross slope (drainage) of carriageways
- provision of redundancy in the tunnel pumpout systems
- minimisation of smoke generation by the use of non bitumen pavement
- investigation of alternatives to a deluge system
- improvement of emergency egress routes and instruction systems
- maximisation of the fire rating of the tunnel structure
- operating, emergency and maintenance procedures and training

The ventilation system and drainage systems are the areas considered most likely to result in significant reductions in risk.

S7 TUNNEL DESIGN REQUIREMENTS

The design features nominated and used for analysis up to this point have been typical of those for a long road tunnel designed for normal tunnel operation requirements which normally exclude the traffic of DG's in bulk and or in packaged form. Wherever the design prescriptions in the EIS are clear and consistent they have been used. Interpretation or development of the design as suggested in the EIS and treatment of some elements not listed has however been necessary.

This section highlights possible changes to the nominal tunnel design which could reduce risk to road users and residents were the M5 tunnels to be used for the passage of DG's. Possible mitigating measures fall into three categories:

- Measures to minimise the extent and duration of an event.
- Measures to improve motorist/resident safety for a given event.
- Measures to minimise the tunnel period of closure following any serious events.

Specific measures that have been identified for these cases are:

(i) Measures to minimise the extent of an event:

(a) Provide longitudinal airflow in tunnel for the maximum possible number of conceivable traffic conditions.

(b) Increase the design fire intensity and exhaust rate of the smoke exhaust system.

(c) Provide cooling systems in the smoke exhaust duct, particularly prior to the exhaust fans to increase the 'survival time' of the system.

(d) Provision of protection or cooling for fan systems.

(e) Modify the drainage system to reduce the extent of flammable liquid spills.

(f) Provide separate lowpoint pumpwells and/or increase the lowpoint pump well capacity to eliminate lowpoint pool fires due to insufficient lowpoint pump well capacity in the case of pump failure.

(g) Provide non-return valves in the tunnel lowpoint to lowpoint sump drain to avoid the backflow of spilt fuel from lowpoint pump well into tunnel lowpoint if deluge system operates. Also provide duplicate tunnel lowpoint to lowpoint pump well drain pipes.

(h) Provide a complete redundant pumpout system at the lowpoint sump to increase security in case of primary pump failure.

(i) Investigate alternatives to a deluge system.

(j) Non-bitumen road surface to minimise smoke generation from structural surfaces.

<u>(ii) Measures to improve motorist / resident safety for a given event:</u>

(a) Provide enhanced VMS systems to give detailed instructions for evacuation.

(b) Provide emergency egress at reduced spacing.

(c) Provide a moveable median strip or other physical barrier to prevent inadvertent entry during a tunnel emergency shutdown.

(d) Provide increased exhaust stack height to enhance dispersion of toxic smoke products and toxic gases and vapours.

<u>(iii) Measures to minimise tunnel closure time in the case of an event occurring:</u>

(a) Increase spares holding of exhaust dampers, fans and other items with long supply periods to minimise time to refit after and event.

(b) Increase the structural fire rating of the tunnel.

(c) Increase the blast resistance of the tunnel.

S8 RECOMMENDATIONS

The study findings suggest that it is likely that design and operational modifications will be capable of reducing risk levels associated with DG transport through the tunnel to a point where they are lower than for the alternative routes. It would be appropriate therefore for further work to be undertaken on a number of aspects. Such work should build on this study: to resolve remaining uncertainties and ensure that there can be high confidence levels in final risk results; to take account of the effect of the changes in design flowing from the study findings; and, to take account of changes in routing and other tunnel features which have arisen for other reasons.

It is therefore recommended that:

(a) Risk 'acceptability' criteria specific to this case should be developed to ensure that the conclusions and decisions made on DG transport and on the level of risk reduction measures to be implemented have an explicit basis and will be acceptable to the Department of Urban Affairs and Planning. The criteria should cover fatality, injury and property damage. Consultation with DUAP would be appropriate in the development of such criteria. Such consultation should also address the acceptability to DUAP of assumptions made in the consequence analysis for the Open Air cases.

(b) The various design and operational elements proposed as risk reduction measures in **Section 8.2** should be worked up to establish their technical and economic feasibility in the context of the tunnel routing and length etc. as it is proposed at that time. Such analysis should pay particular attention to the need to maintain longitudinal ventilation flow above critical velocities under all operational and emergency conditions. As the object of this exercise is risk reduction, it is important that this development and refinement be undertaken with full regard to the effect of measures on incident consequences and to the reliability of systems in atypical circumstances. It therefore needs to be undertaken as a fully collaborative and interactive exercise between risk engineers and tunnel design specialists.

(c) Once the risk reduction options have been worked up (and following review and comment as appropriate) the revised tunnel system should be subject to full risk quantification with the separate identification of the risk reduction contribution of the various risk reduction measures and analysis of their interdependence if any. This will enable formal comparison with the alternative routes and a ranking of risk reduction measures in terms of cost effectiveness.

(d) The tunnel damage analysis should be further developed to include quantification of the likely frequency of incidents resulting in tunnel closure for various durations and the direct and indirect costs of such events. Assessment of the frequency and costs of such events on the alternative routes could also be undertaken for comparative purposes.

(e) Consideration should be given to the development of risk acceptability criteria specific to this case so that any decisions made on DG transport and on the level of risk reduction measures to be implemented have an explicit basis. Consultation with the Department of Urban Affairs and Planning may be appropriate in the development of such criteria.

(f) A detailed analysis of the benefits and consequences of the installation and use of deluges, sprinklers or any identified alternative fire suppression systems should be conducted prior to any decision to incorporate any such system in the tunnel design and the results of that study should be and input to the overall risk assessment of the preliminary and final design

(g) A detailed analysis of the spacing and nature of egress routes should be undertaken in the context of the risk analysis.

(h) Contingent with all the above elements, the cost benefit and economic feasibility needs to be considered.

(h) As part of the overall design process, hazard and operability studies (HAZOP's) should be conducted for all emergency related elements of the project with special attention to the ventilation, drainage and emergency identification and response systems.

Regardless of the findings of further work the following safety related measures should be incorporated into the tunnel design and operating arrangements particularly if a decision to permit DG transport is taken.

(i) A formal and comprehensive emergency plan should be prepared.

(j) A firm requirement of any approval for DG transport through the tunnel should be the development and implementation of a rigorous training programme covering all safety related aspects.

(k) Safety management systems for the tunnel should be subject to periodic independent audit.

1. INTRODUCTION

1.1 BACKGROUND

An increasing variety of hazardous materials is now being transported by road, rail, pipeline and ships. These materials have the potential for incidents which may result in death or injury to people, property damage or damage to the bio-physical environment through the effects of fire, explosion or toxicity.

The M5 East EIS (Manidis, 1994) addressed conceptually the issue of dangerous goods transport through tunnels. The M5 East has been developed as a truck route consistent with the Integrated Transport Strategy, and, as a general principle, should provide facilities for all trucks in order to relieve surrounding suburbs of unnecessary intrusion by heavy vehicles.

A decision was taken on the basis of preliminary work by RiskCorp Australia Pty Ltd (1993 & 1994) that consideration should be given to permitting the passage of dangerous goods through the Wolli Creek M5 Tunnels.

1.2 APPRECIATION OF THE ISSUES

There are substantial volumes of Dangerous Goods (DG) transported by road from the central industrial area and Port Botany to areas of Sydney and more distant destinations, which could use the new section of the M5. Currently these vehicles use a number of routes which travel through industrial, commercial and residential areas. There is a level of risk associated with this transportation. There is risk to people who live, work, attend school, visit shopping centres etc. along these routes and to other road users. There is also some level of risk to the biophysical environment and to property including the transport infrastructure.

The construction of the eastern section of the M5 Motorway creates an opportunity to change the routes used by the Dangerous Goods (DG) traffic. The point at issue is whether permitting the use of the M5 between Mascot and Beverly Hills for DG transportation, with or without partial restriction of load type, time etc, would result in a lower level of risk overall and whether the resultant risk levels would satisfy any risk acceptability criteria which may be relevant.

The principal concern in this regard is risk to road users and adjacent residents arising from possible incidents along the M5 East Motorway, including the Wolli Creek Tunnels, and along the alternative routes. Existing regulations prohibit the movement of certain DG loads through other tunnels and there has historically been a view, based on perceptions of worst case consequences of possible fires, explosions or toxic releases in tunnel environments, that movement of DG's through tunnels is unacceptable. This perception and regulatory approach is not necessarily consistent with a contemporary understanding of hazards, likely incident consequences or risk, and in a number of cases around the world such transportation activity is permitted freely or with some restrictions.

1.3 OBJECTIVES OF THE STUDY

The appropriate way to resolve this issue is through a quantified risk assessment of the M5 and alternative routes. The aim of this study was to provide information which will form the basis for a firm decision as to whether or not dangerous goods (DG) should be permitted to pass through the Wolli Creek M5 Tunnels. Specific objectives of the Study were to:

(a) Describe the extent of DG transport between Mascot and Beverly Hills.

(b) Obtain the views of DG operators whose vehicles presently pass through the area.

(c) Identify sensitive land uses.

(d) Identify options for DG routes between Mascot and Beverly Hills.

(e) Identify which (if any) types of DG should be permitted to travel through the tunnel.

(f) Quantify the necessary physical and engineering features and management processes required in order to permit DG through the tunnels.

(g) Relate probable exposure to potential consequences of any incidents to the various options.

(h) Use QRA techniques to assess the transportation of DG through the proposed tunnel against current and future transport of DG by road.

1.4 OBJECTIVES OF RISK ASSESSMENT

The objectives of the risk assessment component of the study are to

(a) to identify the hazard and analyse the risks from existing and future transport of DG by road on the M5 and alternative routes.

(b) to assess the relative risks from the M5 and alternative routes against each other and relevant criteria.

(c) to identify opportunities for risk management or minimisation and quantify and assess the effect of such measures on risk levels.

(d) to develop recommendations on what restrictions should apply to DG movements through the M5 tunnel and recommendations on appropriate risk minimisation and management measures.

1.5 STUDY AREA

For the purpose of this study, the evaluation and analysis included the assessment of the route along Stoney Creek Road, to the south of the M5 East Motorway, and a route through Marrickville and along Canterbury road to the north (**Figure 1.1**).

1.6 STUDY APPROACH

The scope of the risk assessment component of the study includes:

(a) A quantitative description, analysis and evaluation of the current and likely future cumulative traffic situation in relation to the movements of tankers and flat top trucks carrying dangerous goods likely to use the section of the M5 Motorway between Beverly Hills and Mascot, and the alternative routes. This included data collection of heavy vehicles generation, roads used, traffic composition, land use frontage and crash/incident statistics.

(b) Identification of the hazardous incident potential for different loads on each of the routes taking into account available crash data and other modes of release such as tanker valve failure, loss of load, vehicle fire etc. This analysis has, as far as practicable, taken into account the specifics of tunnel design, road geometry, the range of operating conditions and other relevant variables as identified in the course of the study.

(c) Analysis of the consequences of such incidents in terms of human fatality and injury for other road users, people in surrounding land uses, people in the vicinity of the emergency ventilation system outlet(s) and people in the vicinity of the drainage outlets. The potential for damage to the transport infrastructure (principally the tunnel) and consequential traffic disruption during the repair period have also been covered as has the comparative potential for harm to the biophysical environment from the different routes. This analysis has taken into account the specifics of: drainage and ventilation systems as relevant; the tunnel configurations; safety systems such as emergency deluges, ventilation systems and emergency procedures; and, any other relevant factors identified in the course of the analysis.

(d) Analysis of the frequencies of incidents and of the presence of potentially exposed populations, specific, as far as practicable, to different hours of the day and days of the week.

(e) Estimation of societal and individual risk as appropriate.

(f) Estimation of the frequency of hazardous materials incidents resulting in major damage to infrastructure and likely time taken to repair or reinstate. Factors such as the notional cost of disruption and delay, societal trauma, loss of public confidence and impact on the RTA's and the government's image should even minor incidents occur have also been considered.

(g) Review of the relevance/applicability of risk acceptability criteria and assessment against relevant criteria and comparison of risk between the routes.

(h) Identification of opportunities for risk reduction (including physical design features of tunnel and operational controls).

(i) Assessment of the effect of such measures on risk levels.

(j) Formulation of recommendations on what DG loads should be permitted to use the M5 and what controls and design features should apply.

An important consideration in the assessment of risk management measures is the recognition that systems and controls are fallible - consideration of reliability and residual risk were therefore key elements of the analysis.

1.7 SCOPE OF REPORT

A physical description of the alternative routes is presented in **Section 2** of the report. Relevant information was obtained where available and was supplemented where required by means of field surveys, as detailed in **Section 3.**

An assessment of the traffic and transport issues along the alternative existing routes and the M5 East is included in **Section 4.**

An important feature of this study has been the particular considerations given to the Tunnel section of the Motorway. **Section 5** presents the design and management considerations associated with the tunnels.

The Risk Assessment for each route by type and class of DG is detailed in **Section 6.**

A detailed evaluation of the alternative routes form the basis of **Section 7.**

Section 8 details the conclusions and recommendations of the study.

All technical references and materials including data, calculations and general information have been included in a separate Technical Addendum.

2. DESCRIPTION OF STUDY ROUTES

2.1 ALTERNATIVE ROUTES

2.1.1 M5 Motorway East Route

The M5 East Motorway Route runs from the intersection of O'Riordan Street and Qantas Drive, Mascot, via Qantas Drive, Airport Drive, Marsh Street and then the M5 Motorway to King Georges Road.

2.1.2 Southern Route

The Southern Route runs from the intersection of O'Riordan Street and Qantas Drive, Mascot, via Qantas Drive, Airport Drive, Marsh Street, Wickham Street, Forest Road, Stoney Creek Road and King Georges Road to the intersection of King Georges Road and the M5 Motorway. This route is currently used by Dangerous Goods vehicles to the west and south-west.

2.1.3 Northern Route

The Northern Route runs from the intersection of O'Riordan Street and Qantas Drive, Mascot, O'Riordan Street, Bourke Street, Coward Street, Kent Street, Ricketty Street, Canal Road, Princes Highway, Railway Road, Gleeson Avenue, Railway Parade, Buckley Street, Sydenham Road, Livingstone Road, New Canterbury Road, Canterbury Road and King Georges Road to the intersection of King Georges Road and the M5 Motorway. This route is included for comparison purposes.

2.2 BASIS FOR EVALUATION

2.2.1 Route Sections

Each route was divided into sections to enable their detailed analysis. The sections for the three routes are shown in **Tables 2.1a, 2.1b and 2.1c** for the M5 East Motorway, Southern and Northern routes respectively, and illustrated in **Figure 2.1**. Sections M1-M4 of the M5 Motorway east route are the same as sections S1-S4 of the Southern route.

Table 2.1a
M5 EAST MOTORWAY ROUTE STUDY SECTIONS

SECTION	ROAD	BETWEEN
M1	Qantas Dr	O'Riordan St and Robey St
M2	Qantas/Airport Drive	Robey St and Link Rd
M3	Airport Drive	Link Rd and Marsh St
M4	Marsh St	Airport Drive and M5 Motorway
M5	M5 Motorway	Marsh St and Princes Hwy
M6	M5 Motorway	Princes Hwy and Tunnel Portal
M7	M5 Motorway	Tunnel Portal and Bexley Rd
M8	M5 Motorway	Bexley Rd and Tunnel Portal
M9	M5 Motorway	Tunnel Portal and King Georges Rd

Table 2.1b
SOUTHERN ROUTE STUDY SECTIONS

SECTION	ROAD	BETWEEN
S1	Qantas Dr	O'Riordan St and Robey St
S2	Qantas/Airport Drive	Robey St and Link Rd
S3	Airport Drive	Link Rd and Marsh St
S4	Marsh St	Airport Drive and M5 Motorway
S4A	Marsh St	M5 Motorway to West Botany Rd
S5	West Botany Rd	Marsh St and Wickham St
S6	Wickham St	Marsh St and Princes Hwy
S7	Forest Rd	Princes Hwy and Wolli Creek Rd
S8	Forest Rd	Wolli Creek Rd and Bexley Rd
S9	Forest Rd	Bexley Rd and Stoney Creek Rd
S10	Stoney Creek Rd	Forest Rd and Preddys Rd
S11	Stoney Creek Rd	Preddys Rd and Kingsgrove Rd
S12	Stoney Creek Rd	Kingsgrove Rd and King Georges Road
S13	King Georges Road	Stoney Creek Rd and M5 Motorway

Table 2.1c
NORTHERN ROUTE STUDY SECTIONS

SECTION	ROAD	BETWEEN
N1	O'Riordan St	Joyce Dr and Bourke St
N2	Bourke St	O'Riordan St and Coward St
N3	Coward St	Bourke St and Kent St
N4	Kent St	Coward St and Ricketty St
N5	Ricketty St	Kent St and Canal Rd
N6	Canal Rd	Ricketty St and Princes Hwy
N7	Princes Hwy	Canal Rd and Railway Rd
N8	Railway Rd	Princes Hwy and Unwins Bridge Rd
N9	Gleeson Ave	Unwins Bridge Rd and Railway Pde
N10	Railway Pde	Gleeson Ave and Buckley St
N11	Buckley St	Railway Pde and Sydenham Rd
N12	Sydenham Rd	Victoria Rd and Illawarra Rd
N13	Sydenham Rd	Illawarra Rd and Frazer St
N14	Livingstone Rd	Frazer St and Addison Rd
N15	Livingstone Rd	Addison Rd and New Canterbury Rd
N16	New Canterbury Rd	Livingstone Rd and Marrickville Rd
N17	New Canterbury Rd	Marrickville Rd and Old Canterbury Rd
N18	Canterbury Rd	New Canterbury Rd and Jeffrey St
N19	Canterbury Rd	Jeffrey St and Wonga St
N20	Canterbury Rd	Wonga St and Bexley Rd
N21	Canterbury Rd	Bexley Rd and Kingsgrove Rd
N22	Canterbury Rd	Kingsgrove Rd and Burwood Rd
N23	Canterbury Rd	Burwood Rd and King Georges Rd
N24	King Georges Rd	Canterbury Rd and Moorefields Rd
N25	King Georges Rd	Moorefields Rd and M5 Motorway

2.2.2 Traffic Information

This study has been based on traffic data developed and included as part of the EIS for the M5 East Motorway reports (Manidis, 1994 & SKP 1994 a/b). Modelled traffic volumes information for each section, along the alternative three routes, were obtained for the AM Peak hour period for the Year 1993, 1996, 2001 and 2011. This information was supplemented by RTA published data. Details and usage of this information is included in Section 3.2.1.

2.2.3 Comparison of Routes

The emphasis in this Study was on a comparative risk assessment, rather than on absolute levels of risk along the routes. While individual risk calculations may be appropriate in some circumstances, a societal risk approach is generally more appropriate in the transport risk assessment. It is appropriate and essential in this case to include the population of other road users in the societal risk calculation.

2.3 ROUTE CHARACTERISTICS

2.3.1 Road Hierarchy for Study Area

The road hierarchy of the three routes was determined from records of the various Council's through which the routes passed. The road classification for each of the routes is shown on **Figure 2.1**. Both the Northern and Southern routes are all on arterial or sub-arterial roads. The M5 East will be classified as an arterial road.

2.3.2 Road Inventory

The number of lanes and traffic signal locations along the three routes are illustrated in **Figure 2.2**. The northern route has a time based deviation between New Canterbury Road and Sydenham Road, as noted in **Figure 2.2.** Thus trucks greater than 3 tonnes use Frazer Street from 6.00 am until midnight and Livingstone Road from midnight to 6.00 am to travel between New Canterbury Road and Sydenham Road.

2.3.3 Proposed Works and Developments

From discussions with the relevant local Councils in the study area, proposed future works and developments which may influence the nature of the routes were identified.

<u>(i) Southern Route</u>

The following proposed works and developments within the Hurstville and Rockdale Council areas are relevant to the study:

- Widening of King Georges Road south of Stoney Creek Road by Roads and Traffic Authority. The RTA intends to widen King Georges Road south of Stoney Creek Road from 4 lanes to 6 lanes.

- Rockdale Council has developed a proposal for a road bypass of Forest Road, Bexley. The bypass would see the intersection of Stoney Creek Road and Forest Road relocated east to Harrow Road. The proposal would reduce traffic congestion by bypassing Bexley Shopping Centre.

- Rockdale Council, as part of its Turrella/Arncliffe/Mascot Draft LEP, has identified a site on the south-eastern corner of the intersection of Princes Highway and Wickham Street to be zoned Residential 2(d), for the development of residential flats three storeys and higher. The proposed zoning would see a significant increase in residential density, most likely in the form of a single high rise tower.

(ii) Northern Route

The following proposed works and developments within the Marrickville Council area are relevant to the study:

- Draft LEP No 121 proposes that land bounded by New Canterbury Road, Terrace Road, Consett Street, Hercules Street and the Railway Line be rezoned from Light Industrial 4(b) to Residential 2(c4) "Residential C4" which permits the development of 3 storey residential flat buildings.

- Draft LEP No 88 proposes that land bounded by New Canterbury Road, Union Street and the Railway Line be rezoned from Industrial to Residential 2(c4), which permits the development of 3 storey residential flat buildings.

It is important to note that the proposed closure of Canterbury Hospital is now not proceeding.

(iii) M5 East Motorway Route

The Rockdale Council proposal identified above will be situated within 500 metres of the proposed M5 Motorway.

3. DATA COLLECTION AND SURVEYS

3.1 REVIEW OF PREVIOUS REPORTS

A review of previous studies that have been carried out which are relevant to this study was undertaken. This included the following reports:

- M5 Motorway East Environmental Impact Statement and supporting documents (Manidis, 1994).
- Two working papers by RiskCorp (1993 & 1994) for the M5 Motorway East EIS.
- M5 Motorway East Motorway Traffic Analysis Working Paper No. 1, Existing Situation, Sinclair Knight, 1994a
- M5 Motorway East Motorway Traffic Analysis Working Paper No. 2, Analysis of Options, Sinclair Knight, 1994b

3.1.1 Risk and Hazard

As a starting point, for the hazard analysis and risk assessment part of the study previous reports and studies relevant to the DG transport in the area and the M5 were reviewed. More widely, studies of DG transport and tunnels were also consulted. Studies reviewed included: the two studies undertaken for the RTA by RiskCorp (1993 & 1994); an important comparative study of DG transport through road tunnels in the UK undertaken by Considine *et al* (1989); and the Route Selection Guidelines issued by the then Department Planning, in March 1994, as a Final Draft for comments. The full titles for these studies and an extensive listing of other relevant material consulted are included in the list of references and bibliography.

The review highlighted the limitations of the available data and limited extent of previous work undertaken in quantified risk assessment of hazardous materials transport through tunnels - particularly work attempting to deal with the real design features tunnels instead of simplified models. The limited extent of previous work was confirmed in private communications with senior officers of the UK's Health and Safety Executive.

3.1.2 Traffic Aspects

The traffic aspects of previous reports have been reviewed. The most salient points raised in these reports are:

(a) the M5 corridor is notable for the absence of suitable truck routes between the present eastern termination of the M5 West at King Georges Road and the Botany and CIA truck generating areas;

(b) the road system in the M5 corridor has reached its capacity limits during peak flow conditions;

(c) average travel speeds are lower than comparable routes in other parts of Sydney with many intersections operating at or above capacity resulting in a poor to unsatisfactory level of service;

(d) road safety within the M5 corridor is suffering due to the absence of good standard limited access roads to reduce vehicle conflicts.

3.1.3 Tunnel Aspects

It was noted during the course of the Study that the ventilation system nominated in the EIS (Manidis, 1994) is not sufficiently developed (refer to correspondance with Connell Wagner - (**Addendum 5.1**) to allow a full risk assessment to be carried out. For this reason, an assumed design has been adopted in Section 5.

Voltage drop in the supply to the jet fans distributed along the upstream section of each tunnel is an issue requiring consideration.

3.2 ROUTES AND TRAFFIC INFORMATION

3.2.1 Existing Traffic Volumes

(i) Daily Volumes

The available 1991 and 1993 AADT volumes along the Northern and Southern routes are shown on **Figure 3.1**. Between 1991 and 1993, there has been a 51% increase in traffic on King Georges, south of the M5 Motorway connection. The increase in traffic on King Georges Road north of the M5 Motorway connection for the same period was 10%. The increases over the Southern and Northern routes is generally about 10%. The termination of the M5 West Motorway at King Georges Road has appeared to attract more traffic from the south. The gradual improvements to the economy may have contributed to general traffic growth in Sydney.

(ii) Peak Hourly Volumes

Existing AM and PM peak hour traffic flows shown on **Figure 3.2** were obtained from SKP (1994A) and RTA published figures at different locations along the Southern and Northern routes.

3.2.2 Existing Traffic Composition

A classification survey was carried out from 2.00pm Monday 20 February to 2.00pm, Tuesday 21 February 1995. On the Northern Route, the survey was carried out on Canterbury Road, near its intersection with Orissa Street. On the Southern Route, the counts on Stoney Creek Road were near its intersection with Medway Street. The total number of all vehicles in each direction by type was recorded at both locations.

The classification count for all vehicles is shown in detail in **Addendum 3A** and summarised in **Table 3.1** below for each direction.

TABLE 3.1
SUMMARY OF 24 HOUR CLASSIFICATION COUNT

LOCATION	Light Vehicles	Rigid Trucks	Rigid Truck Tanker	Semi-Trailers	Semi-Trailer Tanker	Total Vehicles
Canterbury Rd/Orissa St						
Eastbound	21,253	425	11	166	13	21,868
Percentage	97.19%	1.94%	0.05%	0.76%	0.06%	100%
Westbound	20,551	532	36	114	16	21,249
Percentage	96.71%	2.50%	0.17%	0.54%	0.08%	100%
TOTAL	**41,804**	**957**	**47**	**280**	**29**	**43,117**
PERCENTAGE	**96.95**	**2.22**	**0.11**	**0.65**	**0.07**	**100**
Stoney Creek Rd/Medway St						
Eastbound	12,624	435	28	884	52	14,023
Percentage	90.02%	3.10%	0.20%	6.31%	0.37%	100%
Westbound	12,408	450	40	754	85	13,737
Percentage	90.32%	3.28%	0.29%	5.49%	0.62%	100%
TOTAL	**25,032**	**885**	**68**	**1,638**	**137**	**27,760**
PERCENTAGE	**90.18%**	**3.19%**	**0.24%**	**5.90%**	**0.49%**	**100%**

From **Table 3.1** it can be seen that there is little difference in volumes by direction of flow for either of the alternate routes. Canterbury Road was carrying 55% more traffic than Stoney Creek Road at the survey locations, but the number of trucks on Canterbury Road was only 48% of the number on Stoney Creek Road. It would appear from these figures that Stoney Creek Road is the preferred route of truck drivers.

3.2.3 Existing Dangerous Goods Traffic

Australia has adopted a system of classification and labelling for dangerous goods based on the United Nations system used in other countries. This system helps people to quickly recognise dangerous goods, their properties and dangers.

Dangerous goods are divided into nine (9) classes according to their dangerous properties. So that people can recognise the inherent hazard of particular dangerous goods, every package, container, bulk transport container, or unit load that is offered for transport must carry the correct Class Label. This label, or diamond sign, has a distinctive symbol and colour to show the class of substance. The classification of dangerous goods is shown in **Table 3.2** and described more fully in **Section 6.2.6.**

TABLE 3.2
CLASSIFICATION OF DANGEROUS GOODS

CLASS	DESCRIPTION	CLASS	DESCRIPTION
Class 1	Explosives	Class 6	Poisonous and Infectious Substances
Class 2	Gases	Class 7	Radioactive Substances
Class 3	Flammable Liquids	Class 8	Corrosives
Class 4	Flammable Solids	Class 9	Miscellaneous Dangerous Goods
Class 5	Oxidising Substances		

(i) 1995 Surveys

All vehicles carrying dangerous goods were recorded by type of vehicle and class of dangerous goods in conjunction with classification survey. The number of dangerous goods by vehicle type and class of goods is detailed in **Addendum 3B**, and summarised in **Table 3.3**, for each direction at each survey location.

TABLE 3.3
SUMMARY OF 24 HOUR DANGEROUS GOODS VEHICLES

LOCATION	DANGEROUS GOODS CLASSIFICATION NO.									Total Vehicles
	1	2	3	4	5	6	7	8	9	
Canterbury Road										
Westbound										
Rigid Truck	0	2	5	0	0	0	0	0	4	11
Rigid Truck Tanker	0	0	2	0	0	0	0	0	0	2
Semi-Trailer	0	0	2	0	0	1	0	0	0	3
Semi-Trailer Tanker	0	1	10	0	0	0	0	0	0	11
TOTAL	0	3	19	0	0	1	0	0	4	27
Eastbound										
Rigid Truck	0	4	1	3	0	0	0	0	3	11
Rigid Truck Tanker	0	1	0	0	0	0	0	2	1	4
Semi-Trailer	0	0	0	0	0	0	0	0	0	0
Semi-Trailer Tanker	0	4	4	0	0	0	0	0	0	8
TOTAL	0	9	5	3	0	0	0	2	4	23
Two Way										
Rigid Truck	0	6	6	3	0	0	0	0	7	22
Rigid Truck Tanker	0	1	2	0	0	0	0	2	1	6
Semi-Trailer	0	0	2	0	0	1	0	0	0	3
Semi-Trailer Tanker	0	5	14	0	0	0	0	0	0	19
TOTAL	**0**	**12**	**24**	**3**	**0**	**1**	**0**	**2**	**8**	**50**
Stoney Creek Road										
Westbound										
Rigid Truck	0	6	1	0	1	0	0	0	6	14
Rigid Truck Tanker	0	1	8	0	1	0	0	5	1	16
Semi-Trailer	0	0	0	0	0	0	0	0	0	0
Semi-Trailer Tanker	0	6	47	2	1	0	0	9	1	66
TOTAL	0	13	56	2	3	0	0	14	8	96
Eastbound										
Rigid Truck	0	3	4	0	1	0	0	3	3	14
Rigid Truck Tanker	0	1	12	0	1	0	0	10	0	24
Semi-Trailer	0	0	1	0	1	0	0	3	0	5
Semi-Trailer Tanker	0	10	34	0	1	0	0	4	1	50
TOTAL	0	14	51	0	4	0	0	20	4	93
Two Way										
Rigid Truck	0	9	5	0	2	0	0	3	9	28
Rigid Truck Tanker	0	2	20	0	2	0	0	15	1	40
Semi-Trailer	0	0	1	0	1	0	0	3	0	5
Semi-Trailer Tanker	0	16	81	2	2	0	0	13	2	116
TOTAL	**0**	**27**	**107**	**2**	**7**	**0**	**0**	**34**	**12**	**189**
Total veh both routes	**0**	**39**	**131**	**5**	**7**	**1**	**0**	**36**	**20**	**239**
% by Classification	**0%**	**16.3%**	**54.8%**	**2.1%**	**2.9%**	**0.4%**	**0%**	**15.1%**	**8.4%**	**100%**

On the day of survey, no vehicles were observed carrying Class 1 or Class 7 dangerous goods, explosives and radioactive substances respectively, on either route. Class 3 dangerous goods, flammable liquids, account for over half of all dangerous goods movements.

Table 3.4 presents the temporal variation of dangerous goods movements. About 70 percent of all movements take place during the day between 6.0am and 6.0pm. The largest concentration of Dangerous Goods vehicles, along the corridor, appear to occur between 1.0pm and 3.pm.

TABLE 3.4
HAZARDOUS VEHICLE SURVEYS
CANTERBURY ROAD & STONEY CREEK ROAD

Time Period			STONEY CREEK ROAD			CANTERBURY ROAD			BOTH ROUTES			
			E/B	W/B	Tot	E/B	W/B	Tot	E/B	W/B	Total	%
0000	to	0100	5	2	7	0	1	1	5	3	8	3.3%
0100	to	0200	2	2	4	0	1	1	2	3	5	2.1%
0200	to	0300	1	3	4	0	1	1	1	4	5	2.1%
0300	to	0400	1	0	1	0	0	0	1	0	1	0.4%
0400	to	0500	7	2	9	0	0	0	7	2	9	3.8%
0500	to	0600	14	1	15	0	0	0	14	1	15	6.3%
0600	to	0700	6	11	17	2	0	2	8	11	19	7.9%
0700	to	0800	5	5	10	2	3	5	7	8	15	6.3%
0800	to	0900	6	4	10	2	0	2	8	4	12	5.0%
0900	to	1000	4	4	8	1	1	2	5	5	10	4.2%
1000	to	1100	7	4	11	1	3	4	8	7	15	6.3%
1100	to	1200	4	6	10	1	2	3	5	8	13	5.4%
1200	to	1300	5	4	9	3	2	5	8	6	14	5.9%
1300	to	1400	6	9	15	6	2	8	12	11	23	9.6%
1400	to	1500	7	5	12	3	5	8	10	10	20	8.4%
1500	to	1600	1	8	9	0	3	3	1	11	12	5.0%
1600	to	1700	1	5	6	1	0	1	2	5	7	2.9%
1700	to	1800	1	6	7	0	1	1	1	7	8	3.3%
1800	to	1900	3	4	7	0	0	0	3	4	7	2.9%
1900	to	2000	0	3	3	1	0	1	1	3	4	1.7%
2000	to	2100	3	1	4	0	0	0	3	1	4	1.7%
2100	to	2200	1	2	3	0	1	1	1	3	4	1.7%
2200	to	2300	0	4	4	0	1	1	0	5	5	2.1%
2300	to	2400	3	1	4	0	0	0	3	1	4	1.7%
Totals			93	96	189	23	27	50	116	123	239	100%

(ii) Classification Data SKP Report

The vehicle classification and number of hazardous goods vehicles at five (5) locations within the study area were obtained from SKP (1994a) and are included in **Addendum 3C**, and summarised in **Table 3.5.**

The proportion of dangerous goods vehicles recorded by SKP, in October 1993, varied between 0.02 and 0.49 percent of all vehicles.

TABLE 3.5
VEHICLE CLASSIFICATION AND HAZARDOUS GOODS TRIPS*

LOCATION	VEHICLE TYPE				HAZARDOUS as %	
	Light	Heavy	Hazardous	Total	Heavy	Total
Canal St	39,701	5,033	93	44,827	1.81%	0.21%
Stoney Creek Rd, Bexley	22,161	4,035	130	26,326	3.12%	0.49%
Campbell St, St Peters	7,901	1,395	14	9,310	0.99%	0.15%
Sub-Total	**69,763**	**10,463**	**237**	**80,463**	**2.21%**	**0.29%**
Mitchell Rd, St Peters	33,514	3,099	9	36,622	0.29%	0.02%
Bexley Rd, nth of Forrest Rd	22,603	1,485	24	24,112	1.59%	0.01%
TOTAL	**125,880**	**15,047**	**270**	**141,197**	**1.76%**	**0.02%**

* Source: SKP (1994a)

(iii) RTA Dangerous Goods Survey

The RTA carried out a survey on use of Stoney Creek Road by heavy vehicles in May 1992 (Brewer, 1992). The RTA survey was carried out for the period 5.45am to 12.00 noon on Stoney Creek Road 20 metres west of Forest Road, Bexley. The results of this survey are compared with the results of the TEC 1995 survey in **Table 3.6.**

TABLE 3.6
DANGEROUS GOODS TRUCKS ALONG STONEY CREEK ROAD

	RTA 6am to 12 Noon			TEC 6am to 12 Noon			TEC 5am to 11am		
	East	West	Total	East	West	Total	East	West	Total
DGs Trucks	38	46	84	34	34	68	45	31	76
All Trucks	931	790	1721	639	493	1132	648	425	1073
All Vehicles	5660	3292	8952	5690	3154	8844	5838	2758	8596
DGs % of Trucks	4.08%	5.82%	4.88%	5.32%	6.90%	6.01%	6.94%	7.29%	7.08%
DGs % of all vehicles	0.67%	1.40%	0.94%	0.60%	1.08%	0.77%	0.77%	1.12%	0.88%

During the 1992 survey, heavy vehicles included trucks with two axles (4 rear tyres) which included vehicles as small as 2 tonnes. The 1995 survey included only trucks with 3 axles and more. As a result of this anomaly, the proportion of DGs trucks as a proportion of Heavy Vehicles is much higher in the 1995 surveys.

The number of DGs vehicles recorded in 1992 is over 20% higher than those recorded in 1995 during the same 6-hours period. However, if compared to the period from 5am to 11am in 1995, a variation of only 10% results.

Given the traffic variations from day to day, let alone the variation in number of DGs vehicles as they may be affected amongst other things by the arrival of ships at Port Botany, it is considered that the two surveys are comparable.

3.2.4 Future Traffic Projections

A traffic model was developed in conjunction with the EIS (SKP, 1994b) to assess the effect of the M5 East Motorway. The model was calibrated for 1993 AM peak traffic conditions. Traffic projections were made for the years 1996, 2001 and 2011. Projected AM peak hourly traffic volumes derived for the EIS were used. These modelled traffic volumes are included in **Addendum 3D** for all sections along the Northern, Southern and M5 East routes.

The actual traffic count information was then used to determine relationships between peak hourly volumes and AADT volumes. Relationships between actual and modelled peak hourly volumes were also derived where available. These relationships were then used to estimate the AADT Volumes for each section of the three routes. These volumes are included in **Addendum 3D** together with similar information for trucks.

An important measure of travel is the "vehicle-kilometres of travel" which is the product of the length of the section of road by the annual total traffic along it as follows:

Distance (km) x AADT x 365 days

This measure, for each section of the routes, is included in **Addendum 3D,** and summarised in **Table 3.7**.

TABLE 3.7
ANNUAL TRAVEL PATTERNS
M.veh.kms

	1993	1996	2001	2011
All Vehicles(M.veh.kms)				
Northern Route	237.30	257.91	269.44	302.53
Southern Route	190.01	166.65	200.43	263.42
M5 East Route		203.94	226.09	280.74
TOTAL	**427.31**	**628.50**	**695.96**	**846.69**
Trucks only (M.trucks.kms)				
Northern Route	11.90	13.23	13.81	15.57
Southern Route	10.08	8.43	10.16	13.50
M5 East Route		14.83	15.98	19.44
TOTAL	**21.98**	**36.49**	**39.95**	**48.51**

3.3 TRAVEL TIME

The 1994 travel speeds for each of the study sections for each route were obtained from the RTA and supplemented by data collected in conjunction with the EIS, (SKP 1994A), for the AM and PM peak periods. The travel times and speeds along the Northern and Southern routes are detailed in **Addendum 3E.**

The existing AM and PM peak travel speeds are also shown in **Figures 3.3a and 3.3b** respectively. These speeds are for the peak direction.

3.4 CRASH AND INCIDENT DATA

3.4.1 Road Crashes

(i) Southern and Northern Routes

Crash data for the Northern and Southern routes was obtained from the RTA and analysed. The information obtained for intersection and mid-block crashes was for the three year period ending June 1994. This information is shown in detail in **Addendum 3F** and summarised in **Table 3.8.**

TABLE 3.8
SUMMARY OF CRASH DATA
3 years period ending June 1994

	CARS				LIGHT TRUCKS				TRUCKS				TOTAL			
	A	K	SI	MI	A	K	SI	MI	A	K	SI	MI	A	K	SI	MI
NORTHERN ROUTE																
Mid bl	395	6	36	128	54	0	7	15	29	0	2	8	478	6	45	151
Int	835	2	49	289	106	2	8	31	76	2	6	20	1017	6	63	340
Total	1230	8	85	417	160	2	15	46	105	2	8	28	1495	12	108	491
SOUTHERN ROUTE																
Mid bl	126	1	20	24	15	0	0	4	29	2	6	14	170	3	26	42
Int	492	2	28	156	60	0	1	18	51	0	6	16	603	2	35	190
Total	618	3	48	180	75	0	1	22	80	2	12	30	773	5	61	232
M5 MOTORWAY West																
Total	41	0	4	10	4	1	1	4	3	1	0	1	48	2	5	15

A = Crashes; K = Killed Si = Serious Injuries Mi = Minor Injuries
Mid bl = Mid-block crash Int = Intersection Crash

Table 3.7 summarises the crash data obtained for the two alternate routes and the M5 West Motorway. The Northern route has about twice the number of crashes as the Southern route. Truck crashes represent about 7% of crashes on the Northern route and 10% of crashes on the Southern route. For the M5 Motorway west, truck crashes are about 6% of the total crashes.

(ii) M5 Motorway west

Crash data was also obtained for the M5 Motorway West between King Georges Road and Heathcote Road for the period 1992 - 1994. This information is also included in **Addendum 3F** and summarised in **Table 3.8.**

The data on crashes on the M5 Motorway West was used to determine the probable crash rates on the M5 Motorway East (refer section 4.3.2).

TABLE 3.9
INCIDENT DATA

Class/packaging/ outcome	Number recorded	Number of cases where characteristic recorded	Percentage of recorded cases[1]	Percentage of total[2]	Average release as percentage of containment breached
Class 1					
Total for class	2	154	1.3	1.3	
Bulk	1	2	50	0.65	
Class 2					
Total for class	12	154	7.79	7.79	
Bulk	7	12	58.33	4.55	
No ignition of release[3]	8	8	100	5.19	
Average loss of load[4]		4			77
Class 3					
Total for class	80	154	51.95	51.95	
Bulk	37	73	50.68	24.03	
No ignition of release[3]	69	77	89.61	44.81	
Average loss of load[4]		48			46
Class 4.1					
Total for class	2	154	1.3	1.3	
Bulk	1	2	50	0.65	
No ignition of release[3]	2	2	100	1.3	
Average loss of load[4]		2			33
Class 5					
Total for class	3	154	1.95	1.95	
Bulk	1	3	33.33	0.65	
Class 6					
Total for class	26	154	16.88	16.88	
Bulk	3	21	14.29	1.95	
Number of Fires[5]	2	17	11.76	1.3	
Average loss of load[4]		11			40
Class 7					
Total for class	1	154	0.65	0.65	
Class 8					
Total for class	27	154	17.53	17.53	
Bulk	7	25	28	4.55	
Average loss of load[4]		17			50
Class 9					
Total for class	1	154	0.65	0.65	
Bulk	0	1	0	0	
Caused by Crash[6]	17	71	23.94	11.04	

[1] Percentage of recorded cases is the number recorded as having that characteristic divided by the number of cases where the relevant characteristic was recorded, (e.g. for bulk, either bulk or packaged recorded) expressed as a percentage.

[2] Percentage of total is the number recorded as having the characteristic divided by the total number of incidents recorded, (154), expressed as a percentage.

[3] For the no ignition of release case, the number of cases where the relevant characteristic was recorded is the number of cases where a release for that class was recorded.

[4] For the average loss of load case, the number of cases where the relevant characteristic was recorded is the number of cases where both a release size and load size were given.

[5] For the number of fire cases, the number of cases where the relevant characteristic was recorded is the number of cases where a type of incident was recorded.

[6] For the caused by crash case, the number of cases where the relevant characteristic was recorded is the number of cases where a cause was identified.

3.4.2 Dangerous Goods Incidents Data

Incident data was sought from the NSW Fire Brigades, the EPA and the WorkCover Authority. Both the Fire Brigades and the WorkCover Authority indicated that the EPA was now the repository of such data and that they had no data to offer themselves that would not be available from the EPA. The EPA provided a report entitled Hazardous Material Incident Statistics 1 July 1993 to 30 June 1994 which included a listing of all reported incidents for that period.

The data items which related to road transport were extracted from the EPA listing and combined with data for the November 1988 to April 1990 period included in Brewer (1992). The incident data is contained in **Addendum 3G.**

Meaningful analysis of this data was difficult due to the small size of the data set and the level of detail recorded. **Table 3.9** was nonetheless generated and the results indicated taken into consideration along with the qualitative information from the listings in determining relevant frequencies and probabilities.

The incident histories from the industry questionnaires also provided some general and qualitative information on the types and frequency of incidents. Transport incident data from other sources including Considine et al, Lagadec (1982), OECD (1987), M&M Protection Consultants (1986), Department of Defence (1992), and the literature on tunnels and general traffic and DG incidents was also considered and drawn upon for the risk assessment as appropriate.

3.5 LAND USE INFORMATION

3.5.1 Land Uses Along Alternative Routes

Land use along the alternate routes is shown in **Figure 3.4.** The percentage of each route fronting Residential, Schools, Hospitals, Commercial/Industrial, Special Uses and Open Space is shown in detail in **Addendum 3H** and is summarised in **Table 3.10.**

TABLE 3.10
LANDUSE FRONTING ROUTES

LANDUSE	NORTHERN ROUTE		SOUTHERN ROUTE		M5 MOTORWAY ROUTE	
	kms	%	kms	%	kms	%
Residential		43.1%		52.6%		19.6%
Schools		2.8%		4.5%		0.0%
Hospital		0.3%		0.0%		0.0%
Commercial/Industrial		51.7%		8.4%		14.4%
Special Uses		0.0%		25.9%		27.1%
Open Space		2.1%		8.6%		38.9%
Length of Route kms	16.77	100%	12.62	100%	12.03	100%

3.5.2 Population Along Alternative Routes

The residential population along the routes were obtained from the 1991 ABS census data. Discussion with local Councils indicated that in general terms population along the three routes has not significantly varied since then. As the collector district boundaries varied in area and shape along the routes, it was considered more appropriate to derive a residential density (persons/km²) for each section of routes. This information is also included in **Addendum 3H** and summarised in **Table 3.11.** The Northern Route has generally the highest population density.

TABLE 3.11
POPULATION FRONTING ROUTES

POPULATION	NORTHERN ROUTE	SOUTHERN ROUTE	M5 MOTORWAY ROUTE
Residential Population Density (pop/km^2)	3,276	2,943	1,445
Number School Pupils	3919	4161	0
Number Hospital Beds	156	0	0
Length of Route kms	16.77	12.62	12.03

The numbers of pupils at all schools along the routes were obtained from the Department of Education and by direct contact with some schools. Canterbury Hospital, which had 156 beds, is the only Hospital fronting the Northern Route. No Hospitals front the Southern route. The highest number of school children are along the Southern route. The population density along the M5 East Motorway route is less than half than that along the Southern and Northern routes. There are no schools or hospitals fronting the Motorway.

3.6 INDUSTRY SURVEY

3.6.1 Questionnaire Survey

Some 40 organisations, likely to generate road transport of Dangerous Goods, in the Port Botany, Kurnell, St Peters areas were contacted in the first instance. Several companies either advised they did not generate such loads or were not interested in completing a questionnaire.

The questionnaire was then delivered by Express Post to the remaining 11 companies. Included with the questionnaire was an addressed Express Post envelope for the return of the completed questionnaires. Of the 11 questionnaires distributed, only five (5) were returned. Those companies which cooperated with the survey were Ampol, BOC Gases, Boral, Chemtrans and ICI. The remainder were contacted by telephone to encourage them to reply, but for various reasons were unable or did not do so.

The responses to the Questionnaire Survey were not exhaustive of all dangerous goods carriers. The number of responses is however considered adequate to determine the preference for the various dangerous goods routes proposed.

3.6.2 Existing Traffic Generation of Dangerous Goods

The number of loads of dangerous goods trips generated by the respondents to the survey are summarised in **Table 3.12**. Arrivals being to the Port Botany/Kurnell region, and departures being from the same region.

The busiest time for truck movements, 35% of arrivals and 43% of departures, is between 6.00 AM and 9.00 AM, on weekdays. Over 85% of weekly movements take place during the weekdays. Weekend movements account for about 12% of all movements.

TABLE 3.12
SUMMARY OF EXISTING TRUCK GENERATION of SURVEY RESPONDENTS

VEHICLE TYPE	Monday to Friday			Weekend			Weekly	
	6 am to 9 pm	9 pm to 6 am	Total	6 am to 9 pm	9 pm to 6 am	Total	Total	%
Arrivals								
Large Lorry (open truck)	12	26	38	0	0	0	38	24.8%
Large Lorry (shipping container)	0	25	25	0	0	0	25	16.3%
Rigid Tankers	27	25	52	0	0	0	52	34.0%
Semi-Trailer (open truck)	1	0	1	0	0	0	1	0.7%
Semi-Trailer (shipping container)	0	0	0	0	0	0	0	0%
Articulated Tankers	13	20	33	0	4	4	37	24.2%
B-Doubles	0	0	0	0	0	0	0	0%
Total	53	96	149	0	4	4	153	100%
Departures								
Large Lorry (open truck)	24	18	42	0	0	0	42	8.0%
Large Lorry (shipping container)	3	3	6	0	0	0	6	1.1%
Rigid Tankers	10	35	45	4	4	8	53	10.1%
Semi-Trailer (open truck)	24	0	24	0	0	0	24	4.6%
Semi-Trailer (shipping container)	0	0	0	0	0	0	0	0%
Articulated Tankers	131	194	325	32	44	76	401	76.2%
B-Doubles	0	0	0	0	0	0	0	0%
Total	192	250	442	36	48	84	526	100%
Total Arrivals + Departures								
Large Lorry (open truck)	36	44	80	0	0	0	80	11.8%
Large Lorry (shipping container)	3	28	31	0	0	0	31	4.6%
Rigid Tankers	37	60	97	4	4	8	105	15.4%
Semi-Trailer (open truck)	25	0	25	0	0	0	25	3.7%
Semi-Trailer (shipping container)	0	0	0	0	0	0	0	0%
Articulated Tankers	144	214	358	32	48	80	438	64.5%
B-Doubles	0	0	0	0	0	0	0	0%
Total	245	346	591	36	52	88	679	100%

3.6.3 Projected Growth

From the respondents to the questionnaire growth predictions were variable, with one company estimating that growth was static between 1995 and 2011. Other companies estimated 20% to 25% increases between 1995 and 2001, with further 20% to 25% increase between 2001 and 2011.

It has been assumed that the proportion of dangerous goods vehicle trips would remain constant in comparison to the total number of vehicle trips.

3.6.4 Transport Operational Costs

Part of the questionnaire sent to transport companies queried the transport operational cost for dangerous goods. The total vehicle operating costs varied from $34 per hour for Rigid Tankers to $85 per hour for Articulated Tankers. The truck delay costs per hour were generally considered to be the same as the total vehicle operating cost.

The weighted average operating cost for each type of vehicle was calculated from the questionnaire. This weighting took into account the number of trips from each operator and the operating cost per hour for the type of vehicle used by each operator. The weighted average operating cost for vehicles is shown in **Table 3.12.**

TABLE 3.12
OPERATING COST FOR VEHICLES

TYPE of VEHICLE	% of Vehicle Type Used	OPERATING COST $/HOUR
Rigid Tanker	18	43
Large Lorry	20	44
Semi-trailer	3	54
Articulated Tanker	59	78

The cost of operating a rigid tanker and large lorry are similar at about $44 per hour. The cost of operating an articulated tanker is about $78 per hour.

3.6.5 Routes Used by Dangerous Goods

The questionnaire responses indicated that over 95% of respondents' trucks carrying dangerous goods travel along the Southern Route. The remainder either used the Northern Route or other alternative roads. This pattern was not however reflected in the field survey (refer section 3.2.3).

The routes used by the companies responding to the survey are based on the economics of the route. As one respondent said, "routes are based on most economic route to clients". If the M5 Motorway East provides the cheapest route between depot and clients, then it is clear from the survey that this route will be used by the respondents. However, the cost of the toll will have to be taken into account and added to the operating costs of vehicles.

3.6.6 Safety Aspects of Transport of Dangerous Goods

The small number of respondent companies limited the extent to which generalised conclusions could be drawn from the questionnaires. The written responses together with follow up discussions with the responding companies' personnel and discussions with contacts from other relevant companies and organisations proved nonetheless to be a valuable source of information on the types of loads carried, the nature of the packaging, sizes of typical cylinders and packages, typical load sizes and the frequency of movements.

The accident and incident history information provided was limited but did provide some insight and confirmation of the types and frequency of the accidents experienced by DG trucks.

The information provided in response to the question on safety precautions emphasised driver training and emergency response capability. It is worth noting in this regard that the close proximity to the Botany industrial complex and Port Botany storage facilities would mean that rapid access to expertise and response equipment is more readily available in this area than in most areas of the state.

The emphasis on driver training is interesting as it shows an increased recognition of its importance to safety compared to ten years ago. The existence of active training programmes in companies which are likely to be major users of the M5 to transport DGs if this is permitted also raises the possibility of building some specific training on incident response in the tunnel to enhance safety.

3.7 METEOROLOGICAL DATA

For the dispersion modelling along the open air sections of the routes and for discharges from the ventilation system wind speed and stability data from Kingsford Smith airport were used. The data is presented in tabular and graphic form in **Addendum 3I.**

4. TRAFFIC AND TRANSPORT ISSUES

4.1 TRAFFIC PATTERNS OF DANGEROUS GOODS

4.1.1 Synthesis of Existing Data

The total number and type of vehicles recorded along Canterbury Road and Stoney Creek Road are summarised in Table 4.1. Dangerous goods account for about 5% of heavy vehicles and 0.31% of all vehicles.

Similar information obtained from the EIS Working Papers (SKP, 1994a) for the 5 recording stations. Dangerous goods account for about 4% of heavy vehicles and only 0.19% of all vehicles. However, when totalling the same information at the three recording stations most likely to correspond to the 1995 counts (Canal St, Stoney Creek Rd, and Campbell St), the proportions of dangerous goods are similar to the 1995 counts.

TABLE 4.1
SYNTHESIS OF HAZARDOUS GOODS TRIPS

VEHICLE TYPES	1995 TEC Weekday		1993 SKP 5 Stations Weekdays *		1993 SKP 3 Stations Weekdays *	
	Vol	%	Vol	%	Vol	%
Light Vehicles	66836	94.30%	134424	95.20%	75239	93.51%
Heavy Vehicles						
Rigid	1842	2.60%	2174	1.54%	1304	1.62%
Semi	1918	2.71%	4329	3.07%	3683	4.58%
Rigid Tanker	115	0.16%	90	0.06%	77	0.10%
Semi Tanker	166	0.23%	180	0.13%	160	0.20%
Total trucks	*4041*	*5.70%*	*6773*	*4.80%*	*5224*	*6.49%*
TOTAL	**70877**	**100.00%**	**141197**	**100.00%**	**80463**	**100.00%**
Dangerous goods trucks						
Number	222		270		237	
% of trucks		5.49%		3.99%		4.54%
% of all vehicles		**0.31%**		0.19%		0.29%

* 2.1 tonnes rigid trucks included as light vehicles

The SKP counts included trucks with two axles (4 rear tyres), whilst the 1995 survey included only trucks with 3 axles and more. As a result of this anomaly, the proportion of DGs trucks as a proportion of Heavy Vehicles is about 20% higher in the 1995 surveys. It is also understood that the truck volumes derived from the models for the EIS included only heavy vehicles with 3 axles and more.

As dangerous goods are also transported by vehicles with less than 3-axles, the proportion of dangerous goods as a proportion of total volumes provides a better mean of estimating the number of dangerous goods movements in the future.

On a typical weekday vehicles carrying dangerous goods accounts for about 0.30% of all vehicles. The weekly distribution for the road transport dangerous goods was derived from industry survey and is summarised in Table 4.2.

TABLE 4.2
WEEKLY DISTRIBUTION OF DANGEROUS GOODS MOVEMENTS

	Arr	Dep	Tot
Monday to Fridays (5 days)	97%	84%	87%
Saturday & Sunday (2 days)	3%	16%	13%
Weekly	**100%**	**100%**	**100%**

This information was then applied to the actual weekday counts to determine a weekly volume of Dangerous Goods vehicles. It was then found that for an average day over a full week, vehicles carrying dangerous goods accounts for about 0.24% of all vehicles.

4.1.2 Typical Volumes of Dangerous Goods Vehicles

The three routes were divided into two segments east and west of Bexley Road, along Canterbury Road, and Preddys Road, along Stoney Creek Road. The modelled daily volumes along the section of routes either side of that screenline were used to estimate the annual volume of Dangerous Goods taken as being representative of the respective segments. The potential number of Dangerous Goods across the Screenlines are included in **Addendum 4A** and summarised in Table 4.3 for the years 1996, 2001 and 2011.

TABLE 4.3
PROJECTED VOLUMES OF DANGEROUS GOODS VEHICLES
Yearly

SCREENLINE	1996	2001	2011
East of Bexley rd & Preddys Rd			
Canterbury Rd (N1 to N20)	15632	16597	19663
Stoney Creek Rd (S1 to S9)	68965	73222	86753
TOTAL	**84597**	**89819**	**106416**
M5 Motorway (M1 to M7)	84597	89819	106416
West of Bexley rd & Preddys Rd			
Canterbury Rd (N21 to N25)	16941	18170	20513
Stoney Creek Rd (S11 to S13)	58863	63136	71275
TOTAL	**75804**	**81306**	**91788**
M5 Motorway (M8 & M9)	75804	81306	91788

Four (4) of the five respondents of the industry survey, gave estimates of the growth in dangerous goods to the year 2001 and 2011. These growth rates have been weighted against the number of dangerous goods trips made in 1995 by these respondents. The growth in dangerous goods trips between 1995 and 2011 is expected to be of the order of about 21%. This is of the same magnitude as the growth of about 24% derived from **Table 4.3**.

4.2 ASSESSMENT OF TRAFFIC CONDITIONS

4.2.1 Level of Service

(i) Intersection Capacity

The concept of intersection capacity and Level of Service (LoS) is defined in the Guidelines published by the RTA (1993), together with criteria for their assessment.

The existing Levels of Service for critical intersections along the Northern and Southern routes were obtained from the EIS working papers (SKP, 1994a). The LoS for these intersections are summarised in **Table 4.4.**

TABLE 4.4
1993 INTERSECTION LEVELS OF SERVICE

INTERSECTION	LEVEL OF SERVICE	
	AM Peak	PM Peak
Northern Route		
O'Riordan St/Robey St	F	D
O'Riordan St/Bourke St	B	A
Coward St /Bourke St	B	B
Princes Hwy/Canal Rd	F	F
Princes Hwy/Railway Rd	C	D
Canterbury Rd/Bexley Rd	F	F
Canterbury Rd/Canary's Rd	B	B
Canterbury Rd/King Georges Rd	F	E
Southern Route		
Princes Hwy/Allen St	F	B
Princes Hwy/Forest Rd	F	C
Forest Rd/Bexley Rd	F	F
Forest Rd/ Stoney Creek Rd	B	C
King Georges Rd/Stoney Creek Rd	C	D

Three of the four intersections shown on the southern route have an LoS of "F" during the AM peak and one intersection has a LoS of "F" during the PM peak. For the northern route four of the eight intersections shown have a LoS of "F" during the AM peak and three of the eight intersections have a LoS of "E" or "F" during the PM peak.

(ii) Carriageway Level of Service

The concepts of carriageway capacity and Level of Service are discussed in **Addendum 4B** together with criteria for their assessment.

Using the modelled AM peak hourly traffic volumes, the LoS of each section of along the three routes was derived for 1996, 2001 and 2011. The results of this analysis are included in **Addendum 4C** and summarised in **Table 4.5.**

TABLE 4.5
SUMMARY OF AM PEAK LoS FOR ROUTES

	Northern Route		Southern Route		M5 East Motorway	
	E'bound	W'bound	E'bound	W'bound	E'bound	W'bound
Length of Route kms	16.77 kms		12.62 kms		12.03 kms	
1996						
% Route with LoS "E"	5%	9%	4%	0%	2%	0%
% Route with LoS "F"	72%	4%	40%	0%	32%	0%
2001						
% Route with LoS "E"	11%	6%	12%	0%	0%	0%
% Route with LoS "F"	72%	4%	47%	0%	34%	0%
2011						
% Route with LoS "E"	3%	33%	0%	0%	26%	0%
% Route with LoS "F"	83%	9%	59%	10%	34%	0%

(i) Eastbound Direction

The Northern Route will have an LoS "F" over 72% of its length in 1996, increasing to 83% by 2011. In 1996, the Southern Route will have an LoS "E" or "F" about 44% of its length increasing to 59% with LoS "F" by 2011.

The M5 East Motorway Route will have 32% and 34% of its length with a LoS "F" in 1996 and 2001 respectively. However, by 2011, it is expected that about 26% of this route will be operating at LoS "E"; furthermore, the section including Qantas and Airport Drives, and Marsh Street will operate at LoS "F" (34%).

It is understood that Qantas and Airport Drives, which form part of the Southern Route and M5 East Motorway route may be upgraded to six lanes divided carriageways with grade separated interchanges at all major junctions. If these improvements take place, then no section will operate at LoS "F".

(ii) Westbound Direction

All sections of the M5 east Motorway route will operate at LoS "A" at least until 2011.

The Southern route will also largely operate at LoS "A" or "C". By 2011, the King Georges Section of this route is expected to operate at LoS "F".

The Northern route provides the worst LoS in the westbound direction with up to 42% of its length operating at LoS "E" or "F" by 2011.

4.2.2 Travel time and Speed

Travel time and travel speed for the M5 East Motorway route and the two alternate routes are summarised in **Table 4.6**. The M5 East Motorway route exhibits the highest average speeds during the AM and PM peak hours, 48 kph and 50 kph respectively.

TABLE 4.6
SUMMARY OF TRAVEL TIME FOR ROUTES

ROUTE	DISTANCE km	AV. SPEED kph	TRAVEL TIME minutes	% of route with speeds <25kmh
Northern Route				
AM peak	16.77	22	47	53%
PM peak	16.77	23	45	43%
Southern Route				
AM peak	12.62	22	34	28%
PM peak	12.62	29	26	21%
M5 Motorway East Route				
AM peak	12.03	48	15	2%
PM peak	12.03	50	14	2%

The northern route has the longest travel time during both the AM and PM peak periods. The Southern route is about 13 minutes and 19 minutes quicker, than the Northern route, during the AM and the PM peak respectively.

The M5 East Motorway route will save about 32 and 19 minutes over the northern and southern routes respectively during the AM peak, and during the PM peak it will save about 31 and 12 minutes respectively over the northern and southern routes.

The Northern Route will provide the lowest level of service with over 50% of its length experiencing speeds less than 25 kph.

4.2.3 Number of Traffic Signals

Figure 2.2 shows the location of traffic signals along each of the routes. The number of signals along each route are summarised in Table 4.7.

TABLE 4.7
NUMBER OF TRAFFIC SIGNALS

	No of Traffic Signals
Northern Route	48
Southern Route	27
M5 east Motorway Route	7

There are 47 sets of Traffic signals along the northern route, 27 sets along the southern route and seven (7) sets along the M5 East Motorway route, including a new proposed signal at the junction of the Motorway with Marsh Street. The M5 East Motorway route is preferable for a truck route over the northern and southern routes when the possibility of having to stop and start a fully loaded vehicle is taken into account.

4.3 CRASH DATA ANALYSIS

The crash data information collected for the Northern and Southern routes and M5 West Motorway, between King Georges Road and Heathcote Road, was used to predict crashes along these routes for 1996, 2001 and 2011. This information is detailed in **Addendum 4D**.

4.3.1 Crash Rates

Interpretation of the accident statistics is best expressed by relating the incidence of crashes for chosen road sections and periods, to the travel activity for that section and period, ie as a crash rate per million vehicle kilometres (acc/mvk).

$$\text{Crash Rate/Mvk} = \frac{\text{Crashes}}{\text{Distance (km)} \times \text{Daily Volume}/1000000 \times \text{No. of Days}}$$

Crash rates were derived for each section along the Northern and Southern routes, and along the existing section of the M5 motorway, west of King Georges Road. The later rates were used to predict crashes along the eastern section of the M5 Motorway. The following three rates were calculated:

- All crashes per M.veh.kms
- Truck crashes per M.veh.kms
- Truck crashes per M.trucks.kms

The information included in **Addendum 3D and 3F** was used to derive the crash rates for 1993 which are included in **Addendum 4D**.

4.3.2 Potential Future Crashes

The crash rate derived for each route section was applied to the estimated travel demands (M.veh.kms) along the section (**Addendum 3D**) to derive the potential number of crashes in 1996, 2001 and 2011. **Addendum 4D** includes the predicted potential number of crashes involving all vehicles and for those involving at least one truck. **Table 4.8** summarises the potential crashes along the three routes.

TABLE 4.8
COMPARISON OF CRASH RATES PER MILLION KM OF TRAVEL

NORTHERN ROUTE	1993[1]	1996	2001	2011
Predicted crashes - Total	498	539	561	631
Predicted crashes - Trucks	35	34	37	41
SOUTHERN ROUTE	**1993**	**1996**	**2001**	**2011**
Predicted crashes - Total	258	198	238	306
Predicted crashes - Trucks	27	17	22	29
M5 EAST MOTORWAY ROUTE[2]	**1993**	**1996**	**2001**	**2011**
Predicted crashes - Total		117	133	171
Predicted crashes - Trucks		12	13	16

1 -average of three year data
2 - prediction based on M5 West data

The highest number of crashes is expected to continue to be along the Northern Route. By 2011, crashes along the Southern route will be less than 50% the number on the Northern Route. The M5 East Motorway route is expected to experience the lowest number of crashes by far.

5 DESIGN AND MANAGEMENT ASSUMPTIONS FOR TUNNEL

5.1 GENERAL

As noted in **Section 3.1.3**, the ventilation system design given in the EIS has been arrived at only for the purposes of approximate sizing of tunnel ductwork and exhaust structures. No specific design size of fire has been allowed in the sizing of the smoke exhaust system (refer to correspondence with Connell Wagner - **Addendum 5A**).

The proposed tunnel design given in the EIS (Manidis, 1994) has been assessed and the following comments are made:

(a) The tunnel cross section proposed in Figure 24 and described in Section 11.2 and Section 20.5 of the EIS suggests a longitudinal ventilation system where the airflow and the traffic flow are in the same direction and fully transverse ventilation system where airflow and traffic flow are opposed. The size of ducting shown is not compatible with the expected required design fire size. It is expected that a 25MW to 50MW design fire size would be adopted which would require much larger ducts than illustrated.

(b) If a design fire size of this magnitude with a fully transverse ventilation system is required, the tunnel cross section nominated must be enlarged significantly from that shown to provide sufficient space for the combined smoke exhaust / air return ducts that this system would require.

(c) The EIS design goal of no air emissions from exit portals (EIS clause 11.2) with all ventilation air carried back to the central stack would be difficult to achieve in practice with fully transverse tunnel ventilation system. Due to the piston effect from vehicle passage and general turbulence inherent in a road tunnel of this nature it is extremely difficult to ensure that vitiated air is not carried out through the exit portal unless additional exhaust stacks are provided at these locations.

Given the probable smoke exhaust requirements, it is our opinion that a semitransverse system with additional exhaust stacks at each exit portal is a more appropriate design in that it can provide enhanced system performance at a lower capital cost. This study is based on the assumption that this type of ventilation system would be used. Additionally the tunnels system incorporates a deluge system and a smoke exhaust system. As a consequence of the above systems, products of combustion are designed around a 25MW fire exhaust rate. Obviously, some elements of the tunnel are suitable for larger fire sizes.

The ventilation system will be the main divergence from the EIS (Manidis, 1994) of this report with other systems being generally in accordance with the requirements specified.

For the purposes of initial assessment the tunnel design and management details are based on the assumption of no dangerous goods entering the tunnel. This would be typical for tunnels constructed to date. Following the risk assessment of this base design, measures which could upgrade the tunnel to suit dangerous goods traffic (particularly bulk flammable loads) were identified and these are reported in **Section 8.**

5.2 INITIAL ASSUMPTIONS

5.2.1 Road Parameters

The road geometry must comply with RTA design standards for a design speed of 80 km/h. In addition to the normal sight distance requirements applying to roads the effect of walls, impact barriers and the ceiling must be taken into account when selecting horizontal and vertical curves. Sight distance for horizontal curves is to be measured along the centreline of the inside lane.

The road pavement would consist of a continuously reinforced concrete base on a drainage layer which would collect seepage under the pavement. In accordance with the EIS (clause 12.2.8) and common practice (eg Sydney Harbour Tunnel) an open graded asphalt wearing course would be provided to reduce noise within the tunnel. Light coloured aggregate would be incorporated into the open graded asphalt wearing course to increase reflectivity

A subsoil drainage system would be provided to collect groundwater from the drainage layer and convey it to the collection pits.

5.2.2 Tunnel Structure

We believe the driven sections of the tunnel, refer to **Addendum 5B** - drawings SK-01 and SK-02, would consist of two individual two lane road tunnels with the roof arch supported by rock bolting and shotcrete where necessary. Within each tunnel a suspended reinforced concrete ceiling would be provided to separate the roadway below from the ventilation space above. Tunnel equipment panel niches would be provided in the walls at 50m centres to house fire hosereels, portable extinguishers, fire telephones, etc.

Cross tunnel passages would be provided as detailed in **Section 5.2.4.**

Impact barriers (New Jersey Kerb) would be provided to protect tunnel walls and systems from vehicle impacts.

5.2.3 Drainage and Sump Pumps

The drainage system collects "clean" water from ground water seepage and "waste" water from washdown or fire fighting and spilled liquids through roadside sumps which discharge to a pipeline beneath the road pavement, refer to **Addendum 5C** - drawings M-02 and M-03. Flame traps should be installed at every second sump (i.e. 100m centres) along the pipeline except that these would be provided at every sump (i.e. 50m centres) on the inclined exit sections.

The pipeline system directs all liquids to the low point in the tunnel. As the "waste" water contains oil and other contaminants deposited in the tunnel, oil separation facilities comprising turbidity monitors, pH sensors, vapour sensors and oil separation pits would be located at the collection sump. From the sump, the waste water is then pumped to near the surface for discharge to the appropriate sewer or stormwater network if determined to be clean water, or deposited in a subsurface reservoir of nominal 25,000 litres capacity for later collection by tanker if determined to be polluted.

From the tunnel long section given in Figures 21.6 through 21.8 of the EIS the fall of the drains is 4.5% from the Western portal to Shaw Avenue (1000m approximately), 1% from Shaw Avenue to the tunnel low point near Minnamorra Avenue (1200m approximately) and 3.5% from the Eastern portal to the low point near Minnamorra Avenue (1200m approximately).

5.2.4 Fire Protection

(i) Deluge System

The fire deluge system would be installed throughout the tunnel systems and would be segmented into separately controlled zones having an area of the width of the carriageway, kerb to kerb, and a length of approximately thirty metres.

A common fire main exists in each carriageway to serve the fire deluge system, fire hydrants and hose reels. The hydraulic design of the fire main would be based on two adjacent deluge zones operating simultaneously plus one hose reel but excluding fire hydrants. It is not intended that the fire deluge system and additional fire hydrants operate simultaneously.

The deluge valves would be of the quick opening type. When held closed by water pressure, the downstream piping would remain dry until a release is activated. The valve would be capable of being remotely opened and closed.

At each deluge zone on the downstream side of the deluge valve an orifice plate would be sized and installed to limit the operation pressure at the most hydraulically disadvantaged nozzle to the required operation pressure.

The fire deluge system is an open system with discharge nozzles providing uniform distribution over the fire deluge zone at a rate of 7 litres per minute per square metre.

Operation of the Deluge System is achieved via Solenoid valves. Confirmation that the System has activated would be sent back to the Fire Indicator Panel (FIP) pressure switches on the deluge valves.

Water flow into the Tunnel Deluge Systems via each fire main feed would be monitored via a flow switch on each main feed pipe. These flow switches indicate back on the FIP.

Following acknowledgment of a fire alarm the operator would decide as to the activation of the Deluge System. The Deluge System can only be operated manually from the Central Monitoring and Control System (CMCS) or one of the FIP stations.

(ii) Smoke/Heat Detectors

Smoke detectors would be provided in all tunnel equipment panel niches and at tunnel plant areas. These detectors provide early warning of fire in critical tunnel systems allowing response to the alarm without disrupting the service or causing a hazard.

Thermal detection is provided throughout the tunnel to avoid nuisance tripping which would result if smoke detectors were used, as a result of the exhaust fumes. This type of detection is slower to operate, requiring heat generated to trigger the device.

The main Fire Indicator Panel is located in the Central Control Room with sub-indicating panels in each discrete building in the tunnel system including substations and valve houses.

(iii) Hydrants/Hosereels

Hydrant points would be provided throughout the tunnel at each tunnel equipment panel niche. Fire mains flow valves would be located in each of the valve houses with connection to the fire indicator panel.

Hose reels would be provided in all tunnel equipment panel niches (ie. at 50m centres).

(iv) Extinguishers

Dry chemical extinguishers would be provided in all tunnel equipment panel niches for use on all fires other than electrical fires. CO_2 extinguishers would be provided in the electrical section of the panels specifically for electrical fires. The panel doors would be equipped with door contacts, monitored from the Central Control Room.

Additional CO_2 extinguishers would be provided throughout the plant areas in accordance with the recommendations of AS2444 and would be located adjacent to all electrical switchboards, control panels and similar equipment.

(v) Means of Egress

Means of egress is provided to effect an orderly removal of patrons from the confines of the tunnel in safety and without panic. For this tunnel system cross tunnel passages would be provided to allow patrons to escape from the emergency tunnel to the non-emergency tunnel and hence into a safe environment.

Cross tunnel passages would be clearly identified and illuminated. They would be spaced so that, even should the smoke exhaust system fail, patrons would be able to pass to a safe environment before the fire can develop to a size, in terms of heat and smoke, which endangers those escaping before the nearest passage is reached. Based on detailed investigations undertaken for the Sydney Harbour Tunnel and consideration of international best practice on distances to cross passages, a tunnel occupant would remain in a "safe" condition in the affected tunnel by moving at a walking speed of 1.5m/s for a maximum period of 3 minutes, shortened by a 30 second reaction time to commence escape. (It should be noted that these design considerations do not take account of incidents involving Dangerous Goods.)

The maximum spacing between cross tunnel passages would therefore be spaced at a maximum of 225 m. Should tunnel features require, some lesser convenient distance may be utilised in some instances.

The minimum acceptable cross tunnel passage would be 2.4m high and 1.5m wide.

Fire rated self closing doors will be provided on cross tunnel passages.

(vi) Fire Control Rooms

Fire Control Rooms would be provided in the Ventilation Station near each portal and in the Main Control Room. This would mean that an emergency incident may be managed from either end of the tunnel section or by the tunnel Operators as best appropriate for each incident.

5.2.5 Ventilation and Smoke Exhaust

Ventilation Stations would be provided at the exhaust station at the centre of the tunnel and at the supply/exhaust stations at each tunnel portal, **Addendum 5C** - drawing M-01. Ventilation Stations would comprise fan halls with exhaust, supply and smoke spill fans, ductwork and dampers for fans isolation. The fan system would be designed such that standby capacity was provided, such that tunnel operation would not be affected during normal maintenance or repair periods.

The duty of the central fan room and stack nominated in the EIS would be reduced from ventilating the entire tunnel to exhausting the upstream halves of both the Eastbound and Westbound tunnels and supplying the central section of both tunnels.

Two extra fanrooms and stacks would be required in addition to the main central fanroom and stack as nominated in the EIS.

At the Western Portal a fan room would be provided to supply the first quarter of both the Eastbound and Westbound tunnels and to exhaust the downstream half of the Westbound tunnel.

At the Eastern Portal a fan room would be provided to supply the first quarter of both the Eastbound and Westbound tunnels and to exhaust the downstream half of the Eastbound tunnel.

Ducting throughout the tunnel would be via the void located between the tunnel roof and a suspended reinforced concrete ceiling above the roadway. This ceiling would incorporate dual purpose supply/exhaust dampers at approximately 100m centres. The system would normally operate as a distributed supply system in each tunnel with exhaust occurring at the centre and at the exit portal. The overall system would be split up into four zones each of which is independent.

In an emergency each zone can serve as a smoke exhaust system with the supply fans serving as exhaust fans in the affected zone of the tunnel. The dampers in this zone would be generally closed except where manually opened remotely by the operators to exhaust smoke from the location of a fire. Adjacent zones would continue to act to supply clean air to assist escaping patrons and to prevent backlayering of smoke.

All ducting would be fire rated for two hours.

5.2.6 Power Supply

(i) Transformer Bays

Transformer bays would be situated at each of the electrical substations and comprise two transformers positioned side by side. The transformers would be connected to separate incoming supplies to enable minimum disruption to the electrical supply in the event of failure of any part of the electrical supply system, including the incoming HV supply from the local supply authority, HV supply cables within the tunnels, the HV switchgear and the transformers. The transformers would be located in bays separate from the electrical switchgear to protect the latter from damage in the event that the transformer explodes. As an approximation, it can be assumed that transformers would occur at spacings of 800m.

(ii) Electrical Switchrooms

The electrical switchrooms would be provided, associated with substations, at locations determined by the electrical load along the motorway. Typically, the switchrooms would be located at ventilation stations and locations which maximise the efficiency of electrical distribution over the distances involved along the motorway. The switchrooms would be designed to house electrical switchboards that would provide electrical supply to all services and include redundancy of circuitry and spare capacity to achieve minimum disruption to services in the event of failure of any of the system components.

5.2.7 Tunnel Lighting

Lighting would be provided throughout the tunnel following the recommendations of "CIE88 - International Recommendations for Tunnel Lighting".

At the entrance zone to the tunnels, reinforcement lighting would be provided to adapt drivers from the external lighting conditions to the interior level of lighting. The tunnel interior lighting would be achieved by ceiling mounted luminaires. The use of reflective wall panels to increase luminance is anticipated only at tunnel entrances and not throughout the tunnel.

Tunnel lighting would be switched in steps according to the external ambient lighting conditions. The arrangements of luminaires would take into account the multi-step switching operation of the luminaires.

The individual fluorescent circuits from adjacent niche points would be overlapped so that some lighting remains in all locations of the tunnel in the event of a loss of supply from any one Uninterruptible Power Supply (UPS).

Emergency fluorescent luminaires in the tunnel would be supplied from the UPS systems to maintain critical lighting in the event of a mains power failure.

Other lighting in the tunnel would include cross passage door indicating lights, exit signs, emergency strobes and plant room lighting.

5.3 MANAGEMENT CONSIDERATIONS

5.3.1 Emergency Systems and Response

Management Systems would be as follows:

(i) Traffic Control Signals and Variable Message Signs

Traffic control signals would be provided throughout the tunnel at 100m centres along straight sections of carriageway. The signals comprise red X, flashing amber and green arrow combinations.

Variable Message Signs (VMS) would be provided at 100m centres. The VMS is capable of displaying messages either from a precompiled selection or any other display manually keyed in from the Central Control Room provided the message length is compatible with the display length.

(ii) Telephones

Telephone systems include PABX, fire telephones, motorist emergency telephones and provision for mobile telephone transmission and reception. A PABX system is provided for maintenance personnel use from the various equipment rooms and is not available for public use.

A fire telephone system would be installed within the tunnel. A fire telephone handset would be provided for use by authorised personnel during a fire at every second niche in the tunnel (ie. at 100m centres), at each mimic panel and fire control panel. The fire telephone system would comprise a self contained switching panel located adjacent to the fire indicator panel together with handsets, independent of all other telephone and electrical services, battery operated under emergency conditions. Each handset is separately connected to the switching panel.

Motorist emergency telephones (METS) are provided at all tunnel equipment panel niches to report accidents or request assistance. This system is independent of other communications systems with telephones connected to separate lines in each tube of the tunnel connected to the operators console in the Central Control Room. Each handset features auto-dial and identification.

(iii) Radio Communications Systems

Radio communication systems includes radio broadcasting of AM radio stations and rebroadcasting of FM radio stations, tunnel operations and emergency services to provide continuity of each service within and outside the tunnels.

Radio rebroadcasting allows the continuance of AM/FM programme material and selected emergency services during the period of travel within the tunnel. It also provides a means of communication with drivers listening to the radio in the event of an emergency by overriding programme material with advisory messages to direct drivers in an appropriate course of action with respect to the emergency.

The system covers all AM/FM broadcast frequencies available in the locality including various emergency organisation frequencies (ambulance, police) and permits the operation of mobile phones.

Tunnel operations radio includes a base station within the Central Control Room and a number of hand held mobile stations allowing base to mobile, mobile to base and mobile to mobile communication within and outside the tunnels.

(iv) CCTV

CCTV cameras would be usually spaced at approximately 150m centres along the tunnels, depending on tunnel features (line of sight, curves etc), individually circuited to the Central Control Room via multicore multimode optic fibre cable. Cameras at the tunnel portals have pan/tilt/zoom capability while cameras in the tunnel would be fixed. TV screens would be provided in the Central Control Room.

(v) Emergency Response

In the event of a major emergency such as fire, major vehicle accident or acts of sabotage, the systems detailed in this report would operate as follows:

Detection

Detection would occur through 24 hour surveillance of the tunnel using the CCTV system or alternatively, activation of heat or smoke detectors in the event of a fire, activation of a motorist emergency telephone, or alarm signal from a fire hydrant/hose reel/extinguisher panel door.

Response

Response to an emergency incident would be through activation of a number of system elements:

- Notification of the emergency to the appropriate emergency response elements would be the responsibility of the tunnel operator after detection.

- The radio rebroadcast system would be utilised to notify patrons of the incident and the appropriate response.

- The VMS system would display messages notifying patrons of the emergency and the appropriate response.

- Emergency lighting systems would be activated if required.

- Patrons would use the egress options afforded as appropriate.

Emergency Containment

- The emergency incident would be attended by emergency response vehicles (ambulance, fire etc.)

- Flame traps would help to prevent the spread of burning liquid fuels.

- Equipment facilities provided would be utilised to facilitate emergency incident containment (ie. hydrants, hose reels, fire extinguishers, fire telephone system, fire control rooms).

Tunnel Closure

When an incident occurs the Traffic Control Signals and Variable Message Signs could be used to stop traffic entering the tunnel.

The entry of Westbound traffic could be stopped at Marsh Street and the Princes Highway by traffic lights or emergency services.

In the case of the Eastbound traffic all vehicles could be diverted by emergency services to exit onto Bexley Road.

There would be no interlocks between the shutdown process and the ventilation, fire detection or deluge systems. This function would be carried out by the operators.

5.3.2 Maintenance

Maintenance requirements for the traffic areas of the tunnel would be limited to replacement of nonfunctioning fluorescent tubes, periodic cleaning of road surface, periodic cleaning of reflective wall panels near tunnel entrances and repair of any damaged equipment.

Lighting would be offset from the tunnel centreline where possible to allow the replacement of fluorescent tubes to be achieved without the closure of both traffic lanes. Road surface and wall panels would be cleaned by water spraying and/or brushing from a specially designed maintenance vehicle. Repair of damaged equipment would be carried out where possible with the closure of only one lane with restricted speed traffic continuing in the other lane and/or work would be carried out at night. Where this is not possible and urgent repair work is needed the tunnel would have to be closed down.

Maintenance requirements for the non-traffic areas would consist mainly of periodic maintenance and lubrication of fan and pump equipment. This would be largely carried out on equipment whenever that particular unit is serving in a standby capacity and would not effect tunnel operation.

6. HAZARD ANALYSIS AND RISK ASSESSMENT

6.1 METHODOLOGY

6.1.1 Special Features of the Study

This study differs from other risk assessments in that it is neither simply a comparative assessment of the type commonly used for route selection nor a quantification of risk from a single system for comparison with risk acceptability criteria. The objectives of the study were such that, as well as developing a basis for the comparison of routes to establish which might be the least risk routes for Dangerous Goods transportation as a whole, the analysis should provide the basis for decisions on which, if any, of the classes should be excluded from the tunnel and what design and management features should be adopted to minimise risk to people, to the tunnel fabric and to the biophysical environment.

The tunnel environment is significantly different to the usual open air circumstances associated with transportation incidents. The physical attributes - such as fire behaviour and intensity, dispersion of gases and vapours, and explosion overpressures and projectiles - of given incidents are likely therefore to be significantly different in the tunnel. These differences and the extent to which they can be influenced by tunnel design and operation necessitate a more comprehensive analysis of the types of incidents that could occur during the transportation of DG's than would be the case for simple comparison of open air routes. In particular the consequences of relatively small scale releases warrants consideration due to the potential for confinement of gases and vapours and the channelling of heat, fire, blast overpressure, fragments, gases, smoke etc along the course of the tunnel.

As input on design and management is required, it was also not appropriate for classes of materials to be entirely excluded from the consequence analysis on the grounds of low frequency of movements and therefore low risk. The current pattern of transport may change and, consistent with the principle of 'avoiding avoidable risk', the full range of possible consequences should be allowed for as far as practicable in the tunnel design.

A further consideration is that there may be differences between the overall risk results and the results for separate classes of goods or types of hazards. Whilst the overall risk assessment might indicate that the M5 route is a lower risk or higher risk route than the urban arterial routes, it is possible that due to the tunnel environment for some classes of materials or some materials within classes the opposite result might hold. It is worth noting in this regard that the codes covering the transport of DG's and specifying the design of packages and vessels, the limits on load sizes and controls on compatibility of loads etc have not been developed with the enclosed environment of tunnels specifically in mind.

Whilst a more comprehensive analysis may be warranted it is still of course not possible to cover every permutation and combination of events. Simplifying assumptions still have to be made and representative cases and materials selected. There is also a need to limit the scope of the exercise by excluding, for example, cases where the likelihood of the circumstances arising which could lead to an adverse outcome is clearly so low that it can be considered to be non-credible or there is likely to be no effective difference between the routes being compared.

It should be noted that a requirement for this study was that it be carried out in a relatively limited time frame and the opportunities for original data collection and data verification were therefore significantly constrained.

6.1.2 Overall Approach

For transport risk assessment studies, the analysis is often organised by type of hazardous incident or consequence eg fire, explosion, toxic release etc. The hazard identification and subsequent stages of the analysis have been organised on the basis of DG classes as control by class is generally considered to be the most practicable basis for operating any restriction on tunnel use.

The classification of materials into classes is inevitably somewhat arbitrary as every material has its own unique properties and many have more than one attribute which could cause death or injury, damage to property or harm to the biophysical environment. It is possible however to select materials which adequately cover the hazardous consequences of release incidents and to use those to represent the whole of that class.

6.1.3 Hazard Identification

The hazard identification involved at the generalised level: analysis of the numbers and volumes of DG loads and the mode of carriage (bulk or packaged); analysis of the road types and the differences between the existing urban arterial roads and the open and tunnel sections of the proposed motorway; analysis of the possible initiating events for incidents involving DG's including crashes and releases without prior crash; identification of the possible incident modes from bulk and packaged loads; and consideration of the presence of possible ignition sources.

The conclusions of this analysis were then applied to the each DG Class and sub-class and representative materials and load sizes selected. The representative loads selected for the open air sections of the road were more limited than those for the tunnel as it was concluded that many events which may be significantly hazardous in the enclosed conditions of the tunnel would not be so in the open.

The selection of representative materials was based on their significance amongst loads of that class and type and on the ability of the materials to adequately represent all relevant aspects of events involving the materials to be covered.

In making these decisions the approach of being conservative but realistic has been adopted: in other words the materials selected tend to be at the more hazardous end of the materials known or believed to be likely to be carried through the area but materials have not been selected which while they may be more hazardous are either not carried or are not carried sufficiently frequently to be major contributors to risk.

A number of limitations and exclusions were adopted to filter out cases not considered relevant to the analysis. These were:

- Exclusion of events involving the coincident release of more than one hazardous material where the materials were not likely to be on the same load were excluded eg calcium hypochlorite and acid. Where materials are incompatible with petroleum fuel or with materials likely to be part of the fabric of motor vehicles or of the roadway/tunnel this incompatibility has been included in the analysis. This exclusion is considered appropriate as the DG traffic density taken together with crash rates and other release incident rates means that such incidents are so unlikely as to not be significant contributors to risk. This exclusion is further justified as the consequences of incidents which could theoretically be caused by such coincident releases would be represented by other incidents to be included in the analysis and in most if not all cases the single material release incidents to be modelled would be clearly the worse cases. (This exclusion does not include the subsequent propagation of incident involving one load initially to other loads within its effect area.)

- Exclusion of consideration of consequences on the grounds that people can't be killed twice ie if one hazardous consequence of an incident is clearly more extensive and severe than another of the same incident consideration of the lesser consequence would amount to double counting eg physical or cryogenic impact from the release of a toxic gas.

- Exclusion of direct crash effects which are in practice not dissimilar to motor vehicle accidents not involving DG's. The principal potential to cause death or injury to other road users in crashes is the mechanical impact of the crash. Additionally, all vehicles carry hazardous materials in the form of flammable or combustible fuels and non-hazardous loads can cause injury through physical impact and possibly suffocation and these have potential to inflict harm on those directly involved in the crash (except for other DG loads). It is considered appropriate therefore to exclude any DG release which would not have an effect beyond 5 metres (one car length) of the DG vehicle. To the extent that a route has a lower crash rate, as do motorways generally when compared with urban arterial roads, the exclusion of the risk attributable to the direct contact effects of DG's (such as being splashed by a corrosive or a dermally toxic substance) would tend to underestimate the risk differential between the routes to the disadvantage of the lower crash frequency route. It was considered unlikely that this effect would be significant.

- The analysis has also not included consideration of chronic effects such as changes in carcinogenicity risk. It was considered that the analysis of acute effects from the range of release case studied would adequately represent the potential for adverse impact and enable the relevant questions to be answered. The consideration of injurious levels of exposure in any event does implicitly involve allowance for some chronic impacts.

The potential influence of these exclusion assumptions on risk results has been considered as part of the ongoing sensitivity analysis throughout the course of the study.

It has been assumed that loads are normally carried in accordance with DG regulations. Some degree of failure to comply with the regulations is however taken into account in the probabilities used in the likelihood analysis as they are based on real incident experience.

6.1.4 Consequence Analysis

The representative loads were developed into scenarios for the consequence and subsequent likelihood analysis using event trees. For each load a tree was developed following through from the movement of the load to the range of credible outcomes including safe completion of the journey.

The development of the release event scenarios drew upon precedents set in previous studies undertaken by McCracken Consulting and others in this country and overseas. Available incident information from this country and overseas was also utilised.

It was concluded in the course of the hazard identification that the issue of the comparative potential for adverse effects of DG releases on the biophysical environment could be best addressed by examination of the relative degrees of control as all the routes essentially drain to the same waters. The potential for releases to the aquatic environment was accordingly covered by separate analysis.

The consequences of the open air scenarios, covering both the existing urban arterial routes and the open section of the M5, were assessed using well established modelling techniques applicable to any releases in the open with modifications as necessary to deal with features found in the transport context such as the absence of secondary containment and lack of control over ignition sources.

For the incidents in the tunnel, analytical 'models' and approaches were developed drawing on the literature on fires and DG releases in tunnels together with McCracken Consulting's models for dispersion in tunnels and first principles. Pool sizes, evaporation rates, dispersion and the concentration of toxic and flammable vapours in the tunnel air, and smoke concentrations and heat output etc., were then estimated using these various approaches.

The approach taken in the analysis, as far as practicable, was to start with the larger credible release events and to work down to smaller events only if consequences of concern were found in the larger cases.

For both the open air and tunnel cases the consequences in terms of physical effects eg extent of the fire, distances to levels of radiant heat output, distances to flammable or toxic concentrations and the duration of events had to be translated into effects on people and property (principally the tunnel structure). As already noted the effects on the biophysical environment were singled out for separate treatment. In the case of effects on people, the analysis involved overlaying the physical consequence footprints over the roadways (including the tunnel) and surrounding lands as applicable and applying relevant criteria for time related exposure to doses of heat or toxicants and explosion overpressure etc. to determine the fatality and injury outcomes that would be likely to result from particular incidents. For the tunnel infrastructure impacts, the results of the physical consequence assessments were supplied to Acer Wargon Chapman who advised on the likely effects of such physical consequences.

The implications of the location of incidents in the tunnel relative to the road and tunnel slope and the operation of the ventilation and drainage systems were considered for each load scenario.

In order to determine the likely numbers of people within the footprints, census data was used to establish population densities along the routes. Road users within the footprints were estimated using traffic densities and vehicle occupancy factors for peak period and daytime average. The vehicle occupancy factor was adjusted upwards to allow for a conservatively high number of multiple passenger vehicles (buses) in the traffic.

The possible presence of other DG loads in the traffic in the vicinity of the incident and its possible subsequent involvement was also considered with particular attention to incidents occurring in the tunnel. Consideration of secondary motor vehicle accidents and their direct consequences was excluded on the grounds that such accidents could be the same for crashes not involving DG's. Detailed consideration of the consequences in terms of damage to vehicles and their loads due to fire or explosion was also excluded from the analysis.

6.1.5 Likelihood Analysis

The likelihood analysis consisted of deriving or extracting frequencies and probabilities and applying them to the event trees. The starting point for all the trees was the frequency of DG movements for the particular class which was apportioned across the representative loads. Other figures used included: proportions of loads packaged and bulk; crash rates; the probabilities of releases due to crashes or other causes; and ignition probabilities.

The figures were drawn from a range of sources including: surveys carried out for this study; other studies/surveys of DG transport in the region and NSW more widely; overseas transportation and tunnel studies; and generic data. In some cases it was possible to use data directly whilst in others some adjustments were necessary to allow for differences between this case and those to which the other figures related.

6.1.6 Risk Estimation

Risk estimation involved the combination of the results of the consequence and frequency analysis to generate societal risk results and F-N curves for each of the routes overall and for each class.

6.1.7 Risk Assessment

The societal risk results for each class and DG's overall for each route were compared and conclusions drawn as to the least risk routes.

Individual risk was considered for the areas around the exhaust ventilation points but not for the tunnel or the road ways themselves.

6.1.8 Sensitivity Analysis

The sensitivity of the results to changes in assumptions or analytical approaches was considered as a routine part of the hazard identification, the consequence analysis and the likelihood analysis. Where risk results were likely to be influential in the development of recommendations and conclusions their sensitivity to changes in assumptions and values used was further reviewed.

6.1.9 Conclusions and the Development of Recommendations

The findings of each stage of the analysis were used as inputs to the process of considering appropriate tunnel design and operating features. Proposed management arrangements, emergency procedures and tunnel design features were reviewed and opportunities identified for the minimisation of the likelihood or consequences of potential hazardous incidents.

The principles of 'avoiding avoidable risk' and sound emergency management were applied in this process as well the comparisons of relative risk outcomes and consideration in the context of criteria levels used internationally.

Findings and recommendations were then developed collaboratively with all members of the consultancy team.

6.2 HAZARD IDENTIFICATION

6.2.1 Analysis of Loads Carried

As indicated in Section 3.2.2 a 24 hour traffic count was carried out for this study on Monday 20 and Tuesday 21 February 1995. That count identified DG trucks by class from placarding. The results of the survey are contained in **Addendum 3B.**

As this traffic count covered only one 24 hour period and the actual numbers of vehicles involved is small, the possibility that it may not accurately represent DG movements had to be considered and the validity of the numbers checked against other available figures. The survey results were therefore compared with those of other studies and surveys including: the responses to the Industry Survey described in **Section 3.6**; a wider survey of DG transport carried out by the EPA in 1992; the Considine *et al* UK study of DG transport through tunnels (1989), the UK Health Safety Commission DG transport study(1991), the international DG transportation risk assessment study reported in Saccomano *et al* (1993) and the Dutch experience as reported in Swart (1990).

On the basis of these figures the general accuracy of the 24 hour survey was confirmed and minor adjustments were made to the figures to round them to whole numbers and to more realistically reflect movements of Class 6 materials. The adjustment to the Class 6 numbers was drawn from the Class 9 category. The numbers of movements recorded as being in Class 9 in the survey included those showing the mixed load placard. As the Class 9 was not considered to warrant separate analysis because the hazards associated with this class were adequately represented by other classes and a substantial proportion of the movements are believed to have been mixed packaged loads, the balance of Class 9 was distributed across the other classes in proportion to the packaged load shares found in the 24 hour survey. A final adjustment was made by assuming one load per week of Class 1 materials. The final figures adopted for use in the study are set out in the **Table 6.1** below and the calculation process and survey and intermediate figures are set out in detail in **Appendix 6A.**

TABLE 6.1
ADJUSTED DG PROPORTIONS

Class	1 Expl.	2 Gas	3 Flam. Liq.	4 Flam. Sol.	5 Oxid. Sub.	6 Pois. Infec.	7 Rad. Act.	8 Corr.	9 Misc.	Total
Adjusted DG Proportions	0.08	18	56.92	2.5	3.5	3	-	16	-	100

For the purposes of the study it has been assumed that the proportion of DG traffic to all traffic is constant over time and that the proportions of classes of DG's also remain constant.

6.2.2 Road Types

The Southern and Northern Routes are urban arterial roads. The section of M5 East Motorway route common to the Southern Route is urban arterial, whilst the M5 East Motorway has expressway conditions with a 3 kilometre tunnel. The roads are described in **Section 2**.

For the purposes of this study the significance of the differences in the road types are:

- differences in the type and frequency of crashes, and
- differences in the consequences of potential releases of hazardous materials.

The motorway would be expected to have a lower crash frequency and some types of crashes are not possible (or very unlikely) due to the separation of directional flows, absence of intersections, no obstruction due to parking/standing of vehicles (except in the event of breakdowns and emergencies), and good road surfaces and road geometry etc.

In terms of the consequences of release, the urban arterial roads have the advantage of being in the open but there are also people on footpaths and in dwellings, schools, shops etc in close proximity to the road. In contrast, the open section of the motorway would be relatively well separated from people in houses, in other development and in the open along its route. The tunnel section of the motorway would be completely separated from surrounding lands except at the portals and exhaust vent(s). The tunnel is also a managed section of road with emergency planning, early incident detection and response, deluges emergency ventilation etc. On the other hand the tunnel has the disadvantage of being enclosed which would affect fire and explosion behaviour and dispersion, of gases, vapours and smoke.

For the urban arterial road sections released liquids and dense gases would flow to existing network of stormwater drains, Cup and Saucer, Bardwell and Wolli Creeks and the Cooks River to Botany Bay. The drainage system for the open section of the motorway would drain to gross pollution traps and thence to Wolli Creek and the Cooks River. The tunnel section would drain via sumps and pumps to a holding tank etc. as described in **Section 5**.

On the urban arterial roads, vehicles could in some circumstances leave the road and release their contents directly inside the confines of surrounding properties. Whilst this may be possible in extreme circumstances on the open section of the motorway it would seem extremely unlikely. The exception to this is the elevated section of road where it may be possible for tankers and trucks to leave the road and fall directly into properties below. In the tunnel it is of course not a possibility.

6.2.3 Initiating Events

Initiating events can be divided into two classes: crashes, and release events not involving a prior crash.

(i) Crashes

Crashes can be described as rollovers, collisions with other vehicles, and collisions with fixed/stationary objects. Vehicle to vehicle collisions can involve head on, side on, side swipe and front to rear impacts. Collisions with fixed objects can involve a number of different modes of impact including side swiping as well as more solid impacts.

All modes of crash are possible on the urban arterial road sections.

On the motorway head on collisions should be relatively rare events. Head on collisions are not however impossible as people from time to time deliberately or accidentally drive in the wrong direction on motorways and where there are no complete physical barriers between the carriageways vehicles do from time to time cross into the oncoming stream. Where such crossovers occur the resulting collisions are typically at higher velocities than would be the case for head-ons on urban arterial roads. Similarly the absence of intersections should mean that side on impacts are not possible on the motorway except on rare occasions where vehicles cross the centre divide in the open section or jack knife type events in open section or the tunnel.

Sideswiping would be possible on the motorway under the rare conditions described for head on or side impacts or could occur between vehicles travelling in the same direction both in the open section and in the tunnel. Under such circumstances the sideswiping may not be noticed by one or both drivers - it also may not be registered in crash statistics.

Front to rear impacts are certainly credible events on the motorway either with both vehicles moving or the front vehicle stationary due to traffic congestion, crash or breakdown. Collision with a stationary vehicle could also occur as a result of maintenance operations.

In terms of collision with a fixed object, on the urban arterial road the possibilities are again many - electricity and lighting posts, structures for signs, walls and embankments, support structures for bridges and buildings of various types. On the motorway, again the opportunities for such collisions would be more limited. power poles and the like will largely be absent and where poles are to be placed in relatively close proximity to the carriage way they would be expected to be of a modern frangible type that would tend to yield on impact. Within the tunnel, provided that vehicles are not over height, the potential for collision should be limited to impact with the walls.

As indicated in **section 5** the walls will be free of solid fixtures and will have New Jersey Kerb installed at their bases so that any collisions should largely be of a glancing type. Refuge bays may provide a point where the angle of impact would be less acute but these represent a small proportion of the total road length and can be designed so that the walls run into the bay on a gradual angle particularly on the downstream side. The portals are also to be designed to ensure that there are no points where an errant vehicle would meet head on with a solid wall or other structure.

One feature of the tunnel section with potential to increase the likelihood of driver error and crashes is the change of light on entering the tunnel. For the purposes of this study it has been assumed, as described in **Section 5.2.7**, that the lighting design will minimise this effect The tunnel environment may also have some potential to induce crashes through the sudden failure of lighting or impairment of visibility due to smoke. Reliability of the lighting system and adequacy of the smoke ventilation system are also therefore matters which need to be addressed in the tunnel design and operating systems. Reliability of the lighting system is assumed to be addressed by overlapping of circuits, dual Uninterruptible Power Supplies supplemented by the provision of emergency lighting. The reliability and adequacy of the ventilation system are addressed further in the consequence and frequency analysis.

As the M5 would be a new road designed with the benefit of current knowledge and materials unlike the existing arterial roads which are a product of historical evolution, the curvatures should be appropriate to speed, and good surfaces therefore crash frequency should be less. In the tunnel the absence of rain should also serve to reduce crash likelihood. There is also evidence that tunnel crash rates may be lower than on equivalent roads due to factors including lack of distraction of the drivers.

The specific tunnel systems and features assumed to be adopted for the purposes of this analysis are indicated in **Section 5** and the crash frequencies and issues of system reliability are covered in **Section 6.4.3** as well as in the balance of this section and the **Section 6.3** on consequence analysis.

(ii) Release Without Prior Crash

It is important to recognise that incidents involving the release of Dangerous Goods during transport is not solely due to vehicle crashes. Significant releases can result from loss of containment or loss of part of a packaged load with consequent loss of containment without the vehicle carrying the load being involved in a prior or subsequent crash.

Packaged loads can fall from trucks if they are not adequately secured or the securing mechanism fails. Lost packages can rupture or suffer valve damage on impact with the road surface, other stationary objects or structures (such as a tunnel wall) or on subsequent impact by another vehicle.

Leakage can occur from tankers due for example to a valve not having been properly closed after filling or failing in transit or gasket/seal failure or corrosion or failure of a tank seam or pipework etc. For packaged goods, including gas cylinders, leakage could result from valve or seal failure on cylinders or minibulks, or from leakage from holes in drums or minibulks (including seam failure etc). There is also the potential for bulk vessels or packages to rupture or vent injurious or corrosive fumes if incompatibles are mixed in loading or the package or vessel material is incompatible with the contents. Ruptures or venting of fumes could also occur due to polymerisation or decomposition triggered by the heat of the sun prior to entry to the tunnel or the motion of the truck. The proximity to the CIA and the Port and hence the filling/loading point of the materials makes this a more credible event in this area than it would be at some more distant location. Solids can also be released from damaged packaging though releases are likely to be too small except possibly for very active materials such as biocides. There is also some potential for released material to penetrate the packaging of another material with adverse consequences such as fire or gas/fume production. In general however the Australian Dangerous Goods Code (ADGC) provisions limit the likelihood of substantial quantities of incompatible materials being in the same load in packaging forms which would be vulnerable. It is however worth noting that the ADGC was not expressly drafted with enclosed spaces such as tunnels in mind and that therefore the limiting quantities set may not be appropriate to the tunnel environment.

A further possibility is a fire in some part of the truck (tyres, fuel system, electrics etc.) and spreading to involve the load or triggering venting of the load due to direct thermal effects or polymerisation. A fire could also occur in some part of the load itself.

6.2.4 Mode of Loss of Containment

(i) Bulk Loads

Losses from bulk gas loads could theoretically involve instantaneous release of the entire contents of the vessel or release from different size orifices in the tank shell (due to impact damage etc.) or from relief valves or from loading/discharge valves or associated pipework. Heating of the vessel during any fire event could also result in releases from relief valves or catastrophic failure of the tank.

Release rates would depend *inter alia* on the size of the orifice, storage pressure and available heat (for expansion of the gas). Release volumes would depend on the release rates and the duration of the release. For liquefied gases the released material could be in liquid form if the source of the release is below the liquid level - this could include points which would normally draw from the vapour space, such as the relief valve if the tanker were on its side or inverted. The behaviour of the released gas or liquefied gas on release would depend on the pressure of the release and the orifice size etc. but also on the density of the gas, ambient and road surface temperatures and the wind speed and degree of turbulence in the outside case and the ventilation rates in the case of the tunnel.

Gases which are heavier than air and liquefied gases will tend to pool and to flow downhill, pools of liquid and gas could form until drained away or vapourised or dispersed by air movement. In the open air lighter than air gases will tend to rise and disperse rapidly but in a confined area such as the tunnel such gases will tend to rise to the tunnel roof and flow uphill.

Gas tankers and isotank pressure vessels are of very robust construction and the likelihood of puncture or rupture under crash conditions has been shown to be relatively low.

In the case of bulk liquids, tankers are usually compartmented with compartments typically in the 5,000 to 8,000 litre range. In circumstances where the hole or valve or pipework failure effect only one compartment, the total potential release quantities would be limited to the contents of the single compartment. However in rollover incidents, sideswiping and high momentum crashes of all kinds it is possible for several or all compartments to be involved and the maximum release therefore to be the entire contents of the tanker.

Released liquids would flow to stormwater drains pooling at low points. Evaporation would occur on release and from flowing liquid and liquid pools. The extent of vapour generation would depend on ambient and road surface temperatures, the vapour pressure of the liquid and the air flow across the surface of the liquid. As with gases, dense vapours would tend to flow downhill while lighter than air vapours would tend to rise, dispersing safely in the open but possibly presenting a problem in the confines of the tunnel.

On the urban arterial roads and the elevated sections of the M5 it would be possible for a tanker leaving the road to spill its load outside the confines of the roadway and under these circumstances the road drainage system would not necessarily be relevant and the potential exposure of people to direct contact with the released material or its vapours.

Liquids retained in a tank but exposed to atmosphere could still be a source of vapours and if flammable or combustible could contribute to fire. Fire could also lead to additional releases of materials due to additional damage to the vessel fabric (often relatively lightweight aluminium in the case of fuel tankers).

(ii) Packaged Goods

The increasing usage of 'minibulks' of one, two or even three thousand litres capacity to replace 200 litre drums and to some extent bulk tanker transportation has somewhat blurred the distinction between packaged and bulk transportation. For the purposes of this study however minibulks have been included in the packaged goods category because they have more in common with that category than with bulk tankers in terms of the modes of release - the quantities which can be released from a single 'package' is in fact the main difference.

The likelihood and consequences of releases from packaged goods is largely determined by how the load is secured or contained on the truck. Where the packaged goods are within shipping containers or a fully gated and tarped truck or a 'taut liner' (one with tensioned roll down sides) the chances of a package falling from a truck would be reduced significantly. For leakage without dislodgement from the truck, transport inside a shipping container also provides some secondary containment and can prevent release to the outside or reduces the rate of release. In crash events including sideswiping and rollover, packaged goods within shipping containers are also less likely to be damaged and some secondary containment may be provided.

Gases are transported in a range of small pressure vessels referred to as cylinders or drums with capacities of up to 920 kilograms. They are generally of robust construction and can withstand quite severe impacts. They can however have valve problems, can release from pressure relief vents, can develop leaks of large or small size and can on occasion fail catastrophically. It would be possible for several vessels to be damaged sufficiently to release substantial proportions of their contents in the event of high momentum collisions, rollovers or sideswipes or the loss of a number of cylinders due to restraint failure or the like. It is unlikely that all vessels in a load would be sufficiently damaged to release contents. If involved in fire, however, the possibility exists for multiple cylinder failure over a period of time.

The behaviour of released gases has been discussed above for the bulk load case. Obviously the main significant difference between the bulk and packaged cases is the load size and the size of possible release events. In many instances gas released from cylinders in the open would disperse safely though the more toxic materials, particularly the dense gases, do have significant potential for injury and fatality consequences over some considerable distances. In the confinement of the tunnel the release of smaller quantities has greater potential for harm to tunnel users.

Packaging for liquids is generally much less robust than packaging for gases and it is entirely credible therefore for multiple package failure to occur during a crash event, particularly a rollover. Similarly in the case of restraint failure a relatively high rate of failure on impact with the road way could be expected in many forms of packaging.

In the case of leakage without a crash the maximum releases size would generally be confined to the contents of a single package although if the cause of package failure were common to a number of packages, such as contamination or package in drums of the wrong material, then multiple package failures could occur.

The behaviour of liquids on release has been described in section 6.2.3.1. As with gases, in many instances the quantities involved in releases in the open may not be significant but in the tunnel they may require more careful consideration.

In the event of a fire engulfing a truck, multiple package failure could occur including violent rupture of drums and drum rocketing where flammable or combustible liquids in steel drums were involved.

In the case of solids, high velocity or high momentum crashes, rollovers and sideswipes there is potential for release of substantial quantities of solid materials particularly when stored in paper or plastic sacks or bulkibags/boxes. Where the solids involved are granular or in solid masses the dispersion of the solid is likely to be extremely limited. In the case of fine powders the dynamics of the crash may lead to considerable dispersion of the material and wind may also carry fine powders away for some considerable distance. In the open, rain may also play a significant part in mobilising the solid material either in dissolved or entrained form. In the tunnel deluges could have a similar effect.

Aerosol packages are a special case as they are solids and liquids mixed with a liquefied gaseous propellant. In the event of rollover or other major crash the potential exists for releases of substantial quantities of the contents of numerous aerosol cans.

Some forms of packaging such as glass bottles or plastic retail packages would also be prone to multiple failure in the event of a rollover or other form of crash.

6.2.5 Ignition Sources

For incidents involving the release of flammable materials the likelihood of ignition is an important consideration. For some loads or where incompatible materials are combined fires or explosions may be initiated without external sources of ignition. For most materials however independent ignition sources are necessary and the likelihood of ignition is determined by the presence and strength of ignition sources within flammable or explosive atmospheres. By definition flammable gases and vapours from flammable liquids are readily ignitable and weak ignition sources would be sufficient in many instances.

On the open air sections and in the tunnel motor vehicles (engines and electrical systems etc.) are relatively strong and always present. Smoking in vehicles adds a further strong ignition source. Where there are a number of running motor vehicles within a flammable atmosphere ignition would be expected to be common.

In crash incidents or where packages fall from trucks sparks occur due to mechanical impact. In crashes damage to electrical systems etc would also increase the likelihood of ignition. For the open air sections the cooking and other appliances in houses, commercial and industrial premises etc. including continuously ignited pilot lights could also be sources of ignition. The tunnel would be free from these sources but the lighting, VMS's and communications fittings etc. could be ignition sources as could static electricity sparks in the ventilation system and the electrics in the fan houses.

6.2.6 Hazard Identification by Class

The likelihood and potential consequences of release events will depend on the characteristics of the materials involved, the way in which they are transported, the quantities released and the way in which they are released. The following discussion considers materials by Dangerous Goods class and covers the potential for adverse impact on people, property and the biophysical environment. The mechanisms for adverse impact considered include: heat radiation and direct involvement in fire, explosion overpressure and projectiles, exposure to toxic concentrations in the air or water, chemical or cryogenic burns and physical impact. The discussion is necessarily generalised as the actual loads carried, the way in which they are packaged and the quantities carried will vary widely, particularly for some classes of goods.

The *Australian Dangerous Goods Code* (ADGC) in line with international classification divides Dangerous Goods into 9 classes. The classes are:

- Class 1 explosives;
- Class 2 gases which have been compressed liquefied or dissolved under pressure;
- Class 3 flammable liquids;
- Class 4 flammable solids, substances liable to spontaneous combustion and substances which in contact with water emit flammable gases;
- Class 5 oxidising agents and organic peroxides;
- Class 6 poisonous (toxic) and infectious substances;
- Class 7 radioactive substances;
- Class 8 corrosive substances;
- Class 9 miscellaneous Dangerous Goods.

A number of the classes are subdivided to distinguish differences in the type and level of hazard associated with different sets of materials falling within the class. **Addendum 6A** sets out in brief the classes and the definitions of the materials within each class and sub class.

<u>(i) Class 1 - Explosives</u>

The explosives category covers a range of materials with differing sensitivity and explosion hazards. There are 6 sub classes: 1.1 substances and articles which have a mass explosion hazard; 1.2 substances and articles which have a projection hazard but not a mass explosion hazard; 1.3 substances and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard, or both, but not a mass explosion hazard; 1.4 substances and articles which present no significant hazard; 1.5 very insensitive substances which have a mass explosion hazard; 1.6 extremely insensitive articles which do not have a mass explosion hazard.

The materials with the most potential for harm are those with a mass explosion hazard (Class 1.1) such as TNT and ANFO. Other sub categories cover materials such as munitions, display fireworks, toy fireworks and materials which due to their packaging or inherent properties are explosive under circumstances which are not likely to arise during transport. Generally the hazard diminishes from Class 1.1 to Class 1.6.

The extent of transportation of explosives of any type through this area would appear to be very limited. The surveys and investigations for this study did not identify any movements of class 1 materials on the routes nor manufacturing of explosives in the CIA. It is considered unlikely that any explosives manufacturing facility would be established there in the future. Similarly no defence establishments which would routinely handle substantial quantities of munitions were identified in the Botany Region.

Explosives are however used from time to time in construction and demolition projects in the areas served by the subject routes including within the CIA and Port Botany. (If the proposed LPG storage caverns were to be constructed, for example, considerable quantities of explosives would be used and depending on the source and type this could involve the transportation of Class 1 materials along the subject routes.) Tight quantity restrictions for Class 1 materials in ports ensure that there would be little if any movement of the higher hazard materials through the Port.

From time to time however these materials may be imported through the airport. The possibility of the use of the Port for military purposes and the transport of munitions along these routes also cannot be entirely ruled out, although except in time of crisis it would be expected to be a rare event. Class 1.3 fireworks could pass along these routes from time to time for special events although this too would be rare given the location of the production facilities and the most likely locations for such displays.

Classes 1.4 and 1.6 can effectively be disregarded as hazards for both the arterial roads and the tunnel because of the low level of consequences of any incident involving these materials. In the quantities which could be carried by truck, Class 1.5 materials can be similarly disregarded.

The remaining three sub-classes have rather more potential for harm. In each case there is some potential for detonation due to impact during collision or rollover and/or due to involvement in fire.

For Class 1.3, on open sections of road, the hazard would largely be confined to other road users, particularly those involved in any collision. In general there would however be expected to be sufficient time for most people to take evasive action. Whilst there is some potential for impact over small areas at some distance from the affected truck eg if display fireworks of the mortar variety were involved, it is considered that the individual risk levels along the route from this source would be negligible given the extent of safety precautions associated with the transport of these materials and the low frequency of transportation. In the tunnel on the other hand, there is the potential for people to be more restricted in terms of the opportunity to take evasive action and for the event to be more intense due to deflection of blast and fragments along the line of the tunnel and to turn the fire and explosive force back on the load leading to more rapid involvement of the whole load.

In the open the intense fire which could result from an incident involving these materials would also be of less significance for personal safety than it would be in the tunnel. If the volumes of materials were large enough, the fire intensity could also be sufficient to cause significant damage to the tunnel structure.

For Class 1.1 and 1.2 the potential exists for major consequences, depending on the size of the load carried. (The maximum civil load size is limited under the Australian Explosives Code to 15 tonnes NEQ but current NSW restrictions limit the maximum civil load in the metropolitan area to 6 tonnes. It is understood, however, that moves to national uniformity may in future result in the 15 tonnes limit applying in the metropolitan area.). There could be significant impacts on road users and in surrounding areas for incidents occurring on the open sections of the road and for road users in the case of the tunnel. Property including the roadway and other infrastructure and the tunnel structure itself could be severely damaged.

The consequences of incidents involving Class 1.1 and 1.2 loads could include pressure wave/overpressure effects, the impact of projectiles and fragments, and the heat radiation and smoke from intense fires. On the open roadways mass blast effects could be injurious or fatal for considerable distances due both to the direct pressure wave and to projected/entrained missiles and building collapse etc. In the tunnel the effects of a blast, the pressure wave and primary and secondary missiles, are funnelled along the tunnel.

The transportation of explosives is particularly tightly regulated, quantities carried are restricted and packaging and loading of vehicles controlled. The numbers of loads, particularly of the more hazardous explosives, would be small. The incidence of crashes involving explosives carrying vehicles should also be relatively small due to extra care taken while driving and checks on the vehicles and, informally, on driver training. Loads are required to be carried in pantechnicons and design requirements for the trucks including fire shields underneath and barriers between load components together with lesser susceptibility to detonation due to fire of most modern high explosives limit the likelihood of detonation even in crash and fire events.

The risk contribution from this source should therefore be small on all types of roads. However, some further consideration is warranted to ensure that if permitted to use the M5 this will in fact be a safer option than use of the existing urban arterial road routes.

It is considered appropriate for some more detailed consideration of the consequences of incidents involving Class 1.1, 1.2 and 1.3 materials to be undertaken covering both the open sections of road and the tunnel. It is considered that in the context of the low frequency of Class 1 loads and the comparative nature of the analysis, these loads can be reasonably represented by TNT for all three sub-classes as a reference explosive widely used in analysis of the consequences of explosive impacts.

The choice of a Class 1.1 material to represent all Class 1 cases is appropriately conservative and is lent some support by the figures for the HSC study (HSC 1991) which reports figures for the UK of Class 1.1 comprising 94% of the aggregate for Classes 1.1, 1.2 and 1.3 in terms of distance travelled.

(ii) Class 2 - Gases

Class 2 has three subdivisions: 2.1 Flammable gases; 2.2 Non-flammable, non toxic gases; and 2.3 Poisonous gases. The analysis of DG movements data outlined in section 2.1 found that Class 2 materials made up about 18 per cent of all DG loads.

Materials in all three categories are routinely transported from production facilities in the CIA and from the Port. To a lesser extent gases produced elsewhere are transported to the CIA and the Port. Trucks and particularly tankers returning from delivery runs are also often not empty and in some circumstances still carry a significant proportion of their loads.

The largest volume of gases transported are Class 2.1. This is principally LPG (propane or butane or a blend of the two) but propylene, hydrogen, acetylene and other flammable gases would also use these routes from time to time.

LPG is transported principally in bulk tankers with a capacity of up to 20 tonnes (40,000 litres) with a typical load being 15 tonnes (30,000 litres). It is also transported in smaller bulk vessels and in cylinders. Propylene and ethylene are also principally transported in bulk tankers with typical units being of 30,000 litres nominal capacity and larger units being up to 40,000 litres nominal capacity. Transportation in cylinders is also undertaken with a typical cylinder size being 45 kilograms and less commonly 90 kilograms. Hydrogen is transported in cylinders of 5.9 m^3 (15ºC 13,700 kPa) capacity and a bulk 'torpedo' trailer of 4049 m^3 capacity (337 m^3 for each of 12 torpedoes - separately valved but manifolded together). Acetylene is exclusively transported in cylinders.

Class 2.2 gases transported to and or from the CIA or the Port would include nitrogen, oxygen, carbon dioxide and chlorodifluoromethane (Isceon). Some Class 2.2 gases are transported both in bulk and cylinders whilst others are transported exclusively in cylinders.

Class 2.3 gases transported through the area would include: chlorine, ammonia and other imported and domestically produced toxic gases. Chlorine is transported in 20 tonne bulk tankers and 920kg drums or smaller cylinders. Ammonia is transported in bulk tankers and cylinders. Other gases in this class may be transported in cylinders or in isotanks the latter typically being of 8,000 litres nominal capacity.

The pressure vessels holding these gases are of robust construction and would generally withstand impacts without sustaining significant damage. During high momentum collisions including head on collisions and collisions with fixed objects the puncturing or rupture of bulk containers or smaller vessels cannot, however, be entirely ruled out. Furthermore the valves on cylinders and the valves and piping on bulk vessels may also be capable of sustaining damage due to impact sufficient for a substantial release to result.

Valve or pipework failure without a crash must also be considered to be a possibility with resultant large or small leakages. Cylinders could also be dropped from a truck and damaged on impact with the road or subsequent impact by another vehicle.

Involvement in fire is another potential cause of release from pressure vessels either due to the failure of the vessels or through the operation of relief valves or other pressure relief devices.

For the Class 2.1 gases, releases could result in jet fires, flash fires or vapour cloud explosions if immediate or delayed ignition were to occur. Following ignition boiling liquid expanding vapour explosions (BLEVE's) could also result. The gases, particularly the dense gases, could also have some asphyxiation potential in confined spaces and may cause cryogenic injuries or injuries due to the physical impacts of release of the pressurised gas.

The Class 2.2 gases are not toxic or flammable but can cause death or injury due to the physical impacts of the release from pressurised storage or due to their low temperature. Some of the materials such as nitrogen and carbon dioxide also have some asphyxiation potential whilst oxygen has the potential to greatly intensify any existing fire as well as increasing the likelihood of ignition. Generally the physical impact would be limited to the immediate vicinity of the release and therefore has been excluded from the analysis as explained in **Section 6.1**. The asphyxiation and fire effects would also be limited to the immediate area of the release if in the open. In the tunnel the asphyxiation and fire cases may warrant further consideration.

Class 2.3 gases on the other hand, whilst they may have the potential to be injurious due to pressure release and temperature etc., are predominantly hazardous due to their toxicity. For these materials even quite small releases have the potential for serious harm. In the case of the heavier than air gases, or those that behave as heavier than air due to their temperature on release, even in the open the distance to concentrations which could be injurious can be very considerable. Again in the confined spaces the potential is even greater though counterbalanced by the ventilation systems to an extent.

For all three classes of gas the physical and cryogenic impact of releases can be considered to be the minor hazard with localised effects and no further analysis of this hazard aspect has been undertaken.

For Class 2.1 gases it is considered that in the case of loads in cylinders releases in the open would generally disperse safely or would involve too little energy if ignited to pose a hazard to people outside the immediate vicinity or not directly involved in a crash.

Fire involving a truck carrying a number of cylinders could result in the violent rupture of the cylinders and rocketing of the cylinders or fragments being projected for some distance but given the combined effects of the numbers of trucks carrying such loads, the crash and fire frequencies, the small total area of impact of each cylinder etc. this effect is not considered to be likely to be a significant contributor to risk to other road users or the surrounding lands.

In contrast, bulk loads of flammable gases must be considered to be a significant potential source of risk to other road users and people in surrounding lands as the effect distances and footprint of some credible incidents such as jet fires, flash fires and BLEVE is relatively large.

In the open, releases of lighter than air gases such as hydrogen will generally safely disperse.

In the tunnel, releases of gas from cylinders must be more rigorously considered as safe dispersal may be less likely unless the ventilation is adequate to ensure rapid dilution to below flammable limits. Fire intensity within the tunnel is also likely to be greater, unless the oxygen demand exceeds supply, and the impact of any given fire on cylinders also greater as there will be less heat loss by convection and more deflection of flames back onto the load. Also within the tunnel the potential exists for the deflection of any projectiles along the length of the tunnel and into road users. Lighter than air gases would also be confined to the extent that the ventilation system does not remove them and, depending on the location of the ventilation system inlets and outlets, dilution could be relatively slow.

Bulk releases must be regarded as credible incidents within the tunnel and could result in jet fires and flash fires. Due to the relative confinement, vapour cloud explosions are also a more likely outcome in the tunnel. Due to deflection of flame from relief valve fires or other jet fires, BLEVE must also be considered to be a more likely outcome of a release incident in the tunnel than it would be outside.

Due to the confinement of the fire and the lack of any opportunity for dissipation of heat to the atmosphere the effects of fire within the tunnel could be particularly significant for the tunnel structure and fittings etc. including the road surface. Flammable gases also have some potential for ignition in ducting and in the fan rooms and theoretically at least at the vent.

The installed operating and safety systems would have a significant influence on the likelihood and consequences of flammable gas incident outcomes in the tunnel. In particular the operation of deluges and the emergency ventilation system could have a significant effect. The behaviour of dense gases and liquid phase releases which would tend to pool and may flow through the drainage system and collect in holding tanks is also an aspect specific to the tunnel which warrants careful consideration.

For Class 2.1 gases then, it is concluded that in the open the consequences of bulk tanker crashes or valve/piping failure require further consideration. For completeness, the case of a fire involving a truck carrying cylinders may also warrant further consideration. In the open, loss of load incidents would not generally have sufficiently severe consequences and lighter than air gas events would also generally result in safe dispersal. For the tunnel section, further analysis of releases from bulk tanks, fires involving trucks carrying cylinders, releases from cylinders and releases of lighter than air gases is considered warranted.

As it is the largest component of flammable gas traffic, LPG is the appropriate representative load for bulk and cylinder transportation of heavier than air gases. Hydrogen, which is produced in the CIA and widely distributed, is considered to be an appropriate representative material for lighter than air gases.

For Class 2.2 gases it is considered detailed analysis of consequences is only warranted for the in tunnel cases as the footprint of any incidents involving these materials in the open is likely to be very limited and any more extensive impacts would be sufficiently rare as not to make any significant contribution to risk. For the tunnel environment, the asphyxiation potential and cryogenic impact of bulk releases of inert gases and the consequences of bulk releases of oxygen also warrant further consideration.

The representative materials selected for this analysis are oxygen for its special characteristic in respect of fire initiation or aggravation and nitrogen as a relatively frequently transported gas with asphyxiation and cryogenic impact potential.

For Class 2.3 gases, bulk loads and cylinders have the potential for significant consequences at some distance from the release and analysis is warranted of both for the open road case and the tunnel. Due to the enclosed environment of the tunnel it is appropriate to consider smaller releases and some consideration is also warranted of small continuous releases in transit.

The most commonly transported highly toxic gas is chlorine and it is therefore appropriate to select it as the representative material for the cylinder transport cases. Ammonia is a common industrial gas and is commonly transported in bulk and is therefore selected as a further representative bulk load. In this case in particular the possible need to assess the sensitivity of the analysis for the tunnel to the use of a more toxic gas was considered.

(iii) Class 3 - Flammable Liquids

Class 3 has two packaging group subdivisions distinguished by the flash point of the liquid. Above a flash point of 61ºC the liquids are regarded as combustible liquids and, while covered by the same storage standards as Class 3's, are not regarded as Dangerous Goods for the purposes of transportation and are not required to carry placarding. These combustible liquids whilst difficult to ignite will burn vigorously once ignited and have consequences very similar to the flammable liquids case.

Flammable liquids are by far the largest component of DG traffic. The analysis of DG movements data outlined in section 2.1 found that Class 3 materials made up about 57 per cent of all DG loads. As no placarding is required for combustible liquids with a flash point above 61°C, DG surveys have generally not included figures for movements of trucks carrying these materials. The EPA 1992 survey grouped petroleum products including combustibles such as diesel together giving a Class 3 plus combustibles figures of 79% by volume. This compares with the Class 3 figure adopted for this study of 55% for movements. This suggests a figure of some 40% of the Class 3 movements might be an appropriate estimate for additional combustible loads which may need to be considered in considering the sensitivity of the results as they relate to this important class. It is of interest to note that the HSC cites figures for the UK which show an equal quantity of motor spirit to other petroleum products.

The largest component of the Class 3 materials traffic is petroleum fuels but industrial solvents and finished products or intermediates containing solvents are also significant in terms of volumes.

Most of the fuel is transported in bulk tankers with a typical capacity of 40,000 litres. A proportion of solvents and other Class 3 liquids are also transported in bulk tankers. Fuel and other tankers are typically divided into compartments of 5,000 to 8,000 litres capacity. Solvents and other flammables are sometimes transported in isotanks typically of 23,000 litres capacity. Relatively small quantities of fuel and larger quantities of solvents and other flammables are transported in 200 litre drums and increasingly in 1,000 or 2,000 litre minibulks. Some loads particularly retail goods, are also carried in smaller packages. Drummed and packaged loads are carried on open trucks or inside shipping containers.

Flammable liquids bulk tanks are of relatively lightweight construction and are relatively easily punctured or ruptured. Large releases also commonly occur in the event of rollover accidents. The typical lightweight aluminium is also susceptible if involved in fire which could lead to the initial release or to subsequent additional releases as other compartments fail. Leakage from tank welds and from valves or pipework can also occur.

Isotanks are generally of more robust construction but are nonetheless capable of being ruptured or punctured on impact. Minibulks and particularly drums are more vulnerable to rupture on impact and the development of holes and leaking seams etc. Releases may also occur due to failure of valves or failure to close and secure valves and failure to secure drum bungs. Isotanks, minibulks, drums and smaller packages may fall from trucks without a crash and rupture or leak as a result of impact with the road surface, other fixed objects or other vehicles. Where packaged goods are transported inside a shipping container they are significantly less likely to be ruptured on impact, leakages will be contained to some extent and the likelihood of partial loss of load will be reduced. As with bulk loads, fires could also be initiated without prior loss of containment and lead to involvement of the load.

As indicated in section 6.2.4 in a traffic environment and particularly where crashes are involved, there are commonly strong ignition sources present. The consequences of releases if ignited could be flowing liquid fires or pool fires. Liquids contained within the truck could also burn in situ. The principle hazard is radiant heat though, particularly for other road users, direct involvement in fire and propagation to other vehicles (including potentially other DG loads) are also real hazards. In the open smoke from fires involving flammable liquids would seldom be a problem as the intensity of the fire would usually ensure that the plume would be driven high into the air for safe dispersion. In the tunnel the fires are likely to be more intense and where ignition is delayed flash fires or explosion could also be possibilities. The principal fire could also act as something of a rolling fireball along the tunnel. Smoke would also potentially present more of a problem in the tunnel depending on the efficacy of the ventilation system - the smoke would be expected to be black and dense because of the involvement of the bitumen road coating in the fire.

In the event that ignition did not occur there could be some asphyxiation hazard from the fumes. It should also be noted that some materials designated as Class 3 DG's but not Class 6 subsidiary risk have significant inhalation toxicity at least in terms of injury eg ethyl acetate.

For packaged goods particularly those in 200 litre drums the possibility of violent drum rupture and rocketing drums must also be considered. In the tunnel this is again more likely to be a significant hazard as it is more likely that any fire involving a drummed flammables load will rapidly progress to involve the whole load and rocketing drums would tend to be deflected along the tunnel passage.

Any fire involving any substantial release of Class 3 materials would be intense and significant damage to structures, particularly the tunnel, directly impinged on by the fire could be expected.

In the case of unignited releases and fires, the residual material may present an environmental pollution hazard depending on the efficacy and capacity of the retention systems. Class 3 materials as solvents could also do substantial damage to underground cabling and the like should materials enter conduits.

The general behaviour of released liquids has been discussed in section 6.2.3. In the case of flammable materials, the effect of the flame trapping on the drainage sumps is a particularly relevant to the outcome of release events. The operation of the fire detection and deluge systems could also have a significant impact on incident progression - not always beneficial impact (see Section 6.3.2.2).

Further analysis of flammable liquids incidents in the open and in the tunnel is clearly warranted. For both the tunnel and the open sections incidents involving the loss of containment from bulk tankers and fires involving whole loads of drums need to be considered. For the tunnel in addition the consequences of loss of load incidents also warrant some consideration. It is considered that these cases can be represented by a full tanker contents incident, a tanker compartment incident, a full 20 tonne drum load and the release of 1000 litres from a minibulk or pallet load of drums.

The consequences due to toxic/asphyxiant properties of Class 3 liquids can be adequately represented by the Class 6 liquids analysis as the latter will be the limiting case. If the consequence analysis indicates a basis for concern then the treatment of these aspects of the consequences may need to be revisited in terms of frequencies and risk contribution.

As it is the most commonly carried flammable liquid and is not significantly dissimilar in terms of relevant properties to other flammable liquids loads petrol can be used as the representative material for these incidents.

Combustible liquids are beyond the scope of the study as they are not designated DG's. It was considered however that their potential to contribute to overall risk in the tunnel case should not be altogether disregarded but held over for further consideration in the sensitivity analysis if the fire and overall risk levels were potentially significant.

(iv) Class 4 - Flammable Solids etc.

Class 4 has 3 sub classes: Class 4.1 covers flammable solids, self reactive and related substances and desensitised explosives; Class 4.2 covers substances liable to spontaneous combustion; and, Class 4.3 covers substances which in contact with water emit flammable gases. There is considerable diversity in the materials within this class and the type of packaging etc. The class includes materials for example which become hazardous or start to burn if they dry out whilst others become hazardous or react if they are exposed to water.

The analysis of DG movements data outlined in Section 2.1 found that Class 4 materials made up about 2.5 per cent of all DG loads. Loads relatively commonly carried would be expected to include nitrocellulose, some metal powders, calcium carbide, activated carbon, molten sulphur and molten napthalene. The latter materials are transported in bulk whilst the others are typically packaged.

The packaging is specific to the material carried and includes some 1,000 kg bulkibags, plastic lined cardboard kegs, steel drums and pails, plastic drums and pails, and paper/plastic sacks. Drums/pails are typically 200 litre, 50 litre or 25 litre. Kegs used to carry wetted nitrocellulose and activated carbon are typically 110 kg or 50 kg, sacks are typically 25 kg and stacked in one tonne loads on pallets. The bulk loads are typically carried in 30,000 litre tankers. The goods are carried both on open trucks and inside shipping containers.

Loss of containment could be caused by crash events including sideswiping and rollover, especially where loads are carried on open trucks. The molten loads would generally solidify rapidly once released and unless ignited whilst still molten, contamination would not pose a problem. Loss of load and rupture of packages could also readily occur, again particularly from open trucks. Leakage from packages could also be significant in this case as loss of the liquid wetting agent or the liquid covering the material could increase the hazard or lead directly to ignition or fire. Exposure to incompatible materials, including water, whilst in transit or contamination of the material during packing could also lead to on truck fire initiation. Exposure to fire not initially involving the load is also a possible initiating event.

Class 4 materials will not flow significantly from the release point and, except in the case of strong winds where fine powders are involved, entrainment in stormwater, the effects of passing vehicles or the motion of the package itself the materials will essentially stay where they are released or involved in fire. Where ignition occurs an intense fire would generally result with possibly harmful smoke. In the case of Class 4.3 materials flammable gases could be generated.

In the open the principal hazard would be heat radiation. Smoke and gases generated would generally disperse safely. In the tunnel as well as the heat radiation effects and direct fire impacts on the tunnel structure, unless ventilation is adequate, smoke could be also problem as could the generation of flammable gases.

In the open only the heat radiation consequence warrants further consideration. In the tunnel the heat radiation, direct involvement in the fire and smoke effect warrant further consideration. As the consequences of releases of flammable gases is to be considered in the analysis of Class 2 materials and gas generation from solids would always be a lesser case than the release of pressurised gas it was considered to be unnecessary to include this aspect in the initial set of cases selected for consequence analysis.

Whilst dust explosion might be a theoretical possibility with some of the loads in this class, it is not considered that the mechanisms necessary for dispersion into a dust cloud of sufficient volume and mass are likely to exist.

The representative materials selected for the analysis is ethanol wetted nitrocellulose. It is a relatively widely used material known to be imported through the Port and transported to destinations which would make the use of the subject routes likely. It was not considered necessary to consider the molten load case separately.

(v) Class 5 - Oxidising Agents and Organic Peroxides

Class 5 is divided into two sub classes: 5.1 oxidising agents; and, 5.2 organic peroxides.

Materials in this class include such commonplace chemicals as hydrogen peroxide, calcium hypochlorite and methyl ethyl ketone peroxide (MEKP) which are widely used in industry and in some cases as consumer products. Peroxides are manufactured in the CIA and imported through the port. Other Class 5 materials are also moved through the Port. The analysis of DG movements data outlined in section 2.1 found that Class 5 materials made up about 3.5 per cent of all DG loads.

The materials are both liquids and solids. In the case of the liquids they are transported in both bulk and packaged form. Bulk peroxides are typically transported in ISOtank of 20 tonnes capacity or 2.5 tonne road tanks. They are also transported in 1 tonne IBC's, 200 litre drums and 25 kilogram carboys. The packaged and minibulk loads would typically be in 18 tonne or 8 tonne loads. MEKP is transported in 5 litre jerry cans packed four to a fibreboard container in 20 tonne loads. Solids such as calcium hypochlorite are typically transported in drums or 25 litre pails.

Releases could occur therefore due to crashes or loss of load incidents. Incompatible packaging or contamination could also lead to incidents involving loss of containment or fires. Package failure due to mechanical damage and to movement of the truck could also lead to releases which could escalate. For some Class 5.2 materials, impact or friction could lead to fires on the trucks without prior loss of containment.

Fires could also result in loss of containment and rapid spread to involve the whole of the load. Liquids could flow down drainage lines. Solids would be relatively immobile unless affected by rain or fire fighting water including water from deluges in the tunnel case.

Class 5.1 materials could exacerbate existing fires or cause fire to occur through the ready liberation of oxygen. Class 5.2 materials may be prone to explosive decomposition and most will burn rapidly. Spillage onto organic material such as wooden truck decking, pallets or packaging could lead to very rapidly developing and intense fires even where no other ignition source is present.

In the open and in the tunnel the consequences of concern would be heat radiation and propagation of fire to other vehicles and loads. In the open the potential for impact due to explosive decomposition would generally be limited to the immediate environs of the truck or package. In the tunnel there may be a greater potential for more extensive impact due to the confinement and there may be greater potential for rapid involvement of the whole load due to reflection of heat and flame back on to the load. Problems with toxic or asphyxiating fumes or reaction gases would also be more likely in the tunnel.

In the open only incidents involving bulk loads or the whole of truck warrant further consideration. In the tunnel, incidents involving lesser quantities of class 5.1 and 5.2 materials and smaller releases of 5.2 materials also warrant further consideration.

Appropriate representative loads would be hydrogen peroxide for the 5.1 materials and MEKP for the 5.2's as these materials are known to be transported to and or from the areas serviced by the road and have properties sufficiently representative of the class. The separate inclusion of calcium hypochlorite was carefully considered but as substantial release of liquids was considered to be more likely it was not included in the initial set of cases selected for consequence analysis.

(vi) Class 6 - Poisonous (toxic) and Infectious Substances

There are three sub-classes within Class 6: 6.1(a) covers materials likely to cause death or serious injury to people if swallowed, inhaled or by skin contact; 6.1(b) covers materials which are harmful to human health if swallowed inhaled or through skin contact; and, 6.2 covers substances containing viable organisms known or believed to be capable of causing diseases in humans or animals.

Class 6.1 materials are produced and used in the CIA and are moved through the Port. The analysis of DG movements data outlined in section 2.1 found that Class 6 materials made up approximately 3 per cent of all DG loads. For the purposes of the analysis it has been assumed that all Class 6 loads are class 6.1.

Materials falling into this class can vary widely as to physical and chemical properties and toxicity. The class covers both liquid and solid materials, materials which require physical contact or ingestion and those with fumes/vapours which are dangerous even in low concentrations.

Some, such as methylene chloride, are carried in bulk tankers typically of 30,000 to 40,000 litres, they are also carried in minibulks, 200 litre drums, 50 litre drum/pails, 25 kg paper/plastic sacks and smaller packages.

Releases could occur due to crashes, lost loads, failures of bulk vessels or packages, including loss of containment in transit and involvement in fires. Many class 6.1 materials are combustible.

Solid materials, except fine powders, are unlikely to spread far from the release point and are thus likely to only affect those directly involved in an incident. Similarly, for materials requiring ingestion or dermal contact the main hazard would appear to be largely to road users or others involved directly in a crash. Liquids, especially those with high levels of toxicity and high vapour pressures, could however potentially have effects over a wider area. Flowing liquids may also spread the problem.

If involved in fire the picture may change to some extent. For most liquids which would support fire, the fires would be relatively intense and in the open good smoke dispersion would generally limit the likelihood of significant exposures. In the case of solids on the other hand, cool smouldering fires could result and even in the open concentrations of concern could result at some considerable distance from the fire.

On the open sections of road generally large spills of liquids would be necessary to result in far field effects and in most circumstances prolonged periods of exposure would be necessary for significant doses to be received. Evacuations and other evasive action could therefore be expected to minimise the extent of exposures. The same observations would apply to smoke from fires and generally response action would be able to limit consequences by limiting the duration of exposure. These considerations taken together with the low likelihood of large spills mean that the risk from these materials is unlikely to be a significant contributor to risk on the open sections of the road. In the tunnel on the other hand relatively small releases could be significantly hazardous to people in the tunnel due to the confinement.

In the tunnel case then, releases from minibulks, drums and other small containers need to be considered. The case of leakage from bulk and packaged loads in transit may also warrant further consideration. Such releases could be of liquids, solids or vapours.

In addition to the potential to affect people, many of these materials are significantly hazardous to the biophysical environment and indeed for biocides they are designed to be toxic to particular types of living organisms. The consequences of releases of these materials to the biophysical environment, essentially to water bodies, also warrants consideration. Generally releases on the M5 and in the tunnel in particular would be better controlled than on the urban arterial roads as specific provision is being, made for retention of stormwater and entrapment of solids and oily substances.

It is appropriate therefore to consider the consequences of large releases of liquids and cool fires on the open road sections but for the tunnel there is also a need to consider the case of smaller releases including continuous releases during transit and to consider the consequences of both cool and hot fires.

The selection of representative materials for class 6.1 is somewhat problematic due to differences in characteristics. Having regard to the volumes transported, the incident mechanisms and the exposure consequences, it is considered appropriate to use methylene chloride as the representative bulk and packaged liquid load, and methyl azinphos (a biocide) as the packaged solid load.

Class 6.2 substances are typically transported in relatively small loads except for hospital wastes and the like. In most cases direct contact with the material would be required and for the more hazardous end of the range the material would generally be carefully packaged and would therefore be unlikely to be released. It is not considered that releases of these materials would be significant contributors to risk nor that there would be significant differences between risk levels for the different routes and road types. It is also not considered that any specific design or operating features for the tunnel would be needed to deal specifically with this class of materials - although emergency planning should contemplate the need to deal with crashes and lost load incidents involving these materials. No further consideration of this material is therefore considered to be warranted.

(vii) Class 7 - Radioactive Substances

There are no sub classes for Class 7.

None of the surveys identified any Class 7 movements. It is clear however that radioactive materials would be regularly and routinely transported through the area in small quantities for medical, scientific and industrial instrumentation purposes and as wastes from these sources. Occasionally also loads could be brought through the area en route between the ANSTO Lucas Heights facility and the Port and airport. The absence of reported movements is in some cases due to the exclusion of this class from consideration but in others it is probably due to the fact that most of these movements would be undertaken in light vehicles and even where placarding is required it may not be as conspicuous as on larger vehicles.

The transport of radioactive materials is covered by the *Code of Practice for the Safe Transport of Radioactive Substances* (CoA 1990) which is based on and closely follows the IAEA 1985 code. For the materials likely to be transported though this area the code specifies two types of packaging. The packaging for smaller quantities and/or less hazardous materials has to be capable of withstanding a 9 metre drop test. The packaging for the more hazardous materials or those carried in larger quantities is still more robust and has to pass both a drop test and a furnace test. Transportation of materials in this second category also requires competent authority approval.

The materials in this class are therefore generally securely contained in robust packaging. It is understood that the policing of the requirements are relatively stringent. Furthermore, inquiries did not identify any examples of incidents which involved any significant loss of containment from such packaging in this state. The loss of containment would therefore appear to be a very low likelihood event.

Any released materials would also generally not disperse widely and only fairly direct contact would have any implications for health risk. An exception to this might be where the materials are involved in a fire though generally a fire of sufficient intensity to spread the material would be likely to result in effective dilution of the material to levels which would not be of concern. Due to small quantities and the general lack of credible mechanisms for the dispersal and exposure away from the site of the release, further consideration of this class is not considered warranted and there would appear to be no grounds for the exclusion of the movement of radioactive materials of the type and quantities routinely transported for medical, industrial and scientific purposes. As the routing and packaging requirements for any larger or more hazardous loads would be subject to separate competent authority approval and subject to specific conditions, the matter of the acceptability of transportation routes, including transportation through the M5 tunnel, would need to be considered on a case specific basis.

(viii) Class 8 - Corrosives

There are no sub-classes for Class 8 which encompasses both solid and liquid materials.

Corrosive materials are produced and used in the CIA and moved through the Port.. The analysis of DG movements data outlined in section 2.1 found that Class 8 materials made up about 16 per cent of all DG loads.

The materials are transported in bulk tankers (typically 40,000 litres with four 10,000 litre compartments), isotanks, minibulks, drums, pails, and paper/plastic sacks. Packaged loads are transported both on open trucks and in shipping containers.

Materials could be released due to crashes or lost load events. As with other loads carried in similar packaging the full range of possibilities of leakage events including leakage from bulk tank and minibulk valves exist. In the case of corrosives the likelihood of packaging or vessel/valve/pipework failure in transit is however increased by the corrosive nature of the materials and the potential for combination with incompatible materials as packaging or as contaminants. A further potential exists for fuming of acids without loss of containment of the liquids.

Apart from the consequences of direct contact with the material, the main hazard for people is the fumes/vapours. The materials could also react with the road surface or other fittings, parts of vehicles or materials from loads to generate toxic or flammable gases. For example any strong acid could react with concrete to generate carbon dioxide, sodium hydroxide could react with aluminium parts of vehicles or their loads, sodium hypochlorite and hydrochloric acid could react to generate chlorine, and nitric acid could react to ignite any spilled organic liquid. In the open it is unlikely that fumes or reaction gases would reach levels of concern beyond the immediate vicinity of the release except perhaps in the case of very large releases.

In the tunnel, fumes and reaction gases from large releases and smaller releases could have some potential to be problematic. Released liquid could be harmful to the road surface or other infrastructure in direct contact. In the tunnel, fittings, ducting and ventilation fan equipment etc could also be vulnerable depending on the concentrations of fumes or reaction gases reached. Larger scale releases of corrosives could be harmful to the aquatic environment until sufficiently diluted.

Further analysis would appear warranted for whole tanker scale releases in the open and the tunnel. For the tunnel some analysis of consequences of releases at the smaller scale could also be warranted although such cases are not likely to be the limiting ones for the ventilation system capacity either in terms of fumes or reaction gases. The question of infrastructure damage could also be dealt with for both the tunnel and outside cases although largely qualitative analysis should suffice in this case. Environmental effects also warrant further consideration as part of a broader comparative analysis of the risk from these and other classes of materials on the route options.

Suitable representative material is concentrated hydrochloric acid for a material generating fumes and reaction gases. Use of sodium hydroxide (caustic soda) for a material reacting to form flammable gas was considered but set aside on the basis that whilst there are circumstances where for example a crash could result in the release of sodium hydroxide and subsequent reaction with aluminium parts of a truck or its load could occur it is very unlikely that an event would result in substantial quantities of flammable gas production.

(ix) Class 9 - Miscellaneous Dangerous Goods

Materials covered by this class are regarded as having relatively minor hazard potential and/or do not fit in to the other categories. The class therefore covers *inter alia* materials which are harmful to the environment but not to people and are not classified by other characteristics. This classification is coming into greater use as the potential for environmental impairment due to the release of materials not regarded as otherwise hazardous is realised.

As with most other classes of DG's, materials fitting into this class are produced and used in the CIA and moved through the Port and are therefore routinely transported through the area. The proportion of DG traffic contributed by this class is relatively small. There are grounds however for believing that its presence is understated due to less rigour in classification for materials that could be said to fall into this class. The survey undertaken for this study identified 8.4 per cent of DG traffic as Class 9 but this figure is overstated as it includes not just the vehicles displaying the Class 9 placard but also those displaying the mixed load placard. As described in **Section 6.2.1** the Class 9 numbers have been distributed to the other classes.

The harmful characteristics of materials in this class are covered by the other classes and the risk contribution from this class has been dealt with by inclusion of the movement numbers in the other categories in proportion to their share of packaged loads. The consideration of the overall risk to the aquatic environment also encompasses the relative risk from these materials.

(x) Goods not Classified as Dangerous Goods but with Hazard Potential

In addition to goods classified as Dangerous Goods there are other loads which may have some relevant hazard potential either due to their direct effects or potential to increase the risk of crashes.

The hazards from such materials could include: radiant heat or direct fire involvement from combustible liquids and solids; toxic or asphyxiating smoke from fires; lubricants or surfactants which could make roads slippery; and, materials which could cause harm to the aquatic environment through fouling or nutrient enrichment or other physical, chemical or biological effects but which are not classified as class 9.

The heat radiation and direct fire events involving combustible liquids would be similar in consequence to those involving flammable liquids but with a lower ignition probability. The contribution to risk in the open from this source, except to people directly involved in an incident, would be so small as not to warrant further consideration. In the tunnel the effects could be more significant but this contribution to risk can be taken up by adjusting the frequencies of the flammable liquids incidents should such refinement be justified by the results of the consequence analysis and risk levels found.

In the tunnel the smoke effects could also be a problem and some analysis of this type of incident may be warranted particularly for loads such as some plastic containers which may burn relatively rapidly and may generate significant volumes of toxic smoke.

Materials which could make road surfaces slippery would appear to make more of a contribution to risk of collision on the arterial road sections with opposing and cross flows of traffic than on the open sections of the motorway or in the tunnel. The exception to this could be a build up of material if road surface cleaning is not adequate or is inappropriate and some wetting of the surface occurs due to cleaning activities or other causes such as rainwater being carried in by vehicles. It is assumed that the cleaning regime for the tunnel will be adequate in this regard and it is a recommendation of the study that special attention be paid to this issue in the development of the road cleaning programme type and frequency. Given this proviso, and considering that this cause of vehicle crashes is incorporated into the generic and specific crash statistics to be used, it is not considered that further analysis of this issue is warranted.

The potential for contribution to environmental risk from this type of traffic could be significant. This aspect is covered in the comparative environmental risk assessment which covers the relevant classes of Dangerous Goods. For the analysis of toxic/asphyxiating smoke a load polythene beads has been selected as a representative load.

6.2.7 Representative Loads Selected for Further Analysis

In summary the following representative loads and have been selected for further analysis.

(i) Open Air Road Sections

- 6 tonne load of TNT as a surrogate for high explosives and other Class 1's.
- 20 tonne LPG tanker.
- A load of 50 x 45 kilogram LPG cylinders.
- A 20 tonne chlorine tanker.
- Chlorine in 920 kilogram chlorine drums and 70 and 33 kilogram cylinders.
- 20 tonne anhydrous ammonia tanker.
- 40,000 litre petrol tanker with 8,000 litre compartments.
- 15 tonne packaged load of petrol (as a surrogate for all class 3's) comprised of 1,000 litre mini bulks and 200 litre drums.
- 10 tonnes of ethanol wetted nitrocellulose.
- 20 tonne tank of hydrogen peroxide.
- 20 tonne load of packaged MEKP.
- 30,000 litre tanker of methylene chloride with 5,000 litre compartments.
- Drummed load containing 5 tonnes methyl azinphos active ingredient.
- 40,000 litre tanker of hydrochloric acid.

The case of environmentally polluting substances is covered by the generalised analysis of the potential for release to the aquatic environment.

(ii) Tunnel

- 6 tonne load of TNT as a surrogate for high explosives and other Class 1's.
- 20 tonne LPG tanker.
- A 50 x 45 kilogram LPG cylinders
- 4,000 m3 load of hydrogen in a 'torpedoes'.
- 25 pallet load of hydrogen in 5.9 m3 cylinders.
- 20 tonne load of liquid nitrogen.
- 20 tonne load of liquid oxygen.
- Chlorine in 920 kilogram chlorine drums and 70 and 33 kilogram cylinders.
- 20 tonne anhydrous ammonia tanker.
- 40,000 litre petrol tanker with 8,000 litre compartments.
- 15 tonne packaged load of petrol (as a surrogate for flammable liquids) comprised of 1,000 litre mini bulks and 200 litre drums.
- 10 tonnes of ethanol wetted nitrocellulose.
- 20 tonne tank of hydrogen peroxide.
- 20 tonne load of packaged hydrogen peroxide.
- 20 tonne load of packaged MEKP.
- 30,000 litre tanker of methylene chloride with 5,000 litre compartments.
- Methylene chloride in 1,000 litre minibulks and 200 litre drums.
- Drummed load containing 5 tonnes methyl azinphos active ingredient.
- 40,000 litre tanker of hydrochloric acid.
- 15 tonne load of polyethylene beads.

As for the open air sections, the case of environmentally polluting substances is to be covered by the generalised analysis of the potential for release to the aquatic environment.

All loads selected for analysis in the open air road sections have also been selected for the tunnel analysis. Additional loads have been included for the tunnel and, as noted in the text, there are also a number of cases where releases or incident outcomes have been excluded from the open air analysis but included in the tunnel analysis. This is particularly true for lost or leaking packaged load events which, with the exception of toxic gases are not considered to be likely to generate significant consequences in the open.

The development of the incident scenarios is covered in Section 6.3.

6.3 CONSEQUENCE ANALYSIS

6.3.1 Scenarios

Event trees were developed for each of the selected representative loads. Separate trees were developed for the open sections of road and for the tunnel to reflect differences in the loads selected, the initiating events considered to potentially lead to consequences of concern, and the differences in incident progression in the different environments. These trees follow through to the progression of possible outcomes for each movement including completion without incident. The trees are included in full as **Addendum 6B** and an example is provided as **Appendix 6B**. The trees in some cases are in several parts with linkages as indicated in each part as applicable.

The Trees in **Addendum 6B** are the trees as originally developed for the consequence analysis. It should be noted that in the course of the consequence and likelihood analysis certain branches or outcomes were found to be not significant or non-credible. The trees as used for the final calculation of incident outcome frequencies were therefore modified versions of the trees in the Addendum. The worked example in **Appendix 6B** shows a tree in the form finally used.

For each representative load type the tree is divided into bulk or packaged (if applicable), then moves down through the various incident initiating modes and the steps in incident progression to the credible outcomes. The analysis of incident progression and of consequences of each of the outcomes are covered in this section.

To enable that analysis to be undertaken the details of the representative loads had to be developed and appropriate assumptions made on details of the loads and load safeguards. Some of these details and safeguards influence the outcomes which can be considered to be realistic possibilities whilst some affect the likelihood of particular outcomes.

The tunnel safeguards and emergency response in the tunnel and on the open sections of road also have some bearing on the likelihood of particular outcomes and on the numbers of people potentially affected. These aspects are considered as applicable in the consequence analysis and subsequently in the frequency analysis.

The properties of the representative materials are presented in **Appendix D.**

(i) Open Air

Load OA1 6 tonne NEQ load with mass explosion hazard. Modelled as TNT. Any detonation is assumed to result in a single explosion involving the whole load. Incident: whole load explosion. Consequences assessed: explosion overpressure and projectiles.

Load OA2 20 tonne LPG tanker. Release cases: catastrophic rupture (instantaneous release); continuous releases from 50 mm orifice (including relief valve venting) 10 mm orifice. Consequences assessed: flash fire, jet fire, VCE and BLEVE, heat radiation, explosion overpressure and direct involvement.

Load OA3 A load of 50 x 45 kilogram LPG cylinders. Release cases: Fire involving the whole load. Consequences assessed: radiant heat from fireballs and rocketing vessels.

Load OA4 20 tonne chlorine tanker. Release cases: catastrophic rupture (instantaneous release); continuous releases from 50 mm and 10 mm orifices. Consequence assessed: toxic concentrations.

Load OA5 Chlorine in 920 kilogram chlorine drums and 70 and 33 kilogram cylinders. Release cases: catastrophic rupture, continuous releases from 25 mm, 10 mm orifices, and 1mm orifices. Consequence assessed: toxic concentrations.

Load OA6 20 tonne anhydrous ammonia tanker. Release cases: catastrophic rupture (instantaneous release); continuous releases from 50 mm and 10 mm orifices. Consequence assessed: toxic concentrations.

Load OA7 40,000 litre petrol tanker with 8,000 litre compartments. Release cases: whole tank 40,000 litres, whole compartment 8,000 litres. The consequence of small releases was assumed to be not significant except for propagation to the whole load. Tanker fires were assessed as whole of load pool fires. Consequences assessed: heat radiation from pool fires, flowing liquid fires.

Load OA8 15 tonne packaged load of petrol (as a surrogate for all Class 3's) comprised of 1,000 litre mini bulks and 200 litre drums. Release case: whole of load fire. Consequences assessed: heat radiation from pool fire/fireballs, rocketing drums.

Load OA9 10 tonnes of ethanol wetted nitrocellulose. Release case: whole of load fire. Consequence assessed: heat radiation.

Load OA10 20 tonne tank of hydrogen peroxide. Release case: rupture -whole of load. Consequences assessed: fire aggravation, heat radiation, direct damage.

Load OA11 20 tonne load of packaged MEKP. Release case: rupture of packages, fire on contact with organic materia or igntion source, whole of load fire. Consequences assessed: heat radiation, fire aggravation.

Load OA12 30,000 litre tanker of methylene chloride with 5,000 litre compartments. Release cases: whole tank 30,000 litres, whole compartment 5,000 litres. Consequences assessed:generation of vapours from pools and flowing liquid, toxic concentrations.

Load OA13 Drummed load containing 5 tonnes methyl azinphos active ingredient. Release case: cool fire involving whole load. Consequences assessed: toxic smoke evolution and toxic smoke concentrations.

Load OA14 40,000 litre tanker of concentrated hydrochloric acid with 10,000 litre compartments. Release case: rupture - whole of load, whole of compartment 10,000 litres. Consequences assessed: concentrations of fumes from pool and flowing liquid.

(ii) Tunnel

Load T1 6 tonne NEQ load with mass explosion hazard. Modelled as TNT. Any detonation is assumed to result in a single explosion involving the whole load. Incident: whole load explosion. Consequences assessed: explosion overpressure, secondary projectiles/fragments.

Load T2 20 tonne LPG tanker. Release cases: catastrophic rupture (instantaneous release); continuous releases from 50 mm orifice (including relief valve venting); 10 mm orifice; relief valve venting. Consequences assessed: flash fire, jet fire, VCE and BLEVE, heat radiation, explosion overpressure and direct involvement.

Load T3 A load of 50 x 45 kilogram LPG cylinders. Release cases: Fire involving the whole load. Consequences assessed: radiant heat from fireballs and rocketing vessels.

Load T4 - 4,000 m3 load of hydrogen in 'torpedoes'. Release cases: catastrophic rupture of 2 torpedoes 670m3 (@15ºC 13,700 kPa), 25 mm orifice, 10 mm orifice, and 1mm orifice, fire involving whole load. Consequence assessed: flammable concentrations, flash fire, jet fire, VCE, explosion overpressure and fragments.

Load T5 - 25 pallet load of hydrogen in 5.9 m3 cylinders. Release cases: rupture, 25 mm orifice, 10 mm orifice, and 1mm orifice, fire involving whole load. Consequence assessed: flammable concentrations, flash fire, explosion overpressure and fragments, heat radiation, rocketing cylinders.

Load T6 20 tonne load of liquid nitrogen. Release cases: catastrophic rupture (instantaneous release); continuous release from 50 mm and 10 mm orifices. Consequence assessed: asphyxiating concentrations.

Load T7 20 tonne load of liquid oxygen. Release cases: catastrophic rupture (instantaneous release); continuous releases from 50 mm and 10 mm orifices. Consequences assessed: fire initiation/aggravation.

Load T8 20 tonne chlorine tanker. Release cases: catastrophic rupture (instantaneous release); continuous releases from 50 mm and 10 mm orifices. Consequence assessed: toxic concentrations.

Load T9 - Chlorine in 920 kilogram chlorine drums and 70 and 33 kilogram cylinders. Release cases: catastrophic rupture, continuous releases from 25 mm, 10 mm, and 1mm orifices. Consequence assessed: toxic concentrations

Load T10 20 tonne anhydrous ammonia tanker. Release cases: catastrophic rupture (instantaneous release); continuous releases from 50 mm and 10 mm orifices. Consequences assessed: toxic concentrations, flash fire and VCE.

Load T11 40,000 litre petrol tanker with 8,000 litre compartments. Release cases: whole tank 40,000 litres, whole compartment 8,000 litres. The consequence of small releases were assumed to be not significant except for propagation to the whole load. Tanker fires assessed as whole of load pool fires. Consequences assessed: heat radiation from pool fires, flowing liquid fires, flammable concentrations, flash fire, explosion, asphyxiating concentrations, smoke generation/combustion products and concentrations.

Load T12 15 tonne packaged load of petrol (as a surrogate for all class 3's) comprised of 1,000 litre mini bulks and 200 litre drums. Release cases: whole of load fire, 1,000 litres spill. Consequences assessed: heat radiation from pool fire/fireballs (for whole of load), rocketing drums, heat radiation from 1,000 litre pool, smoke/combustion products generation and concentrations.

Load T13 10 tonnes of ethanol wetted nitrocellulose. Release cases: whole of load fire, fire involving one pallet (lost load). Consequences assessed: heat radiation, smoke/combustion products generation and concentrations.

Load T14 20 tonne tank of hydrogen peroxide. Release case: rupture -whole of load. Consequences assessed: fire initiation/aggravation, heat radiation, direct damage.

Load T15 20 tonne load of packaged hydrogen peroxide. Release case: loss of containment full contents of single pallet (1,000 litres). Consequences assessed: fire initiation/aggravation, heat radiation, direct damage.

Load T16 20 tonne load of packaged MEKP. Release cases: rupture of 10 per cent of containers, rupture of 50 per cent of containers on single pallet, fire on contact on contact with organic matter, whole of load fire. Consequences assessed: heat radiation, aggravation of fire, smoke.

Load T17 30,000 litre tanker of methylene chloride with 5,000 litre compartments. Release cases: whole tank 30,000 litres, whole compartment 5,000 litres. Consequences assessed: generation of vapours from pools and flowing liquid, toxic concentrations.

Load T18 Methylene chloride in 1,000 litre minibulks and 200 litre drums. Release cases: 1,000 litres, 200 litres. Consequences assessed: generation of vapours from pools, toxic concentrations.

Load T19 Drummed load containing 5 tonnes methyl azinphos active ingredient. Release cases: cool fire involving whole load, cool fire involving 10 per cent of load. Consequences assessed: toxic smoke evolution and toxic smoke concentrations.

Load T20 40,000 litre tanker of concentrated hydrochloric acid with 10,000 litre compartments. Release cases: rupture - whole of load, whole of compartment 10,000 litres. Consequences assessed: concentrations of fumes from pool and flowing liquid.

Load T21 15 tonne load of polyethylene beads. Release case: fire involving whole of load, fire involving 10 per cent of load. Consequences assessed: toxic or asphyxiating smoke generation, smoke concentrations.

6.3.2 Analysis and Estimation of Physical Consequences

After determining the scenarios the next step is the analysis of the progression of the postulated incidents and the estimation of the physical consequences. The analysis covers the way in which released liquids and gases, fires and explosions behave in the context of the specific circumstances of the representative cases. These consequences are therefore expressed in terms of physical concepts such as heat flux, explosion overpressure, toxic or flammable concentrations etc. they are also translated into likely consequences in terms of human injury or fatality and damage to property or the biophysical environment. The translation into impact on people (and other species where applicable) often involves time related exposures whereby doses of toxicants, heat etc. are received.

This sub section deals with these physical consequences essentially without regard to the size of populations potentially exposed, the vulnerability of structures or the vulnerability of the potentially affected areas of the biophysical environment. These latter aspects are dealt with in later sub-sections of **Section 6.3**.

6.3.2.1 Behaviour of Releases and Fires

The schematic layout of the tunnel and the drainage and ventilation systems is shown in **Appendix 6C.**

(i) Liquid Spills

The approach to the modelling of liquid spill behaviour in this study represents a substantial step up in the complexity of the analysis for both tunnel and outside cases. The usual approach has been to assume flat roads without drainage. That approach, whilst reasonable for comparative route analysis generally, would not allow due regard to be had to the effects of drainage systems and road slope. As the objectives of this study included the recommendation of design and operational features which might overcome any risk barriers to the transport of DG's through the tunnel, consideration of the effects of these factors was essential.

Simple liquid spill models which take account of the effects of slope and drainage were developed and used to estimate pool sizes and event durations for each of the scenarios involving liquid releases. The models are described in detail in **Addendum 6C** of the report.

(ii) Ventilation and Dispersion

For gaseous releases and releases of liquids which can generate toxic, asphyxiating or flammable vapours and for fire events generating toxic or asphyxiating smoke, dispersion is a major determinant of consequences. In the open, dispersion is a function of the wind speed and stability conditions as well as the buoyancy of the gas, vapours or combustion products. In the tunnel the situation is very complex. The factors influencing the pattern of dispersion include: the ventilation system (in normal or emergency mode); the buoyancy/density of the material, the slope of the tunnel and the turbulence and other effects of the incident (including oxygen demand in the case of fires). The interactions between these factors are complex and subject to change throughthe course of an event - particularly where fire is involved. The dispersion modelling is discussed further below.

Before dispersion can be considered, however, the rate of release must be determined.

The methodology for the estimation of the release rates and the dispersion of released vapours, gases and smoke is outlined below and in **Addendum 6D.**

Release of Gas from Vessel Containing Compressed or Liquified Gas

The effective release rates from pressurised gas tankers and cylinders for catastrophic failures and losses from large and small orifices and from above and below the liquid levels were estimated using standard discharge equations. The methodology and the resultant release rates are set out in **Addendum 6D** and the resultant release rates shown for each relevant case in **Addendum 6G.**

Release of Toxic and/or Flammable Vapour due to Loss of Containment of a Volatile Liquid

The size of the pools resulting from the various release incidents as indicated was determined using the methodology described in the relevant addendum. To determine the vapour release rate that would result from each pool standard equations were used The methodology and equations are set out in **Addendum 6D.**

A significant variable in those equations is the air velocity (wind) across the surface of the pool. In the tunnel the 'wind' was that generated by the ventilation system. The vapour generation in the tunnel is therefore affected by all those factors which affect the ventilation system as outlined later in this section.

The resultant release rates are shown for each relevant case in **Addendum 6G.**

Dispersion in the Open Air

Dispersion in the open air cases was modelled using the methodology described in **Addendum 6D** using the meteorological data as described in **Section 3.7** and **Addendum 3I.**

Dispersion and Ventilation in the Tunnel

It was a basic assumption of the analysis that if the ventilation system was not operating at full design capacity the tunnel would be closed to all vehicles or at least all DG vehicles. The likelihood of a DG incident coinciding with the short time between power failure, or other major system failure and closure of the tunnel was considered to be sufficiently low that consideration of such cases was not warranted. For the consequence analysis therefore the only cases considered without ventilation are those where the incident itself could cause ventilation system failure. The findings of the analysis only remain valid as long as this assumption holds.

For the tunnel cases key questions are:

- Can the ventilation system maintain a release of toxic and/or flammable gas, due to rupture of a pressurised tank truck or cylinders, below the IDLH/LC_{50} and/or lower flammable limit concentrations?

- Will flammable/explosive concentrations be reached in the ducting or fan rooms?

- . Can the ventilation system maintain a release of toxic and/or flammable vapour, due to loss of containment of a volatile liquid, below the IDLH/LC_{50} and/or lower flammable limit concentrations.?

- . Can the ventilation system prevent backlayering of smoke, due to a fire within the tunnel.?

- Will concentrations in the air discharged from the stacks or air intake points (when the system is operating in emergency mode) be below levels which would result in IDLH/LC_{50} at any of the surrounding land uses?

The assumed ventilation system in the tunnel is described in **Section 5** and depicted in the schematic in **Appendix 6C**. As well as the normal operating mode the system has an emergency smoke ventilation mode.

In normal operation air is fed into the tunnel in four sections through vents set above the New Jersey barriers and extracted at a vent at the mid point and near the downstream portal. The system has an excess of supplied air to extracted air and does not of itself ensure longitudinal flow relying on the piston effect of the traffic to maintain such flow.

In the emergency mode the normal exhaust fans are turned off and the airflow is reversed through one of the supply sections which draws air from the incident tunnel at double the usual section supply volume as, in the emergency mode, it serves only one tunnel. Switching to the full emergency mode condition is assumed to take about 2 minutes as the fans have to be stopped and then sequentially restarted to avoid power overload.

Under normal operating conditions there is a substantial longitudinal flow which increases in velocity along the tunnel. Once traffic flow ceases, as it would in most incidents, the longitudinal flow would decay over an estimated period of 2 to 6 minutes. The operation of the emergency mode or the turbulance of a fire or major gas release would cause the decay to occur faster. With the assumed system therefore the longitudinal flow can only be influential at best for the first few minutes of any incident.

Other critical factors influencing dispersion in the tunnel are: the road slope; the density/buoyancy of the gases/vapours, and the thermal effects of fires. The ventilation outcomes therefore depend on the location of the incidents within the tunnel and any action taken in respect the ventialtion system.

With all these variables the modelling of dispersion within the tunnel is particularly complex. The methodology used for dispersion modelling in the tunnel is described in **Addendum 6D**. The issue of backlayering is covered in **Addendum 6E** on fire behaviour in the tunnel.

Emissions from Tunnel Ventilation Stacks and Portals

For incidents occuring in the tunnel the ventilation system would clear some or all of the released material or combustion products through the normal or emergency mode exhaust systems. If cleared by the normal system the material would exit to air via the elevated ventilation stacks. If cleared by the emergency mode it would exit at the air intake point closer to the ground. In some instances the mechanical ventilation system would not handle the full volumes or would fail in the course of the incident and under these circumstances discharges fom the stacks or air intakes may occur due to chimney effects and the balance would exit via the portals.

Discharges from the stacks would be at lower concentrations, higher elevations and greater exit velocities than for the equivalent incident in the open and therefore would have lower levels of consequence than on the urban arterial roads. The lower crash rates and lower frequency of non-crash incidents in the tunnel would also serve to keep risk levels lower than for the urban arterial roads. On the other hand as the stacks concentrate the discharges that would otherwise be dispersed the risk which would otherwise be dispersed over the length of the route is concentrated, albeit at a lower base level. This would affect the individual risk levels and not the societal risk unless the stack points were located in areas of particularly high density land use. The more stacks there are the less significant this effect would be. To the extent that incident severity and propagation to other DG loads is worse in the tunnel, principally related to fire, this may increase the consequence and risk.

These effects are critically dependent on the design of the ventilation system and the conclusions of the consequence and risk analysis indicate that the system will need to be substantially modified if DG's are to be transported through the tunnel. It is recommended that this aspect be further considered as part of the design input, once the ventilation concept is better established, and in the hazard analysis of the final design.

(iii) Fire Modelling and Fire Behaviour in the Tunnel

In the open, fire modelling was undertaken using well established models for liquids, solid and gas fires. The methodology used is described in **Addendum 6E.**

Fire behaviour in the tunnel is particularly complex and variable being influenced by all the factors described under ventilation and dispersion above plus the influences of air supply and fire dynamics. The approach taken to the estimation of fire consequence is described in **Addendum 6E.**

(iv) Explosions

The modelling of VCE's and conventional explosions in the open used standard models as described in **Addendum 6F**.

Explosion consequences in the tunnel were estimated using the approach described in Considine et al. The approach is described in **Addendum 6F**.

6.3.2.2 The Effects of Sprinklers/Deluges

It is proposed that a deluge system be installed in the M5 tunnel as described in **Section 5**. The proposed system would be manually operated with dry piping to the heads.

There is disagreement as to the desirability of deluges in tunnels. For some types of fires, if activated early and in the right part of the tunnel, they would serve to suppress some incipient fires. They may also have some value in knocking down gases or vapours. However, the literature reports (see for example Egilsrud, Mizutani and Inokuma, and Lowndes) that they can also have substantial adverse impacts, particularly where Dangerous Goods are concerned. Identified adverse impacts include:

- spreading and increasing the violence of flammable liquids fires;
- if suppression of a flammable liquids fire is achieved the tunnel may be filled with vapours generated and spread by the water and steam which can subsequently reignite explosively;
- producing large quantities of steam which can be as hazardous as the combustion products;
- increasing the demand on drainage systems and so slowing the clearance of spilled liquids;
- cooling smoke so that it drops to lower levels and causing greater dispersal of smoke, consequently interfering with the effective operation of the smoke extraction systems;
- interfering with ventilation flows and possibly affecting the critical velocity for backlayering of smoke;
- reducing visibility due to the effects on smoke, the deluges themselves and the production of steam and the real possibility of causing crashes as motorist drive through; and,
- possible application to loads which react with water.

Even in circumstances where the operation of deluges at the right time and in the right section of the tunnel would be beneficial it is by no means clear that they would be operated appropriately. A degree of expertise would necessary to ensure that the effect of the deluges is not to aggravate the situation. Information on the materials involved and the extent of progression of any fire is also necessary to enable such judgments to be made.

If rigorous and regular training were to be given to operators this could overcome the lack of expertise to some extent but, as is usual with infrequently performed tasks in high stress situations, a high rate of error would still be expected. Furthermore, in many cases the necessary information would not be available to the tunnel operators.

It is therefore difficult to factor in the uncertain effects of deluges on release incidents and in the time available for this study it was not possible to fully take account of this element. In particular the effects of deluges on fire or smoke behaviour have not been covered in the consequence modelling though their possible effects have been considered as far as practicable in a qualitative way.

If the decision is taken to proceed with the tunnel and to permit the movement of DG's through it, then it would be appropriate for a separate and detailed examination of the effect of a deluge system on tunnel safety and the features any such system should have, including provision of training and detailed emergency planning. It would be appropriate for the effect of deluges on the risk levels to be reviewed as part of that study.

6.3.2.3 Incident Response

The M5, and the tunnel in particular would differ from the urban arterial roads in the extent of active management. The opportunities for early detection of incidents and early intervention to stop traffic flows into the potentially affected areas and to trigger emergency service response and evacuation are therefore greater. As indicated in **Section 5** it is proposed that the tunnel be equipped with closed circuit television monitors, heat sensors for fire detection (and smoke sensors in electrical equipment panels), motorists emergency telephones and alarms on hydrant/hose reel/fire extinguisher panel doors. The proposed tunnel design and operating systems also incorporate a number of provisions for intervention in the event of DG incidents. These include: the manual operation of deluges; the manual control of the ventilation system to extract smoke and maintain positive pressure in the unaffected tunnel; operation of the VMS's to slow or stop traffic; and the use of the radio rebroadcast system to advise motorists of the nature of any emergency situation and appropriate action.

The principal potential effect of the features is to reduce the numbers of people exposed to any incident and the duration of such exposure. There is also some potential to affect the severity of the incidents themselves by extracting smoke and fumes/gases at a point close to their source. As indicated the deluge system could in some circumstances suppress fires but the overall net benefit of such a system is yet to be established.

The affect of these systems on the presence of people was mainly dealt with as part of the likelihood analysis and is described in **Section 6.4.3.** As all evacuation and control systems must be regarded as less than 100% effective and less than 100% reliable, the effect of evacuation and prevention of vehicle entry was not taken into account in the consequence analysis and the cases examined therefore included the circumstances where no evacuation occurred and traffic continued to build up behind the incident for the duration of the incident. In the case of exposure to toxicants however exposure was assumed to be limited to a maximum of 30 minutes and in the case of heat radiation to a maximum of 5 minutes as reasonably conservative upper bounds for the calculation of doses potentially received. The open air cases were similarly treated with no allowance made for incident specific evasive action but a 30 minute maximum for toxic exposures and a 60 second exposure for heat radiation. These limits were used to avoid unrealistic estimates doses received.

6.3.2.4 Impact on Other DG Loads

As indicated in the outline of methodology in **Section 6.1.3** the coincident release of more than one hazardous material where they are not carried on the same load has been excluded from the analysis on the grounds of very low likelihood. There is however some potential for the propagation of an incident to other DG loads where those loads are affected by direct fire involvement, radiant heat or projectiles overpressure from explosions.

Due to the effect of channeling in the tunnel, the potential for propagation to other loads is likely to be greater for any given incident. In the tunnel case as well, the duration of a major fire event is likely to be affected by the involvement of cars and non-DG trucks which would be expected to add considerably to the overall fuel and the potential for propagation to other loads.

The potential for propagation could be analysed with the help of some 'rules' such as:

- Any Class 2.1, Class 3, Class 4 or Class 5.2 load directly impacted on by flames from any Class 2.1, Class 3, Class 4 or Class 5.2 fire incident would become fully involved in the fire.
- Any Class 2.1, Class 3 Class 4 or Class 5.2 load affected by a specific heat flux or temperature for a specific duration would become fully involved in the fire.
- Any Class 2.1, Class 3, Class 4 or Class 5.2 load in the confines of a BLEVE fireball would become fully involved.

As the time constraints on the study prevented the inclusion of propagation to secondary loads in the risk estimation the 'rules' were not fully developed. Similar rules would need to be developed to cover the impact of fires on toxic and other loads and the effects of explosion overpressure, projectiles etc.

The consequences of such involvement would be the same as for those loads totally involved in the intiating events. The likelihood of the involvement of additional DG loads is covered in **Section 6.4.5.**

In most cases the involvement of secondary loads would be more relevant in terms of damage to the tunnel structure and fittings as people would usually either have been killed by the initial event in the case of rapidly developing events or have evacuated successfully if not within the consequence zone of the intial event.

As indicated, the potential also exists for the spread to other vehicles within the tunnel including vehicles carrying combustible loads with high fuel values such as diesel fuel, paper, timber and some plastics. Such fire spread could substantially increase the intensity or duration of a fire event. Again this consideration would have more significance for tunnel structure than for the impact on people.

A further contributor to fire events could be the burning of the bitumen in the road surface which could be expected to give off thick black smoke.

The effects of the involvement of these other vehicles or the road surface have not been incoporated into the consequence or likelihood analysis. It is however recommended that such analysis be done as an input to the design process and as part of hazard analysis of the final design.

6.3.3 Estimation of Consequences by Class

In accordance with the Department of Urban Affairs and Planning's approach, the consequence analysis for open air events has generally been based on the starting assumption that there is no protection for people within the incident footprint and that no evasive action is possible. Where this assumption has been varied it is mentioned in the text.

6.3.3.1 Class 1 - Explosives

One scenario was selected for consequence analysis for Class 1, the detonation of 6 tonnes of TNT in a truck. In the tunnel case, this is assumed to occur half way through the tunnel. The detonation is assumed to involve the whole load in a instantaneous mass explosion, and could be initiated by a fire in the truck, a crash, a loss of load, or spontaneous detonation.

For the open air cases the overpressures of the air blast from the explosion were determined using the TNT model and the effects of the overpressures were determined using the ICIAE (1987) figures for people in the open for those in the traffic and people in buildings for the population in the surrounding lands. The methodology and results are set out in detail in **Addendum 6G** and the results summarised in **Table 6.2**.

TABLE 6.2
SUMMARY OF EXPLOSION RESULTS
Open Air

Peak Overpressure [kPa]	Distance from explosion [m]	% killed (ICI guide)
3.5	525	0
7	304	0
14	180	1
21	139	2
35	103	12
55	78	48
70	70	100

For the tunnel cases, the methodology described in Considine *et al* was followed. This methodology uses calculations for the four major mechanisms by which explosions can harm people. They are direct blast damage, impact from primary missiles, impact from secondary missiles, and tertiary damage. The methodology for calculating the distances to consequence levels attributable to each of these mechanisms and the results of the calculations are described in **Addendum 6G.**

The overpressure effects were found to clearly dominate as the cause of fatality at all distances and the fatality consequences were therefore caluated using scaled distances for overpressures. The fatality probabilities generated by Considine *et al* based on probits for lung haemorrhage were significantly lower for any given overpressure than those generated using the ICIAE graph. As the ICIAE figures are the same as those cited by the NSW Department of Planning (*Guidelines for Hazard Analysis*) and were those used for the open air cases they were also used for the tunnel cases in this study. The results of the calculations are given in **Addendum 6G** and summarised in **Table 6.3**.

TABLE 6.3
SUMMARY OF EXPLOSION RESULTS
Tunnel

Peak Overpressure [kPa]	Distance from explosion [m]	% killed (Considine)	% killed (ICI guide)
14	563	0	1
21	515	0	2
35	466	0	12
55	406	0	48
70	393	0	100
100	382	1	100
125	371	16	100
150	362	62	100
175	353	90	100
200	342	99	100
300	313	100	100
400	284	100	100

6.3.3.2 Class 2 - Gases

(i) Class 2.1 - Flammable Gases

Two materials, LPG and hydrogen, were selected to represent flammable gases. For each of the gases there were a number of different cases and outcomes. In each case, essentially three release cases were selected for consequence analysis, an instantaneous release due to catastrophic rupture, a continuous major release from a 50 mm or 25 mm orifice (including relief valve venting), and a continuous minor release from a 10 mm orifice. The consequences assessed for these release cases included: BLEVE, flash fire, jet fire, 'pool' fires involving liquid releases, fire involving an entire packaged load, and VCE.

The full range of events was considered for LPG. As hydrogen is transported as a compressed gas which is not liquefied the BLEVE and pool fire cases are not applicable. Hydrogen releases were modelled as either explosions for a catastrophic release or a jet fire for smaller releases (see below). Delayed ignition and hence flash fire or VCE were not considered as hydrogen is extremely flammable and there would be large number of ignition sources within the tunnel.

The methodology employed for the open air and tunnel cases is described in **Addendum 6G**. The results are also presented in that addendum.

(ii) Class 2.2 - Non-flammable, Non-toxic Gases

Class 2.2 materials were only identified in the hazard identification as being relevant to the tunnel environment. For the Class 2.2 gases the hazards considered were asphyxiation, cryogenic impact and, in the case of oxygen, aggravation of existing fire.

It was found that asphyxiating concentrations of nitrogen would not be experienced at any significant distance as long as the ventilation system was operating. The main hazards then were the cryogenic effect which was only of any real significance in the case of catastrophic failure of a tanker and aggravation of an existing truck fire in the oxygen case.

The methodology and results are set out in **Addendum 6G**.

(iii) Class 2.3 - Toxic Gases

Chlorine and ammonia were selected as representative materials for Class 2.3. Both bulk loads and cylinders were considered for chlorine whilst bulk only was considerd for ammonia. Release cases modelled were: an instantaneous release due to catastrophic rupture, a continuous major release from a 50 mm or 25 mm orifice (including discharge from a relief valve), and a continuous minor release from a 10 mm orifice.

The methodology and assumptions used for the open air and tunnel cases are outlined in **Addendum 6G**. The results are presetned in that addendum.

In the tunnel case the analysis incorporated consideration of the effects of chlorine flowing to the tunnel low point and of the gas discharges from the ventilation stacks and tunnel portals. On the basis of the assumed design it was found that LC50 concentrations would not be reached at ground levels from stack discharges. Significant ground level concentrations were however found from the portals and the consequences of these releases factored into the analysis.

6.3.3.3 Class 3 - Flammable Liquids

Petrol was selected to represent all Class 3 loads. Representative loads were assumed to be either bulk tankers or 20 tonne drummed loads. The methodology detailed in **Addendum 6C** was used for the estimation of pool sizes and durations. The overall methodology for Class 3 incidents is described in **Addendum 6G** and the methodology for the determination of hazard ranges in **Addendum 6E**.

The results are set out in **Addendum 6G**.

6.3.3.4 Class 4 - Combustible Solids

Class 4 was represented by a 10 tonne load of nitrocellulose wetted with ethanol and carried in fibre kegs. The methodology and results are set out in **Addendum 6G**.

6.3.3.5 Class 5 - Oxidizing agents and Organic Peroxides

Class 5 was represented by hydrogen peroxide and MEKP. The consequence assessed was heat radiation. The methodology and results are set out in **Addendum 6G**.

6.3.3.6 Class 6.1 - Poisonous Substances

The methodology for the analysis of the Class 6.1 materials is set out in **Addendum 6G**. The materials selected were methylene chloride and methyl azinphos.

The methylene chloride case was modelled as a liquid spill with the pool sizes and durations being determined by the liquid spill model described in **Addendum 6E**. The vapour release rate and the dispersion were determined using the the methods described in **Addendum 6D**. From this analysis it was determined that the concentrations and durations necessary for fatalityy would not be reached. Injurious levels were however reached in the the open air and particularly in the tunnel.

The methyl azinphos was modelled as a cool fire which would generate the most smoke. For hot fires the analysis found that in the open the toxic combustion products would be driven high into the air and disperse safely. In the tunnel radiant heat from combustion products and the effect of toxic gases generated from the other fuel necessarily involved would dominate in terms of fatality effects and that this was not really an effect of the DG load. It was found that for the cool fires the smoke ventilation system would comfortably cope with the necessary smoke extraction. The methodology for this analysis is described in **Addendum 6G**.

6.3.3.7 Class 8 - Corrosives

The methodology for the analysis of the Class 8 materials is set out in **Addendum 6G**. The materials selected initially were hydrochloric acid and sodium hydroxide. Preliminary analysis concluded that there were no credible mechanisms for the generation of relevant fataility or injury consequences in the open or in the tunnel

The hydrochloric acid case was modelled as a liquid spill with the pool sizes and durations being determined by the liquid spill model described in **Addendum 6E**. The vapour release rate and the dispersion were determined using the the methods described in **Addendum 6D**. From this analysis it was determined that the concentrations and durations necessary for fatality would not be reached. Injurious levels were however reached in the the open air and particularly in the tunnel.

6.3.3.8 Non-classified Loads

A load of polyethylene beads was selected as the representative case for non-DG loads. This load was only considered in the tunnel. Using the fire modelling methodology described in **Addendum 6E** with specific allowance made for the fire being well aerated beads but melting to form a molten pool which burns as a pool fire. After period of establishment the would be a short period of higher intensity and then the fire would settle down to an 18MW fire of about 7 hours duration. This would not have significant fatality or injury consequences as the smoke exhaust system could cope with a fire of this magnitude. The long duration of the fire could however have implications for the tunnel strucutre.

6.3.4 Population Exposed

To translate physical consequences into effects on people the population exposed to the incident must be established by overlaying the incident footprint on the relevant land area and identifying the population density and presence factors.

There are essentially two types of population to be considered in this case: road users and people living, working, attending school etc. in the lands along each side of the route. Both population groups are variable for different sections of the routes and variable depending on the time of day and week. The road user population is also variable to the extent that traffic congestion may occur from time to time. Additionally the road user population is variable to an extent depending on the nature and lead time for the incident as traffic may continue to approach a release event after an initial accident has blocked traffic (eg BLEVE of a flammable gas tanker following crash and ignition of leaking gas). A further factor in the variability is the opportunity for and the extent of successful evacuation or other evasive action.

The densities used in the analysis are discussed below. The presence factors are discussed in **Section 6.4**.

6.3.4.1 Surrounding Lands

Detailed mapping of land use was not available from councils and the time and budget available for the study did not allow for field surveys to develop this information. The approach used to determine the population densities therefore relied on surveys of the land uses fronting each of the routes to establish percentages of residential, business/industrial, schools, hospitals, special uses and open space. Census data was used to determine residential population densities for each route segment, typical densities were taken for business/industrial and open space and actual numbers used for schools and hospitals.

The residential densities were obtained by dividing the population for each of the 1991 Census collectors districts on either side of the routes by the estimated area of the district. The population densities were assumed to be constant for the three years covered.

As indicated in **Section 2.3.3** the likely future development along the routes was considered. The identified developments was not of such type or magnitude as to justify changing the estimated population. The land use percentages and the residential densities are set out in Tables in **Addendum 3H.**

The residential densities were generally found to be in the range which would be typical for single dwelling house areas which are the dominant form in these areas. However as the residential density figures were census populations averaged over the whole of the estimated collectors district areas, which are not exclusively residential, they would tend to understate residential population densities to some extent, particularly for some areas. This has been accounted for to some extent in the treatment of the other land use figures but it was nonetheless decided to use the the raw residential population density figures for each traffic sector rather than estimating day and night or mean 24 hour populations. To the extent that the incidents would in practice be concentrated in the daytime and evening this may tend to overstate the population exposed. This effect would be offset by the fact that no specific allowance has been made for the presence of pedestrian traffic.

The field surveys of land use did not separately identify business and industry and no route specific commercial and industrial population data was available. Typical density was used, 250 per hectare for commercial and 55 per hectare for industrial (Searle, personal communication), combined to give an average business/industrial figure of 15,250 people per square kilometre.

The population density of any school or hospital fronting the road in a section was calculated using actual school populations and estimated areas.

The population density for special uses, in this case mainly the airport, was assumed to be equivalent to business/industrial.

The density for open space, in this case mainly golf courses and low intensity usage park areas, was assumed to be 1,000 per km^2.

For calculation of densities, the real areas of identified schools and hospitals were used and the balance of the footprint area was assumed to be that for the other uses in the proportions as explained in **Section 6.4.**

6.3.4.2 Road Users

For the estimation of the potential road user population exposed vehicle densities were calculated for each route sector for peak periods and for daytime business periods. A figure was also generated for packed (bumper to bumper) densities, assumed to be one vehicle every 6 metres of each lane. The figures expressed as vehicles per hundred metres of road are presented in **Addendum 6H**

To translate vehicle density into population density it was assumed that vehicle occupancy was 1.5 people. This figure is on the high side to allow for the possibility of bus traffic and to err on the side of conservatism. Its effect on the route to route comparisons is limited as the same factor is applied to all roads. For the tunnel where the only affected population is road users where larger consequence distance events are involved this may tend to overstate the fatality numbers.

6.3.5 Fatality Consequences

The fatality consequences resulting from the application of consequences to populations have been factored into the risk analysis. Samples of the results are included in **Addendum 6G.** These results do not take account of the likelihood of the events. The assessment of likelihood is reported on in **Section 6.4** and the combination of likelihood and consequence in **Section 6.5**.

6.3.6 Property Damage

The analysis of property damage was essentially limited to consideration of damage to the tunnel structure and systems as this was seen as the area most relevant to the analysis. It should however be noted that some hazardous materials incidents in the open would have some potential for significant damage to property, principally to road surfaces and other infrastructure such as cabling in trenches, drains etc. For some events, such as explosions and fires, direct damage or propagation to buildings on surrounding lands would be possible but the frequency and extent of such damage would be expected to be low.

In both the tunnel and open air cases there is also potential to involve other vehicles in fire events. The likelihood and consequences of involvement of other DG vehicles has been covered in **Section 6.3.2.4**. Cars, non-DG trucks (including trucks carrying combustible liquids), buses and other vehicles can also burn with significant heat outputs (about 10 to 20 MW for a car, or bus and much higher or trucks carrying combustible loads) and smoke generation.

In the open the extent of propagation to other vehicles would generally be limited to those vehicles directly involved in a crash, although other vehicles within a burning pool or in the path of a flowing liquid could also be expected to be ignited.

In the tunnel the extent of direct fire involvement and the heat fluxes received would be such that more extensive involvement of cars and trucks could be expected. The contribution of these secondary fires to the duration of the event and consequently to the extent and severity of structural damage could well be significant and has been considered in developing the conlcusions on tunnel damage below.

The consequences in terms of losses of motor vehicles and their cargoes has not been quantified or analysed as it was not considered central to the objectives of the study. It should however be noted that this effect could add substantially to the overall cost of incidents in the tunnel and would be expected to be much more significant for the tunnel than for the open air sections. The lower level of potential for impact on infrastructure would be an offset to this effect. If it were to be determined that such potential losses should be factored in to the equation the risk and dollar cost consequences could be readily estimated in a separate analysis.

The incident outcomes identified as having significant potential for damage to the tunnel structure or systems were:

- Class 1 - 6 tonne TNT explosion
- Class 2.1
  LPG bulk - Jet fires (several sizes), BLEVE, pool fires (several sizes) vapour cloud explosion VCE (several sizes), explosive/flammable concentration in ventilation ducting/fan house
  LPG cylinders - fire involving the whole load
  Hydrogen - jet fire (several sizes), BLEVE, VCE, explosive/flammable concentration in ventilation ducting/fan house.
- Class 3 - petrol pool fires, vapour explosions, tanker fire, roadway spill fire, drummed load fire.
- Class 4 - nitrocellulose load fire
- Class 5.2 - MEKP load fire
- Class 8 - hydrochloric acid fumes and vent system shut down.
- Non-DG - polyethylene bead fire.

Indicative consequence results relevant to damage to the tunnel are included in **Addendum 6I**. The likely consequences of these scenarios and the equivalent open air cases where applicable are discussed below.

Class 1 - Loads OA1 and T1

The explosion overpressures for the Class 1 load scenarios are presented in **Addendum 6G.**

Based on the results for the open air cases the extent of damage to properties on surrounding lands would be likely to be extensive with substantial property damage for up to half a kilometre.

Without detailed geotechnical investigation and finite element analysis it is not possible to be definitive about the effects of a blast of this magnitude on the tunnel.

Any detonation of this magnitude is going to cause major damage to the tunnel finishes, tunnel services and ductwork. We suggest as a minimum 500 to 1000 metres of the affected tunnel would need to be totally gutted and refitted after such a blast. In addition the likely effects on the main tunnel structure would be as follows for the various possible blast locations:

Detonation in the Cut and Cover section of a tunnel - It is almost certain that the blast would blow the roof and overburden off the tunnel and highly likely that the tunnel separation would be ruptured with significant damage to the adjacent tunnel. This also applies to the transition structure between the cut and cover and driven sections of the tunnel although the probability of breaching the separation between tunnels lessens as you proceed further from the surface.

Detonation in the minimum cover sections of the driven tunnel - Detonation in the section of driven tunnel where the rock cover is least (eg. approximately 5 metres near Bardwell Park station) would likely result in the failure of the tunnel structure and the blast penetrating to the surface. Thus, as well as extensive damage to the tunnle secondary missile and shockwave damage would be expected at the surface.

Detonation in the maximum cover sections of the driven tunnel - Detonation in the section of the driven tunnel where the rock cover is greatest (eg. approximately 55 metres near Minnamorra Avenue) is unlikely to result in the failure of the tunnel structure although a significant shockwave would be experienced at adjacent residences. Thus, major damage will likely be limited to the confines of the tunnel.

Detonation in areas of intermediate cover - Damage resulting from detonation in a section of intermediate cover (say 10 to 30 metres) is hard to quantify. There will certainly be a significant shock wave and possibly some fracturing of the rock but eruption of debris is not considered likely.

Detonation near major ductwork causing shockwaves to travel to a fan station - Detonation in these locations would most likely completely wreck the fan station and could result in some secondary blast debris damage in both the area of the air intake/exhaust and in the adjacent tunnel due to some of the blast energy flowing through the ductwork to these locations.

Breaching of the separation between the tunnels in not considered likely unless the detonation occurs at a fault in the rock or in the cases noted above.

The likely effect of any detonation is the closure of the M5 for a significant period (say 3 to 9 months) for repair work and the subsequent disruption to traffic patterns that this would cause.

Class 2.1 - Loads OA2, OA3, T2, T3,T4 and T5

The pool fire, jet fire, BLEVE and VCE consequences of incidents involving these loads are given in **Addendum 6G.**

Based on the results for the open air cases the extent of damage to properties on surrounding lands would not be likely to be extensive though clearly property in the immediate vicinity of these incidents could be damaged severely and some damage could be sustained further afield.

Vapour Cloud Explosions - The overpressures generated by the Hydrogen and LPG Vapour Cloud Explosion models are very similar to those generated for the Class 1 explosion. Property damage consequences of these events can be assumed to be as for the Class 1 explosion with the exception that damage to the exhaust system is more likely as the explosive gas mixture would probably have filled the ducting and possibly the fan casings prior to detonation.

Similar shutdown periods to those suggested for the Class 1 detonation can be expected.

LPG BLEVE - The overpressures generated by the LPG BLEVE are much less than those for the cases previously considered. Damage would likely be limited to local damage to the ductwork and damage to tunnel finishes unless the blast occurred near to major ductwork causing shockwaves through the ducts. An extended tunnel shutdown is not anticipated for this event. The fire effects would be of such short duration as not to cause damage except to electrical fittings and the like. Secondary fires involving othe vehicles could however result in prolonged fires and substantial damge to large areas of the tunnel.

Jet Fires - Jet fires can be considered similar to Class 3 flammable liquid fires nominated below. Fires with a large heat output but short duration would not cause extensive structural damage while fires with a moderate heat output and duration of several hours could be expected to cause local structural failure. All property damage consequences noted under the Class 3 flammable liquid section can also be applied to jet fires. Again secondary fires could add to the extent of consequences.

Class 3 - Loads OA7, OA8,T11 and T12

In the open air cases fire could propagate to structures directly in the flame area and possibly spread from these structures to others. Any structures impinged on by the flames from the flowing liquids could also become involved. The extent of these effects would generally be expected to be limited.

Three generic cases were considered to indicate the nature of the effects of flammable liquid fires in the tunnel:

- A full scale pool fire - say represented by 1000MW fire load
- A slower burning tanker/drummed load fire - say represented by 200MW fire load
- The design fire intensity of 25MW but with a longer duration.

1000MW Pool Fire - In the case of large pool fires the smoke exhaust system if activated would be operated to destruction, but with a design capacity of 25MW the system would not provide significant smoke control for a fire of this size and intensity.

Because of the limited duration of such a fire, no significant structural damage is anticipated (some local spalling only) however the smoke control system would probably be severely damaged requiring the replacement of a significant number of fans. If other vehicles became involved, as would be likely, the duration of the fire would be likely to be extended and the damage greater.

The key factor determining the length of a tunnel closure after such a fire would be the supply of these fans. It is expected that a six month closure would occur.

200MW Tanker/Truck Fire - With the assumed smoke ventilation system this fire would be similar in effect to the 1000MW case but would be of longer duration but still within the fire rating period for the tunnel structure unless other vehicles became involved - this must be considered to be likely. The discussion of the 25MW design case below gives some indication of the likely consequences of a prolonged fire even at a lower intensity.

25MW Car/Truck Fire - The following is based on the assumption of an ongoing 25MW fire such as could occur with more than one vehicle involved. Fires of less than two hours duration will not be as onerous.

The smoke exhaust system would function for approximately two hours before failure of the fans due to overheating of the motors.

After the system has ceased functioning the next thing to fail would probably be the suspended ceiling/smoke duct which would collapse due to spalling of the concrete and subsequent failure of the reinforcing. This failure is expected at approximately two to four hours from the start of the fire depending on the development time and the intensity of the fire. Failure of the emergency egress doors adjacent the fire in the affected tunnel will occur at a similar time.

After this point the structure of the tunnel will be directly exposed to the fire. This leads to two possible scenarios:

- Fire occurring in driven tunnel section: A fire in the driven tunnel section will, after collapse of the ceiling, expose the shotcreted/rockbolted tunnel roof to direct flame impingement. Spalling of the shotcrete in the areas of most intense combustion is likely but failure of the rockbolts in the area of the fire is considered unlikely due to the small area of rockbolt exposed to the flame in relation to the large volume of rock available to each rockbolt for heat dissipation.

- Fire occurring in the cut and cover tunnel section: A fire in the cut and cover section of the tunnel will, after the collapse of the ceiling, expose the reinforced concrete of the roof to direct flame impingement. This structure will be designed in accordance with any normal fire rated concrete structure to resist fire. Eventually (say six to eight hours from the start of a fire) this structure would collapse in the fire affected carriageway due to the spalling of the concrete exposing the reinforcement and the subsequent failure of this reinforcement due to overheating. Failure of the adjacent carriageway is unlikely.

Thus, the consequences of a fire of this nature could include structural failure of the tunnel and would invovle extensive damage to tunnel fittings. In addition, replacement of the section of roadway where the spill has flowed is likely to be required due to the degradation of asphalt surfaces from the effect of Class 3 materials on bitumen.

The possible tunnel closures would range from a few weeks in the case of a fire causing no structural damage up to six months or more for repair of a collapsed cut and cover section.

Class 4 - Loads OA9 and T13

No extensive propagation or property damage except possibly to infrastructure would be expected in the open air cases.

Because of the relatively slow burning rate of the nitrocellulose material this case would have consequences similar to the 25MW fire considered under the Class 3 flammable liquids section above.

Class 5.2 - Loads OA11 and T16

As with Class 4 no extensive propagation or property damage except possibly to infrastructure would be expected in the open air cases.

Because of the moderate burning rate of the Class 5 materials considered this case is similar to the 200MW tanker fire nominated under the Class 3 flammable liquids section above. The duration of the fire is not likely to be sufficient to cause any structural collapse unless other vehicles are involved. The spread to other vehicles is less likely in this case than for the Class 3's or Class 2.1's but is still a realistic possibility.

Class 8 - Load T20

The property damage consequences of spillage of corrosives are not likely to be sufficient to require a significant shutdown of the tunnel. The concrete drainage system pipes, pits and sump will be etched by the acid and neutralising of the residual acid would be advised before the tunnel is reopened to prevent further damage.

The sump pumps would be likely to corrode severely and there would be some damage requiring rectification of the ventilation system ductwork and fans due to their handling acidic vapours.

Non-DG - Load T21

Fires involving non-DG's are less likely to spread to other vehicles but may still involve substantial heat outputs and may have a sufficient duration to cause damage to the tunnel and fittings. In the case modelled the fire would be intense at first but would settle quickly to a pool fire with a heat output of about 18MW. The fire would last for approximately 7.5 hours in the absence of intervention. Applying the principles outlined in the discussion of Class 3 fires above, a fire of this magnitude would be coped with by the smoke exhaust system for an extended period but would probably fail well before the end of the fire. Because of the long duration some structural damage could be expected.

6.3.7 Consequences for the Biophysical Environment

As identified in **Section 6.2**, there are a number of classes of materials with some potential for adverse impact on the aquatic environment. Whilst the nature of the materials and their impacts on the aquatic environment may cover a wide range and some impacts could be quite significant, this study is only concerned with comparative risk as it is a starting assumption that all the materials will be carried along one or more of the routes.

The northern route drains via Bardwell Creek, Wolli Creek and the Cooks River to Botany Bay. The southern route drains to Botany Bay via Wolli Creek, Bardwell Creek (which flows into Wolli Creek) and the Cooks River. All the sections of the M5 route except the sections in common with the southern route at the eastern end would drain via Wolli Creek. The eastern sections would drain to the Cook's River.

For all routes, therefore, the downstream receiving waters (the lower Cook's River and Botany Bay) are common. Whilst for some of their lengths the northern and southern routes drain to Wolli Creek direct and the southern route drains to the lower part of Wolli Creek via Bardwell Creek,the effect of diversion of DG loads to the M5 would be to increase the concentration of such traffic within the catchment of Wolli Creek, particularly of its upper reaches. It should be noted however that in terms In terms of the length of road draining to the upper reaches of Wolli Creek the existing routes involve lengths at least equal to the open air sections of the M5. At the same time as concentrating DG traffic in the Wolli Creek catchment, a proportion of the DG traffic would be removed from the catchments of the other creeks and of the section of the Cook's River above the junction with Wolli Creek.

The crash rates and the rates of releases due to other causes for the M5 including the tunnel would be less than for the other routes. The northern and southern routes are understood to have few pollution barriers. The M5 tunnel as analysed would have some 30,000 litres of retention capacity. This retention capacity provides a substantial degree of protection against the passage of any materials released in the tunnel to the waters of Wolli Creek. The open air sections of the M5 are described in the EIS as having a system of gross pollutant traps, porous drains and sediment traps. Whilst these features would only provide some limited protection against released materials reaching the Creek, they are nonetheless greater than the protection on the alternative routes.

Having regard, then, to the relative likelihood of initial release and the relative provision of pollution mitigation measures it is clear, without further analysis, that the M5 route will have a lower risk to the aquatic environment overall. It is also clear that, in terms of risk to the biophysical environment, unless the upper reaches of Wolli Creek were considered to be of significantly greater importance and/or sensitivity than the waters of the other Creeks in the area and the relevant sections of the Cook's River, use of the M5 route for the transport of all types of DG's with a potential to harm the aquatic environment is to be preferred.

6.3.8 Release Cases to be Carried Forward for Likelihood Analysis

The following representative DG loads have been found to have consequence potential sufficient to warrant likelihood analysis.

(i) <u>Open Air</u>

Load OA1 6 tonne NEQ load with mass explosion hazard.

Load OA2 20 tonne LPG tanker. Fireball, VCE and flash fire from tank rupture, BLEVE, jet fire, pool fire and flash fire from 50 mm orifice, jet fire and pool fire from 10 mm orifice, and BLEVE and jet fire from relief valve.

Load OA3 A load of 50 x 45 kilogram LPG cylinders. Fire involving the whole load, jet fire from 25 mm orifice, jet fire from 10 mm orifice, and jet fire from relief valve.

Load OA4 20 tonne chlorine tanker. Toxic concentrations from tank rupture, 50 mm orifice, 10 mm orifice and relief valve.

Load OA5 Chlorine in 920 kilogram chlorine drums and 70 and 33 kilogram cylinders. Toxic concentrations from catastrophic rupture, 25 mm and 10 mm orifices.

Load OA6 20 tonne anhydrous ammonia tanker. Toxic concentrations from tank rupture, 50 mm orifice, 10 mm orifice and relief valve.

Load OA7 40,000 litre petrol tanker with 8,000 litre compartments. Tanker fire and 36,000 litre pool fire.

Load OA8 15 tonne packaged load of petrol comprised of 1,000 litre mini bulks and 200 litre drums. Whole of load fire.

Load OA9 10 tonnes of ethanol wetted nitrocellulose. Whole of load fire.

Load OA10 20 tonne tank of hydrogen peroxide. Aggravation of truck fire from tank rupture.

Load OA11 20 tonne load of packaged MEKP. Whole of load fire.

(ii) Tunnel

Load T1 6 tonne NEQ load with mass explosion hazard.

Load T2 20 tonne LPG tanker. Fireball, VCE and flash fire from tank rupture, BLEVE, jet fire, and pool fire from 50 mm orifice, BLEVE, jet fire and pool fire from 10 mm orifice, and BLEVE and jet fire from relief valve.

Load T3 A load of 50 x 45 kilogram LPG cylinders. Fire involving the whole load, jet fire from 25 mm orifice, jet fire from 10 mm orifice, and jet fire from relief valve.

Load T4 - 4,000 m3 load of hydrogen in 'torpedoes'. VCE from whole load release, VCE from catastrophic rupture of 2 torpedoes, jet fire from 25 mm orifice, jet fire from 10 mm orifice, and jet fire from relief valve.

Load T5 - 25 pallet load of hydrogen in 5.9 m3 cylinders. Fire involving whole load, cylinder rupture, jet fire from 25 mm orifice, jet fire 10 mm orifice, and jet fire from relief valve.

Load T6 20 tonne load of liquid nitrogen. Asphyxiating concentrations from tank rupture, 50 mm orifice, 10 mm orifice and relief valve.

Load T7 20 tonne load of liquid oxygen. Release cases: catastrophic rupture (instantaneous release); continuous releases from 50 mm and 10 mm orifices. Consequences assessed: fire initiation/aggravation.

Load T8 20 tonne chlorine tanker. Toxic concentrations from tank rupture, 50 mm orifice, 10 mm orifice and relief valve.

Load T9 - Chlorine in 920 kilogram chlorine drums and 70 and 33 kilogram cylinders. Toxic concentrations from catastrophic rupture, 25 mm and 10 mm orifices.

Load T10 20 tonne anhydrous ammonia tanker. Toxic concentrations from tank rupture, 50 mm orifice, 10 mm orifice and relief valve.

Load T11 40,000 litre petrol tanker with 8,000 litre compartments. Tanker fire and 36,000 litre pool fire.

Load T12 15 tonne packaged load of petrol comprised of 1,000 litre mini bulks and 200 litre drums. Whole of load fire.

Load T13 10 tonnes of ethanol wetted nitrocellulose. Whole of load fire.

Load T14 20 tonne tank of hydrogen peroxide. Aggravation of truck fire from tank rupture.

Load T15 20 tonne load of packaged hydrogen peroxide. Aggravation of truck fire from 1,000 litre package rupture.

Load T16 20 tonne load of packaged MEKP. Whole of load fire.

6.4. LIKELIHOOD ANALYSIS

6.4.1 Introduction

The likelihood analysis involved deriving or extracting frequencies and probabilities and applying them to the event trees for the loads which were found to have significant consequences - those loads indicated at the end of section 6.3. Some further event trees were also developed to cover aspects of likely responses and reliability of systems in the tunnel.

In selecting the frequency and probability values, the likely sensitivity of the analysis to changes in the variables was carefully considered with particular regard to the possibility of biasing the analysis in favour or against one or other of the routes. This aspect was particularly important in respect of the tunnel cases relative to the open air cases and particularly important for population exposure issues and incident rates.

Generally conservative likelihood figures were used, particularly where their effect was judged to be neutral across the cases. To the extent that any conservative number adversely affects the M5's relative position then a stronger basis is established for confidence in relative risks once risk reduction measures are implemented.

As indicated in **Section 6.1.5** the figures were drawn from a range of sources including: surveys carried out for this study; other studies/surveys of DG transport in the region and NSW more widely; overseas transportation and tunnel studies; and generic data. In some cases it was possible to use the data directly whilst in others some adjustments were necessary to allow for differences between the cases under study and those to which the other figures relate.

Due to the shortcomings or absence of domestic data, a number of values adopted were based on a review of overseas data as published in the literature.

In some cases estimated values had to be derived from general principles, an assessment of the specific factors influencing each case and available relevant indicative data. As an ongoing part of the analysis the likely sensitivity of the study outcomes to the values adopted was kept under review and as reported on in **Section 6.5.5** the affect of changes in these figures was a particular focus of the sensitivity analysis.

The values adopted are set out below for each item. The basis for the adoption of the figures is set out in the text or where appropriate is described in detail in **Addendum 6K.**

6.4.2 Frequencies and Probabilities Used

6.4.2.1 DG Truck Movements

The number of DG truck movements were estimated for two screenlines (east of Bexley Road and west of Bexley Road) for each of the subject years. The method used for this estimation involved a review of the available surveys and traffic data to establish a relationship between DG movements and overall traffic. This relationship was then applied to the predicted traffic volumes for the northern and southern routes at the screenline points to derive total DG traffic movements. As it was assumed for the purposes of the study that either all DG traffic would use the M5 or would be distributed across the two existing routes in accordance with the 1993 proportion, the DG traffic volumes thus derived were also applied to the M5. The figures are presented in **Addendum 4A.**

For the generation of the frequency figures all recorded DG trucks were assumed to be fully laden. The DG movement figures were based on observation of trucks carrying placards and therefore any truck displaying a DG placard was counted unless it was an empty flat bed truck. In the absence of other figures, and in the light of industry advice that bulk tankers frequently return with part loads rather than being empty, it was decided to use this conservative approach.

As the loads particularly on bulk tankers are likely to be less than full this overstates the risk due to large releases to an extent by overstating the number of DG movements with that potential. It also overstates the risk in the eastbound direction to an extent but how much is not known. As this assumption is consistently applied to all three routes it should not bias comparisons.

6.4.2.2 DG Truck Movements by Class

The results of the 24 hour survey of DG movements undertaken for this study and described in Section 3 provide the only figures of DG movements by class directly applicable to the routes being studied. As the survey was only for one 24 hour period it was considered appropriate to compare it with the results of other surveys and those used or cited in other studies which might be considered to be relevant.

Addendum 4A sets out the identified figures. It was concluded from the review of the figures that, with some small adjustments, the results of the 24 hour survey were probably the most reliable general indicator of the approximate proportions of the DG traffic. Points worth noting in support of this conclusion are:

- The 79 percent figure in the EPA survey is for all petroleum products not just petrol and goods such as diesel and heating oil which are not classified as DG's are therefore included in that number.
- The Considine UK figures show a larger proportion of flammable liquids by volume but as would be expected the share comes down considerably for movements. It is noted that in the UK, according to the HSC report, while the bulk of petroleum fuel is transported by road the flammable and toxic gas loads are predominantly transported by rail. As the EPA survey shows road is the dominant transport mode for all classes of DG's in NSW.
- The HSC and Canadian studies used proportions amongst the three classes shown and were not attempts to define the overall pattern of DG movements. These figures are included to indicate the approach taken in other studies and the relativities assumed.

As well as the figures indicated in the table, the proportions of DG's were compared to the results of the questionnaires sent to companies. From these answers and the consultants' knowledge of the movements of Class 6 materials it was felt that this class might be under represented in the 24 hour survey and an adjustment was accordingly made to that number by transferring some of the Class 9 proportion to Class 6. The other figures were also rounded to whole numbers.

Some further adjustment of the figures was considered warranted as the movements in Class 9 for which no representative loads were selected would be left out of the risk equation unless distributed in some way to the other classes. Mixed loads (which would be almost exclusively packaged goods) were apparently recorded in the 24 hour survey as Class 9 and it is considered most likely that such loads made up the majority of the recorded Class 9 loads. It was therefore determined that the figures should be distributed on the basis of the relative proportions of packaged goods by classes. The calculation method for this adjustment and the adjusted figures used to determine the numbers of movements for the classes are shown in the table in **Appendix 6A**.

In the absence of any record of movements of Class 1 materials a nominal 1 movement per week was assumed for the purposes of the analysis and this share was taken from the largest class, flammable liquids.

(b) Provide emergency egress at reduced spacing.

This measure is a moderate cost but effective method safety improvement. Reducing the spacing of emergency egresses would reduce the required safe evacuation time for motorists. When used in conjunction with an improved VMS system above substantial reductions in evacuation time could be achieved. It is noted that the Board of Fire Commissioners preferred spacing is 60m at this point in time. Further evaluation of the preferred spacing should be undertaken in the context of the risk analysis given the measures described in (i) above.

(c) Provide a moveable median strip or other physical barrier to prevent inadvertent entry during a tunnel emergency shutdown.

This measure is a cost effective and appropriate method of safety improvement. Operational experience on many tunnels, in particular the Sydney Harbour Tunnel, has shown that traffic signals alone are relatively ineffective at preventing motorist entry in the case of tunnel emergency closure and the radio rebroadcast override with emergency messages is not effective until in range and requires the radio to be turned on. The Sydney Harbour tunnel is in fact investigating retrofitting a moveable median strip to the northbound carriageway to improve closure effectiveness.

(d) Provide increased exhaust stack height to enhance dispersion of toxic smoke products and toxic gases and vapours.

This measure is a cost effective and appropriate method of safety improvement. The dispersion of toxic smoke products or inherently toxic substances improves rapidly with increases in stack height at moderate cost. Visual impacts and community resistance to discharge at stack locations could be significant barriers to this measure.

(iii) Measures to minimise tunnel closure time in the case of an event occurring:

(a) Increase spares holding of exhaust dampers, fans and other items with long supply periods to minimise time to refit after and event.

Fans of the size required for tunnel ventilation have very long supply times (approximately 6 to 9 months) and are predominantly sourced overseas. Dampers have a shorter, but still considerable, supply time. The likelihood of running to destruction all the fans in whichever fan room is used to control even a light truck fire is high and it is a virtual certainty for a fire of any flammable liquids spill. Given this status, the holding of sufficient spare fans to re-equip one fan room completely would need to be assessed carefully. Standardisation and interchangeability of fans throughout the system (and possibly with other tunnels existing or proposed in NSW) should be maintained as far as possible.

(b) Increase the structural fire rating of the tunnel.

This measure is a cost effective and appropriate method of safety improvement. The cost differential between a two hour fire rating as opposed to a four hour fire rating, for example, are negligible in a project of this nature. The maximum feasible fire rating should be used for all structures that could be exposed to fire.

(c) Increase the blast resistance of the tunnel.

No data is available at this time on methods of improving the blast resistance of a tunnel however this is considered to be an expensive exercise. It is probable that military research data is in existence on this topic but access to this data may be limited. No firm recommendation on this matter made at this point.

8.3 RECOMMENDATIONS

The study findings suggest that it is likely that design and operational modifications will be capable of reducing risk levels associated with DG transport through the tunnel to a point where they are lower than for the alternative routes. It would be appropriate therefore for further work to be undertaken on a number of aspects. Such work should build on this study: to resolve remaining uncertainties and ensure that there can be high confidence levels in final risk results; to take account of the effect of the changes in design flowing from the study findings; and, to take account of changes in routing and other tunnel features which have arisen for other reasons.

It is therefore recommended that:

(a) Risk 'acceptability' criteria specific to this case should be developed to ensure that the conclusions and decisions made on DG transport and on the level of risk reduction measures to be implemented have an explicit basis and will be acceptable to the Department of Urban Affairs and Planning. The criteria should cover fatality, injury and property damage. Consultation with DUAP would be appropriate in the development of such criteria. Such consultation should also address the acceptability to DUAP of assumptions made in the consequence analysis for the Open Air cases.

(b) The various design and operational elements proposed as risk reduction measures in **Section 8.2** should be worked up to establish their technical and economic feasibility in the context of the tunnel routing and length etc. as it is proposed at that time. Such analysis should pay particular attention to the need to maintain longitudinal ventilation flow above critical velocities under all operational and emergency conditions. As the object of this exercise is risk reduction, it is important that this development and refinement be undertaken with full regard to the effect of measures on incident consequences and to the reliability of systems in atypical circumstances. It therefore needs to be undertaken as a fully collaborative and interactive exercise between risk engineers and tunnel design specialists.

(c) Once the risk reduction options have been worked up (and following review and comment as appropriate) the revised tunnel system should be subject to full risk quantification with the separate identification of the risk reduction contribution of the various risk reduction measures and analysis of their interdependence if any. This will enable formal comparison with the alternative routes and a ranking of risk reduction measures in terms of cost effectiveness.

(d) The tunnel damage analysis should be further developed to include quantification of the likely frequency of incidents resulting in tunnel closure for various durations and the direct and indirect costs of such events. Assessment of the frequency and costs of such events on the alternative routes could also be undertaken for comparative purposes.

(e) Consideration should be given to the development of risk acceptability criteria specific to this case so that any decisions made on DG transport and on the level of risk reduction measures to be implemented have an explicit basis. Consultation with the Department of Urban Affairs and Planning may be appropriate in the development of such criteria.

(f) A detailed analysis of the benefits and consequences of the installation and use of deluges, sprinklers or any identified alternative fire suppression systems should be conducted prior to any decision to incorporate any such system in the tunnel design and the results of that study should be and input to the overall risk assessment of the preliminary and final design

(g) A detailed analysis of the spacing and nature of egress routes should be undertaken in the context of the risk analysis.

(h) Contingent with all the above elements, the cost benefit and economic feasibility needs to be considered.

(h) As part of the overall design process, hazard and operability studies (HAZOP's) should be conducted for all emergency related elements of the project with special attention to the ventilation, drainage and emergency identification and response systems.

Regardless of the findings of further work the following safety related measures should be incorporated into the tunnel design and operating arrangements particularly if a decision to permit DG transport is taken.

(i) A formal and comprehensive emergency plan should be prepared.

(j) A firm requirement of any approval for DG transport through the tunnel should be the development and implementation of a rigorous training programme covering all safety related aspects.

(k) Safety management systems for the tunnel should be subject to periodic independent audit.

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There were also no recorded movements for Class 7. As most Class 7 materials are understood to be moved in cars or light commercial vehicles, not heavy vehicles, they tend to be missed by field surveys even when they are not expressly excluded on grounds such as of the different regulatory arrangements applying to this class. As this class was excluded from further analysis at the hazard identification stage no estimates were made for movements in this class.

6.4.2.3 Packaged and Bulk Proportions by Class

The proportion of packaged loads to bulk loads was determined separately for each representative load. These proportions were based on the proportions found in the 24 hour survey together with specific information provided from the industry questionnaire, direct contact with transporters and other surveys and studies. The figures derived are presented **Table 6.4.**

TABLE 6.4
PERCENTAGES PACKAGED & BULK
Survey Data

Quantity/Class	1	2	3	4	5	6	8
Percentage of class transported in bulk	0	64	89	40	57	0	84
Percentage of class transported in packages	100	36	11	60	43	100	16

Specific information was provided by industry for LPG, chlorine, MEKP and hydrogen peroxide. These figures are presented in **Table 6.5.**

TABLE 6.5
PERCENTAGE PACKAGED& BULK
Industry Data

Quantity/Material	LPG	Chlorine	MEKP	Hydrogen Peroxide
Percentage of class transported in bulk	95	20	0	56
Percentage of class transported in packages	5	80	100	44

6.4.2.4 Type of Secondary Containment for Packaged Loads

The information from surveys on the extent to which packaged loads were transported in shipping containers or otherwise enclosed trucks as opposed to essentially open trucks was very limited. For the purposes of the analysis the enclosure of loads by shipping containers or other means was represented by the descriptor 'shipping container' and the differential effect of the various types of containment on the likelihood of loss of load, release, and fire propagation was reflected in the probabilities used for those outcomes.

The heavy vehicles survey results given in Brewer (1992) show that some 16% of all heavy vehicles, including bulk loads, were carrying containers. The industry survey information did not identify any use of shipping containers other than a small proportion of inwards loads. On the other hand industry information suggested an increasing trend to the use of taut liners which would offer some degree of protection against packages falling from the truck and fire propagation.

In the absence of better information it was therefore decided to adopt a 20% probability that a packaged load (not including cylinders) was in a shipping container or taut liner or equivalent. This allows 10% for actual shipping containers and 10% for others which would be expected to be more numerous but less effective.

'Shipping containers' were assumed to be effective in preventing release beyond the confines of the container in half the cases. This includes slowing down the rate of release to levels that would have no significant consequence potential.

6.4.2.5 Crashes

The crash probabilities used were derived separately for each urban arterial road route section by applying the annual truck crash rate for each section, derived from the actual truck crashes for the period July 1991 to June 1994, to the projected DG movements. For some sections the actual crash figure was zero. Where this was the case, a figure was used that was the average of the rate for the sections either side of it. The crash figures are given in **Addendum 4D.**

For the M5 sections of the route the crash rate derived from the existing sections of the M5 was 0.62 x 10-6 per DG vehicle kilometre. This rate was compared to overseas data for urban roads of various types, including motorways and tunnels. Representative rates are listed in the likelihood the data listed in **Addendum 6J**. The comparison showed the number to be reasonably conservative but realistic.

The use of the general truck crash rate may tend to overstate the DG truck crashes to the extent that DG truck drivers are better trained and more aware of the potentially serious consequences of crashes. There is some evidence to support the view that the DG truck accident rate is (or was) lower than that for all trucks (eg. Egilsrud, 1983). On the other hand an extensive survey in the U.S. found that DG trucks were more likely to be involved in crashes (Moses and Savage, 1993). Comparisons with overseas DG crash rate data and inferred crash rates from DG incident data showed the identical rates to be at the high end of the range. As the scale and even direction of adjustments to the crash rate was unclear and the truck crash statistics were available for each route section, it was decided to apply the general truck crash rate.

An issue arising from the crash ratees consideration is the definition used for a 'crash'. It is likely that the basis for inclusion of 'minor' crashes in studies and statistics differ markedly. This has implications for the use of other probabilities and frequencies related to crash outcomes drawn from those studies.

6.4.2.6 Loss of Containment Following Crash

Not every crash results in a loss of containment so probabilities needed to be derived for loss of containment as a result of a crash. These probabilities relate both to whether or not there is some significant loss of containment and the size of the release. The probabilities of this outcome vary with the type of load and containment. It should be noted that these estimates are based on probabilities from various sources which may calculate their crash rates differently, as noted in **Section 6.4.2.5**. The bases for the derivation of the adopted probabilities and the adopted figures are set out in **Addendum 6K.**

6.4.2.7 Loss of Containment without Prior Crash

As discussed in **Section 6.2.3** there are a number of possible causes and mechanisms for loss of containment without prior crash. Probabilities have been derived for all causes of leaks without prior crash for bulk and packaged loads. The causes have been generally covered with one probability as most of the available data does not distinguish between causes. The bases for the derivation of the adopted probabilities and the adopted figures are set out in **Addendum 6K.**

6.4.2.8 Fire in Truck

Fire in a truck describes fire initially involving the truck - engine, cabin, tyres, fuel etc. - but not the load. Such a fire may occur with or without a prior crash and may or may not propagate to the load. This item does not include incidents where the initial fire involves the load whether released or not. It should be noted that these estimates are based on probabilities from various sources which may calculate their crash rates differently, as noted in **Section 6.4.2.5.**

The bases for the derivation of the adopted probabilities and the adopted figures are set out in **Addendum 6K** .

6.4.2.9 Probability of Propagation to Load

The probability of propagation of a truck fire to the load will vary depending on the class, bulk or packaged load, whether it is in shipping containers or not, whether it is in the open or in the tunnel, and whether a crash has occurred or not.

Estimates for the probability of propagation of a vehicle fire to the load are based on a number of factors. Factors taken into account and the probabilities derived and used are set out in **Addendum 6K.**

6.4.2.10 Ignition of Released Material

This item covers the ignition of material which has been released from a load by whatever means, with or without a crash and includes fire which is initially in the load. The probability of ignition of released material will vary depending on the class, the size of the release, and whether it is in the open or in the tunnel. For all releases of flammable gases and all releases of flammable liquids caused by fire in the truck, the ignition probability has been assumed to be 1.

The bases for the derivation of the adopted probabilities and the adopted figures are set out in **Addendum 6K.**

6.4.2.11 Load Specific Probabilities

Some DG's have specific characteristics and modes of ignition, detonation, exothermic polymerisation etc. In most cases these modes of initiation have been subsumed within more generalised concepts as specific data is often not available.

For example no relevant data was found on the ignition in transit of flammable solids represented by nitrocellulose. It was assumed in this case that the ignition in transit case would in practice be adequately represented by the truck fire probability.

The explosives case is also a special case but in this case separate data was available and has been utilised as described in **Addendum 6K.**

6.4.3 Emergency Detection and Response

As discussed in Section 6.3 and Section 5 the assumed tunnel design incorporates several systems for the detection and notification of incidents and for response to detected incidents. The effectiveness of the operation of these systems has some bearing on the likely exposure of people to incidents. The systems and their likely roles in determining incident outcomes are discussed briefly below.

6.4.3.1 Incident Detection

Before any response can be initiated it must be detected. The assumed detection measures are: closed circuit TV cameras, thermal heat detectors, motorists emergency telephones and alarms on hydrant/hose reel/fire extinguisher panel doors. These systems report to the tunnel control centre which is assumed to be staffed by two operators at all times.

The likelihood of timely detection of incidents can be established using an event tree. The tree developed for these purposes is included in **Addendum L.** The probabilities for each of the steps in the tree are influenced by a number of factors including the reliability of the equipment and the performance of the operators.

The material involved and the type of incident will also affect the likelihood of early detection and the interpretation of timeliness. In particular the information observable on the closed TV system may be limited as the position of vehicles may partly obscure the view of the release and or the DG placarding. Similarly some incidents such as gas releases may obscure the view of cameras.

The probabilities used and the outcomes of the trees would therefore ideally be worked through for each load and incident. However due to the time limitations on this study and the absence of any detailed information on the maintenance and operational procedures and emergency planning and operator training to be applied some generalised assumptions were made. The validity of the findings of this analysis would be reduced by the extent to which performance fell below the assumed levels.

The assumptions applied were:

- That the CCTV cameras are maintained in good working order, that they will be replaced as necessary to ensure a low frequency of failure and that any cameras (or monitors) which fail will be replaced promptly ie within a few hours. With this assumed level of performance the coincidence of a DG incident with a camera failure (except where the incident causes the failure) should be so low as to be non-credible.
- That all other alarm equipment is maintained in good working order.
- That operators diligently observe the monitor screens and do not leave them unattended at any time.
- That operators respond promptly to all observed incidents,alarms and calls.
- That fires should be readily visible and are likely to be detected by heat sensors but that for other classes of incidents the nature of the release or the materials involved may be less clear and detection (in the sense of understanding the nature of the incident) on average is therefore likely to be slower.
- That the standard operating procedure would be for immediate closure of the tunnel as soon as a fire is identified but that such action would not be immediately taken for other incidents.

Based on these assumptions it is judged that any DG fire incident in the tunnel would be detected by operators within one minute and that a further minute would elapse before any effective intervention measures would be activated.

For events without fire it is assumed that a delay of five minutes occurs before effective intervention measures are implemented.

It would be appropriate for the final design and proposed operational and maintenance systems to be subject to a final hazard analysis and a hazard and operability (HAZOP) study.

6.4.3.2 Available Intervention Actions

Intervention actions available to the tunnel operators are: stopping the entry of further traffic; slowing or stopping traffic within the tunnel; use of variable message signs to instruct motorists; activating the emergency (smoke) ventilation system; and use of the rebroadcast system to alert and instruct motorists. Operation of an installed sprinkler or deluge system is another option which may be available but for reasons given in **Section 6.3.2.2** this has not been factored in to the analysis. Any response by emergency services has also not been taken into account on the grounds that in most incident scenarios such emergency service action would be likely to be too late to save lives.

In the open air cases no allowance has been made for intervention.

6.4.3.3 Intervention to Stop Traffic Flow

The tunnel operators could use the VMS's at the tunnel portals and inside the tunnel to slow traffic and possibly to stop entry. The operation of traffic signals at Marsh Street and Princes Highway could also be used to stop additional westbound traffic flow to the M5 and control at the toll plaza to stop eastbound traffic flow.

It is assumed that the VMS's at the tunnel entrances are sufficiently conspicuous and clear and are supported by signage and physical barriers as necessary so that all traffic stops when they are activated. The back up action at the M5 entry points and the toll plaza, whilst still appropriate, is not considered to have any effect on traffic numbers in the tunnel. All traffic entry to the tunnel is therefore assumed to be stopped at two minutes from fire ignition and five minutes from initiation of a release not initially involving fire.

6.4.3.4 Evacuation

The opportunity for evacuation and appropriate evacuation response will be incident specific. Where incidents are instantaneous or of very short duration from initiation to outcome, eg detonation of explosives or catastrophic failure of a gas vessel, evacuation is essentially irrelevant. Even for longer duration events in some cases staying in the motor vehicles (possibly with the vehicle closed and the ventilation turned off) may provide the best protection, eg some toxic release cases whilst in others escape via the passages between the tunnels would be the better course of action. The limitations on information available to the operators would be a significant factor limiting the opportunity for effective matching of response to the specific hazard as the images available from the type of TV cameras proposed would in many cases not be sufficient to gain any reliable indication of likely load type.

Furthermore as the cameras are fixed and look at the oncoming traffic and ventilation airflow, at least initially, would direct smoke towards the camera its view could be rapidly obscured in the case of a rapidly developing fire. If DG's are to be allowed through the tunnel this whole issue would need to be the subject of careful attention in emergency planning and operator training.

Once a decision is taken to initiate evacuation the operators would be able to advise of the appropriate course of action via the VMS's and the rebroadcast system provided that these had not been disabled in the incident. For some fire, most toxic and some flammable gas and liquids incidents where ignition has not yet occurred these systems should either be unaffected or remain intact for as long as is relevant. In other cases the incidents would rapidly obscure or disable either or both these systems. In the absence of definite indicators that a life threatening situation is likely to develop or clear instructions to evacuate people would be likely to simply stay in their vehicles. A further factor is that in stressful situations the reaction of people is not always consistent with instructions or with their best interests - not everyone will hear/see or heed the instructions. The time available for the study did not permit the fully detailed consideration of the likely interaction between incidents and these systems and instead the following assumptions, believed to be realistic but erring on the conservative side. It should be noted that these observations relate only to the people within the fatality effect zones evacuation would be of greater benefit to people in zones where injury or irritant effects may be experienced.

- No attempted evacuation is successful prior to instructions being issued.
- Load T1 evacuation has no effect.
- Load T2 for cold catastrophic failure with or without ignition and all other releases with immediate ignition evacuation has no effect. For delayed ignition events evacuation has no effect as ignition is assumed to occur within the first five minutes and traffic is continuing to arrive. For BLEVE, evacuation is 50% effective as it typically has a relatively long lead time after ignition.
- Load T3 as there would be likely to be significant time from initial fire to whole load involvement evacuation is 50% effective.
- Loads T4 and T5 for immediate and delayed ignition cases evacuation has no effect as ignition is likely to occur within the first five minutes.
- Load T6 evacuation has no effect as the period of relevant exposure is shorter than 5 minutes.
- Load T7 evacuation has no effect as any consequences of concern occur within the first five minutes.

- Load T8, T9 and T10 for catastrophic failure and other release events evacuation has no effect unless caused by fire in which case evacuation is 50% effective.

- Load T11 for people within the length of tunnel partially or fully covered by any pool at any stage of its progression where ignition occurs evacuation has no effect. Where fire propagates from a truck fire to the load evacuation is 50% effective. Where vapours are ignited evacuation has no effect.

- Load T12 for immediate ignition as the development of the fire to involve a substantial part of the load would take some time evacuation is 50% effective. For delayed ignition as evacuation is not initiated until after the start of the fire or for five minutes and delayed ignition is assumed to occur within five minutes evacuation is still only 50% effective.

- Load T13 for immediate or delayed ignition evacuation is assumed to be 50% effective as some time would be taken to involve the whole load and for propagation to the load it is 75% per cent effective.

- Load T14 as fire is the consequence of concern and it will occur only during direct involvement, evacuation has no effect for people within the length of the tunnel covered by any pool at any stage of its progression. Where propagation to the load is involved some time would elapse from ignition to total involvement and as the subsequent event would be limited evacuation is 75% effective.

- Load T15 as fire is the consequence of concern and it will occur only during direct involvement, release volumes are likely to be small and fire would take some time to fully develop evacuation is assumed to be 50% effective.

- Load T16 for immediate ignition the fire would develop very rapidly and therefore evacuation would have no effect. fro propagation from a truck fire evacuation would be 50% effective.

- Load T17 and T18 any people seriously affected within 5 minutes are assumed to be unable to evacuate (this is assumed to be anyone within the IDLH level) and for people outside this time frame 50%.

- Load T19 as the event is a fire it is assumed that any people seriously affected within 2 minutes (this is assumed to be anyone within the IDLH level) are unable to evacuate and evacuation for others is assumed to be 50% effective.

- Load T20 any people seriously affected within 5 minutes are assumed to be unable to evacuate (this is assumed to be anyone within the IDLH level) and for people outside this time frame 50%.

- Load T21 as the event is a fire it is assumed that any people seriously affected within 7 minutes are unable to evacuate and evacuation for others is assumed to be 50% effective.

6.4.3.5 Ventilation System Operation

The operation of the emergency ventilation system has been described in section 5 and analysed in section 6.4 and **Addendum D**. An event tree developed for the analysis of the factors affecting the reliability of this system in operation is included in **Addendum L**.

It is assumed that the ventilation system is always operating normally at the outset. After observing the incident the operator must decide whether to switch to the emergency mode. It is understood that for practical operational reasons it would be unlikely that this decision would be taken immediately except when a fire was evident (this assumption is clearly amenable to change depending on operating procedures). The operator has to choose which duct damper to open and there is a significant likelihood that because of error or lack of information for reasons given above the wrong section or damper might be opened. Whether the correct damper is opened or not there is a possibility that the system may fail on demand for a variety of reasons including attempting too rapid a start up sequence or the system overheating from the fire combustion products between stopping restarting in the reverse direction. If started successfully the system may fail due to the effects of the incident.(overheating).

These factors have been taken into consideration in the consequence analysis (see Section 6.3 and **Addendum D**) and in determining the frequencies and probabilities used. As indicated elsewhere in the study, the currently proposed ventilation system will need to be substantially modified if DG's are to pass through the tunnel. Procedures will also have to be developed. It would be appropriate for the final design to be subject to full hazard analysis and HAZOP.

6.4.3.6 Drainage System Operation

The operation of the drainage system system has been described in section 5 and analysed in section 6.3 and **Addendum C**. An event tree developed for the analysis of the factors affecting the reliability of this system in operation is included in **Addendum L**.

The currently proposed system is designed to operate automatically. It could fail to operate fully if the pipe(s) to the pump well were blocked; if the sump were already full or part full; if transfer pump(s) failed on demand (pump failure, switch/sensor failure, power supply failure) or under the stress the incident service (eg transferring a material incompatible with the pump); or the release rate or the rate of arrival at the pump well (significantly) exceeds the pump capacity. The operation of a deluge system or the use of other firefighting water could add significantly to the liquid volumes involved If the non-return valves preventing overflow from one tunnel to another failed to operate an incident could spread to involve both tunnels.

These factors have been taken into account in the consequence analysis. To the extent that they are found to be in need of upgrading they are all amenable to design to meet the needs of DG transport. As it was clear that features of the proposed design would require modification and some aspects of the system were necessarily unknown at this stage, detailed estimation of system reliability was not undertaken but the following conservative best estimates were made: probability that the single drain grate/sump at the low point of the tunnel was blocked for an incident occurring at or near the sump 10%; combined probability of failure of the pump well transfer system (including pipe blockage) 1% effective complete failure. It is noted that these figures may be on the high side but in view of the unknowns and the inclusion in the two cases of the likelihood of partial blockages and failures - due to necessary simplification - they are not considered to be unreasonable for this comparative analysis based on broad design concepts. It would be appropriate for the final design to be subject to full hazard analysis and HAZOP.

6.4.4 Population Exposure

The estimation of the density of the population on the roads and in surrounding lands was dealt with in **Section 3.5**. The following sections cover the presence factors - the proportions of time that the population is assumed to be present at each estimated density and hence potentially exposed to incidents.

6.4.4.1 Road Areas

For the purposes of calculating the areas impacted on by incident footprints it was assumed that all incidents were centred on the centre line of the road. All incidents with a consequence distance greater than half the width of the relevant road section therefore impacted both on the road and the surrounding lands whilst those with a smaller consequence distance impacted only on the road. For each footprint with a consequence distance beyond the roadway the area of surrounding lands affected was calculated by multiplying the consequence distance by the road width and subtracting the resultant area from the total footprint to give the footprint are applying to the surrounding lands.

The road widths adopted for the area calculations are:

Urban Arterial Roads

4 lane	25 metres
6 lane	35 metres

Motorway

Open air	50 metres

These figures allow 3 metres each side for footpaths for urban arterial roads and double the width of the carriageway plus a 3 metre median strip for the M5.

6.4.4.2 Surrounding Lands

For the surrounding lands, in the absence of full information on the pattern of land use, it was assumed that for each sector the incidents impacted on each population density in proportion to the percentage of road frontage. That is if the residential frontage was 50% and 50% commercial/industrial then each incident footprint (less the proportion of footprint that fell on the road area) was applied at half the incident frequency to the residential density and half to the commercial/industrial density. The exception to this approach was for schools where it was assumed that their contribution to exposed population was half of their frontage and where an incident footprint was larger than the school area the balance of the area was assumed to be that of the dominant use for that road sector.

6.4.4.3 Road Users

For road users it was necessary to establish probabilities that, given that an incident has occurred, the various traffic densities would apply. This is not simply a matter of distributing the densities in proportion to their occurrence in real time as the DG traffic and accident likelihoods are not evenly distributed. In particular the survey results show that DG movements tend to be concentrated in the morning peak and at very low levels overnight. As an approximation, then, the adopted probabilities are for peak flows one sixth of the time and business hours densities five sixths of the time.

The third condition, packed, arises in two different sets of circumstances: first when traffic congestion occurs due to other causes and second when it is due to traffic building up behind the initiating event but before the outcome of concern (such as a LPG truck crash leading to a BLEVE). To account for the prior congestion it has been assumed that on the urban arterial roads the probability of packed condition is 0.025 (based on an assessment of the proportion of the time traffic is queued at intersections). Assuming that 80% of packed conditions are associated with the peak periods and 20% with business the probabilities for urban arterial roads are: peak 0.147, business 0.828 and for packed 0.025. The probability of packed conditions arising as a result of an incident is specific to each incident increasing with the delay between initiating event and the hazardous outcome. This is balanced to some extent by the extent to which people have more opportunity to evacuate the area. The incident specific probabilities are dealt with in the next subsection.

Based on the relatively low traffic volumes predicted and the maintenance of the toll it would appear that congestion on this route would be relatively rare. For the motorway therefore it is assumed that the packed condition will arise much less often. A probability 0.001 is assumed which is comparable to the experience of unscheduled shutdowns for the Sydney Harbour Tunnel. As before it is assumed that this is split 80:20 and thus the probabilities for the M5 are: peak 0.1657, business 0.8331 and packed 0.001.

6.4.4.4 Packed Condition Probabilities for Specific Incidents

As previously indicated the road users affected by any incident will be those in vehicles within the incident footprint at the same time as the hazardous consequence of concern. For events which are instantaneous, such as detonation of explosives involved in a crash, the vehicles affected will simply depend on the traffic density at the time. For incidents where there is some delay between initiating event and full development of the consequence and there is some disruption to traffic eg BLEVE or flammable liquid fire the cars downstream of the incident will move away but the upstream traffic will continue to approach until stopped by intervention or visible signals (such as smoke) sufficient to deter approach. Organised or spontaneous evacuation may also serve to reduce the numbers.

For the purposes of this study it is assumed that all significant incidents result in traffic flow being blocked at the point of the incident in both directions (except in the tunnel). The numbers of road users within the footprint therefore would be the number of vehicles present at the time of the initiating event under the traffic conditions prevailing at the time plus the number of vehicles which arrive within the footprint on the upstream side between the time of the initiating event and the full development of the incident less the number of vehicles moving out of the footprint on the downstream side in that period. The vehicles moving out of the area is of course limited to the maximum number present on the downstream side at the time of the initiating event while the number approaching the incident is limited only by time. Vehicles are assumed to form an increasing tail at the assumed bumper to bumper density of one car every 6 metres. The evacuation effect has been dealt with separately above.

Some account of the likely extent of evasive action such as sheltering from fires in the open has been taken into account in the determination of heat and toxicant dose levels in the consequence analysis (see **Section 6.3.2.3**). The assumed effectiveness of evacuation in the tunnel has been covered in **Section 6.4.3.4.** As stated in that section, no allowance was made for the effect of evacuation in the open air cases.

Other things equal traffic continuing to approach a release event is more likely in the open road case as the roads are not as actively and directly controlled. There is also likely to be a longer lead time to detection of the incident by officials and effective intervention to control traffic. It has been assumed therefore that there is no intervention to stop approaching traffic in the open and that, as indicated in **Section 6.4.3.3**, that for incidents in the tunnel initially involving fire the entry of traffic will be stopped after 3 minutes while for other incidents entry will be stopped after 5 minutes. Whatever traffic is in the tunnel upstream of the initiating event and all traffic entering the tunnel during the next 3 or 5 minutes (using the same basis as for evacuation outlined in **Section 6.4.3.3**) is assumed to continue to approach the incident until they reach the stationary traffic.

6.4.5 Probability of Propagation to Secondary DG Loads

The possibility of propagation from one DG load incident to others in the traffic was discussed briefly in **Section 6.3.2.4** and some basic 'rules' outlined which could be applied to this potential for propagation. Whilst those rules were not fully developed as the constraints of this study prevented full consideration of this aspect it was nonetheless considered worthwhile to briefly address the likelihood of such circumstances arising.

The likelihood of a DG load being amongst the traffic affected by an incident can be estimated by applying the proportion of DG trucks in total traffic to the number of vehicles in the relevant effect zone (which is of course variable with the incident and the traffic conditions etc. applying at the time). The likelihood of that DG truck being of a particular load type can be estimated by applying the DG proportions and the packaged and bulk proportions and any other relevant probability such as assumed load split. Taking the 1996 traffic estimates from **Table 4A1 (Addendum 4A),** the total M5 tunnel traffic is 14,072,940 and the total DG traffic is 84,589. The percentage of vehicles which is DG traffic in the tunnel therefore is 0.6%. Therefore for packed density the likelihood that there is a DG vehicle in 100 metres of traffic (2 lane) is 0.006 x 33 = 0.198. That is for this case there is approximately a one in five chance that there is another DG truck in any 100 metres of packed density traffic in the tunnel. Applying the adopted DG proportions **(Addendum 6H)** 0.198 x 0.5692 = 0.1127 there is an 11% chance that there is a Class 3 vehicle in the 100 metres and 0.198 x 0.07 = 0.0139 a 1.4% chance of a Class 2.1 vehicle in the 100 metres.

The figures overstate the case to the extent that the packed density figures were based on closely spaced cars with no allowance for the presence of heavy vehicles. Whilst an adjustment for this would reduce the number of vehicles in any 100 metres it would not reduce the number of vehicles forming the tail behind an incident as this is based on the number of vehicles - the final tail for both peak and normal business conditions would however cover a slightly greater distance. A factor that may offset the effect of this overstatement is the possibility that trucks may tend to bunch up to an extent because they cannot move as freely as cars to overtake any slower moving vehicle and that therefore they may on average be more likely to be close to another truck than a simple random distribution through the traffic would suggest.

These figures would appear to be large enough to warrant further consideration. However the inclusion of DG vehicle propagation into the already complex analysis of tunnel scenarios (and as indicated in **Section 6.3.2.4** this question is most relevant in the tunnel damage context) would necessarily involve substantial additional processing and analytical time and therefore, due to the time constraints placed on the study, has not been able to be incorporated in the estimation of societal risk levels.

6.5. RISK ESTIMATION AND ASSESSMENT

6.5.1 Basis of the Risk Estimation and Assessment

As this study involves the assessment of alternative routes for DG's it has been principally based on comparative societal risk analysis. Due to the possibility of the concentration of risk at or near the stacks and air intakes some consideration of individual risk was also however considered appropriate.

As is common practice the study has focused on fatality risk and injury risk levels have not been quantified. Injury risk has however been considered in the hazard identification and consequence analysis to some extent and where relevant is covered in the class by class assessment.

Throughout the consequence and likelihood analysis generally conservative assumptions and models were used. This is consistent with the approach advocated by the Department of Urban Affairs and Planning and usually helps to ensure that risk results and decisions made on the basis of those results err on the side of safety. As previously pointed out, in this case, where comparison between alternatives rather than assessment against criteria is the main focus, the effect of such conservatism is not necessarily so unambiguous particularly where there are fundamental differences in the character of the routes.

For comparisons between open air road systems the effect of many conservative assumptions would usually be much the same on all routes. In such circumstances the overall level of risk may be overestimated but this does not matter so long as the relativities are right. In this case, however, where one route involves a significantly different system component, the use of conservative frequencies and probabilities and, particularly, conservative assumptions in consequence modelling, has a serious potential to bias the results. The likely nature and scale of these effects on the assessment of risk for each class is discussed in the class by class assessment below and further dealt with in **Section 6.5.4.**

In other countries and elsewhere in Australia to some extent societal risk acceptability criteria have been adopted. Some of these criteria levels are included for reference in **Appendix 6E**. However, as no criteria levels have been adopted in this state and there are real difficulties in the application of such criteria, the observations here are generally limited to comparisons.

Extreme care should be exercised in using the absolute risk numbers and comparing them with criteria levels as, apart from inherent interpretational difficulties, the conservative approach is likely to have led to some overestimation particularly for the open air.

6.5.2 Societal Risk Calculations

Societal or 'group' risk is calculated by pairing the fatality number for an incident outcome (N) with a frequency of occurrence (F) to generate a series of F-N pairs. The F of the pairs is summed to give a frequency of killing N or more people. The results can be plotted as an F-N curve on a graph - usually on a log-log scale. In interpreting these graphs comparatively the further from the intersection of the 'x' and 'y' axes the worse the case.

For a situation such as is being dealt with in this study, there can be many F-N pairs with both the frequency and fatality number being affected by a wide variety of variables including: route sections; crash rates; traffic densities; surrounding land population densities; position in the tunnel; and a myriad of different factors affecting the incident progression and outcomes. The combination of these factors is necessarily iterative, painstaking and time consuming. The analysis for 2011 generated 20,032 F-N pairs.

The societal risk/F-N curves derived for each of the relevant classes are included in **Appendix 6E**. The F-N pair numerical results are included as **Addendum 6N.**

The traffic components of the study were carried out for 1996, 2001 and 2011. For the purposes of understanding the likely significance of the changes in traffic volumes between these years some of the societal risk analysis results were generated for both 1996 and 2011 (Classes 1, 2.1 and 3). As can be seen from a comparison of the tabular and graphic results the effect of the growth on risk levels and particularly relativities is so small as to be negligible. In view of this the F-N curves for the other classes were only generated for 2011.

6.5.3 Interpretation of Results and Assessment by Class

The following discussion covers the findings of the risk assessment component of the study for each of the DG classes and other relevant aspects of the assessment. It draws not only on the quantified risk results but the findings of each stage of the study as relevant.

<u>(i) Class 1 - Explosives</u>

Societal risk curves for explosives are included in **Appendix 6E**. Curves are presented for the years 1996 and 2011 for the M5 and the southern and northern routes separately and for the southern and northern routes combined as this is the more appropriate basis for comparison.

The curves show that there is relatively little difference between the routes for this class of DG's with the M5 being the safer route when compared with the other two routes together but not when they are viewed separately. They also show that the differences between 1996 and 2011 are small and do not change the relativities.

The Class 1 analysis is relatively straight forward as the detonation case has been taken as a function of road length not related to crash rate. The only variables in practice therefore were the numbers of movements, the consequence distance and the population presence. The number of loads assumed in this case was entirely arbitrary but changes in numbers of loads would change risk levels not relativities.

(ii) Class 2 - Gases

Class 2.1 - Flammable Gases

The 2011 societal risk curves for Class 2.1 are included in **Appendix 6E**.

The curves show the M5 as having the lower risk levels for some parts of the F-N range and the alternative routes having a lower risk for other parts. Again, the comparison of the 1996 and 2011 curves shows only minor change and, as would be expected, no change in the relativities.

As the Class 2.1 case is relatively complex and involves ignition and evacuation/exposure considerations it is potentially more sensitive to changes in values and assumptions. The assumption used of making no allowance for protection from heat radiation or for evasive action in the open air cases may be significant in this regard and is discussed in **Section 6.5.4.**

Class 2.2 - Non-flammable, Non-toxic Gases

Because no loads in this class were selected for analysis in the open air cases the loads were grouped with Class 2.3 and the combined results are commented on under that heading. The consequence analysis did in fact find that there was some potential for fatalities in the open beyond the 5 metre adopted minimum distance for cryogenic effects from nitrogen and oxygen but as the numbers involved were small and the frequencies low, this was not pursued.

Class 2.3 - Toxic Gases

The 2011 societal risk curves for Class 2.2 and 2.3 combined are included in **Appendix 6E**.

The curves show the M5 as having the lower risk levels for some parts of the F-N range and the alternative routes having a lower risk for other parts.

(iii) Class 3 - Flammable Liquids

Societal risk curves for flammable liquids are included in **Appendix 6E.** Curves are presented for 1996 and 2011 for the M5 and the southern and northern routes separately and for the southern and northern routes combined.

The curves show that, whilst for the low fatality number events the M5 route has the lower risk levels, for the higher fatality events the other routes would be significantly lower in risk.

The risk levels generated for the open air cases clearly do not reflect reality as the estimated frequency of fatal incidents and the maximum potential numbers killed are significantly higher than those actually being experienced on these and similar roads. As indicated in the sensitivity analysis below, it is considered likely that this is due to an overly conservative basis for modelling exposure to heat radiation.

(iv) Class 4 -Flammable Solids

Societal risk curves for flammable solids are included in Appendix 6E. Curves are presented for 2011 for the M5 and the southern and northern routes separately and for the southern and northern routes combined.

The curves show that for the lower fatality number events, when compared with the two routes combined, the M5 route has the lower risk levels, for the higher fatality number events the other routes would be significantly lower in risk.

These results would also appear to be rather too high for the open air routes. As heat radiation is the sole cause of fatality for the open air cases the results or this class would also be sensitive to changes in the consequence modelling as discussed in **Section 6.5.4**.

(v) Class 5 - Oxidising Agents and Organic Peroxides

Societal risk curves for oxidising substances and organic peroxides are included in **Appendix 6E**. Curves are presented for 2011 for the M5 and the southern and northern routes separately and for the southern and northern routes combined.

The curves show that, except for the higher fatality number events, the other routes would be higher in risk.

The curves combine the results for the 5.1 and 5.2 sub-classes. Consideration of the figures separately reveals that it is the relatively low volume but relatively high hazard organic peroxides which are mainly responsible for the higher N numbers in the tunnel and that for the 5.2 alone the cross over between the graphs would occur at lower N value.

As with other classes where the heat radiation is the cause of fatality for the open air cases, the results or this class would also be sensitive to changes in the consequence modelling as discussed in section 6.5.4.

(vi) Class 6 - Poisonous and Infectious Substances

The consequence analysis for the representative loads for Class 6.1, methylene chloride and methyl azinphos, found that in the open and in the tunnel neither case generated fatal consequences. In the methylene chloride case it was found that, provided that the tunnel ventilation system continued to operate fully, the vapours would not reach fatal concentrations but that injurious levels could still result.

In the methyl azinphos case it was found that a typically slow fire which would generate the most toxic smoke would be of long duration but low intensity and would be readily able to be dealt with by the smoke ventilation system. Furthermore, such a fire would not significantly hamper evacuation and could be readily approached and successfully suppressed provided the fire fighters were equipped with breathing apparatus.

It is likely that the analysis for this class, particularly for events in the tunnel, would be sensitive to the consideration of other materials which were more toxic or volatile or were likely to burn more intensely but still generate significantly toxic smoke. This is considered further in section 6.5.5.

Class 6.2 substances were eliminated from further consideration in the hazard identification on the grounds that, having regard to the nature of the materials and the credible release mechanisms, they would not make a significant contribution to risk levels and furthermore there would not be a significant difference between the risk level on the M5 and on other routes.

(vii) Class 7 - Radioactive Substances

Class 7 materials were eliminated from further consideration in the hazard identification. The grounds for this elimination were that for loads of the type which would normally be moved through this area there was no credible mechanism for significant exposures of significant numbers of people and that controls on larger or more hazardous loads would require specific approvals for the routes.

(viii) Class 8 - Corrosives

The consequence analysis for the representative load for Class 8, hydrochloric acid, found that in the open and in the tunnel fatal consequences were not generated. It was found that, provided that the tunnel ventilation system continued to operate fully, the vapours would not reach fatal concentrations but that levels could result which would be seriously injurious. Such injuries possibly including severe chemical burns and permanent eye damage (blindness).

It is likely that the analysis for this class, particularly for events in the tunnel, would be sensitive to the consideration of other materials which were more toxic or volatile. This issue and the question of injury risk are considered further in section 6.5.5.

(ix) Class 9 - Miscellaneous Dangerous Goods

Detailed analysis of Class 9 miscellaneous DG's was also eliminated at the hazard identification stage. Where the loads fall into this category because of their potential for harm to the biophysical environment, the conclusions of the analysis on risk to the biophysical environment as outlined below would be applicable. Where they fall into this category for other reasons it is not clear whether the M5 or the alternative routes would be safer - in practice this would depend on the specifics of the loads.

(x) Mixed Loads

As with class 9 materials, no conclusions can be reached from the risk results as to whether the M5 or the alternative routes would be safer because the results are not uniform and the consequences of incidents and therefore risk levels would vary with the type of hazard.

(xi) Non-Dangerous Goods

Non-dangerous goods were considered as a 'control' (in the scientific experiment sense). The premise was that if some loads of goods which were not considered to be DG's were found to pose a level of hazard or risk in the tunnel comparable to that of DG's then restriction of DG's might be questionable.

For the load studied this was not found to be the case. This finding could however be sensitive to the choice of materials.

(xii) Dangerous Goods Overall

Societal risk curves were also generated for all DG's and are included in **Appendix 6E.** Curves are presented for 2011 for the M5 and the other two routes combined.

The curves show that whilst at the lower and higher N numbers the tunnel would be the lower risk route, for a substantial part of the mid range the reverse is true. Again this result could not be said to unembiguously favour one routing alternative over the others.

(xiii) Risk to the Biophysical Environment

The assessment of risk to the biophysical environment found that the M5 route was preferable for all materials with potential to harm the aquatic environment because the arrangements for containment were superior to those for the other urban arterial road routes and the releases were also less likely due to the lower crash rates.

(xiv) Property Damage Risk

The analysis of property damage potential focused on the tunnel. It was found that there were a number of cases where severe damage to the tunnel could result and which could possibly involve closure of the tunnel for repair for extended periods. Indicative frequencies for such events are presented in **Appendix 6E**. This potential needs to be set against the potential for damage to infrastructure and private property on the other roads which was beyond the scope of the study.

(xv) Risk from Bulk Loads versus Packaged Loads

The review of the results of packaged and bulk loads showed that no general conclusion could reasonably be drawn which would be valid for all classes. As Class 6 and 8 bulk loads for example were found to pose no fatality risk it would be difficult to justify exclusion of bulk loads of these materials on fatality risk grounds.

(xvi) Risk from Portals and Stacks

No ground level fatal concentrations were found to result from any discharges from stacks or air intakes. Significant concentrations were however found for the the portals. Individual fatality risk from this source and injury risk could warrant further detailed analysis if these considerations are deemed to be important.

6.5.4 Sensitivity Analysis

The time constraints on the study were such that a full and systematic sensitivity testing of each variable and any extensive rerunning of the risk estimation calculations and F-N curves was not possible. Instead, the event trees and the consequence and likelihood inputs were reviewed to identify likely key variables and the impact of changes in these variables was considered. The results of that analysis are presented in brief below.

Conducting a more comprehensive sensitivity analysis would most likely provide useful insights of benefit to the tunnel design process recommended in section 8 and should be carried out in any event as part of the hazard analysis and risk assessment of the final design if a decision is taken to permit DG traffic.

Radiant heat exposure - The assumption used for the assessment of fatality due to exposure to heat radiation in the open air cases was an adaptation of the conservative approach widely used for risk assessment for the development approval and planning system in NSW. This approach essentially assumes that any person within the effect area of a fire is unprotected by structures (or clothing) and is unable to take any evasive action. It is commonly assumed that the exposure period is the duration of the fire but in this case the less conservative assumption of limiting exposure to 60 seconds was adopted.

It is clear from comparisons with actual experience and overseas studies that this approach has produced fatality numbers and frequencies for the open air cases which are unrealistically high. This is particularly clear for the largest category of DG's, Class 3 - flammable liquids. Accordingly additional F-N curves were run for 2011 with an assumed reduction in fatality rates for potentially exposed people by a factor of 10. The results are shown in the figures in **Appendix 6E**. The effect of this is to show the M5 route to be the higher risk route for all areas of the F-N field except the low N number.

If similar adjustments are made to the open air case assumptions for the other loads where heat radiation is the only or the main cause of fatality ie. Classes 4, 5 and to a lesser extent 2.1 then a similar reduction in the N numbers would occur. This would result in the M5 clearly having the higher risk levels for all parts of the F-N range for Classes 4 and 5 and almost certainly the same position for Class 2.1.

F-N curves were run for overall DG's with the adjusted Class 3 heat radiation results and are included in **Appendix 6E**. As can be seen, the curves at the lower and higher N numbers, the M5 is still the lower risk option but the rangewhere the M5 is the higher risk option is wider and the extent of the difference greater.

In view of the unrealistically high fatality results generated by the original assumptions and the effect of the change in assumptions in bringing outcomes into line with the findings of other studies it is believed that this value should be adopted. Any similar adjustment is not considered warranted for the tunnel cases as in these cases the analysis of the mechanisms for fatality from fires were worked through from first principles to be more specific and applicable to the particular circumstances of the tunnel.

Other materials - It is important to note that this study has had to rely on information on the make up of DG loads likely to use this route that was far from comprehensive. The representative load selection is therefore not based on a full review of all DG materials transported but on the best available generalised information from industry data, surveys and the experience of the consultants. Even if comprehensive data on materials were available the selection of materials would inevitably involve the exclusion of particular materials which would be worse in some circumstances. It is appropriate therefore to briefly consider the sensitivity of the analysis to the use of different materials. This is most easily done by identifying the classes where such considerations might be significant.

Class 2.3 - There are toxic gases which have higher toxicity levels than chlorine, such as fluorine, but apart from the fact that they are not common the frequency of their transportation through this area is unknown. The consequences of releases of these gases could be worse than for the cases studied however the frequency of movements are significantly lower and the quantities involved typically less. It is considered therefore that any effect of a change to worse case gases would amount to a distortion of the risk levels and possibly of relative levels rather than a shift to a more accurate reflection of reality.

The possible impacts of worse case gases should nonetheless be covered by emergency planning for the routes used where such gases are identified and consideration should be given to case specific analysis of least risk routes where particularly hazardous gases are identified.

Class 4 - This class encompasses materials with a range of different characteristics but the ultimate hazard is still fire and whilst it might be the case that ignition probabilities or some other aspects may change, it is not considered that the levels of risk would change greatly or the relativities change significantly.

Class 6 - This class covers materials with a wide range of toxic properties and volatilities. Some of these materials would be worse than the representative materials chosen and could conceivably result in fatality levels in the tunnel case though they would be unlikely to do so in the open except at close range. Most of the more hazardous materials are not carried frequently in bulk so the consequence potential is limited. It is considered that the possible use of more toxic or more volatile materials would tend to work against the tunnel and therefore M5 route.

Class 8 - The position for this class is similar to that for Class 6. There are worse materials eg hydrogen fluoride but such materials would not generally be expected to be carried frequently or in large loads and therefore would not be expected to contribute significantly to overall risk. This does not however rule out the possibility that incidents involving such materials could occur in the open or in the tunnel which would have fatality consequences. In general however the use of worse case materials in this category would work against the M5.

Injury risk - Without detailed analysis of the injury risk issue it is not possible to reach any real conclusions as to which route(s) would have the lower level of injury risk. The upper bound on the number of people potentially affected in the tunnel may however mean that the use of the tunnel would reduce exposure levels for some forms of injury risk such as exposure to toxins. If the injury risk considerations are deemed to be important, supplementary detailed analysis could be carried out. The effect of discharges from the ventilation stacks and intakes and the tunnel portals would need to be carefully considered in any such analysis.

Laden trucks in both directions - This assumption affects the overall levels of risk but is neutral in terms of relativities. The maximum effect even on the level of risk would only be a factor of two - of no great significance.

Overall movement numbers - Changes within reason to these numbers would not affect the relativities unless the effect of the involvement of secondary loads in the tunnel were to be factored in to the analysis.

Load sizes - The cases assessed have taken typical loads as far as practicable. However it is known that there are also numbers of movements involving smaller loads, particularly of packaged goods. There are also movements of larger trucks in some instances and B doubles. Clearly the smaller loads have less potential for significant consequences but the available data does not allow any meaningful judgment on this sort of detail to be made. As the effect would impact on both the M5 and other routes the influences would offset each other to some extent.

Involvement of secondary DG loads - This consideration would make the tunnel a worse case because load to load propagation is much more likely in the tunnel environment. The extent of such an effect on people is however limited as it is likely that they will have either been victims of the first incident or have evacuated safely by the time of the secondary load involvement. The implications for tunnel damage would however be more significant.

Population density - The population density/presence factor could be effected for road users by changes in assumptions on future traffic volumes and speeds and for surrounding lands by the extent and nature of new development. The known or likely redevelopment of the lands along the affected routes was not considered to have a significant effect on population density in net terms. Changes in the road users projections could affect the results, particularly for the M5 route.

Packed density vehicle numbers - Changes to the assumed vehicle density would possibly affect the tunnel case more than the outside cases but the effect would be marginal. The more serious incidents in the tunnel tended to extend beyond the end of the tailed back traffic and packed conditions were disregarded in all cases where a high momentum crash was considered a necessary ingredient for the relevant release to occur.

Persons per vehicle - Changes in the assumed 1.5 persons per vehicle would affect the tunnel/M5 case more than the outside cases as essentially only motorists are effected by incidents in the tunnel whereas in the open motorists and other people are affected. The changes would however be expected to be marginal and unlikely to change the overall results.

Distribution of the position of incidents in the tunnel - The consequences of incidents in the tunnel is dependent on the position of their occurrence relative to the slope and ventilation system. Many of the incidents were modelled on the basis of selecting a single position as reasonably representative. The distribution of incidents proportionately through the tunnel would involve significant increases in the complexity of the analysis and it is not clear without carrying out the analysis what the net effect of such changes would be on outcomes.

Extended version of the tunnel - The extended version was not considered in any detail. It is however clear that, other things equal, the increased length of the tunnel would most likely make the risk levels for the M5 route worse.

Deluge system - As indicated in section 6.3 the overall net effect of the operation of deluges in the tunnel has yet to be resolved. At this stage it is considered most likely that the deluge system would make the risk levels in the tunnel higher rather than lowering them.

Drainage and ventilation system modifications - Appropriate changes to the drainage system including up sizing of pipes, increasing the sideways slope of the road, provision of a bigger pump well would significantly reduce the size and duration of pool fires and the available surface areas of released liquids and liquefied gases and thereby significantly reduce the size, severity and duration of incidents. Modification of the ventilation system to ensure that substantial longitudinal flow is maintained even when traffic comes to a halt would ensure that most of the effects of incidents, including the backlayering of combustion products from fires and the chimney effect on the tunnel downslopes and toxic gas releases would be largely eliminated. The provision of several air extraction points (say at least four per tunnel) and thus the division of the tunnel into ventilation segments would also assist by limiting the maximum numbers of people potentially exposed to any incident. If this can be achieved then it is highly likely that the M5 would become the safer route for all classes of DG's (except for Class 1 for which the M5 was found to be the lower risk route). Recommendations covering these features are contained in **Section 8.**

7. OVERALL EVALUATION OF ALTERNATIVE ROUTES

7.1 DEVELOPMENT OF ASSESSMENT CRITERIA

7.1.1 Background

There has been a growing community concern in recent years over the hazards and risks associated with the production, storage and transportation of hazardous materials. In particular much attention has been focussed on accidents during the transport of such materials, particularly transport by road.

The Department of Urban Affairs and Planning has developed and implemented a comprehensive approach to land use safety planning based on the assessment and management of risk. This approach involves systematic hazard analysis and risk quantification. It is applied to transportation as well as fixed sites and is particularly useful for the identification of least risk options and cost effective risk reduction measures. In the transport case, it is particularly effective in identifying least risk routes. The following principles and criteria included in the latest DoP Draft Guidelines (issued early in 1994) for Route Selection formed the basis of the assessment of the routes in terms of the estimated risks and relevant other factors.

7.1.2 Principles

The classification and ranking of the various route options for the transport of hazardous materials, from an environmental/land use safety planning viewpoint, should reflect a systematic identification of hazards, together with a qualitative and quantitative (as applicable) assessment of resultant risk levels.

To satisfy the public and provide a sound and defensible basis for decision making the analysis needed to be demonstratably comprehensive and show that for recommended DG land usage, the M5 will be at least as safe as alternative routes.

In general, the risk along a route used for the transportation of hazardous materials is a function of the population exposed (along that route) and the rate and severity of releases due to motor vehicle crashes and releases not involving motor vehicle crashes (eg loss of drums from trucks, leaking valves etc). The population exposure along the route is dependent on the nature and extent/intensity of land use and traffic volumes. Crash rates depend on the type of vehicles, traffic density and road condition, and severity is linked to the nature and quantity of materials being carried.

7.1.3 Criteria

The overall environmental and land use safety criteria for route selection is that the route which has the lowest risk value to surrounding people, property and the natural environment should be selected. In this case, the risk to other road users must also be factored in as this is the principal concern with tunnels. In this context, risk is determined in terms of the cumulative combination of the probability of hazardous material incidents and the consequences of such incidents.

These two elements of risk are dependent on the extent of population exposed and number and nature of properties or extent and sensitivity of natural environment ecosystems and the incident rates. In general, roadways with the smallest adjacent population as well as incident rate, will have the lowest risk values.

The density of population on the roadway (including in the tunnel) will also be a significant factor and the possibility of certain incident types resulting in large single incident fatality numbers must be considered.

Due regard must also be had to the presence of sensitive populations and associated land uses. Qualitative criteria such as avoidance of hospitals, schools and routes with consequences for environmental areas and ecosystems can also be relevant. The risk and consequences of major damage to the tunnel from incidents must also be assessed against some form of criteria.

The emphasis in this Study was on comparative risk assessment, rather than on absolute levels of risk along the routes. While individual risk calculations may be appropriate in some circumstances, a societal risk approach is considered generally more appropriate in the transport risk assessment. It was appropriate and essential in this case to include the population of other road users in the societal risk calculation.

7.2 EVALUATION OF ALTERNATIVE ROUTES

7.2.1 Road and Traffic Factors

The road and traffic factors along the three routes are summarised in **Table 7.1.** It is clear from a traffic perspective that the M5 East Motorway route is the most preferred route between the M5 West Motorway, at King Georges Road, and the Qantas Drive /O'Riordan Street /Joyce Drive intersection. The M5 East Motorway route has shorter route length and higher average travel speeds, and thus shorter travel times than either the Southern or Northern routes.

The M5 East Motorway will also provide the best Level of Service. Whilst the Southern Route will experienced the lowest M.Veh.kms of travel. This is largely due to the availability of the faster route along the M5 East Motorway which will thus attract more traffic.

TABLE 7.1
TRAFFIC SERVICE FACTORS

	M5 East Motorway		Southern Route		Northern Route	
Route Length km	12.03	✔✔	12.62	✔	16.77	-
Travel Time & Speeds						
Average Speed km/h AM peak	48	✔✔	22	✔	22	✔
km/h PM peak	50	✔✔	29	✔	23	-
% of Route with Speeds < 25 km/h AM	2	✔✔	28	✔	53	-
PM	2	✔✔	21	✔	43	-
Average Travel Time mins AM peak	15	✔✔	34	✔	47	-
mins PM peak	14	✔✔	26	✔	45	-
Travel Parametre						
Yearly M Veh km travel 1996	203.94	✔	166.65	✔✔	257.91	-
2001	226.09	✔	200.43	✔✔	269.44	-
2011	280.74	✔	263.42	✔✔	302.53	-
Level of Service						
% of Route with LoS F East/b 1996	32%	✔✔	40%	✔	72%	-
West/b 1996	0	✔✔	0	✔✔	4%	-
% of Route with LoS F East/b 2001	34%	✔✔	47%	✔	72%	-
West/b 2001	0	✔✔	0	✔✔	4%	-
% of Route with LoS F East/b 2011	34%	✔✔	59%	✔	83%	-
West/b 2011	0	✔✔	10	✔	9%	-
Number of Traffic Signals	7	✔✔	27	✔	48	-

✔✔ = Preferred *✔ = Alternative*

7.2.2 Road Safety Factors

The road safety factors along the three routes are summarised in **Table 7.2.** On all account the M5 East Motorway will provide the safest route by far in terms of potential crashes.

TABLE 7.2
ROAD SAFETY FACTORS

	M5 East Motorway		Southern Route		Northern Route	
Crash Rates						
All Crashes/M.veh kms	0.58	✔✔	1.36	✔	2.1	
Truck Crashes/M.veh.kms	0.06	✔✔	0.14	✔	0.15	
Truck Crashes/M.trucks.kms	0.87	✔✔	2.65	✔	2.94	
Predicted Crashes						
all Vehicles 1996	117	✔✔	198	✔	539	-
Trucks 1996	12	✔✔	17	✔	34	-
all Vehicles 2001	133	✔✔	238	✔	561	-
Trucks 2001	13	✔✔	22	✔	37	-
all Vehicles 2011	171	✔✔	306	✔	631	-
Trucks 2011	16	✔✔	29	✔	41	-

✔✔ = Preferred *✔ = Alternative*

7.2.3 Environmental and Land Use Factors

From **Table 7.3,** it can be seen that the M5 East Motorway route has the least effect on residential and commercial/industrial frontage. There are no hospitals along the Southern and M5 East Motorway routes, and no schools fronting the M5 East Motorway route. The M5 East Motorway route fronts open space for 38.9% of its length, compared with the Northern and Southern routes which front only 2.1% and 8.6% open space respectively.

TABLE 7.3
LAND USE FACTORS

	M5 East Motorway		Southern Route		Northern Route	
Population						
Land Use Population Density	1,445	✔✔	2,943	✔	3,276	-
Number School Pupils	0	✔✔	4,161	-	3,919	✔
Number Hospital Beds	0	✔✔	0	✔✔	156	
Land Use						
% of Route Residential	19.6%	✔✔	52.6%	-	43.1%	✔
length of route Residential	2.36	✔✔	6.64	✔	7.23	-
% of Route Schools	0.0%	✔✔	4.5%	-	2.8%	✔
% of Route Hospitals	0.0%	✔✔	0.0%	✔✔	0.3%	-
% of Route Commercial/Industrial	14.4%	✔	8.4%	✔✔	51.7%	-
length of route Commercial/Industrial	1.73	✔	1.06	✔✔	8.67	
% of Route Open Space	38.9	✔✔	8.6	✔	2.1	-
Works and Developments Factors		✔✔		✔		-

✔✔ = Preferred *✔ = Alternative*

The proportion of residential development fronting the routes varies from 19.6% on the M5 East Motorway route to 52.6% of the Southern route. When taking the length of the routes into account this equates to residential development fronting 7.23km of the Northern route, 6.64km of the Southern route and 2.36km of the M5 East Motorway route. Similarly the length of Commercial /Industrial development fronting the Northern route is 8.67km, the Southern Route 1.06km and the M5 East Motorway Route 1.73km. Table 7.3 shows the M5 East Motorway route will have the least effect on Residential and Commercial/Industrial developments.

7.2.4 Hazards and Risk Factors

The differences in the risk levels are principally driven by the tunnel section of the M5. For the open air sections, the M5 would clearly be the preferred route as it is better separated from other land uses and is expected to have a significantly lower crash rate than the other urban arterial roads.

The effect of the tunnel environment on hazardous incident frequency and severity is not consistent across classes. Accordingly the results do not show a consistent pattern which might justify a blanket decision to permit or to prohibit DG's. The following conclusions can however be reached on a class by class basis.

(i) Risk to People

For the assumed tunnel design, the outcomes of the study indicate that in terms of people:

- It would be preferable to transport Class 1 DG's via the M5. If they were to be moved only at night then this conclusion would be more strongly supported.
- The M5 would not be the least risk route for Class 2.1's having due regard to the likely effects of changes in assumptions on heat radiation consequence modelling.
- For Class 2.2 and 2.3 materials neither the M5 nor alternative routes can be identified as clearly preferable on risk grounds.
- For Class 3, the M5 is not the least risk route once the revised heat radiation fatality assumption is used.
- The M5 would not be the least risk route for Class 4's, particularly once the revised heat radiation fatality assumption is used .
- The M5 would not be the least risk route for Class 5's once the revised heat radiation fatality assumption is used.
- There would appear to be no impediment on fatality risk grounds to Class 6 loads using the M5/tunnel. (This may not be the case if injury risk were to be taken into account.)
- There would be no impediment on fatality or injury risk grounds to Class 7 loads using the tunnel (subject to route specific assessment for any major loads in line with regulations.)
- There would be no impediment on fatality risk grounds to Class 8 loads using the M5/tunnel. If injury risk were to be taken into account, however, it is considered likely that the open air routes would prove to be preferable.
- No conclusions can be reached on Class 9 materials or mixed loads as the findings for the separate classes are not uniform.
- For DG's taken as a whole the M5 route is the least risk route for parts of the N range only and is substantially higher in risk for other parts. Neither the M5 nor the alternative routes could therefore be clearly said to be preferable on risk grounds.
- If DG loads are permitted to use the tunnel there would be credible scenarios with potential for substantial damage which would require prolonged closure.

It is noted that for all classes of materials were transportation to occur at night, in the hours when traffic volumes on all roads would be small, the consequences on all routes would be reduced as the potentially affected motorists would be relatively few. The effect on the M5 risk levels would however be the greatest as motorists are the only people effected in tunnel incidents and for the open air sections of the M5 the separation distances to other land uses are greater than for the other urban arterial roads.

The preliminary investigation of possible design modifications to the tunnel indicates that such changes should be able to change the risk profile for all DG Classes such that the M5 would become the least risk route. It would be expected that the measures put forward in section 8 would achieve this end. It would however be appropriate for the effect of these measures on risk levels to be assessed once design concepts have been worked up and again on the final design.

These conclusions are specific to this case with its specific DG traffic volumes , DG load mix, tunnel length and drainage and ventilation system, traffic density, crash rates etc. and to the population density, crash rates etc. of the alternative routes. They should not be applied to any other tunnel case.

(ii) Property Damage

The analysis of property damage was essentially limited to consideration of damage to the tunnel structure ans systems as this was seen as the area most relevant. In the tunnel the extent of direct fire involvement and the heat fluxes received would be such that more extensive involvement of cars and trucks could be expected. The contribution of these secondary fires to the duration of the event and consequently to the extent and severity of structural damage could well be significant and has been considered in developing the conclusions on tunnel damage below.

The consequences in terms of losses of motor vehicles and their cargoes has not been quantified or analysed as it was not considered central to the objectives of the study. It should however be noted that this effect could add substantially to the overall cost of incidents in the tunnel and would be expected to be much more significant for the tunnel than for the open air sections. If it were to be determined that such potential losses should be factored in to the equation, the risk and dollar cost consequences could be readily estimated in a separate analysis.

For the assumed tunnel design, the outcomes of the study indicate that the following incident outcomes would have significant potential to damage the tunnel structure, fittings and operating systems:

- **Class 1** - 6 tonne TNT explosion
- **Class 2.1**
  LPG bulk - Jet fires (several sizes), BLEVE, pool fires (several sizes) vapour cloud explosion VCE (several sizes), explosive/flammable concentration in ventilation ducting/fan house
  LPG cylinders - fire involving the whole load
  Hydrogen - jet fire (several sizes), BLEVE, VCE, explosive/flammable concentration in ventilation ducting/fan house
- **Class 3** - petrol pool fires, vapour explosions, tanker fire, roadway spill fire, drummed load fire.
- **Class 4** - nitrocellulose load fire
- **Class 5.2** - MEKP load fire
- **Class 8** - hydrochloric acid fumes and vent system shut down.
- **Non-DG** - polyethylene bead fire

These events could result in tunnel closures for repairs of up to 9 months. Fire events involving flammable liquids, the largest class, could involve closures of up to 6 months. As indicated, the extent of involvement of other vehicles, as fuel, to increase the duration and or intensity of the fire event could be a significant factor in determining severity. Detailed consideration of this aspect was beyond the scope of this study but could be incorporated in the second phase of the work.

If such further work is to be undertaken it would be appropriate for the cost of disruption to travel due to such closures as well as direct damage and repair costs to be taken into account. Comparison with the direct costs and disruption costs of similar events on the alternative routes could also be factored into the analysis.

As the principal focus of this study was directed towards risk to people, quantification of the likely frequency of events resulting in tunnel closures was not included. It would be appropriate for further work to be undertaken to identify the likely frequency of events resulting in tunnel closures of various durations and for that information to be fed into the tunnel design and decision making processes.

7.2.5 Operating Cost Factors

It has been derived, in section 3, that about 59% of all dangerous goods are carried by articulated tankers. Articulated tankers are the most costly vehicles to operate, at approximately $78 per hour. Due to the time based cost in running heavy vehicles the owners and operators look for the most cost effective route on which to operate.

Based on route length and travel time the comparative cost of using the routes has been calculated based on $60 per hour, being a representative average vehicle operating cost. For the M5 East Motorway route an option of $4 toll per truck has also been assumed. The comparative costs of using the routes is shown in **Table 7.4**

TABLE 7.4
OPERATING COSTS FACTORS

	M5 East Motorway		Southern Route		Northern Route	
Operating Cost Factors AM peak	$15	✔✔	$34	✔	$47	-
PM peak	$14	✔✔	$26	✔	$45	-
AM peak + $4 t	$19	✔✔	$34	✔	$47	-
PM peak + $4 t	$18	✔✔	$26	✔	$45	-

✔✔ = Preferred *✔ = Alternative*

Including a Toll, the M5 East Motorway provides the most economical route between Port Botany and the M5 west Motorway.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The overall assessment of the alternative DG transport route has found that on all grounds other than risk the M5 route is superior (see **Section 7**). The risk assessment also found that the open air section of the M5 route would pose a lower risk than the alternative routes. With the assumed design however the risk attributable to the tunnel section of the M5 route was sufficient for some classes to bring it to a level greater than that applying to the alternative routes.

In the course of the risk assessment a number of aspects of tunnel design and operating and emergency systems were identified which if amended or attended to in the light of DG use should be capable of ensuring that the M5 would be the least risk route. The identified measures need, however, further development and refinement in the context of careful consideration of their technical and economic feasibility. This assessment should be carried out in conjunction with the preliminary and/or final design of the Tunnel . Following such further development it will be possible to quantify the extent of the effect of the measures on risk levels.

It is important to recognise however that in developing the set of measures the focus has been as much on eliminating potential incident outcomes and reducing their consequences as on reducing likelihood. Furthermore, the principle of "avoiding avoidable risk" has been applied to help ensure that if DG's are to be permitted to use the tunnel then it will be as safe as practicable.

Tunnel features identified as warranting attention include:

- the ventilation system
- the capacity of drainage systems and sumps
- the cross slope (drainage) of carriageways
- provision of redundancy in the tunnel pumpout systems
- minimisation of smoke generation by the use of non bitumen pavement
- investigation of alternatives to a deluge system
- improvement of emergency egress routes and instruction systems
- maximisation of the fire rating of the tunnel structure
- operating, emergency and maintenance procedures and training

The ventilation system and drainage systems are the areas considered most likely to result in significant reductions in risk.

These options are examined in detail in **Section 8.2.** In **Section 8.3** some further recommendations are made regarding appropriate further work to be undertaken in later phases of the study.

8.2 TUNNEL DESIGN REQUIREMENTS

The design features nominated and used for analysis up to this point have been typical of those for a long road tunnel designed for normal tunnel operation requirements which normally exclude the traffic of DG's in bulk and or in packaged form. Wherever the design prescriptions in the EIS are clear and consistent they have been used. Interpretation or development of the design as suggested in the EIS and treatment of some elements not listed has however been necessary.

This section highlights possible changes to the nominal tunnel design given in Section 5 which could reduce risk to road users and residents were the M5 tunnels to be used for the passage of DG's. Possible mitigating measures fall into three categories:

- Measures to minimise the extent and duration of an event.
- Measures to improve motorist/resident safety for a given event.
- Measures to minimise the tunnel period of closure following any serious events.

Specific measures that have been identified for these cases are:

(i) Measures to minimise the extent of an event:

(a) Provide longitudinal airflow in tunnel for the maximum possible number of conceivable traffic conditions.

It has been found during the risk analysis that DG spill events are generally much less serious where a longitudinal airflow is maintained past the event site. This is due to the avoidance of smoke products and/or toxic gases flowing back towards motorists trapped behind the event. As it is difficult to ensure such flow for all conditions with either a semi-transverse or fully transverse ventilation system, it is proposed a hybrid longitudinal/semi-transverse system be investigated to maintain adequate longitudinal velocity. The fans would only be required to operate when the traffic speed drops to a point at which the piston effect becomes insufficient to maintain an adequate longitudinal airflow. This measure would be a moderate cost but effective method of safety improvement

(b) Increase the design fire intensity and exhaust rate of the smoke exhaust system.

Due to the excessive duct sizes that are required for smoke exhaust from large fires and the effect that this has on tunnel construction costs and fan sizing it is generally not considered feasible to provide smoke exhaust for fires greater that 50MW. The design capacity of the system nominated in Section 5 of this report is 25MW which is considered the requirement for tunnels where a deluge system is installed. It should be noted that the pool fires generated by the 40,000 litres tanker spill generates a fire greater than 1000MW. In general, measures to limit the fire size will be much more effective than controlling established fires of this nature.

(c) Provide cooling systems in the smoke exhaust duct, particularly prior to the exhaust fans to increase the 'survival time' of the system.

Evaporative cooling 'Conditioning' sprays prior to fans handling hot gases are used extensively in high heat industries such as cement and steel manufacturing. These limit the temperature of gases at the fan to a safe temperature for equipment operation. In fact, the adaptation of such a system to a tunnel duty is used on the Sydney Harbour Tunnel. The drawback of these systems is that the ducts would still need to be sized for the volume of hot gases generated adding significantly to the tunnelling costs. These systems are designed to operate on a continuous basis and adaptation of the technology to an on-demand duty such as this would be difficult, and, these systems are expensive.

(d) Provision of protection or cooling for fan systems.

It is possible to configure the fans and fan rooms such that the drives, bearings and other heat sensitive components are located out of the hot gas stream. This can be achieved by substituting centrifugal fans for axial fans and providing water (or similar) cooling to the fan bearings. The drawback of these systems is significantly higher equipment costs for the same system capacity and these fans require significantly more space requiring larger above ground fan buildings or more below ground excavation to accommodate the plant room.

(e) Modify the drainage system to reduce the extent of flammable liquid spills.

This measure is a cost effective and appropriate method of event limitation. Drainage systems should be designed to rapidly remove liquid entering the carriageway with the maximum conceivable spill rate from a ruptured tanker to avoid or minimise roadtop spill fires. This could be achieved by a combination of increasing the drain pipe size and by increasing the number of kerbside sumps. The design would also need to ensure pipe sizing to allow for slower flow in pipe sections which are downstream of steeper sections to prevent overflow from sumps. Furthermore, sump grilles must be capable of allowing entry to the sumps from road surface flows at the pipe design rate and flame traps must not restrict flow.

(f) Provide separate lowpoint pumpwells and/or increase the lowpoint pump well capacity to eliminate lowpoint pool fires due to insufficient lowpoint pump well capacity in the case of pump failure.

This measure is a cost effective and appropriate method of event limitation. Lowpoint pump wells should be sized to take the entire capacity of a spilled tanker in addition to a reasonable amount of deluge system discharge. This measure should effectively eliminate lowpoint pool fires in all but the most unlikely circumstances. Note that effective operational procedures would need to be established to ensure that the lowpoint pump well is kept empty at all times to ensure effective performance in an emergency situation.

(g) Provide non-return valves in the tunnel lowpoint to lowpoint sump drain to avoid the backflow of spilt fuel from lowpoint pump well into tunnel lowpoint if deluge system operates. Also provide duplicate tunnel lowpoint to lowpoint pump well drain pipes.

This measure is a cost effective and appropriate method of event limitation. Duplication of drains and provision of effective non return valves would eliminate the backing up of liquid fires into the tunnel regardless of the quantity of firefighting water used.

(h) Provide a complete redundant pumpout system at the lowpoint sump to increase security in case of primary pump failure.

This measure is probably secondary to the increase in sump size nominated above and would need cost/benefit analysis to determine viability. Regardless, it would provide an increase of security at a relatively low price.

(i) Investigate alternatives to a deluge system.

As noted previously, the effectiveness of deluge systems is mixed depending on the type of fire being fought. In many cases, for tunnel fires the operation of deluge systems has been observed to cool the stratified smoke layer making extraction difficult and has magnified the spread of flammable liquid fires. Deluge systems are also extremely sensitive to correct application point and timing and are thus subject to operator error. It is recommended that alternatives to a deluge system be investigated.

(j) Non-bitumen road surface to minimise smoke generation from structural surfaces.

A possibly significant component of the smoke generation from some fire events studied is smoke generated by the combustion of the bitumen road surface. Alternatives to bitumen, such as concrete, should be investigated.

<u>(ii) Measures to improve motorist / resident safety for a given event:</u>

(a) Provide enhanced VMS systems to give detailed instructions for evacuation.

This measure is a cost effective and appropriate method of safety improvement. Studies have shown that motorists do not tend to evacuate until a fire or other event reaches a certain perceived danger level. Any enhancement of the VMS system to improve appropriate response in the case of evacuation could take advantage of this "wasted time" and could also reduce confusion and inappropriate response when evacuation is initiated.

Appendix 6A
Proportions of DG Movements by Class

Table 1: Percentage by Volume or Number of Movements for Class of Dangerous Goods[1]

Source \ Class	Basis[2]	1	2	2.1	2.2	2.3	3	4	5	6	7	8	9	Other
DG Survey 1995[3]	M	0	16.3	-	-	-	54.8	2.1	2.9	0.4	0	15.1	8.4	-
EPA Survey 1992[4]	V	-	10	-	-	-	79	1	1	3	-	5	1	-
Considine UK Study 1989 (a)[5]	V	-	7	3	2	2	75	0.5	-	2	-	16	-	-
Considine UK Study 1989 (b)[5]	M	-	9	3	3	3	64	5	-	3	-	19	-	-
HSC Major Hazards Report 1991 (a)[6]	V	-	-	2.9	-	0.6	96.5	-	-	-	-	-	-	-
HSC Major Hazards Report 1991 (b)[6]	M	-	-	4.6	-	0.9	94.4	-	-	-	-	-	-	-
Canadian Corridor Exercise 1993[7]	M	-	-	28	-	36	36	-	-	-	-	-	-	-
Netherlands, 1990[8]	M	0.2	-	19.2	-	0.8	63	-	-	1.6	-	-	-	15.2
Adopted DG proportions	M	-	16	7	3	6	55	2	3	2	-	15	7	

[1] The figures in this table are derived from surveys and studies undertaken in NSW and overseas. They are not directly comparable as different bases have been used as indicated in the notes for each survey or study.

[2] There are two different bases for these figures, by movements of trucks (M) or by volume of material transported (V).

[3] 24 hour survey undertaken for this study by Traffic and Transport Surveys Pty.Ltd. It is described in Section 3.

[4] Survey undertaken by the Environment Protection Authority (EPA) and provided details of the total quantity of material from each class transported, as provided by petroleum, gas and chemical manufacturing, storage and transport companies. Classes 1, 6.2 and 7 were excluded from the survey, and the amount of packaged goods was believed to be understated. The figure of 79% reported for Class 3 is overstated since it includes combustible liquids such as diesel, hence the other figures are understated.

[5] These figures were taken from the Considine, Parry and Blything of the risk assessment of the transportation of hazardous substances through road tunnels in the UK. Classes 1, 5, 7 and 9 were excluded from the study.

[6]Taken from the Health and Safety Commision (HSC) study on the major hazard aspects of the transport of dangerous substances in the UK. The figures shown are proportions of the four sample substances (Petrol, LPG, Chlorine and Ammonia) and therefore these classes have been overstated.

[7]Taken from Saccomanno, Leeming and Stewart's comparative risk assessment study of a hypothetical DG route in Canada. The numbers only show the relationship between LPG, Chlorine and Petrol, and are based on the assumption of equal total tonnages of the three materials.

[8] Netherlands figures from Swart.

Notes: Classes 1 and 7 are special cases. Class 7 goods are subject ot different regulations and are generally not transported in heavy vehicles. Class 1 materials would be carried only infrequently and a figure of 50 movements per year has been assumed for this class.

A breakdown of class 1 into sub-classes (HSC, 1991) based on distance travelled is as follows:

Class 1.1	94%
Class 1.2	2%
Class 1.3	4%

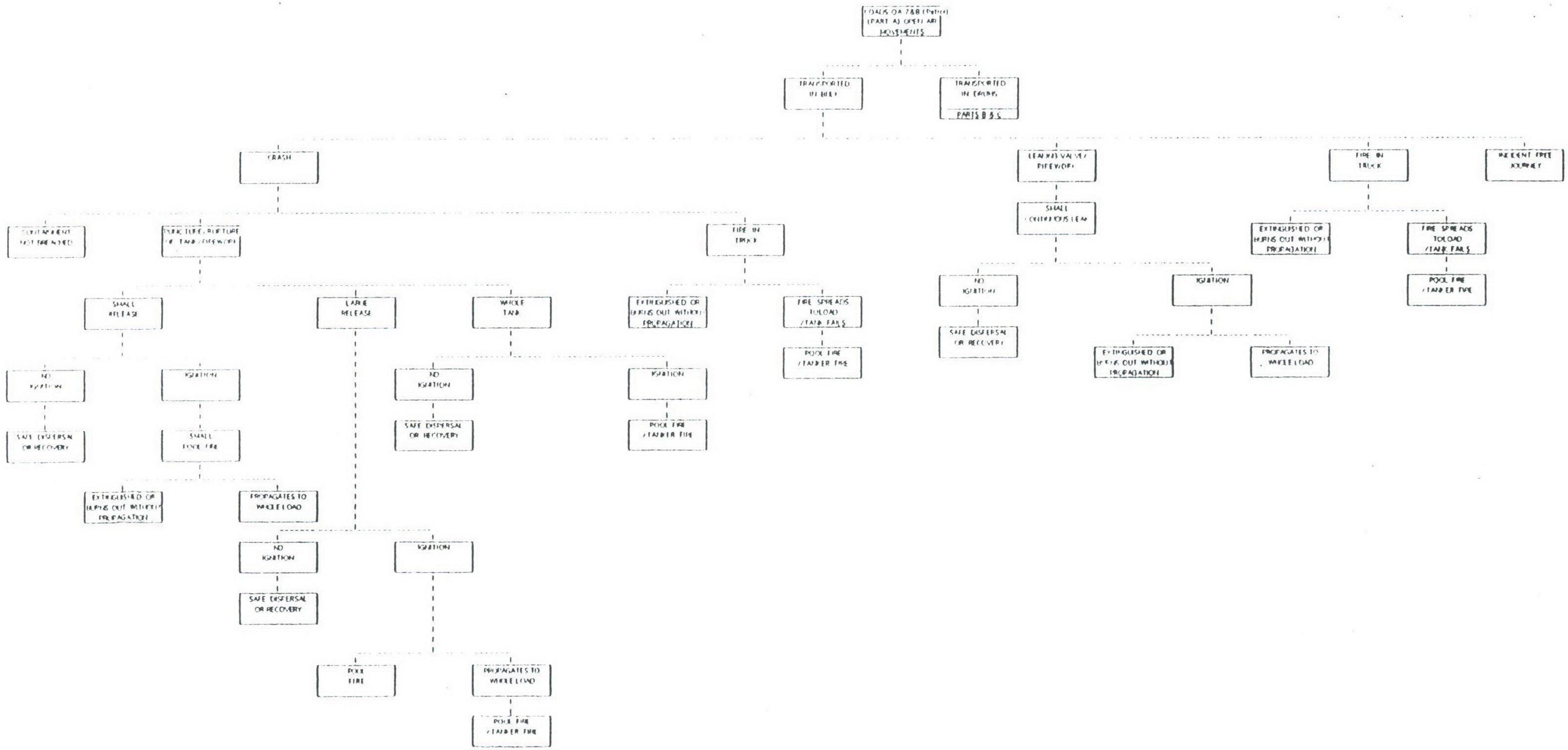
Table 2 : Values used in the Adjustment of Percentage by Number of Movements for Classes of Dangerous Goods

Quantity/Class	1	2	3	4	5	6	7	8	Total (excluding Class 9)	9	Total
Adopted DG Proportions	-	16	55	2	3	2	-	15	93	7	100
Percentage of class transported in bulk[1]	0	64	89	40	57	0	0	84	N/A	22	N/A
Percentage of class transported in packages[1]	100	36	11	60	43	100	100	16	N/A	78	N/A
Percentage of total DG transported in packages by class	-	5.8	6.0	1.2	1.3	2	-	2.4	18.7	5.4	24.1
Packaged DG's as a percentage of total classes 1-8	-	31	32	6.4	6.9	10.7	-	13	100	-	-
Class 9 DG's share redistributed over other classes	-	2	2	0.5	0.5	1	-	1	7	-	-
Adjusted DG Proportions	0.08	18	56.92	2.5	3.5	3	-	16	100	-	-

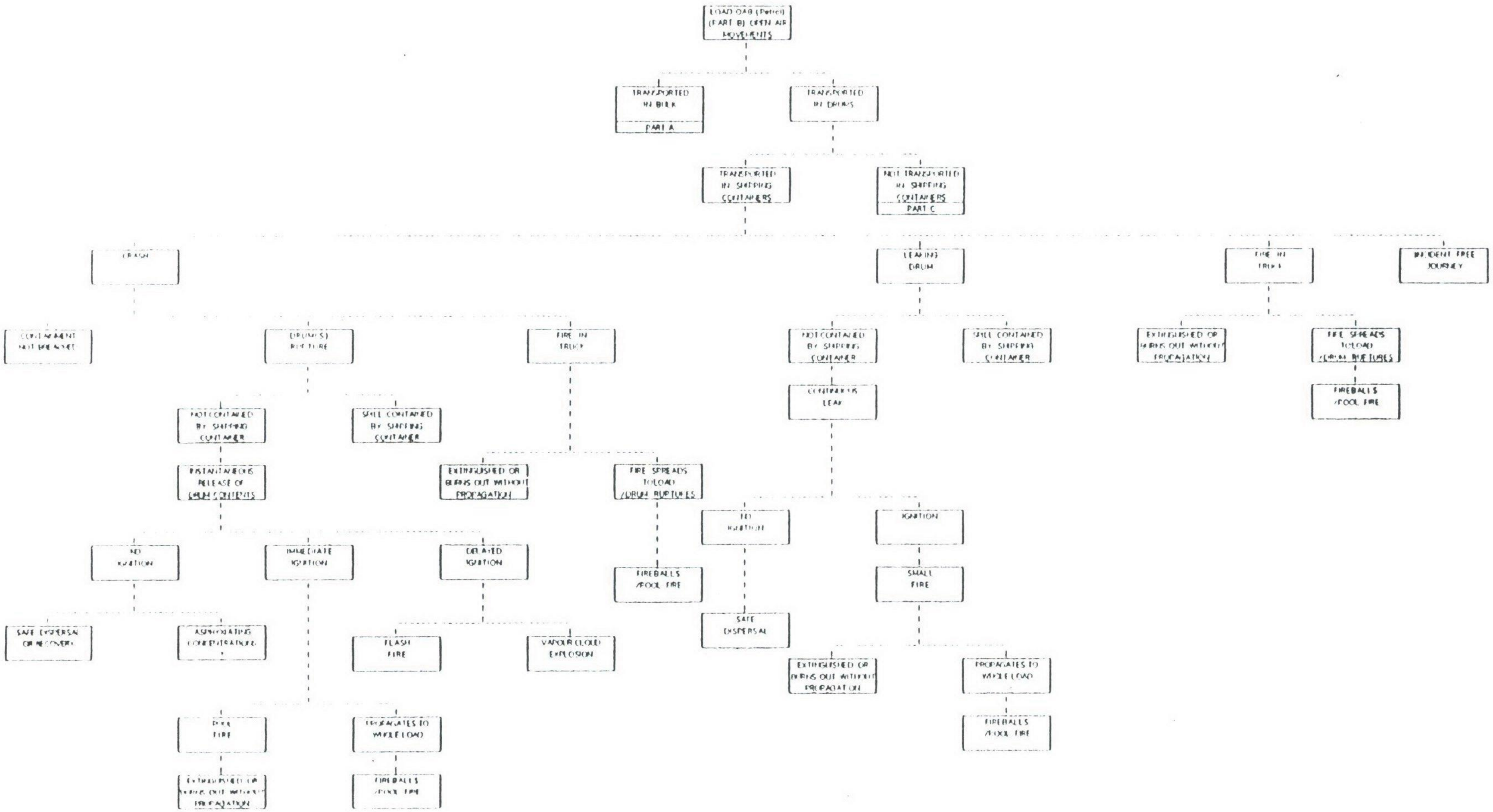
[1] Based on the DG survey undertaken by Traffic and Transport Surveys Pty. Ltd. for this study.

Appendix 6B
Event Trees

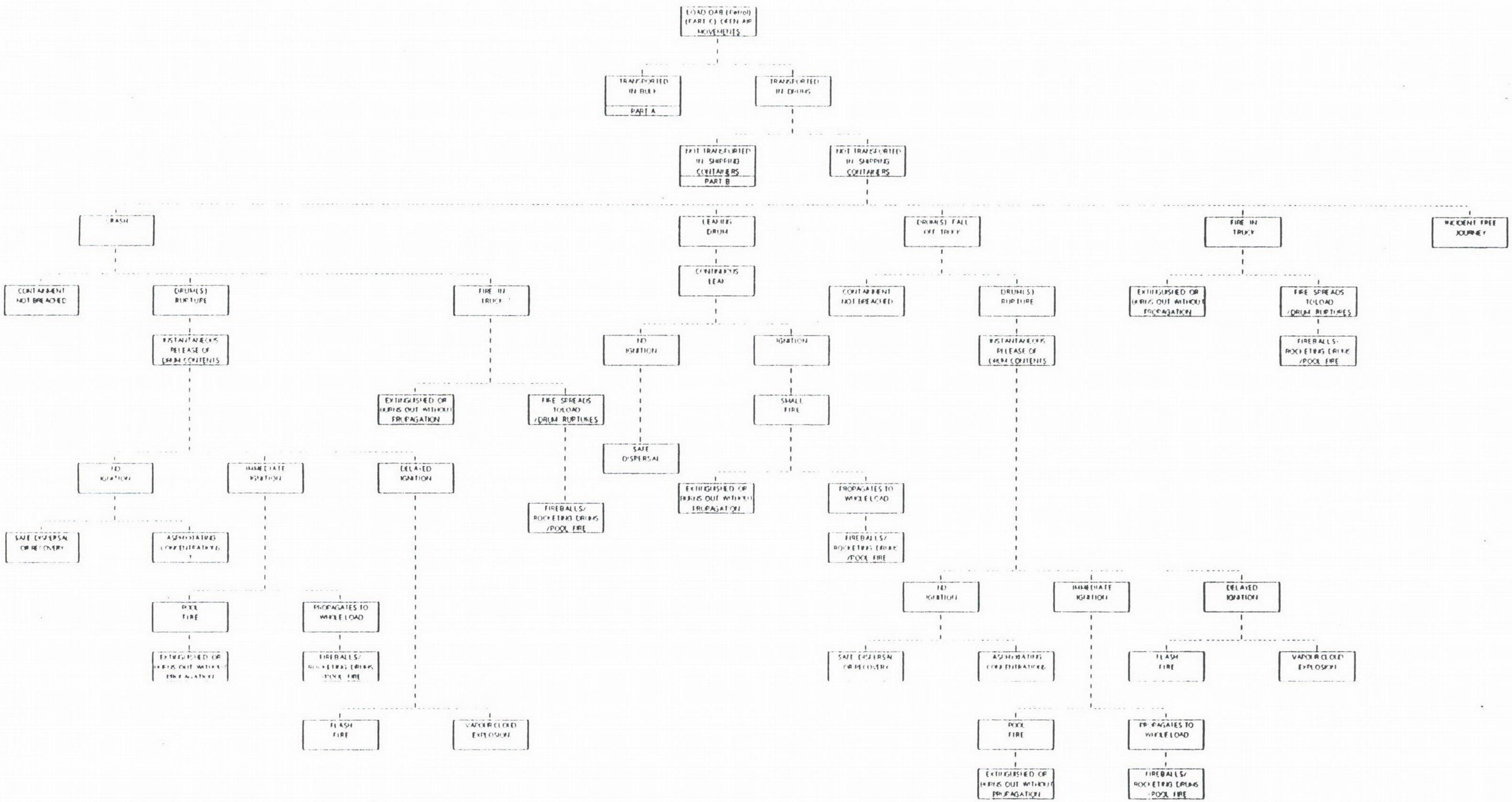
EVENT TREE FOR LOADS OA 7 & 8 (Petrol) Part A



EVENT TREE FOR LOAD OA8 (Petrol) Part B

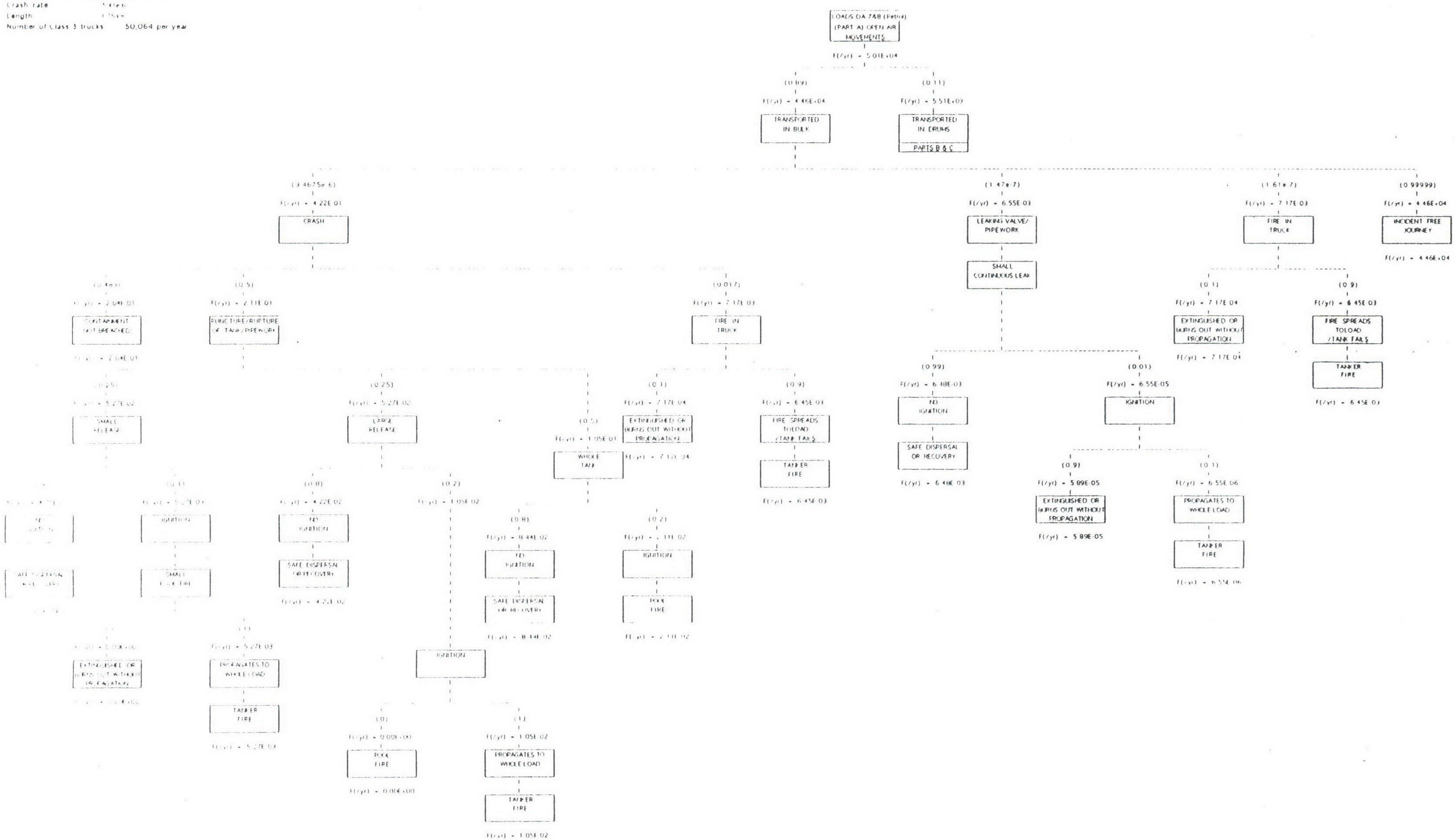


EVENT TREE FOR LOADS OA8 (Petrol) Part C

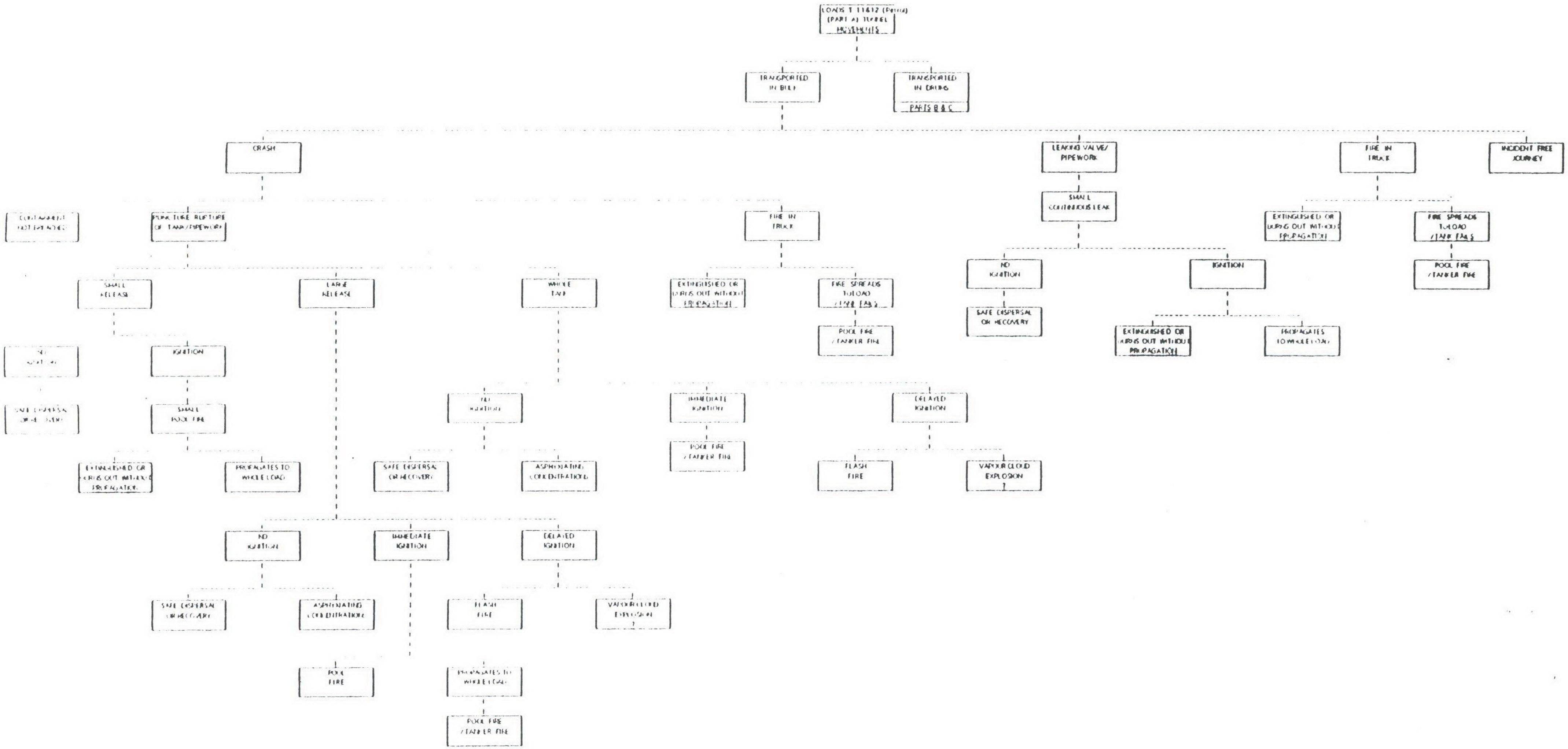


EVENT TREE FOR LOADS OA 7 & 8 (Petrol) Part A

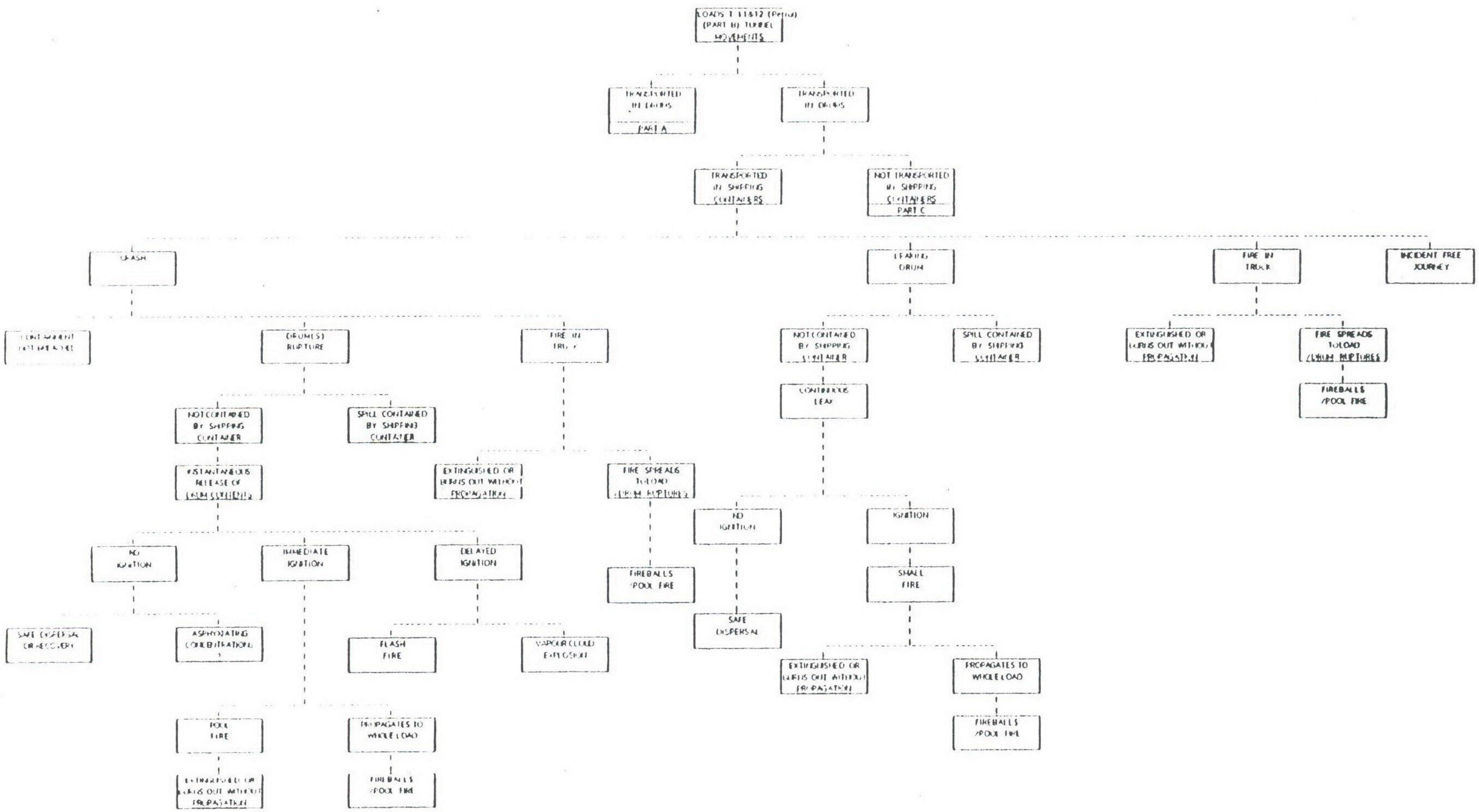
For Section 12 of Southern Route in 2011
Crash rate [illegible]
Length [illegible]
Number of Class 3 trucks 50,064 per year



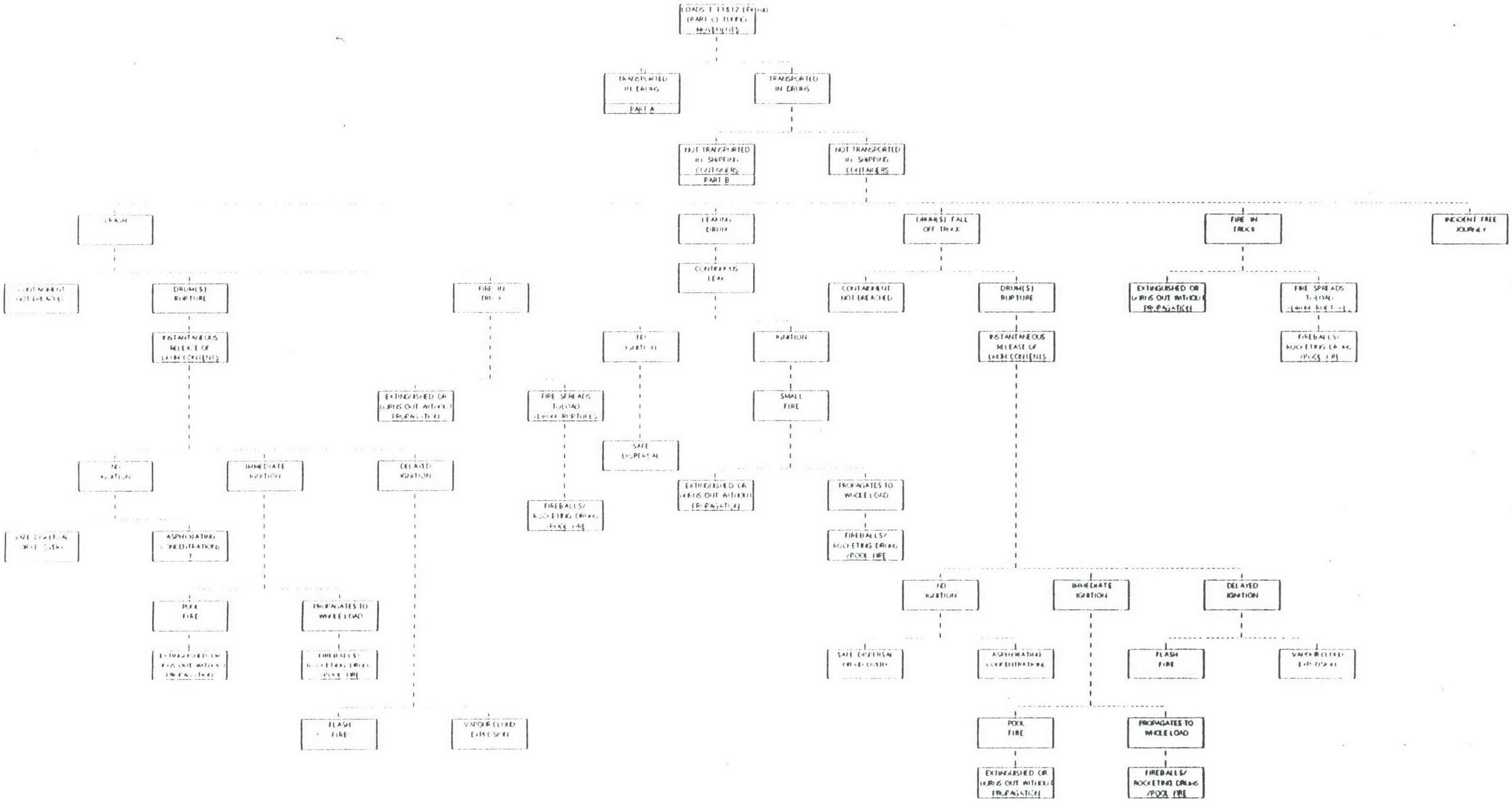
EVENT TREE FOR LOADS T 11 & 12 (Petrol) Part A



EVENT TREE FOR LOADS T 11 & 12 (Petrol) Part B

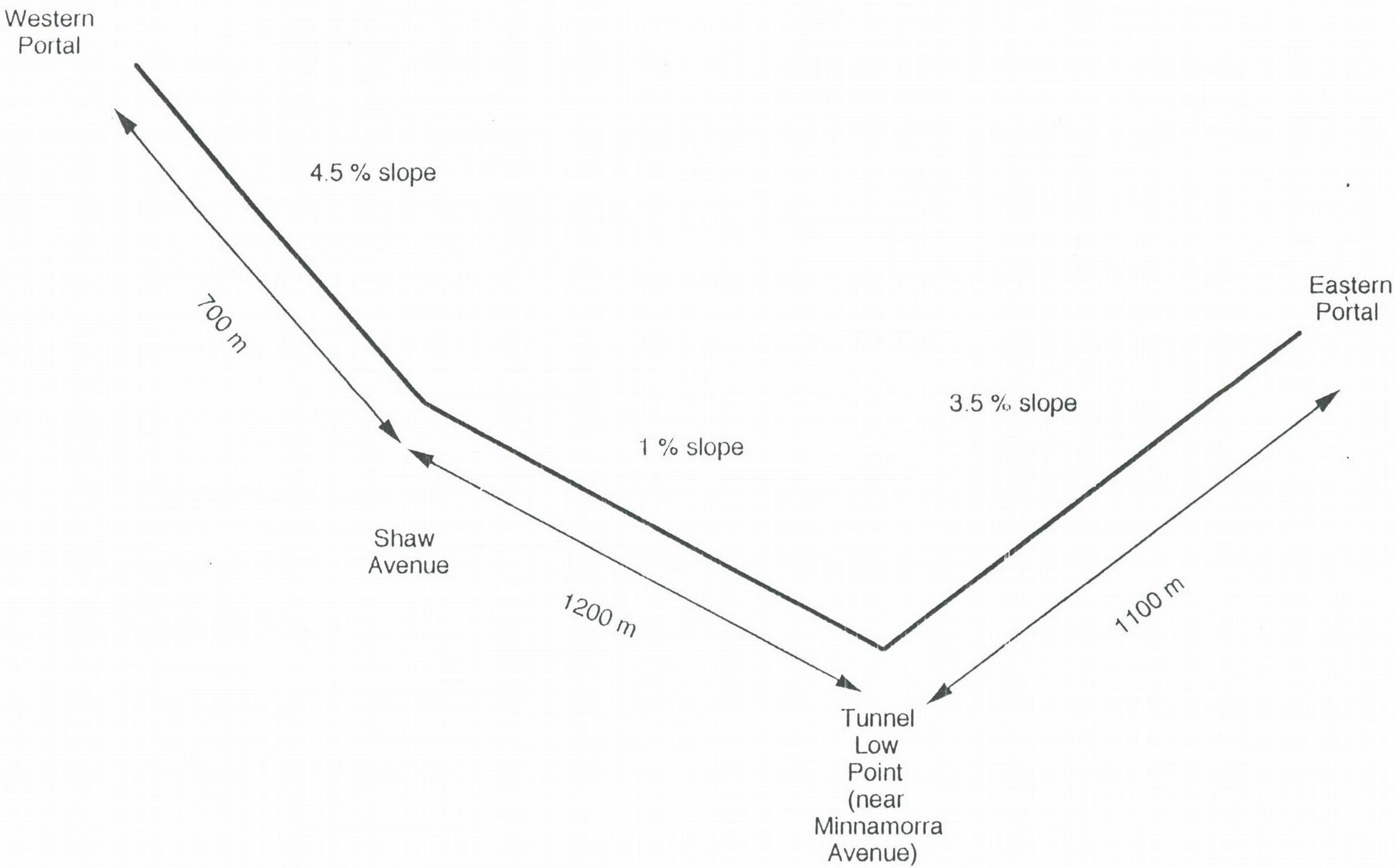


EVENT TREE FOR LOADS T 11 & 12 (Petrol) Part C

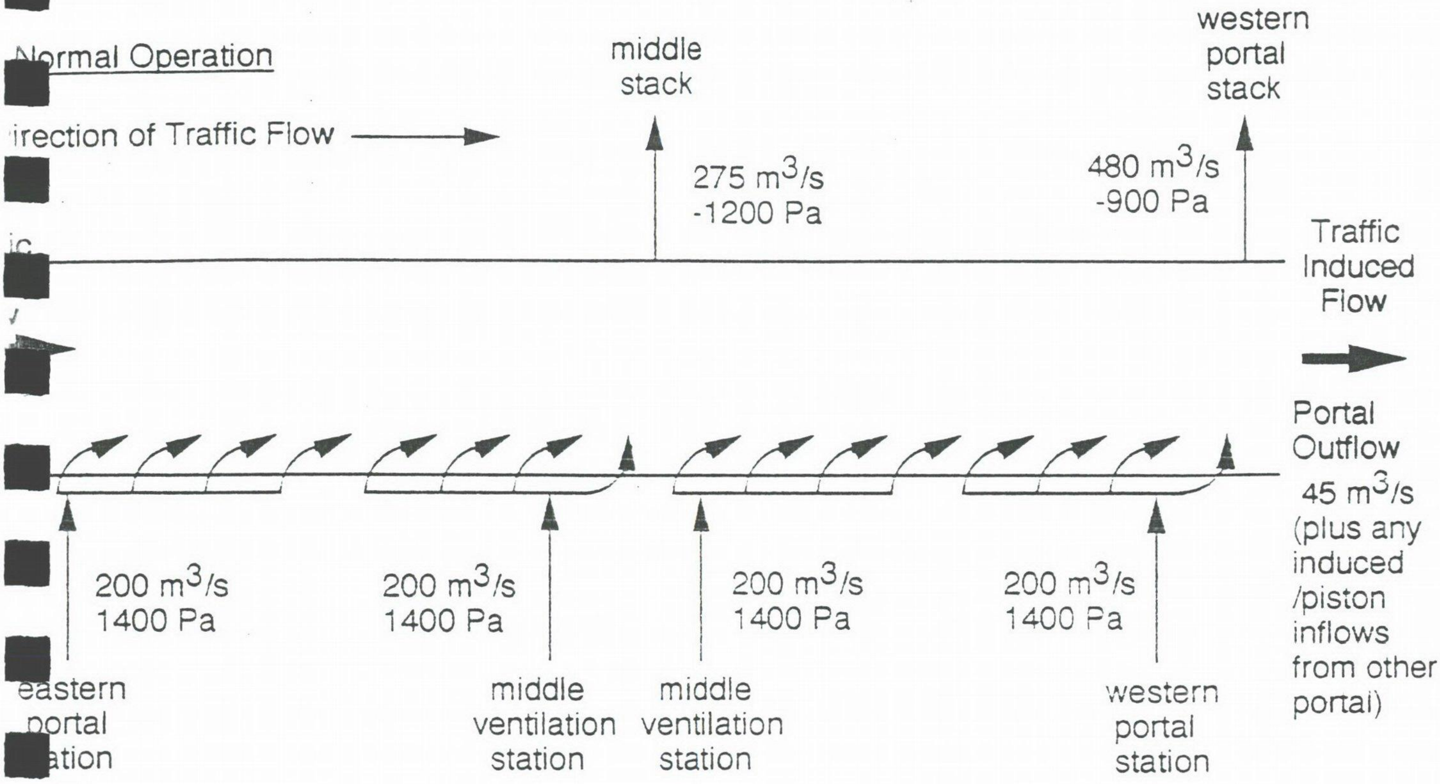


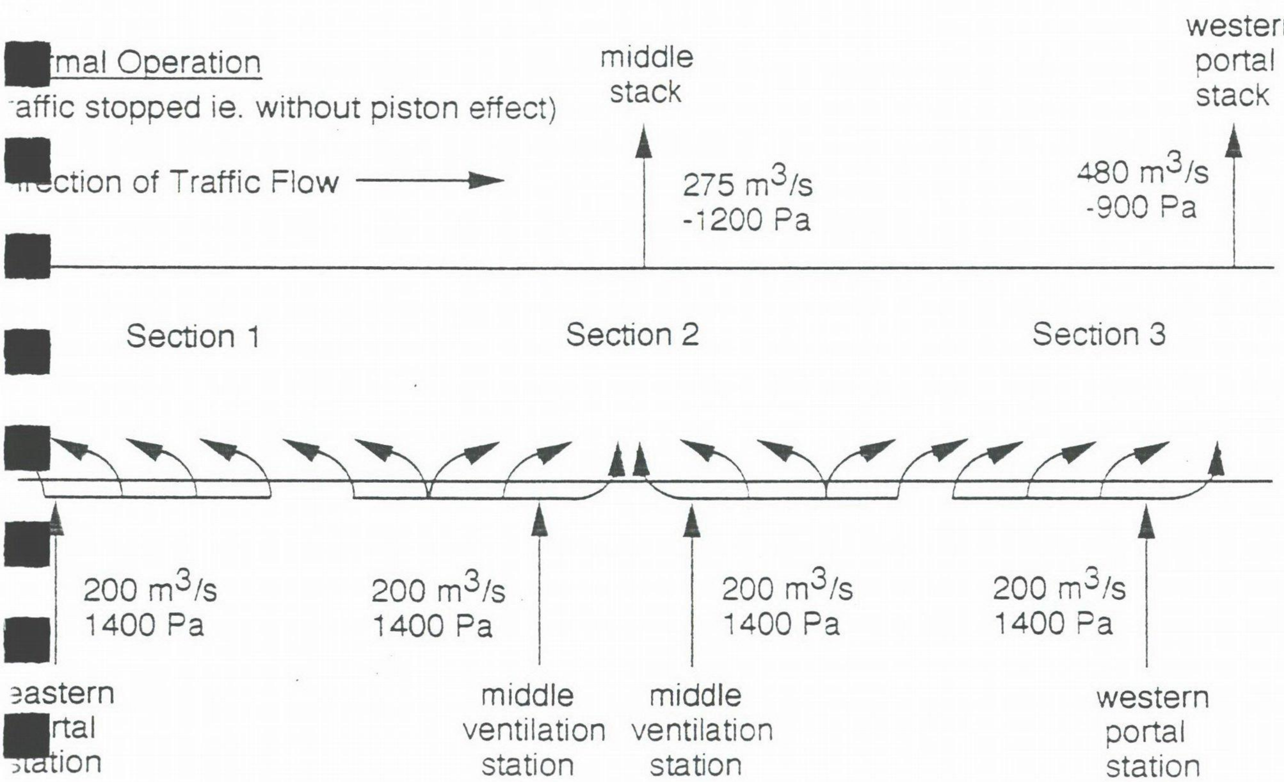
Appendix 6C
Drainage and Ventilation Schematics

DIAGRAM A6C1 Slopes of Proposed Tunnel



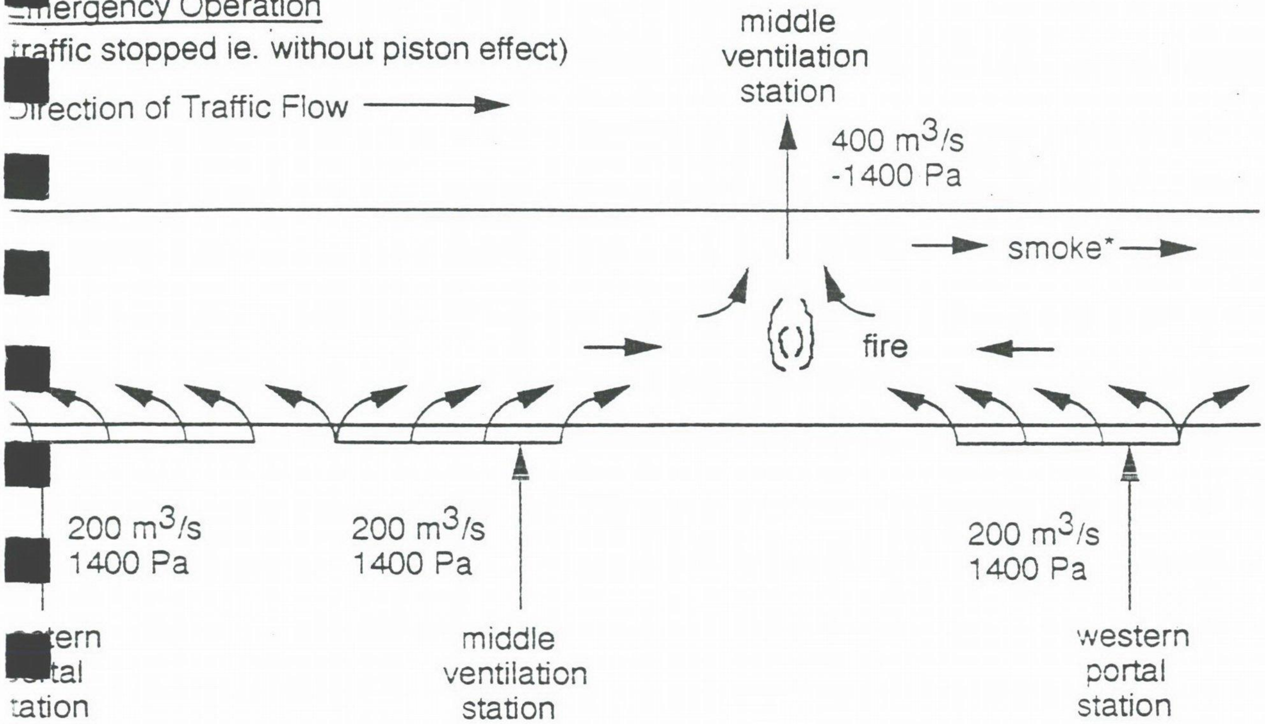
IAGRAM A6C2a Simplified Schematic of Proposed Tunnel Ventilation System



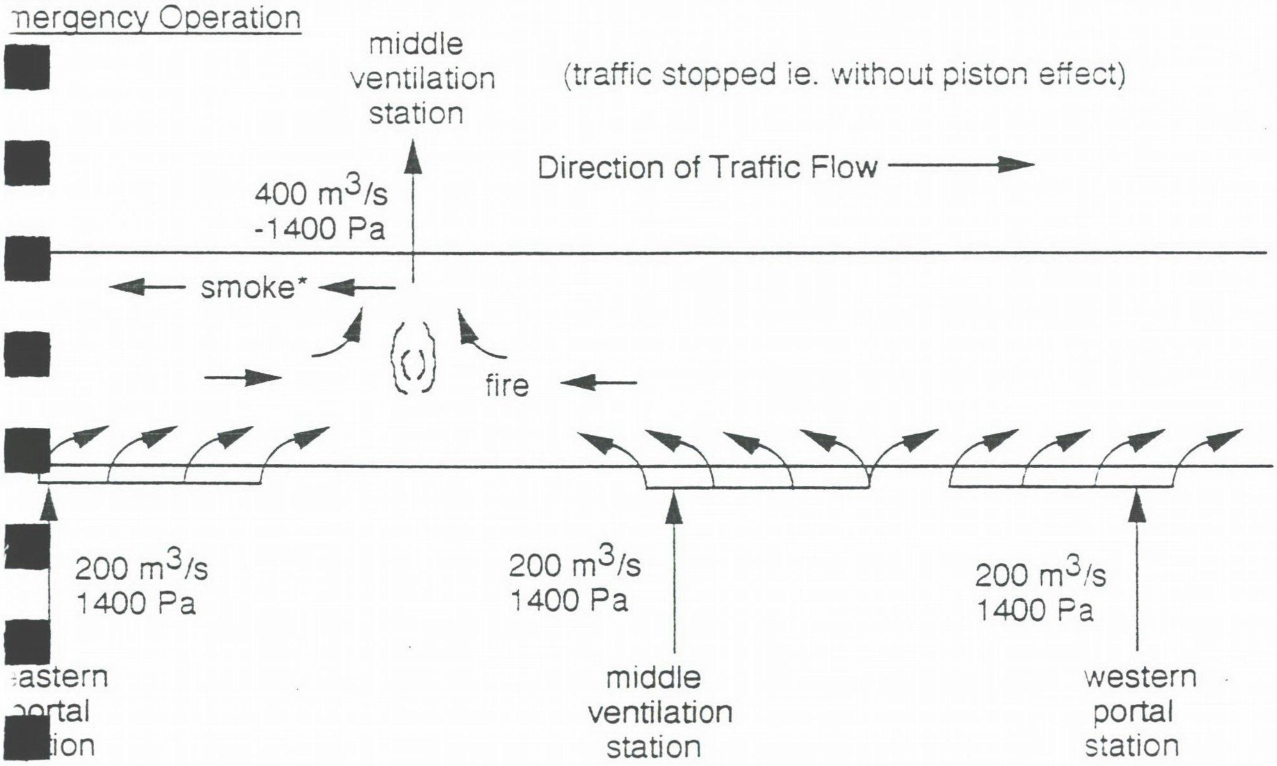


GRAM A6C2b Simplified Schematic of Proposed Tunnel Ventilation System (cont.)

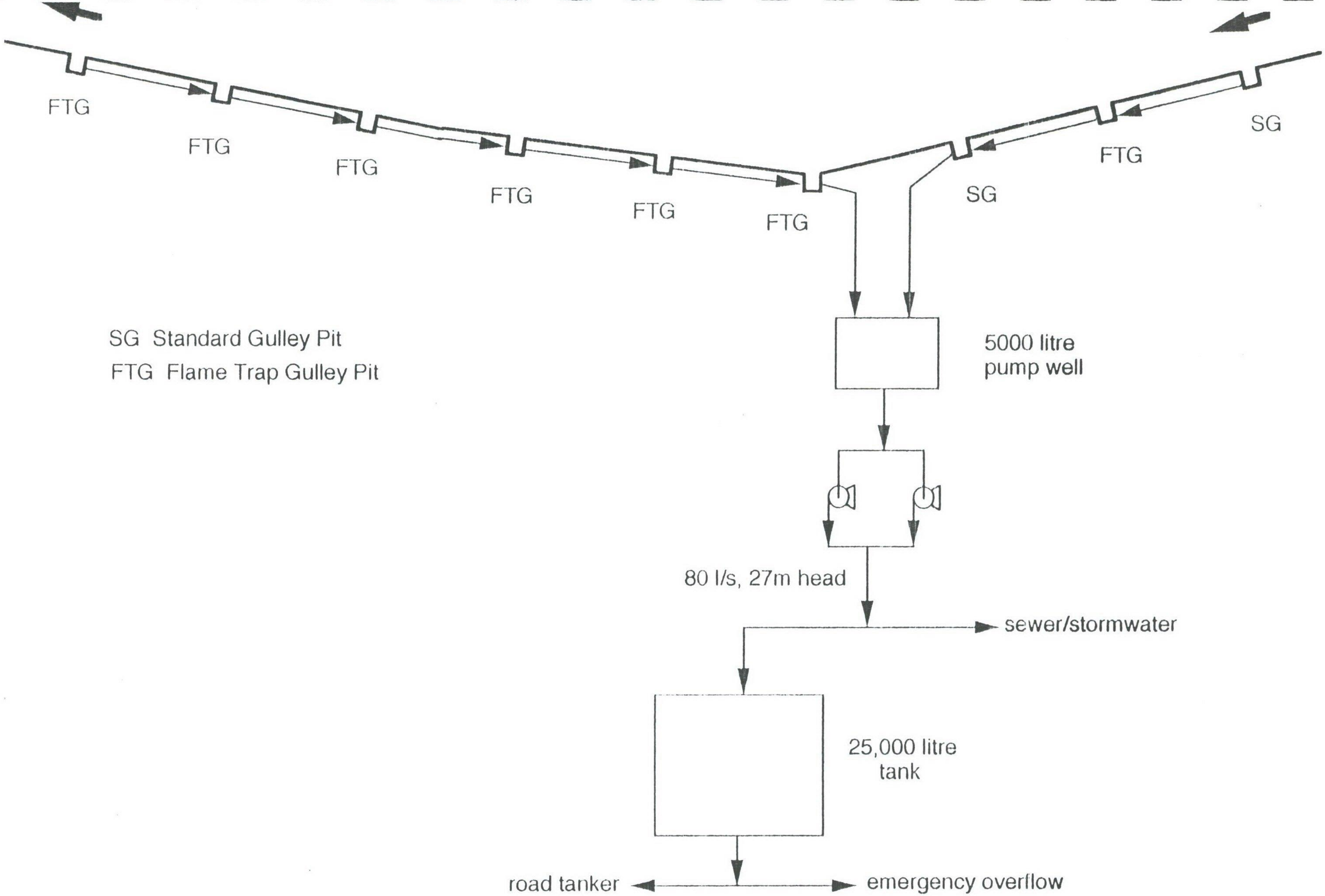
mergency Operation
traffic stopped ie. without piston effect)
Direction of Traffic Flow →



mergency Operation



* If fire is large enough, direction determined by slope of tunnel.
If fire causes failure of smoke exhaust then chimney effect is stronger.


FTG
FTG
FTG
FTG
FTG
FTG
SG
FTG
SG
SG Standard Gulley Pit
FTG Flame Trap Gulley Pit
5000 litre
pump well
80 l/s, 27m head
sewer/stormwater
25,000 litre
tank
road tanker
emergency overflow

Appendix 6D
Properties of Representative Materials

[redacted]	[redacted] toluen [redacted] 17	[redacted] 389	[redacted]	[redacted]	S [redacted]	yellow [redacted] tals	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
2.1	Liquified Petroleum Gases (LPG) (Propane/Butane)				G G		F F		100.4 -73.3	2.12 vol. 1.86 vol.	9.35 vol. 8.41 vol.		-42.1 -0.5
2.1	Hydrogen Gas	1049			G	colourless, odourless gas	F			4 mol.	75 mol.	-259.1	-252.7
2.2	Nitrogen Gas				G	colourless gas						-209.86	-195.8
2.2	Oxygen Gas				G	colourless, odourless, tasteless gas, slightly denser than air						-218.4	-183
2.3	Chlorine Gas	1017			G	green-yellow gas						-101.6 (P)	-34.1 -34.6 (P)
2.3	Ammonia Gas				G	colourless gas				15 (vol)	28 (vol)	-77.7	-33.4
3	Petrol (modelled as hexane)				L	colourless liquid, dyed for recognition, characteristic odour colourless liquid (hex)	F F		-40 (NFPA)	1.4 (vol)	7.6 (vol)	-94 (hex)	30-180 69 (hex)
4	Nitrocellulose (wetted with alcohol)	2555/6			S	soild fibrous material	Flammable		12.7				
5.1	Hydrogen Peroxide (35%)	2014			L	Clear, colourless liquid with sharp odour	Inert		-0.41 (pure)			-33	108 152.1 (pure
5.1	Calcium Hypochlorite				S	white, feathery crystals or powder with pungent odour							
5.2	Methyl Ethyl Ketone Peroxide (MEKP)												
6.1	Methylene Chloride	1593			L	Colourless liquid	Inert Combustible (NZ)			13	23		40.2
6.1	Methyl Azinphos				S		C	in fibre keg					
8	Hydrochloric Acid (20 Baume, conc., 35%)	1789			L	Clear, colourless to slightly yellow fuming liquid with pungent irritating odour	N						65.6-110
8	Sodium Hydroxide (Caustic Soda)(50%)	1824			L		Inert						
	Polyethylene Beads				S		C						

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	wher[redacted]ved in[redacted]toxic f[redacted]evolved[redacted]	[redacted]
2.1	0.51 0.58			948 kPa @25 C 400 kPa @ 25 C				
2.1	0.071				2.1cc per 100g 1.8 v/v @20 C	auto ig 571 C		
2.2	0.808				2.35cc per 100g			
2.2	1.14				4.89cc per 100g			
2.3	1.4 @20 C 1.56 @ -35 C			666kPa @20 C	very slightly, 0.7 % 310cc per 100g	reacts with iron above 100 C		293 ppm for 1 hr (UNIDO)
2.3	0.639 @ 0 C 0.7 @ -33 C					ig. temp 651 C (NFPA)		8800ppm for 15 min. (Newcastle, p.89) 11590 for 1 hr (UNIDO)
3	0.735 0.659 (hex) @20 C 0.716	0.0004			0.0014g/100g@15 C		irritant, toxic by inhalation, swallowing and through the skin	
4					not soluble	autoig. 170 C autoig. 160 C (MAX)		
5.1	1.133		3.3 at 30 %	23 @ 30 C	100% soluble	unstable, liberates O2	irritant, corrosive	2000 rat, 227ppm mouse, >2000ppm rat 8h (90% H2O2)
5.1						may decompose violently		
5.2								
6.1	1.335			380 (MAXWELL) 433.1 @25 C (ECD) 350 (phil)	2% w/w	-> phosgene, HCl ig. temp 556 C (NFPA)	Toxic by inhalation and ingestion. Eye, nose and throat irritant	88000 rat 30m, 14400 mouse 7h
6.1								152
8	1.16-1.1789			84 @20 C	fully miscible		Corrosive; Oxidizer; Unstable	1000-2000 ppm can be fatal inhalation (rat) 3124 ppm (1 hour)
8							Corrosive	

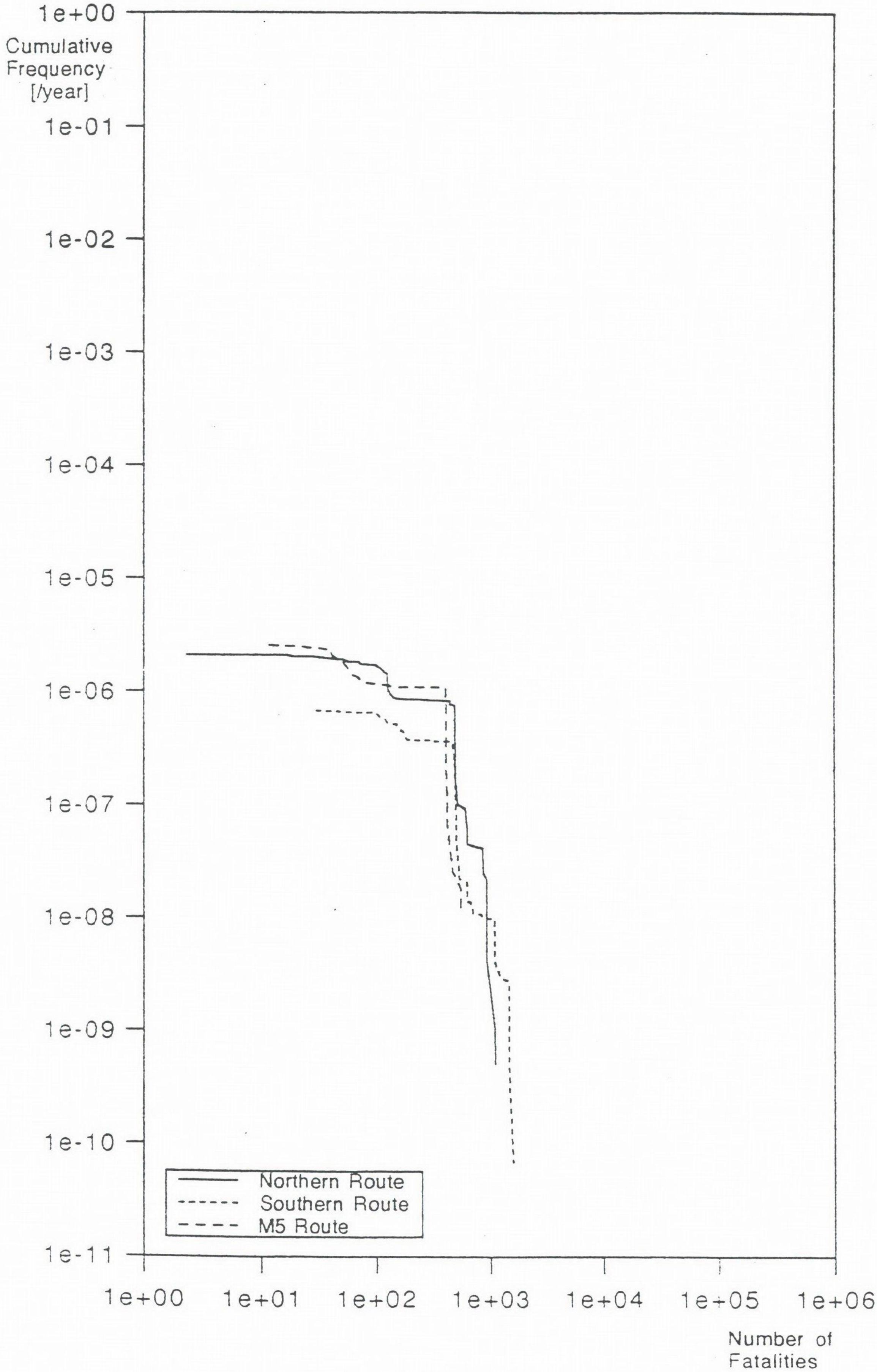
1 1				
2 1				
2 1				
2 2				
2 2				
2 3				25ppm (NZ) 72.6
2 3				500ppm (newcastle, p.89) 348
3				
4				
5 1	700 rabbit D (90% H_2O_2), 9200 rabbit D (70% H_2O_2), 75 rat O (75% H_2O_2)			
5 1				
5 2				
6 1	LDLo 357 Human O	Decomposes->HCl and phosgene		17347
6 1	16 4, 250	Y - SO_2, P_2O_5, NO_x		
8				147, 100ppm. Levels of 10-35ppm can cause i
8				200 (NZ)

1 1	
2 1	
2 1	oxidising agents
2 2	
2 2	
2 3	acetylene, turpentine, alcohols, anhydrous ammonia, fuel gas, hydrocarbons, oil, hydrogen, finely divided metals
2 3	
3	
4	
5 1	Unstable with contaimination, leads to rapid release of O2. Incompatible with cyanides, hexavalent chromium compou May react dangerously with rust, dirt, iron, copper, heavy metals or their salts, alkalis and organic materials. Conta
5 1	reacts violently with acids, may cause fire in contact with organic materials such as wood, cotton, straw or vegetable oils. In the presence of moisture, corrosive to most metals
5 2	
6 1	strong acids, alkalis, oxidisers, alkali metals, aluminium and magnesium powders
6 1	
8	alkalis, metals, cyanides, mercuric sulfate, perchloric acid, carbides of calcium, cesium, rubidium, acetylides of cesium and rubidium, phosphides of calcium and lithium silicide, and sodium hypochlorite
8	

Appendix 6E
Societal Risks

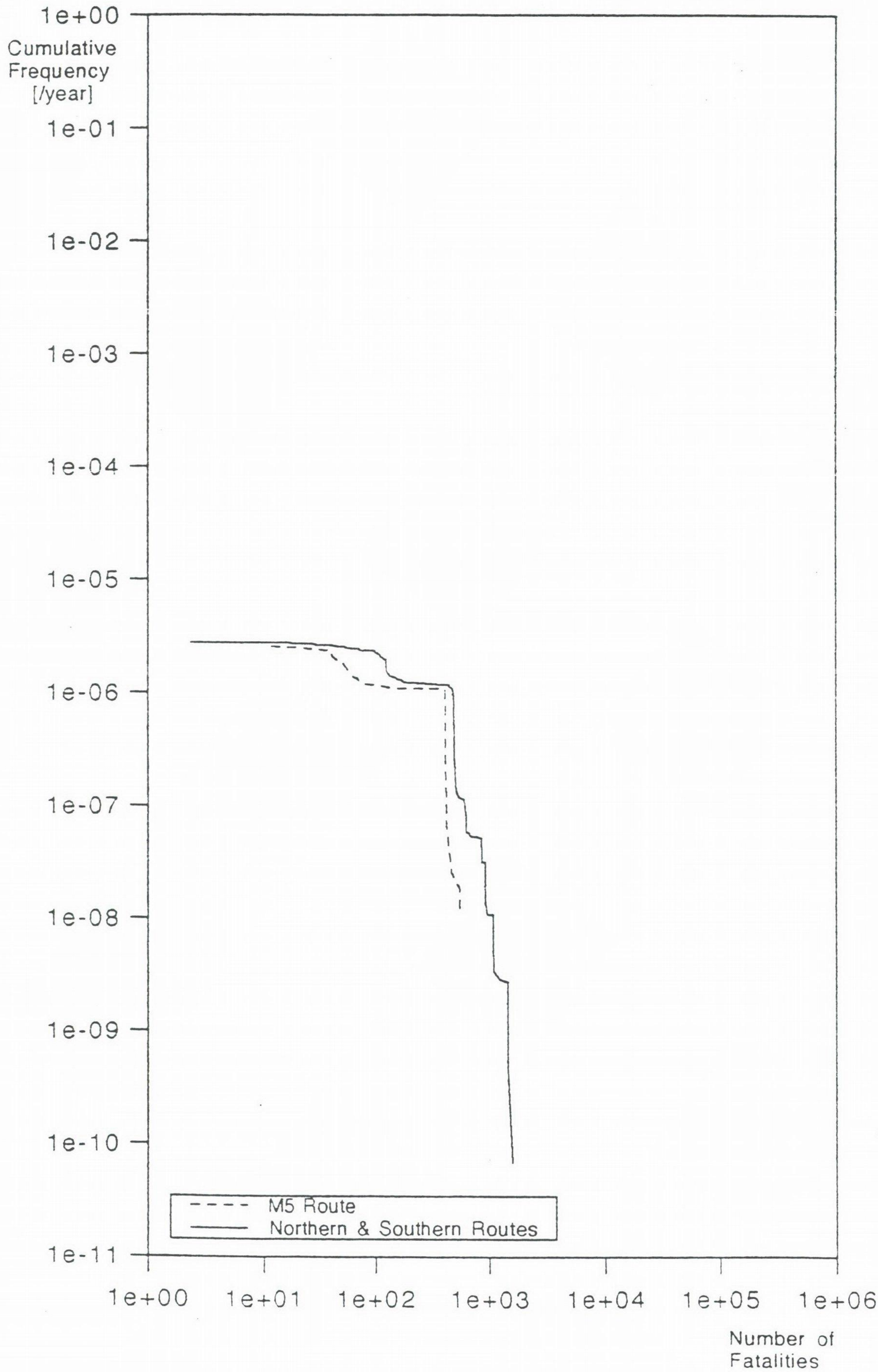
Societal Risk from DG Class 1

1996 M5, Northern and Southern routes



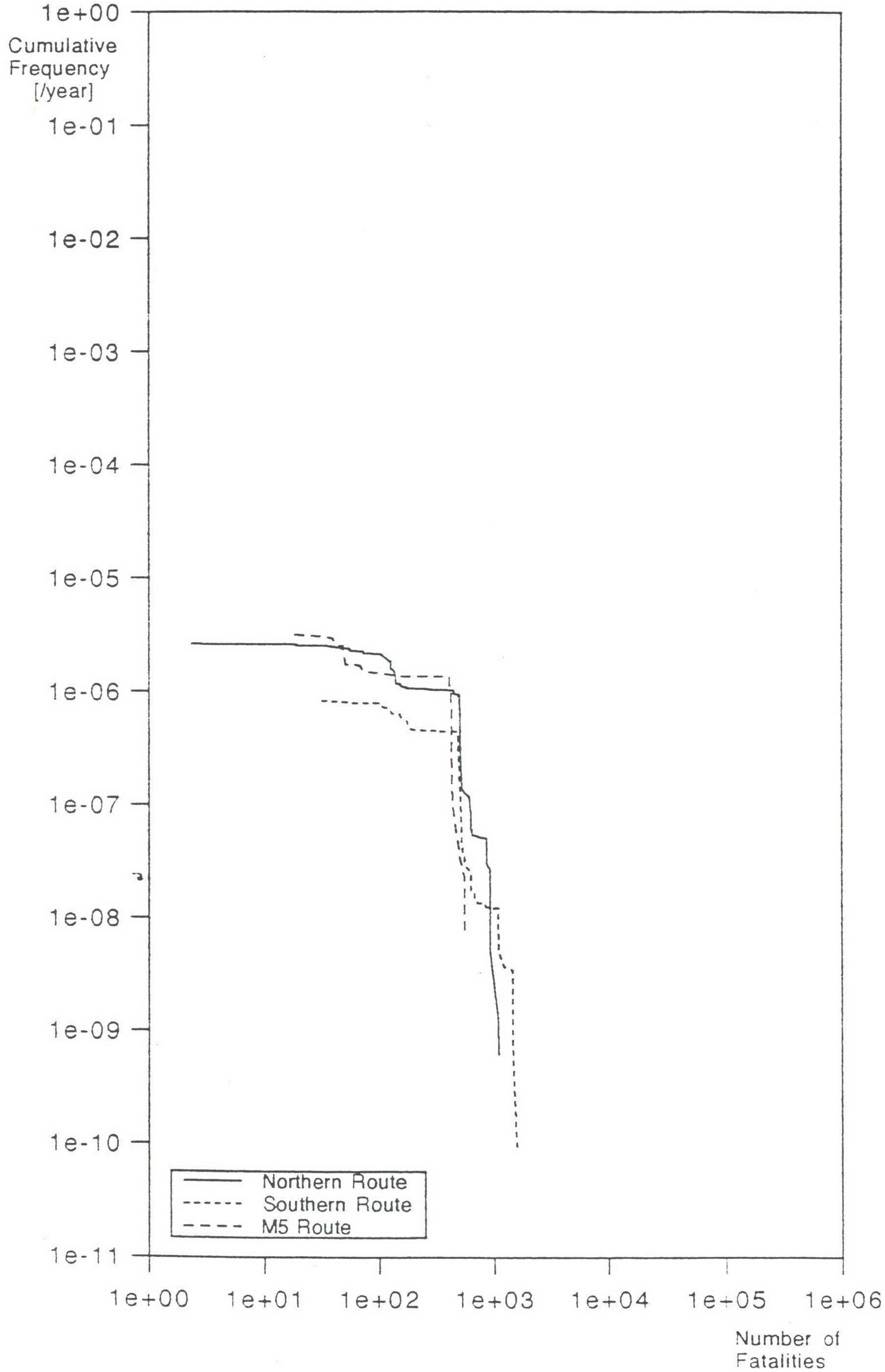
Societal Risk from DG Class 1

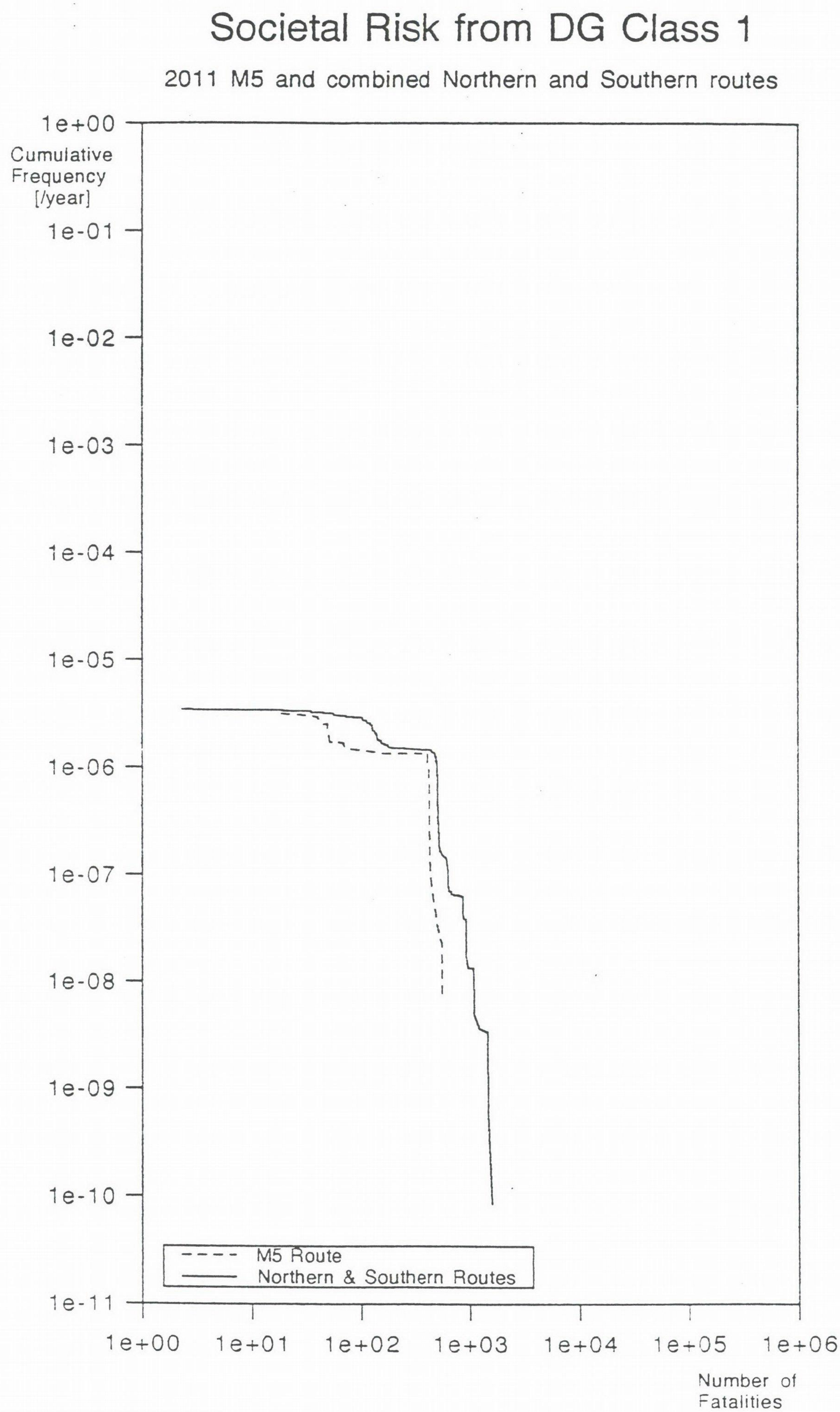
1996 M5 and combined Northern and Southern routes

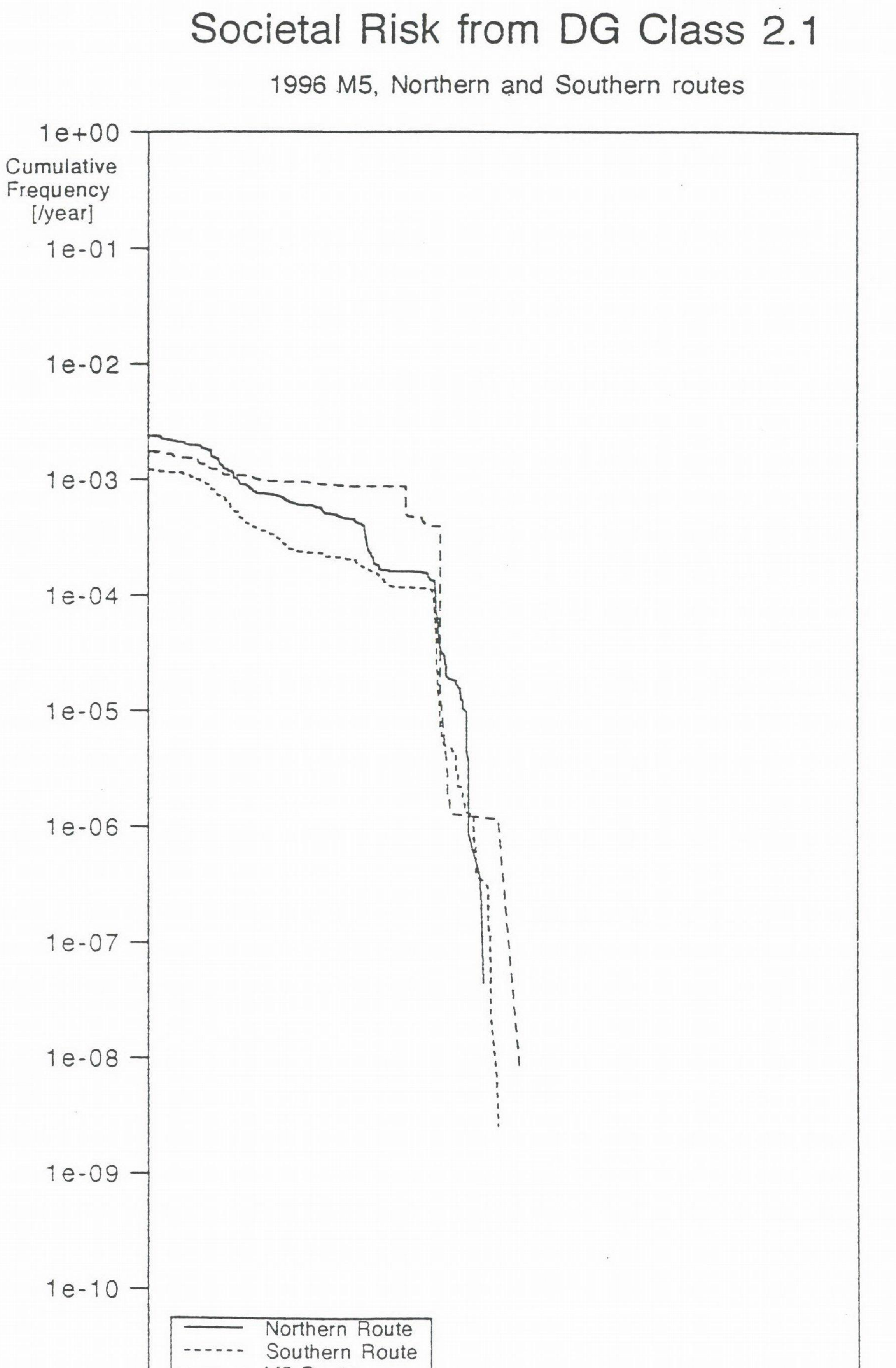


Societal Risk from DG Class 1

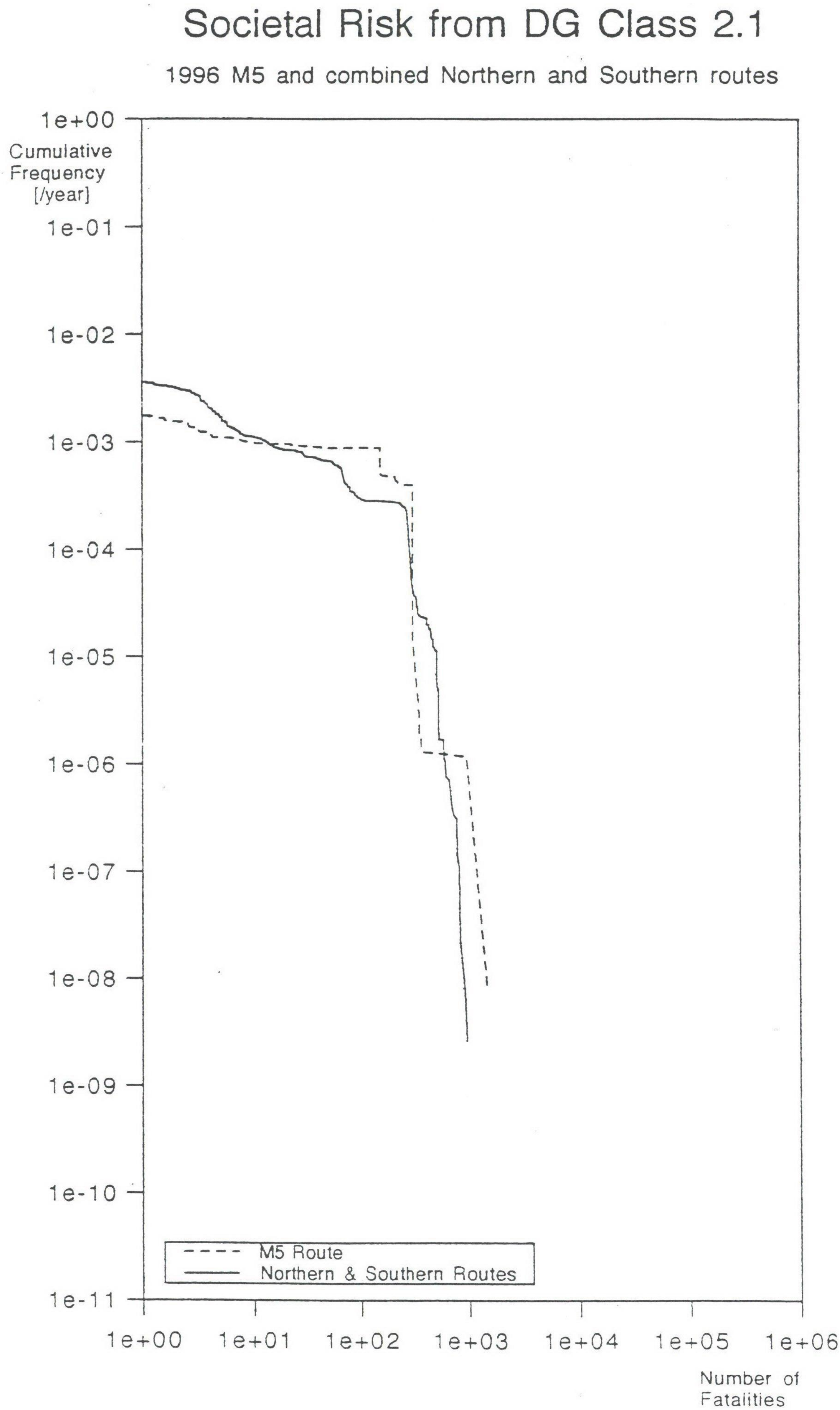
2011 M5, Northern and Southern routes




Societal Risk from DG Class 1
2011 M5 and combined Northern and Southern routes
Cumulative Frequency [/year]
1e+00
1e-01
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
M5 Route
Northern & Southern Routes
1e+00
1e+01
1e+02
1e+03
1e+04
1e+05
1e+06
Number of Fatalities



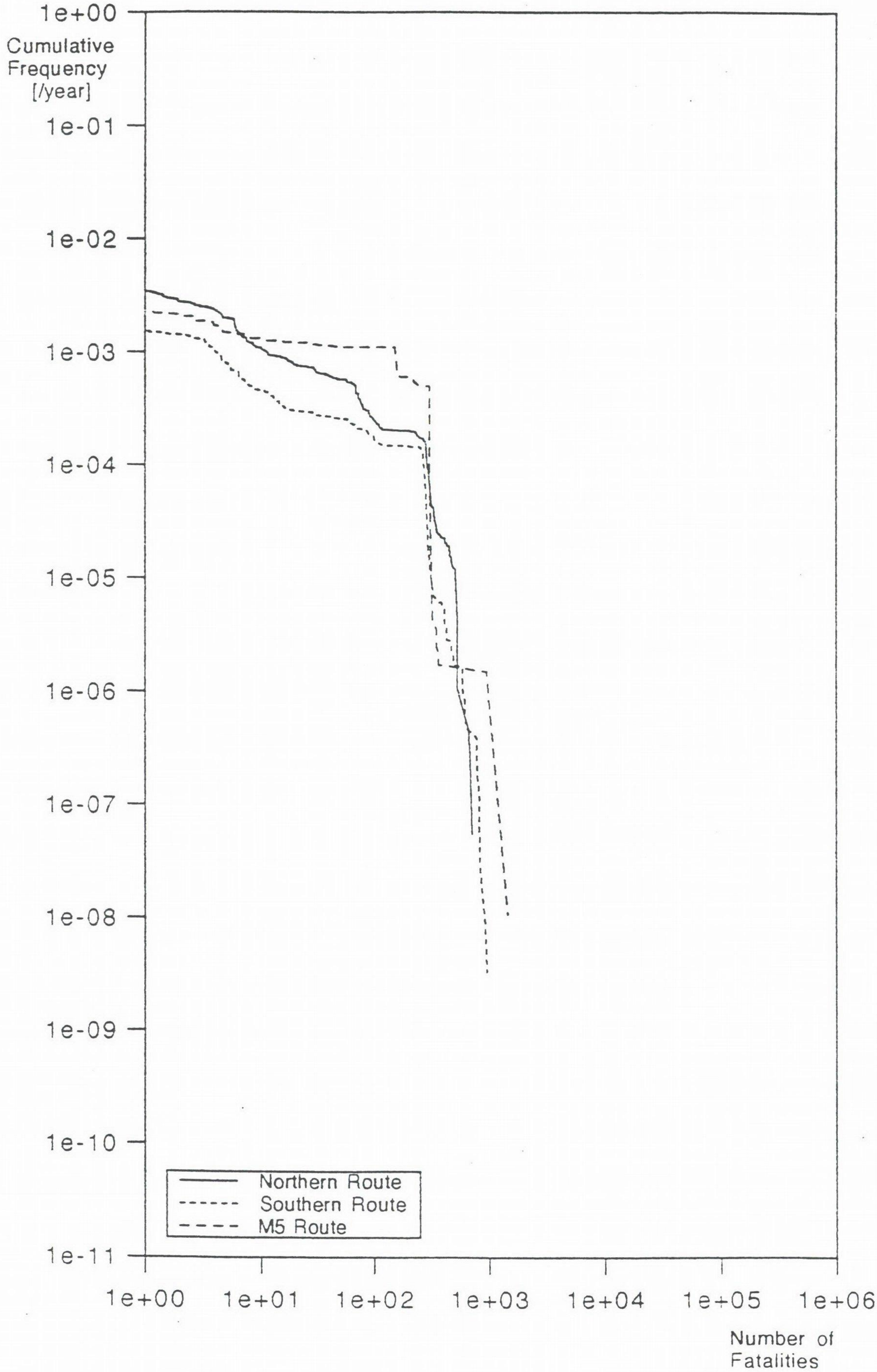
Societal Risk from DG Class 2.1
1996 M5, Northern and Southern routes
Cumulative Frequency [/year]
1e+00
1e-01
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
Northern Route
Southern Route
M5 Route
1e+00
1e+01
1e+02
1e+03
1e+04
1e+05
1e+06
Number of Fatalities



Societal Risk from DG Class 2.1
1996 M5 and combined Northern and Southern routes
Cumulative Frequency [/year]
1e+00
1e-01
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
M5 Route
Northern & Southern Routes
1e+00
1e+01
1e+02
1e+03
1e+04
1e+05
1e+06
Number of Fatalities

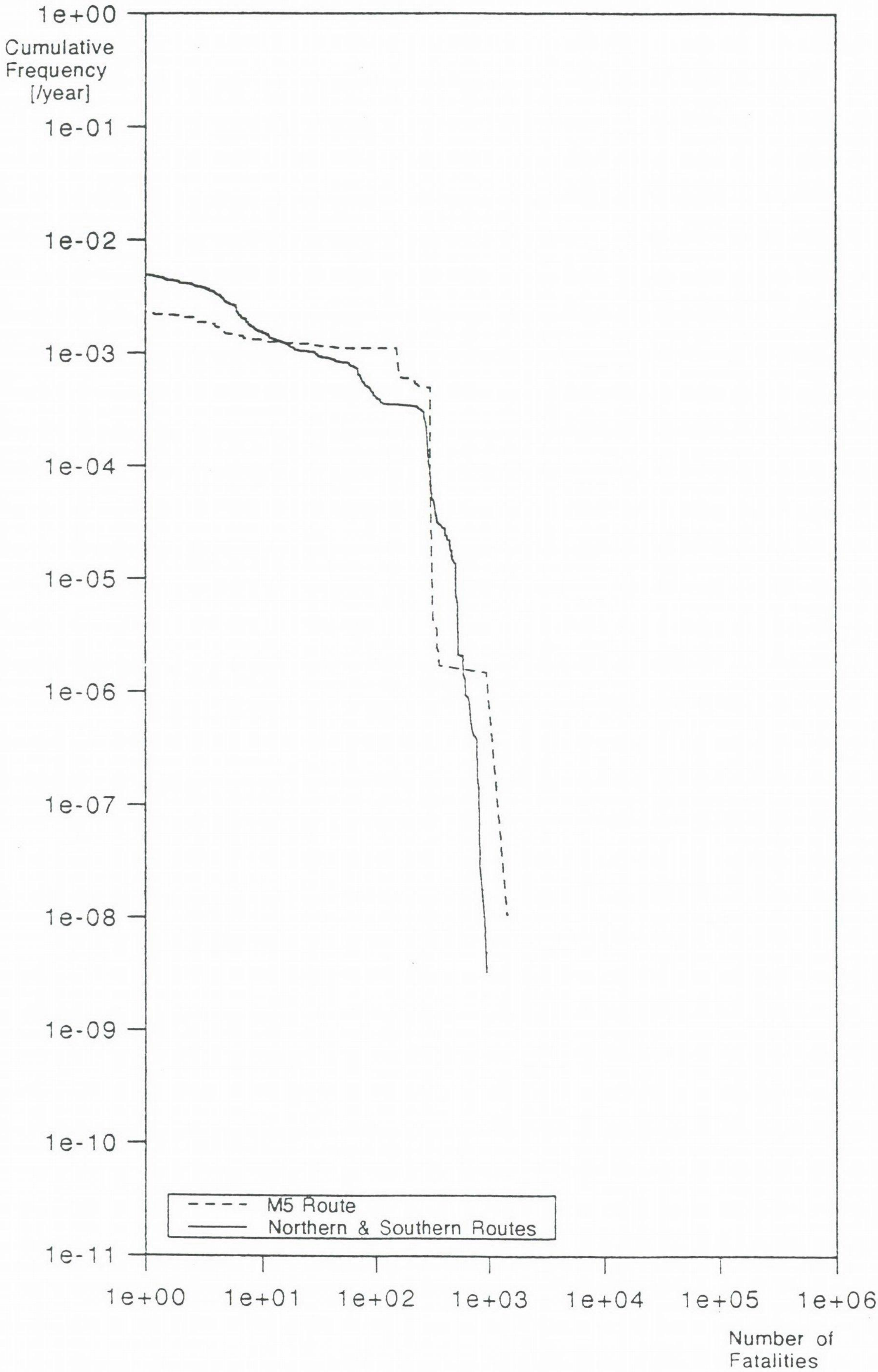
Societal Risk from DG Class 2.1

2011 M5, Northern and Southern routes



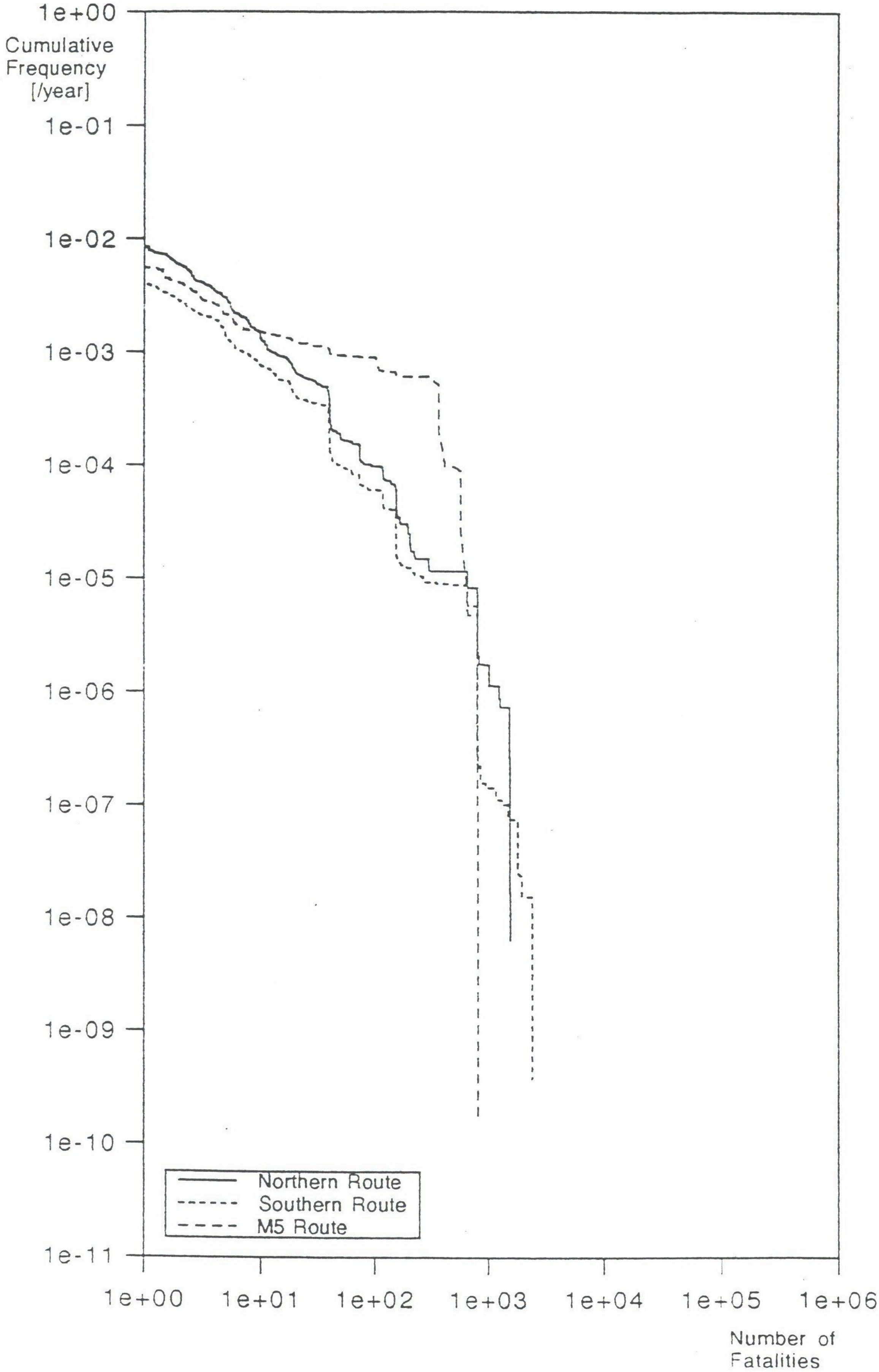
Societal Risk from DG Class 2.1

2011 M5 and combined Northern and Southern routes



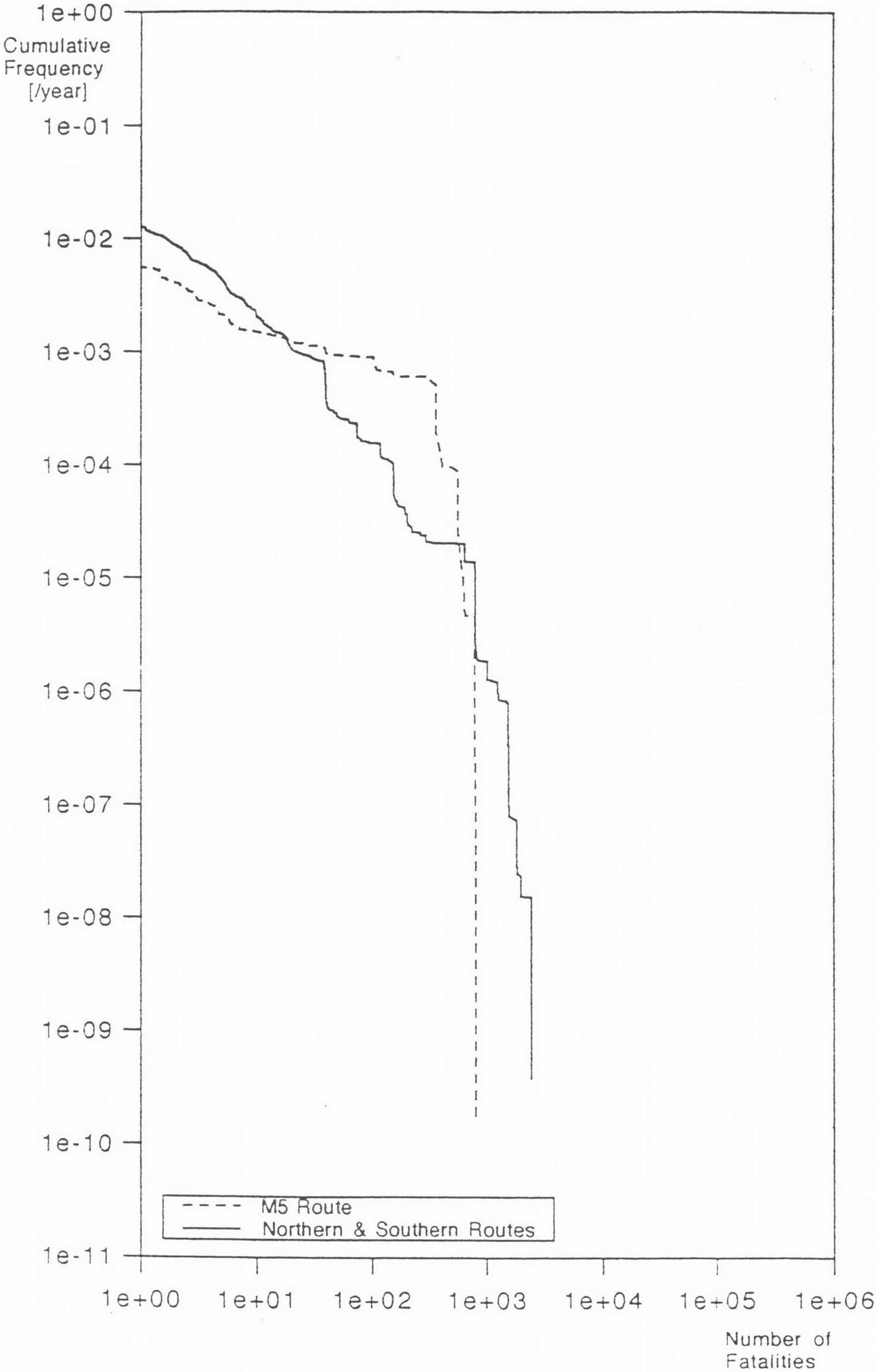
Societal Risk from DG Class 2.2/2.3

2011 M5, Northern and Southern routes



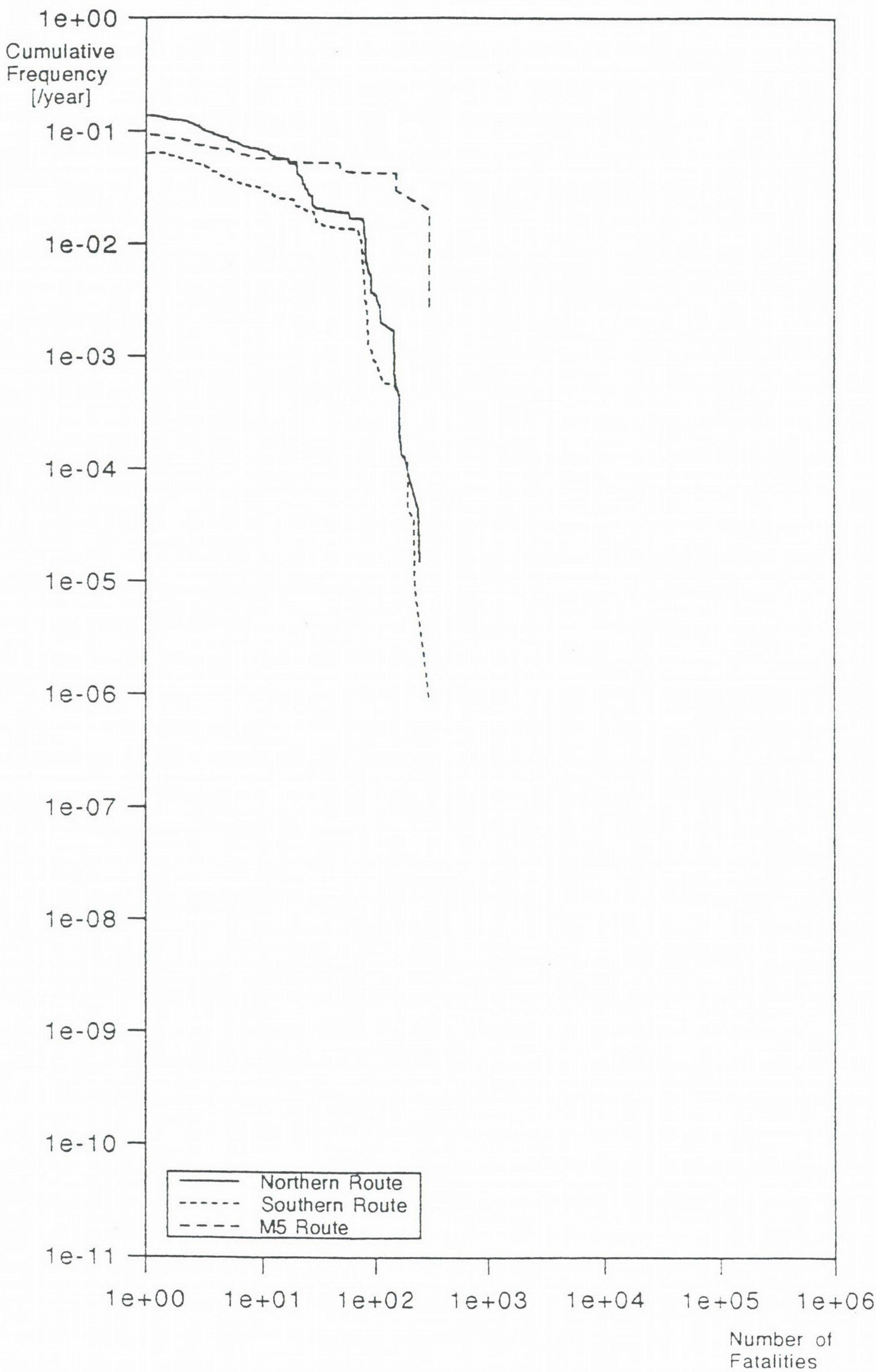
Societal Risk from DG Class 2.2/2.3

2011 M5 and combined Northern and Southern routes



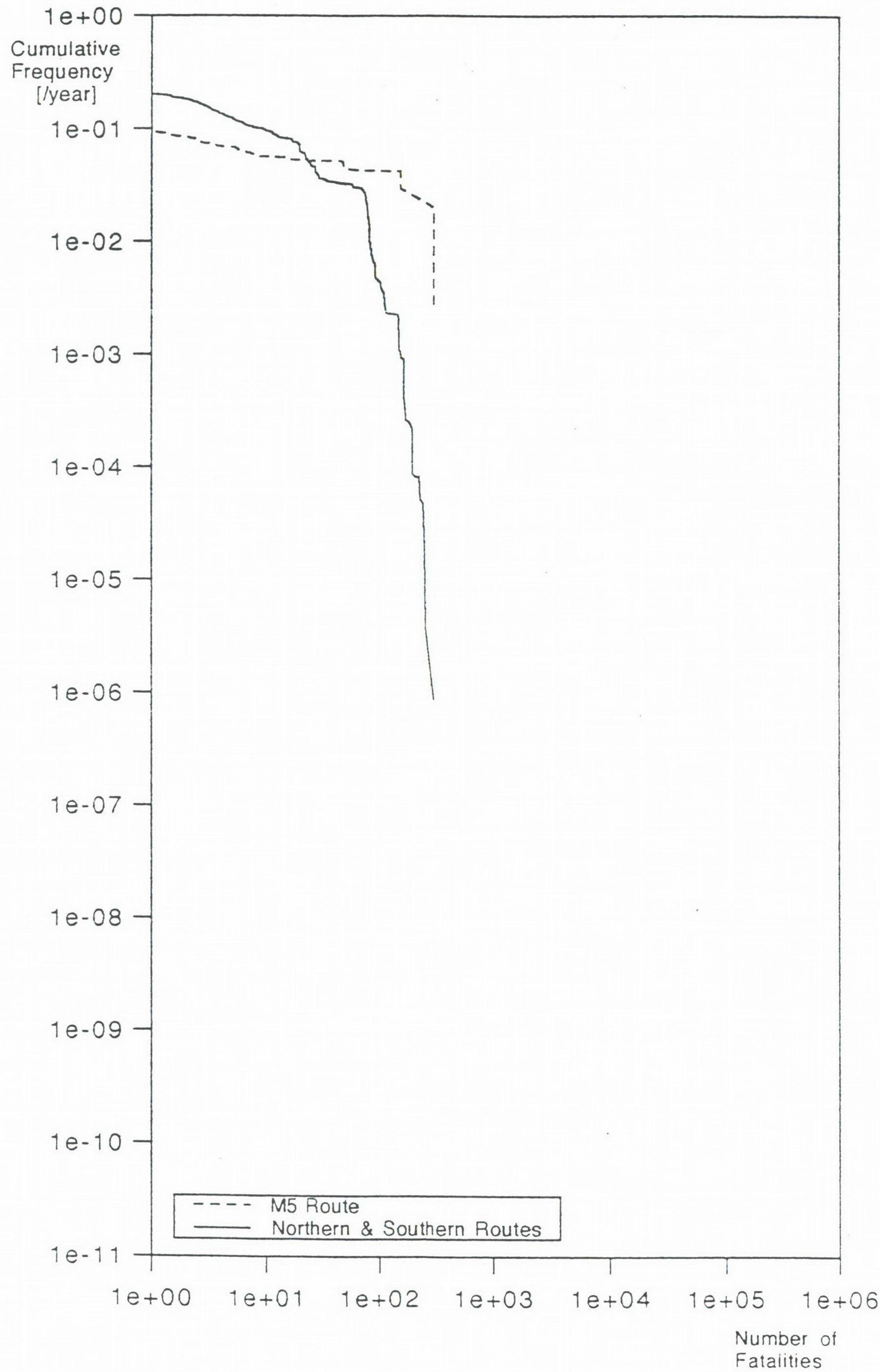
Societal Risk from DG Class 3

1996 M5, Northern and Southern routes



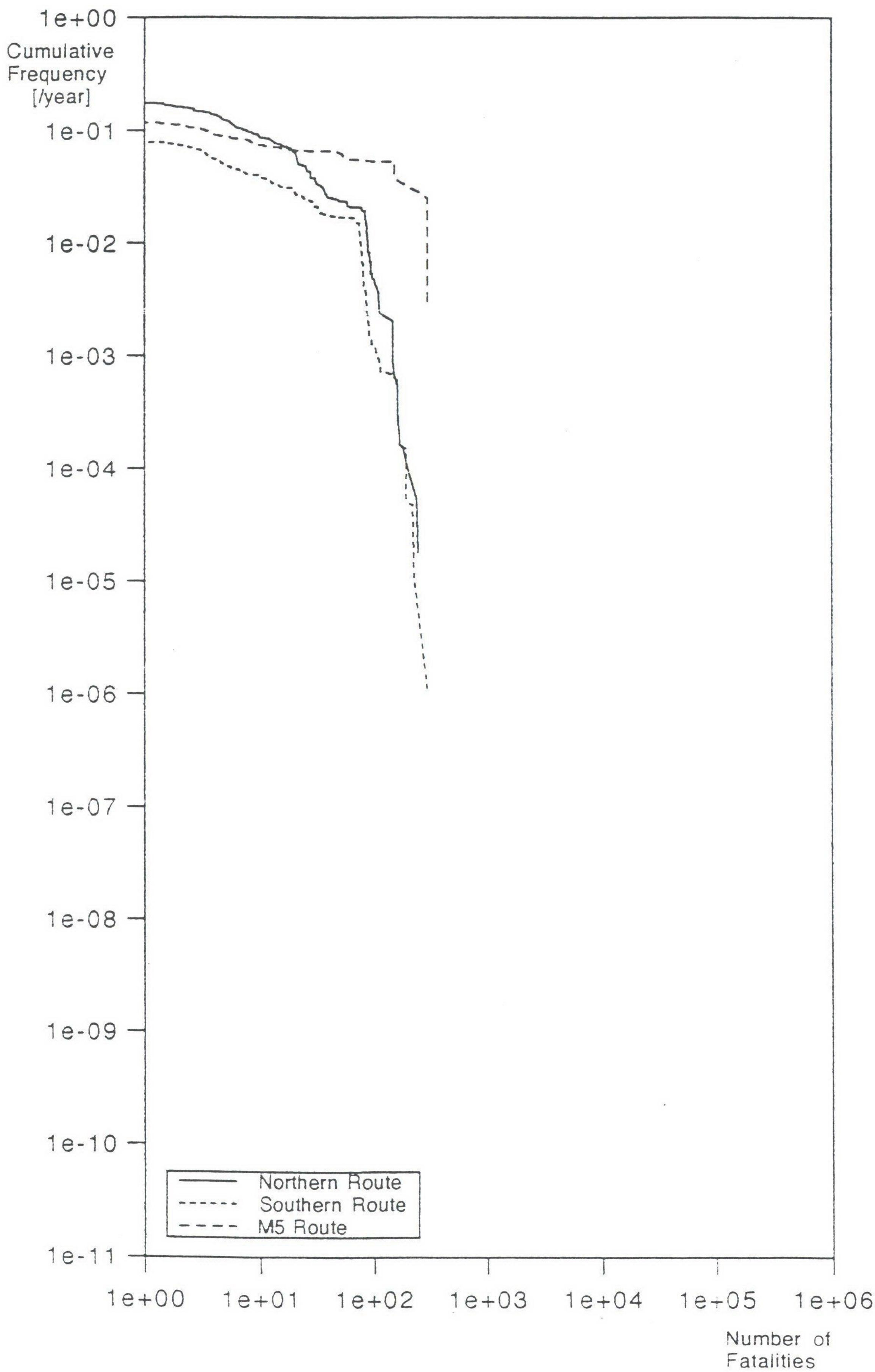
Societal Risk from DG Class 3

1996 M5 and combined Northern and Southern routes



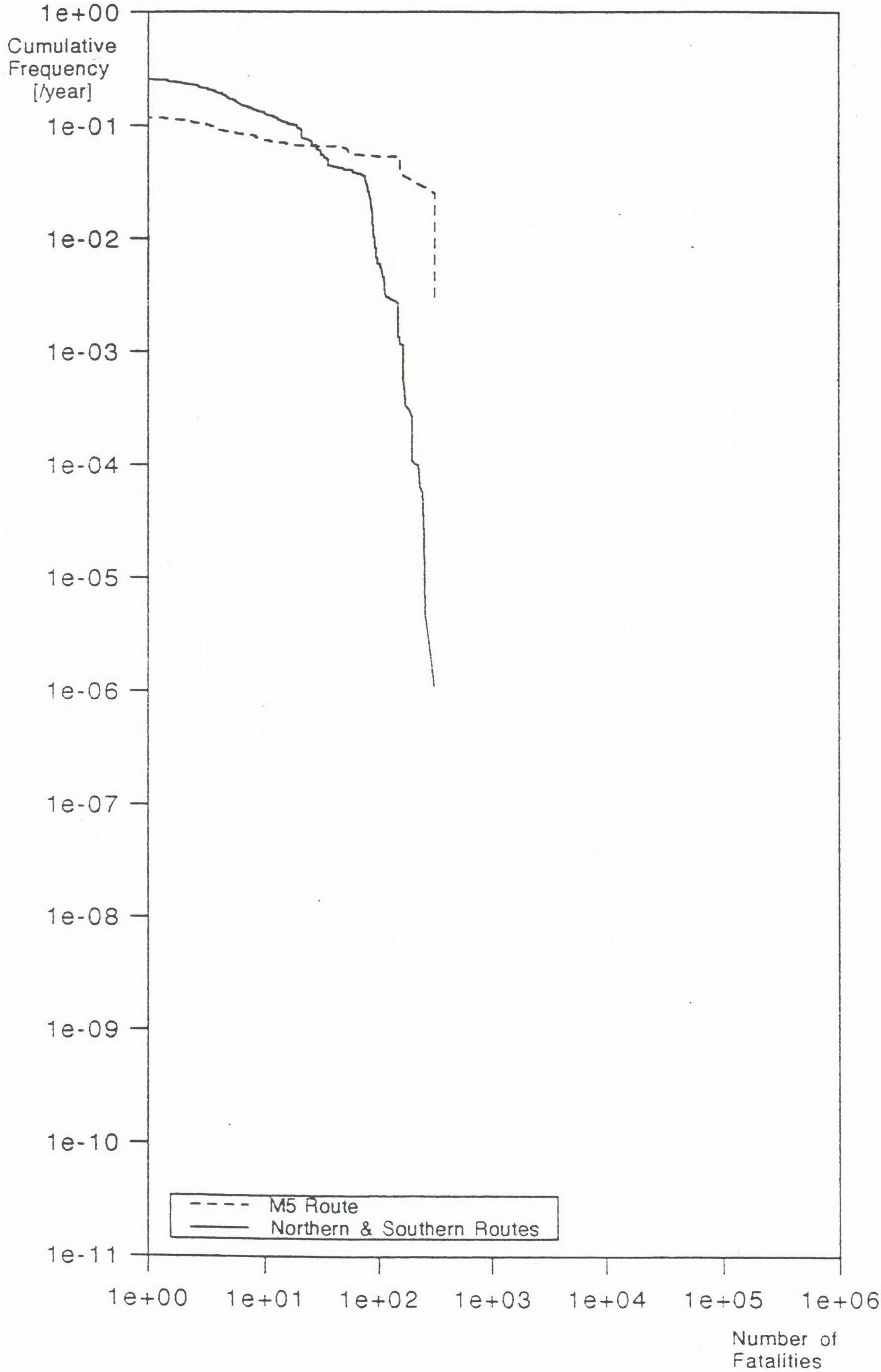
Societal Risk from DG Class 3

2011 M5, Northern and Southern routes



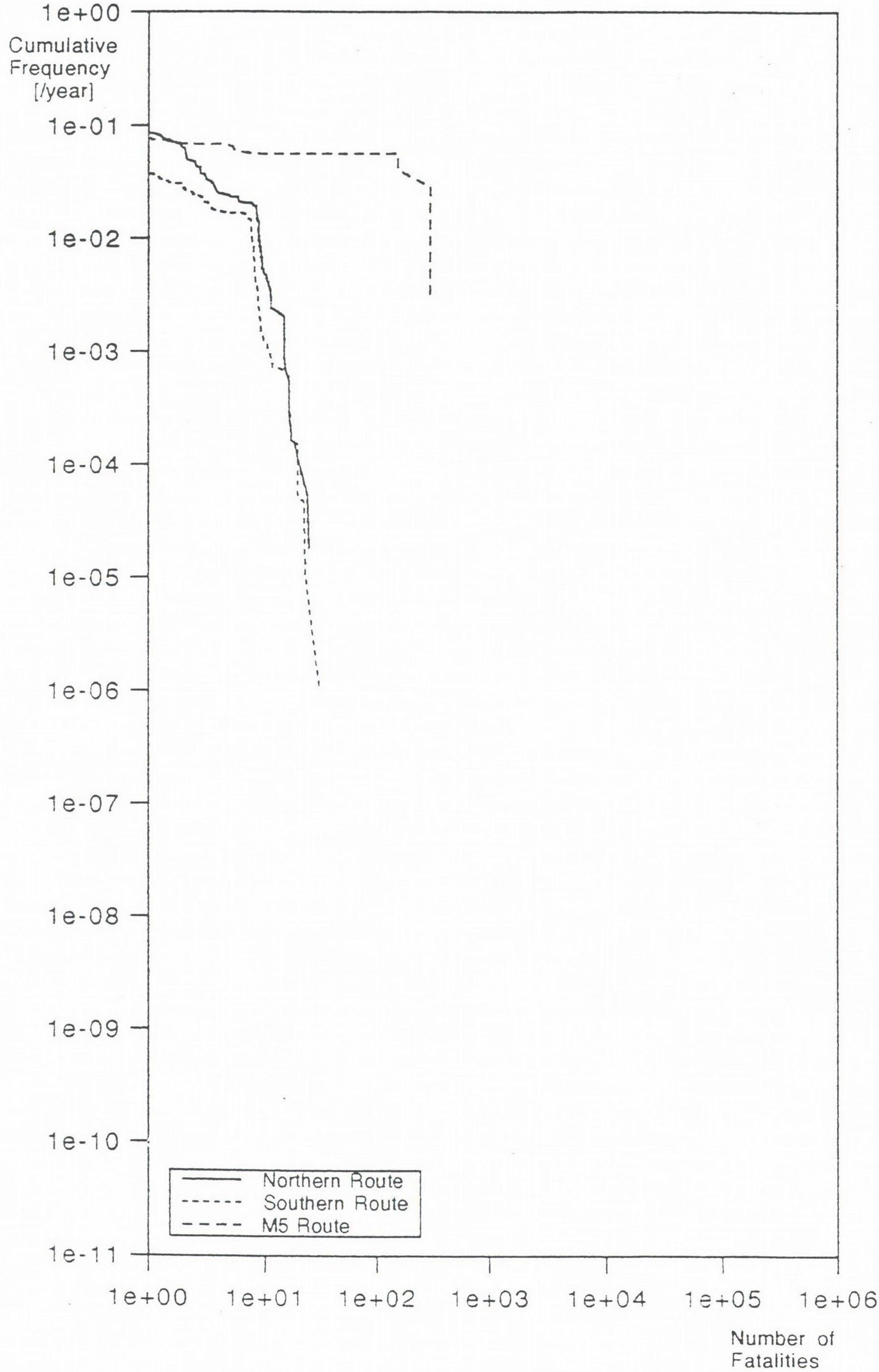
Societal Risk from DG Class 3

2011 M5 and combined Northern and Southern routes



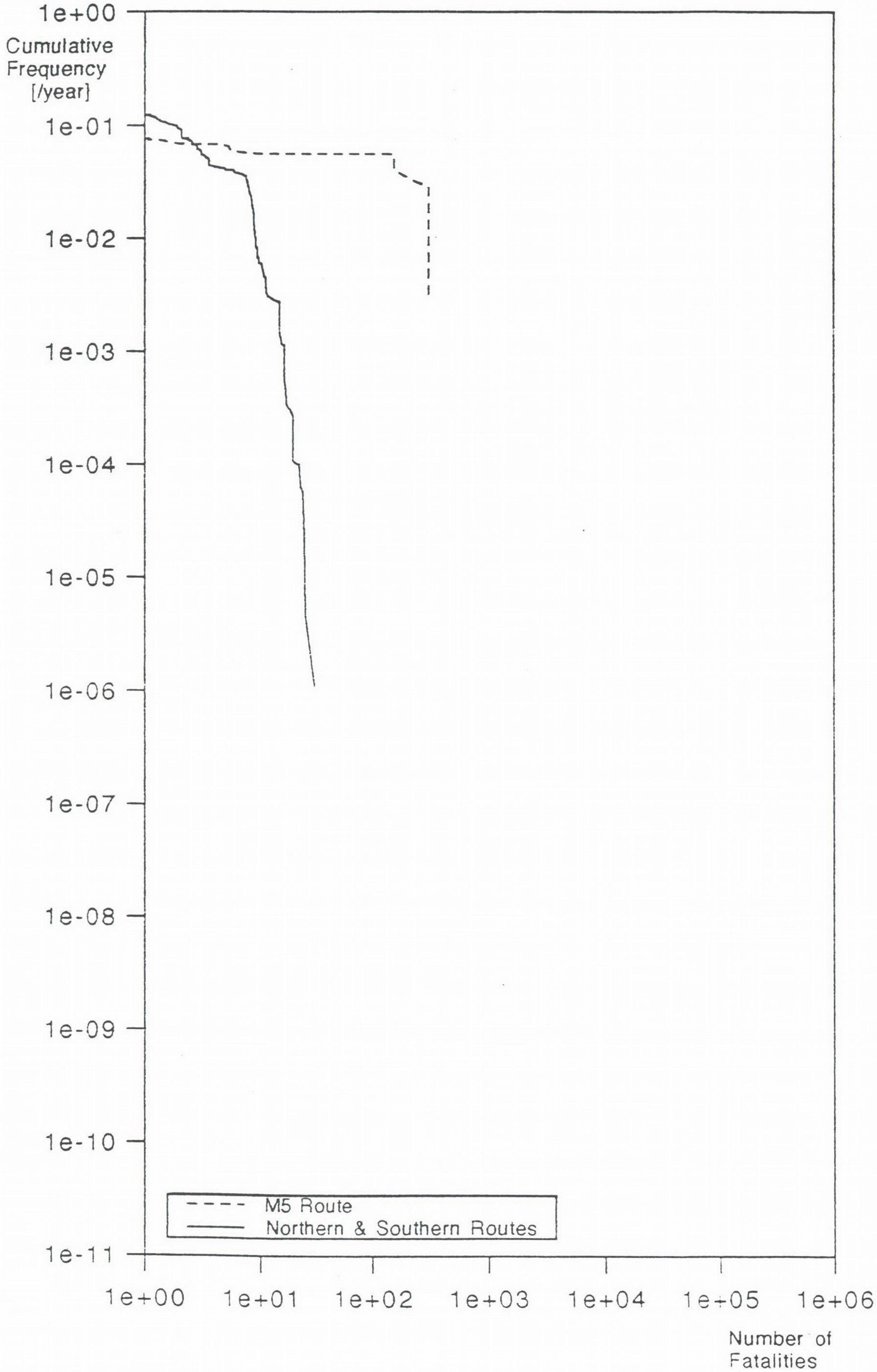
Societal Risk from DG Class 3 - Review of Sensitivity

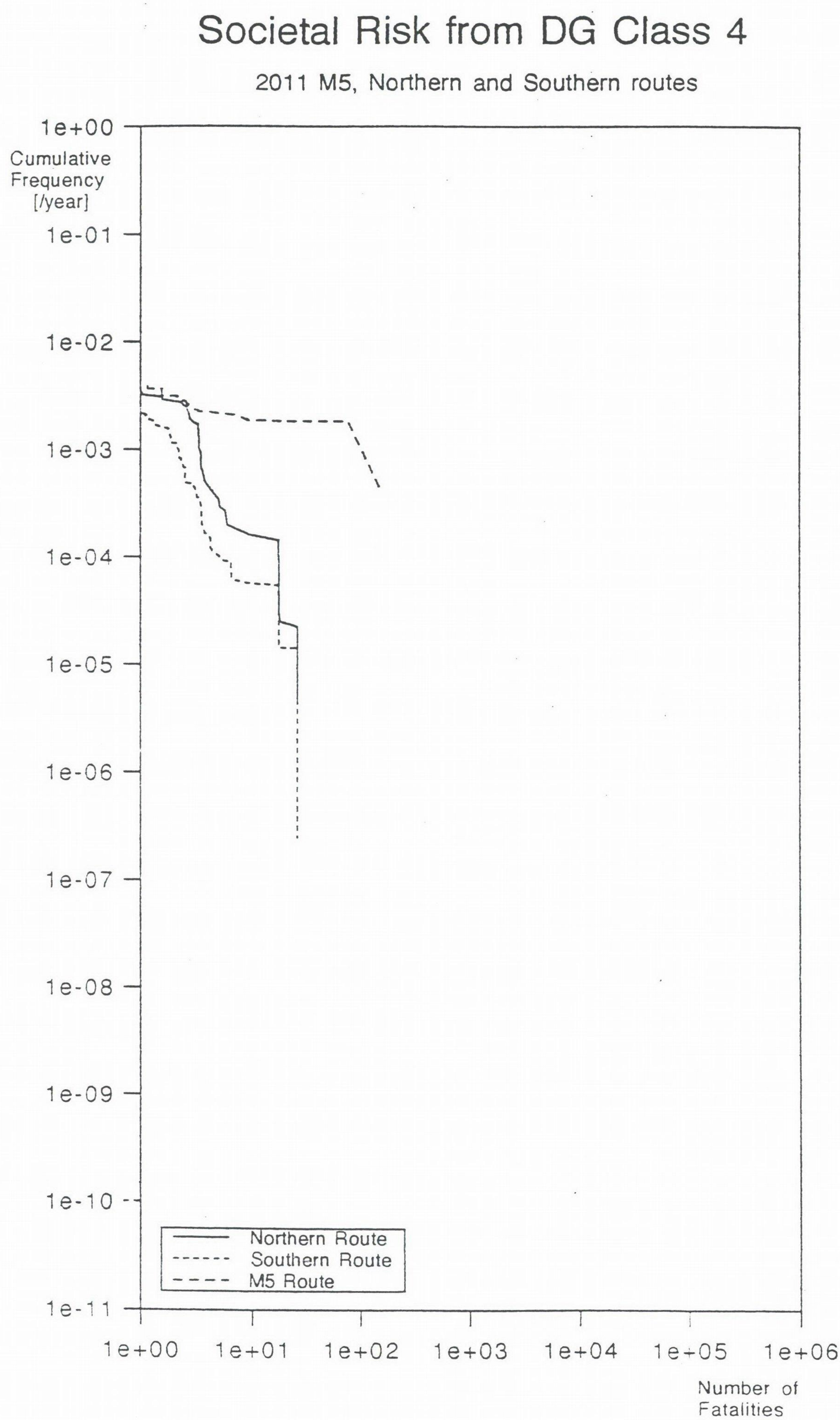
2011 M5, Northern and Southern routes



Societal Risk from DG Class 3 - Review of Sensitivity

2011 M5 and combined Northern and Southern routes

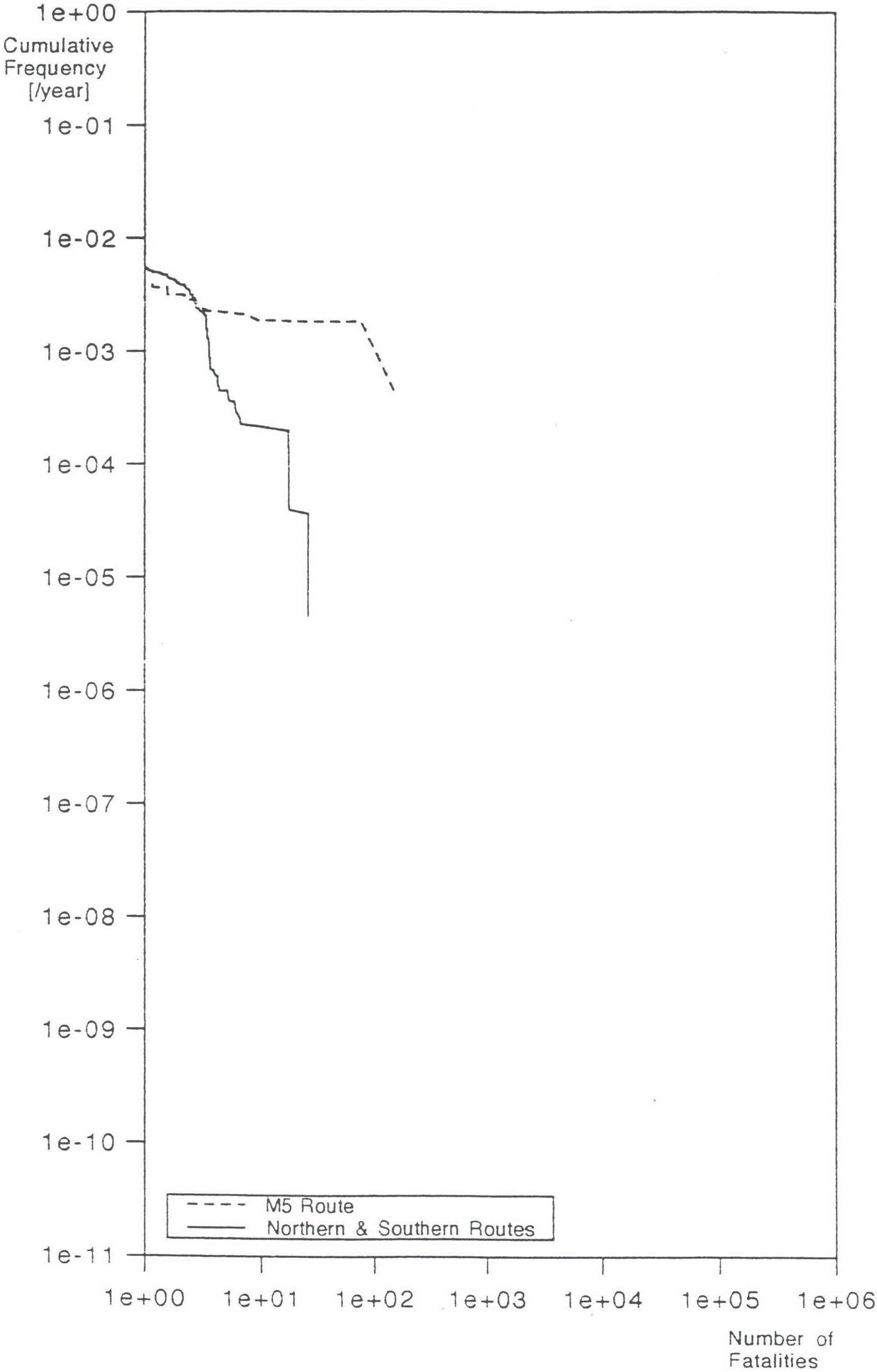




Societal Risk from DG Class 4
2011 M5, Northern and Southern routes
Cumulative Frequency [/year]
1e+00
1e-01
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
Northern Route
Southern Route
M5 Route
1e+00
1e+01
1e+02
1e+03
1e+04
1e+05
1e+06
Number of Fatalities

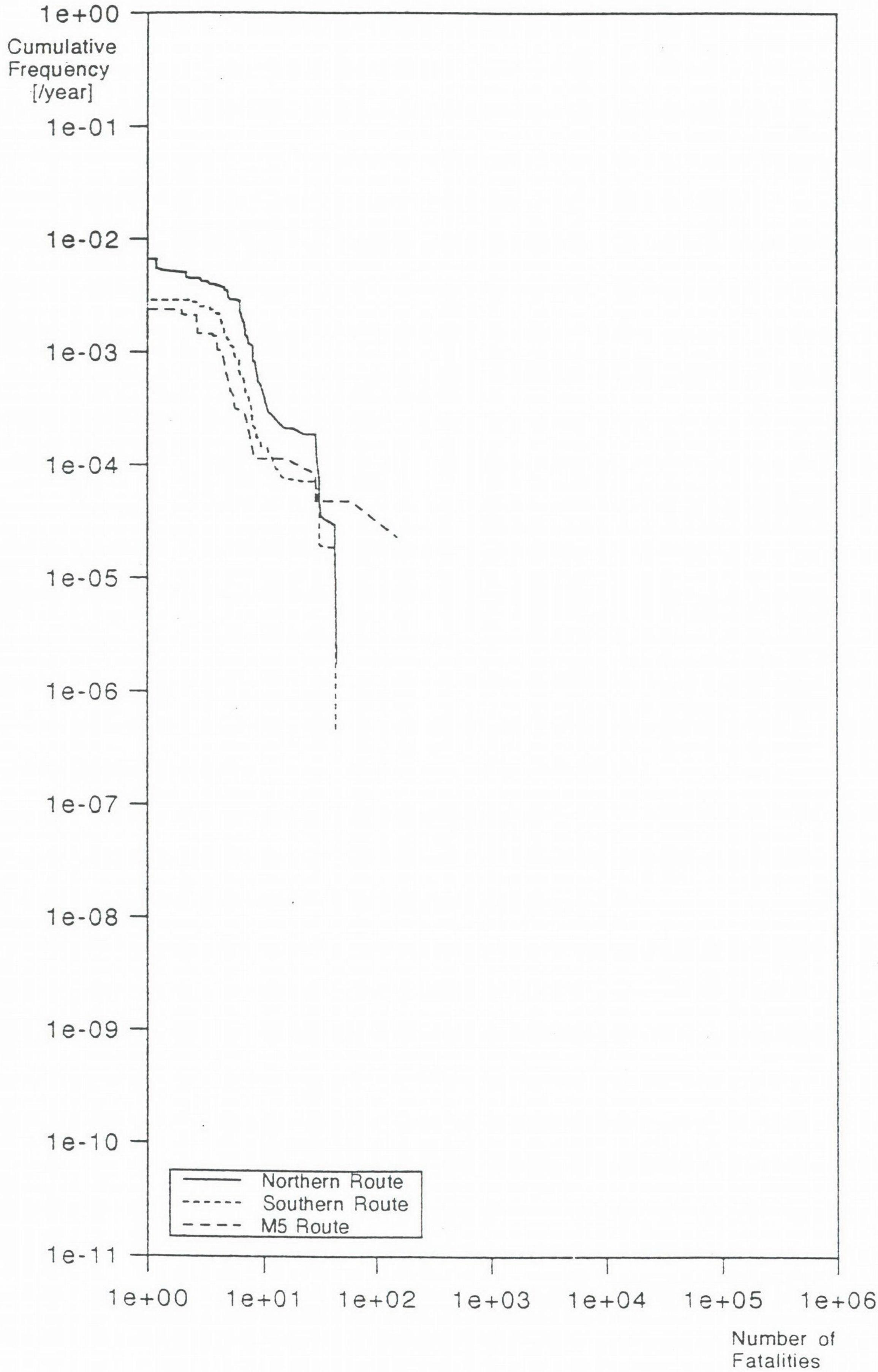
Societal Risk from DG Class 4

2011 M5 and combined Northern and Southern routes



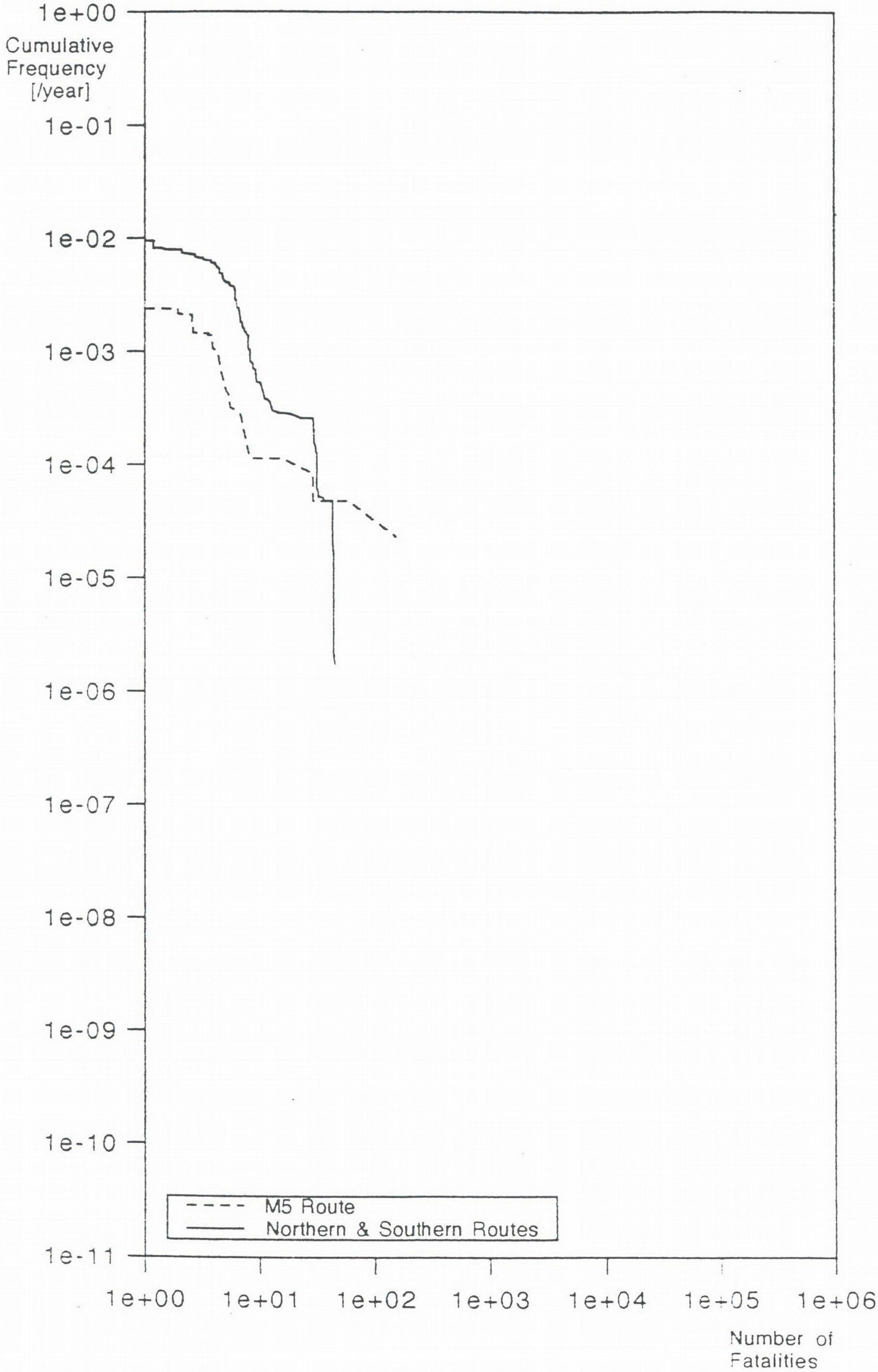
Societal Risk from DG Class 5

2011 M5, Northern and Southern routes



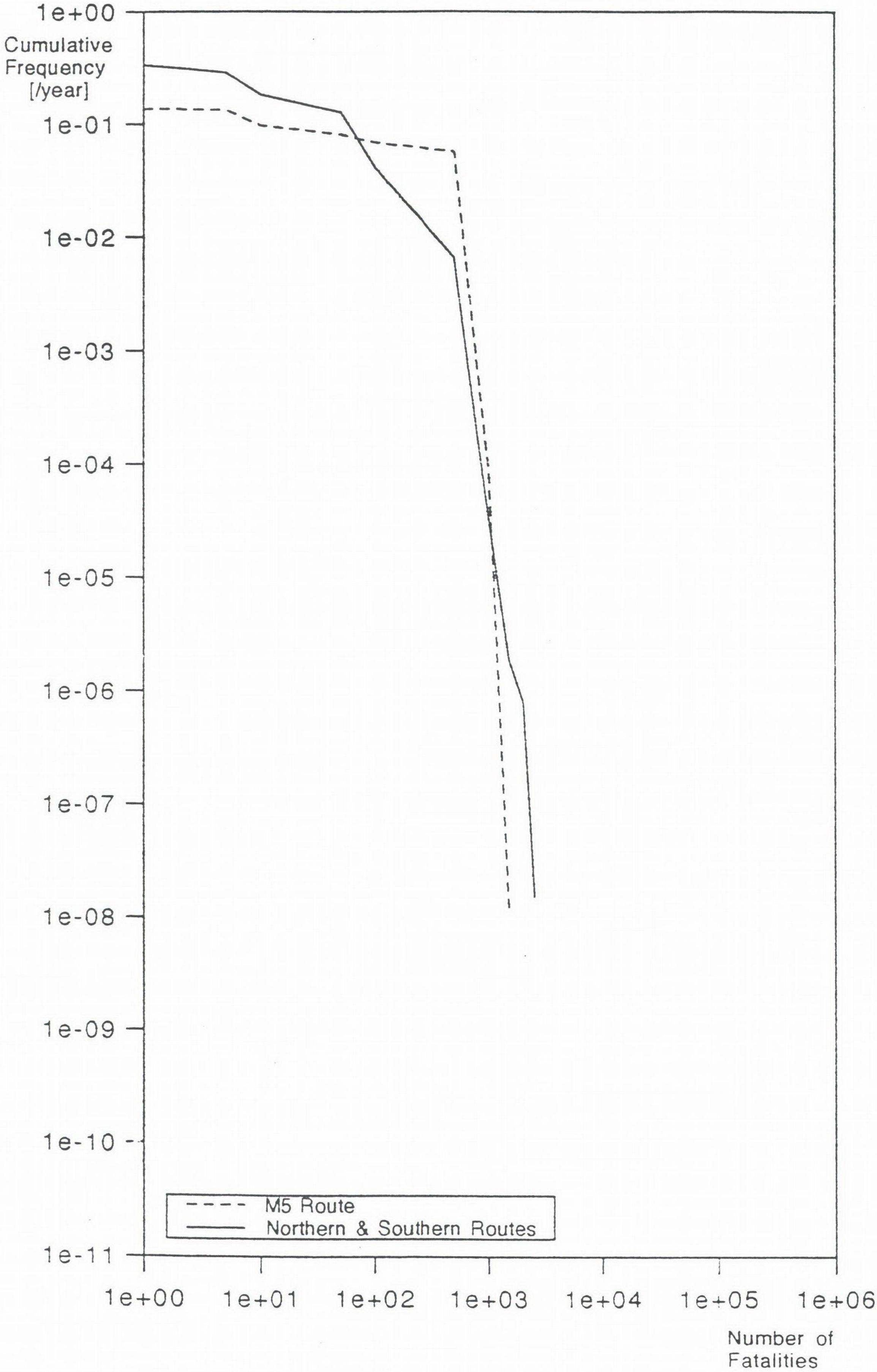
Societal Risk from DG Class 5

2011 M5 and combined Northern and Southern routes



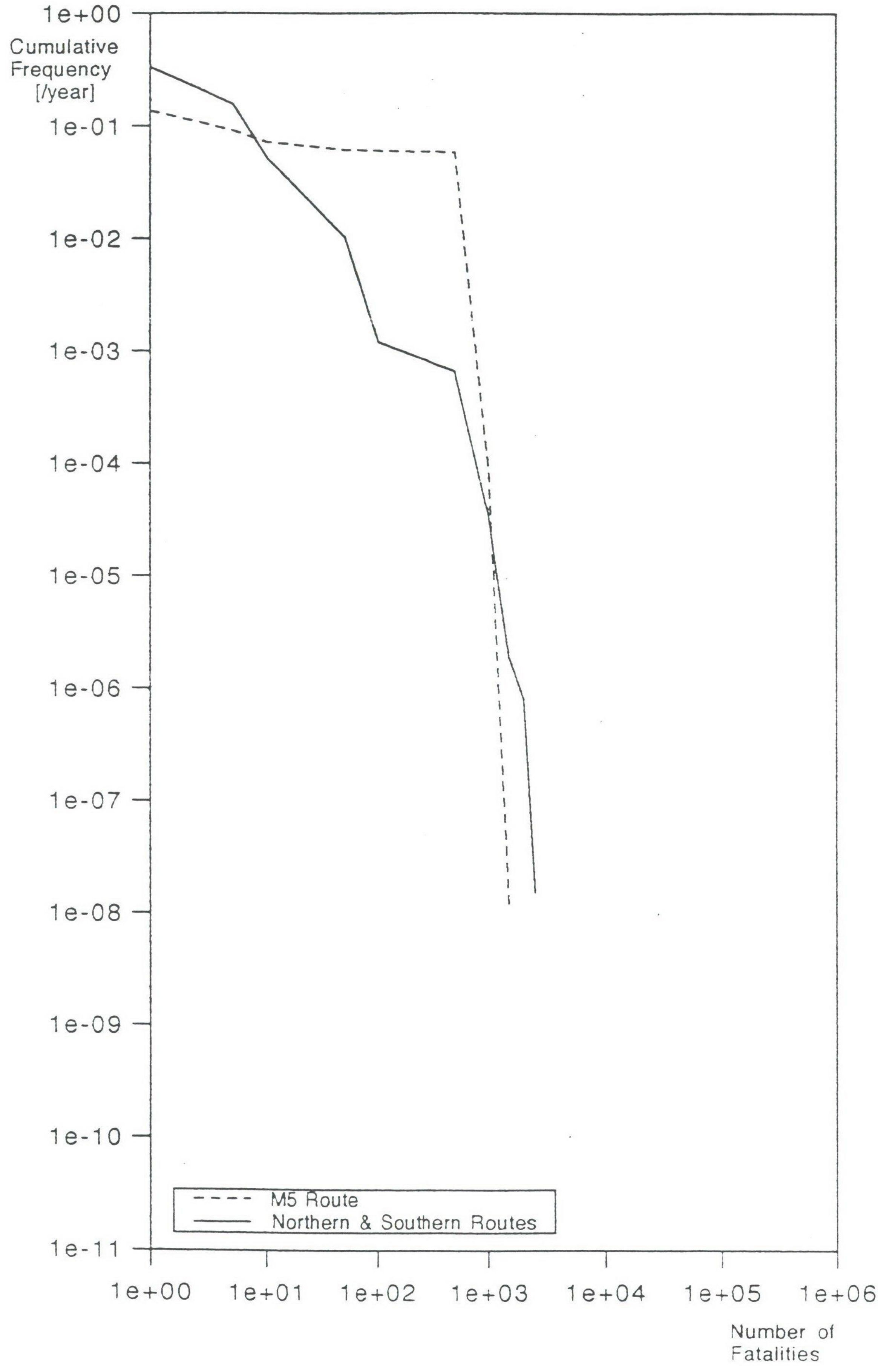
Societal Risk from All DG Classes

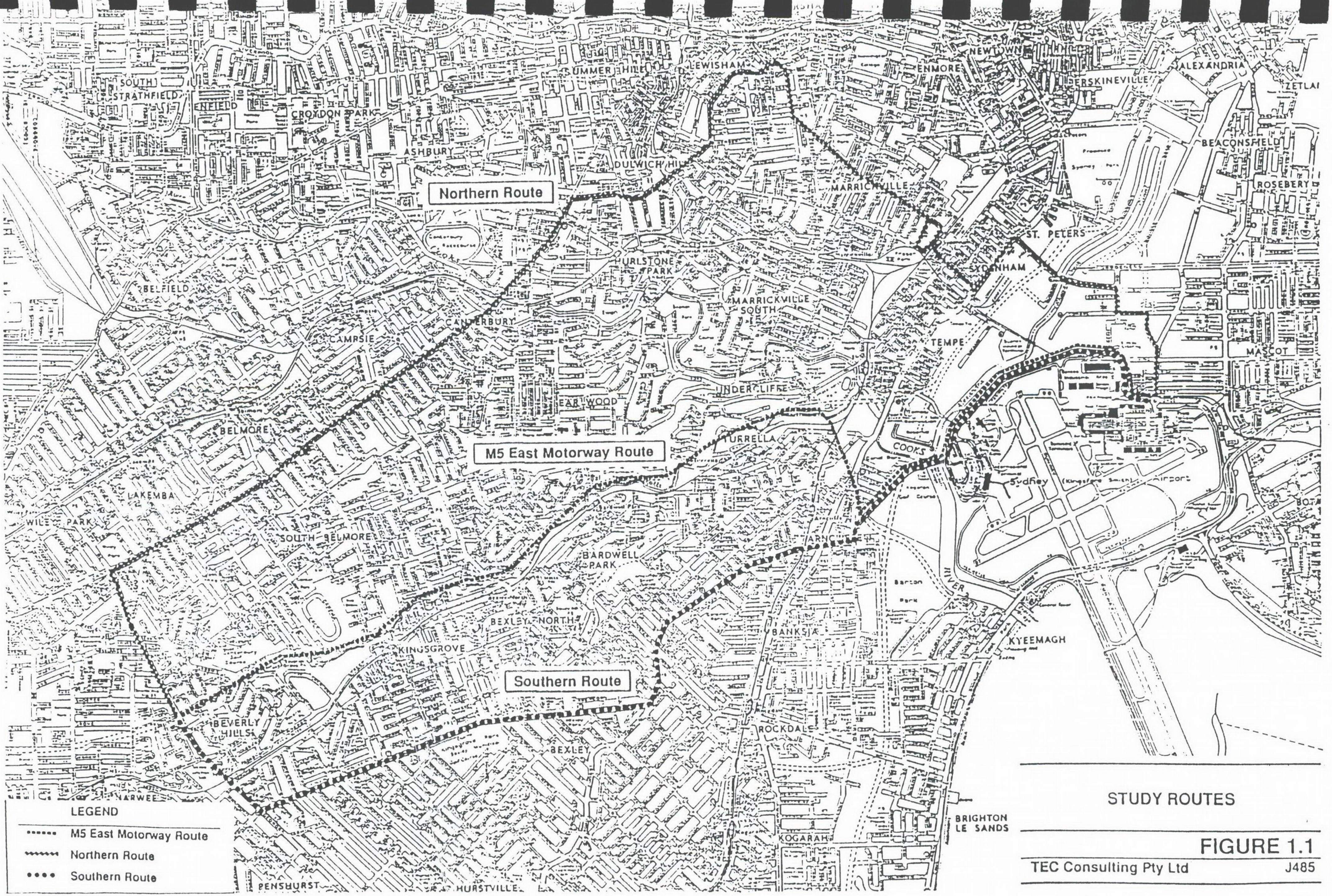
2011 M5 and combined Northern and Southern routes



Societal Risk from All DG Classes - Review of Sensitivity

2011 M5 and combined Northern and Southern routes

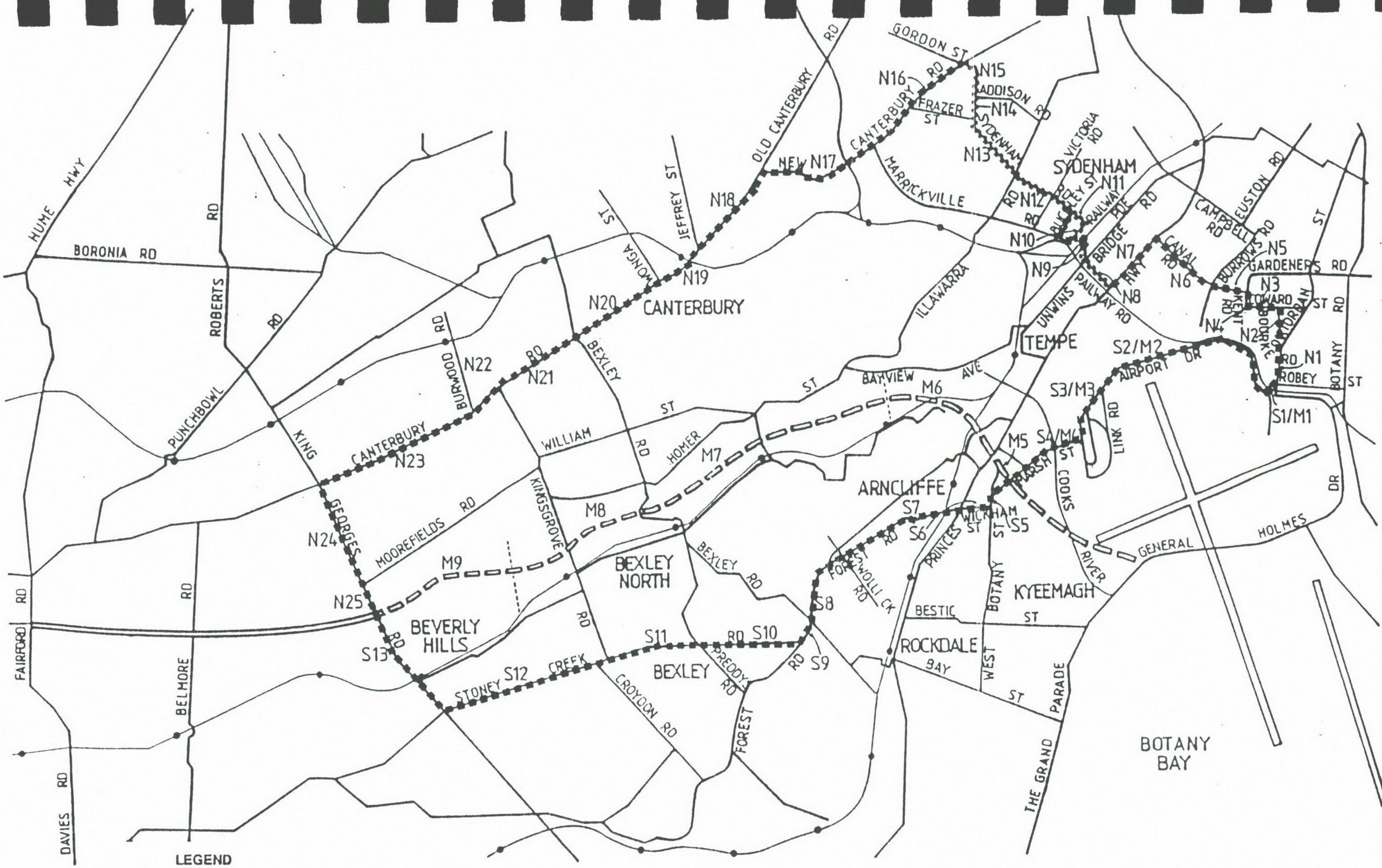




STUDY ROUTES

FIGURE 1.1

TEC Consulting Pty Ltd J485



LEGEND

■■■■■ ARTERIAL ROAD

∿∿∿∿∿ SUB-ARTERIAL ROAD

N# NORTHERN ROUTE SECTION No.

S# SOUTHERN ROUTE SECTION No.

M# M5 EAST MOTORWAY ROUTE SECTION No.

ROAD HIERARCHY AND ROUTE SECTIONS

FIGURE 2.1

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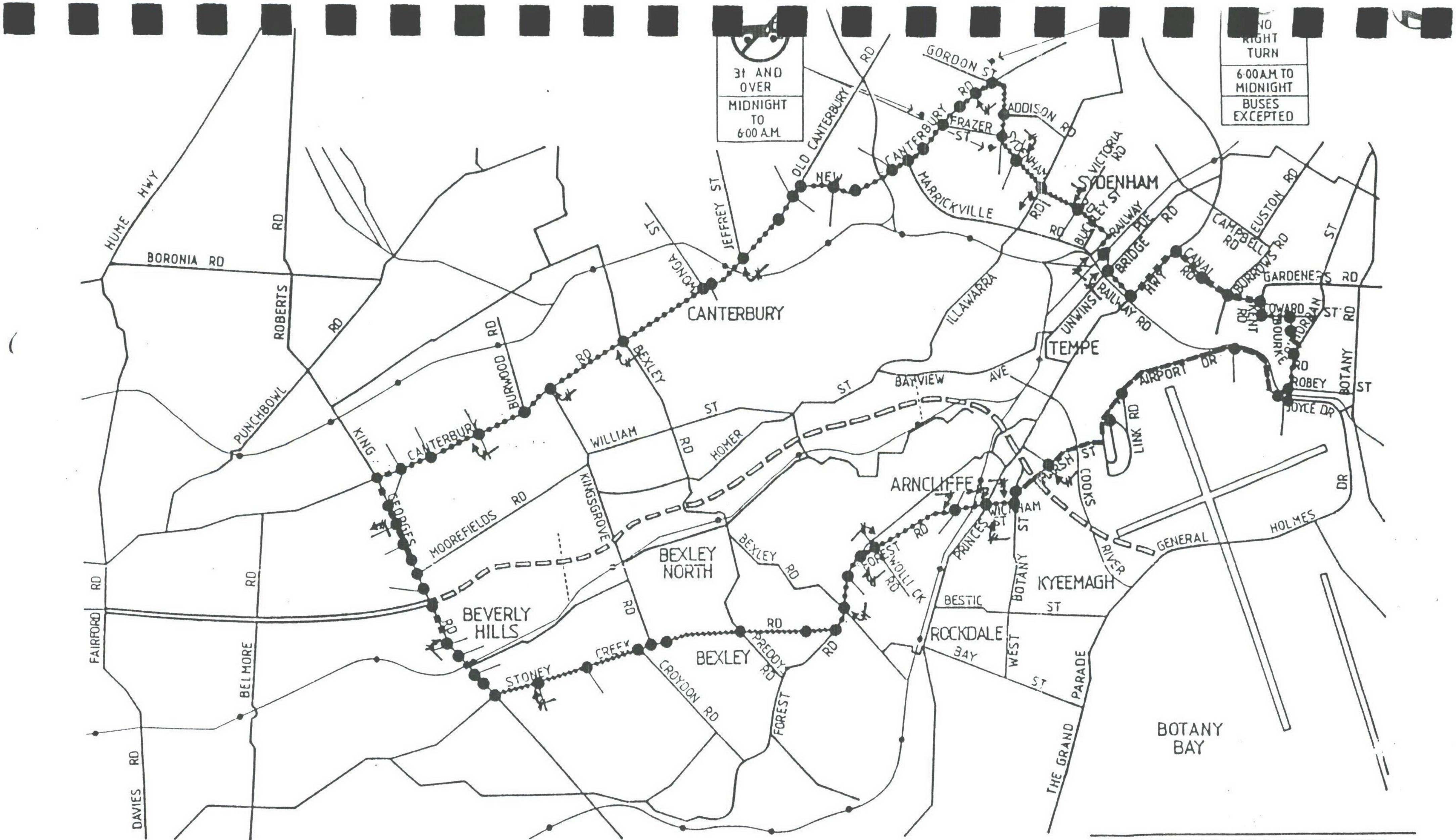

LEGEND

- ● TRAFFIC SIGNALS
- ■■■ 6 LANES DIVIDED WITH CLEARWAYS
- ▬ ▬ 4 LANES DIVIDED WITH CLEARWAYS
- •••• 4 LANES UNDIVIDED WITH CLEARWAYS
- ······ 4 LANES UNDIVIDED WITHOUT CLEARWAYS

INVENTORY OF ALTERNATIVE DANGEROUS GOODS ROUTES

FIGURE 2.2

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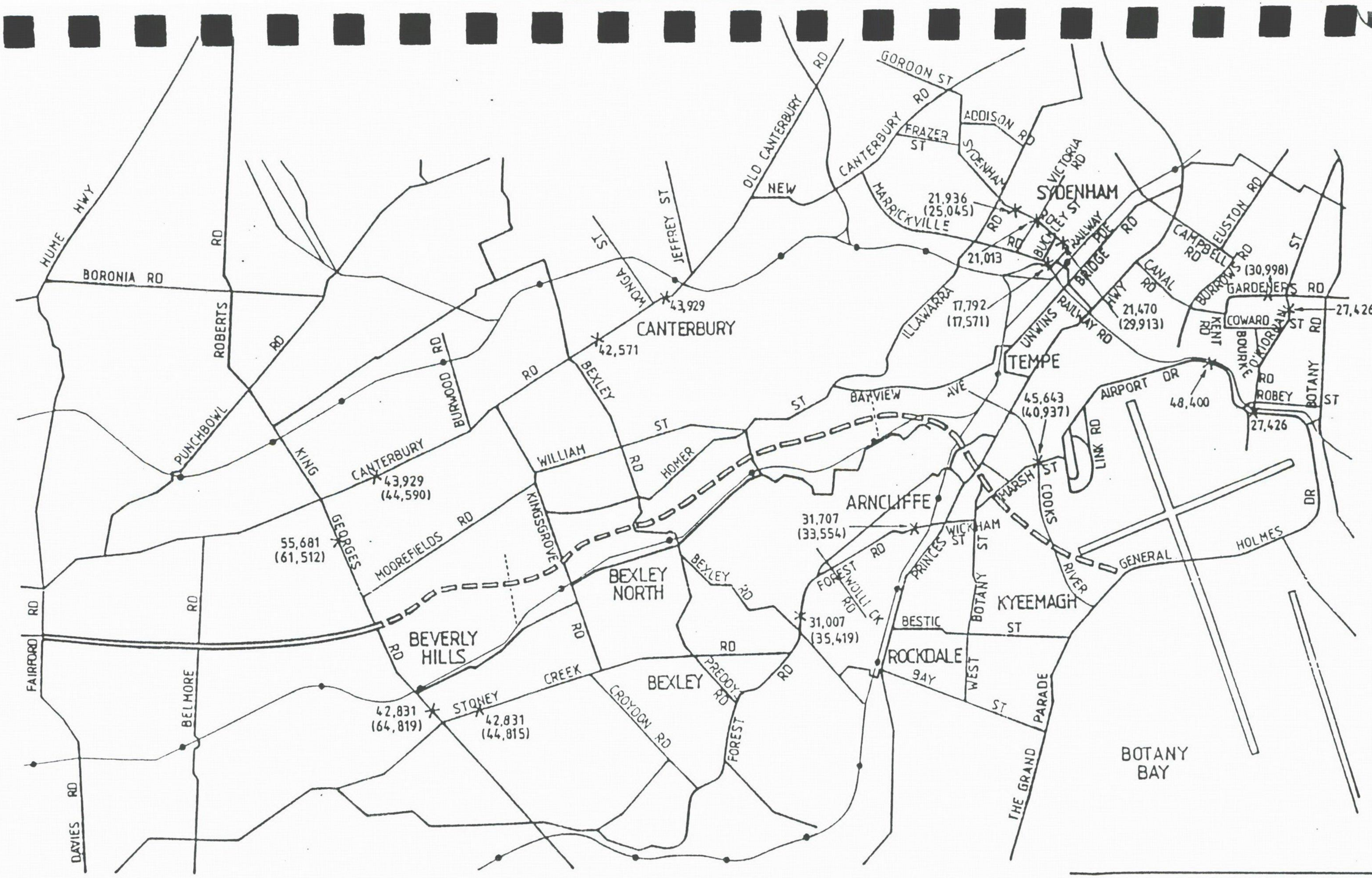

LEGEND

XX 1991 AADT

(XX) 1993 AADT

1991 & 1993 TRAFFIC COUNTS FOR ALTERNATIVE DANGEROUS GOODS ROUTES

Figure 3.1

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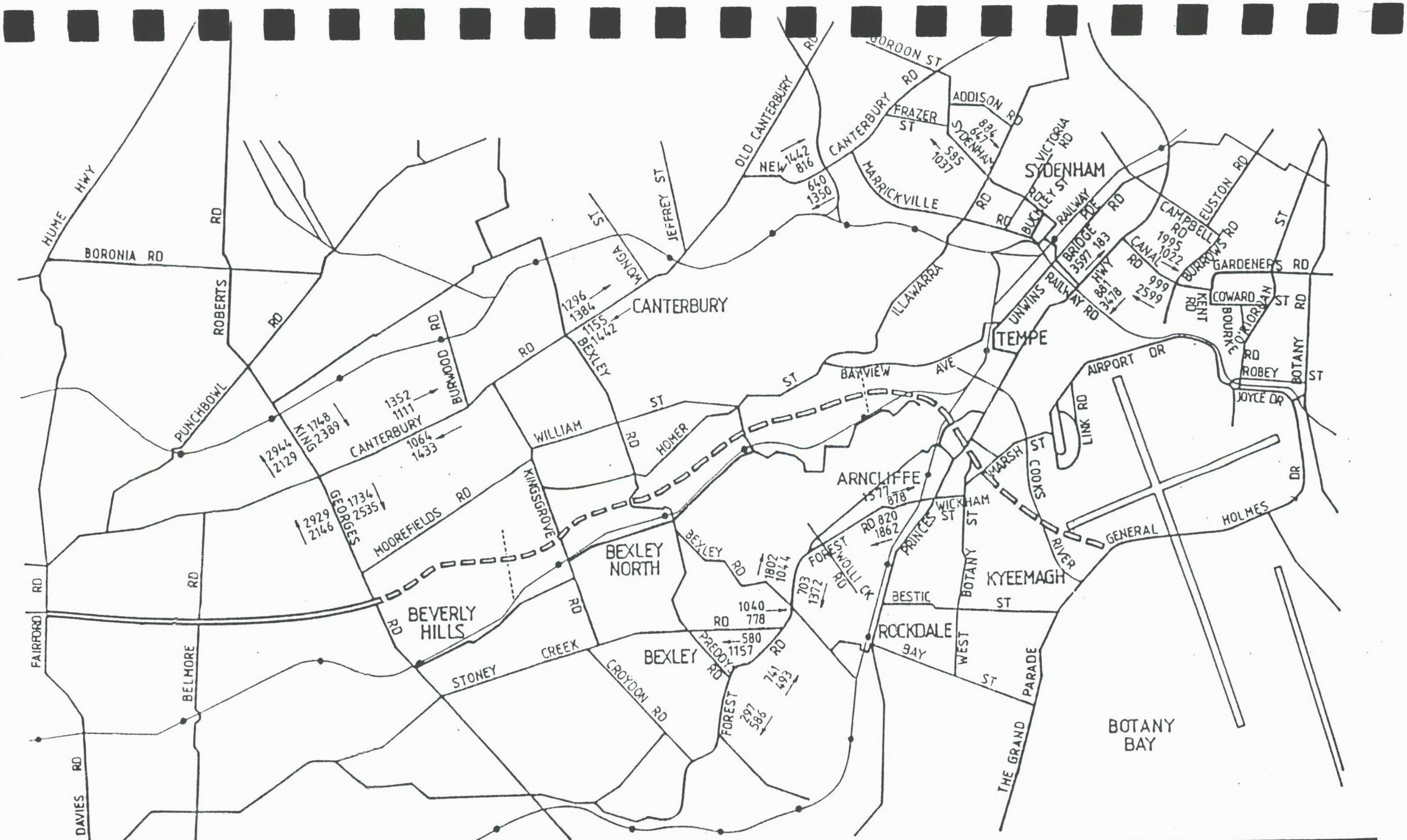

LEGEND

XXXX AM PEAK

YYYY PM PEAK

→ DIRECTION OF TRAFFIC

EXISTING PEAK HOUR TRAFFIC FLOWS

FIGURE 3.2

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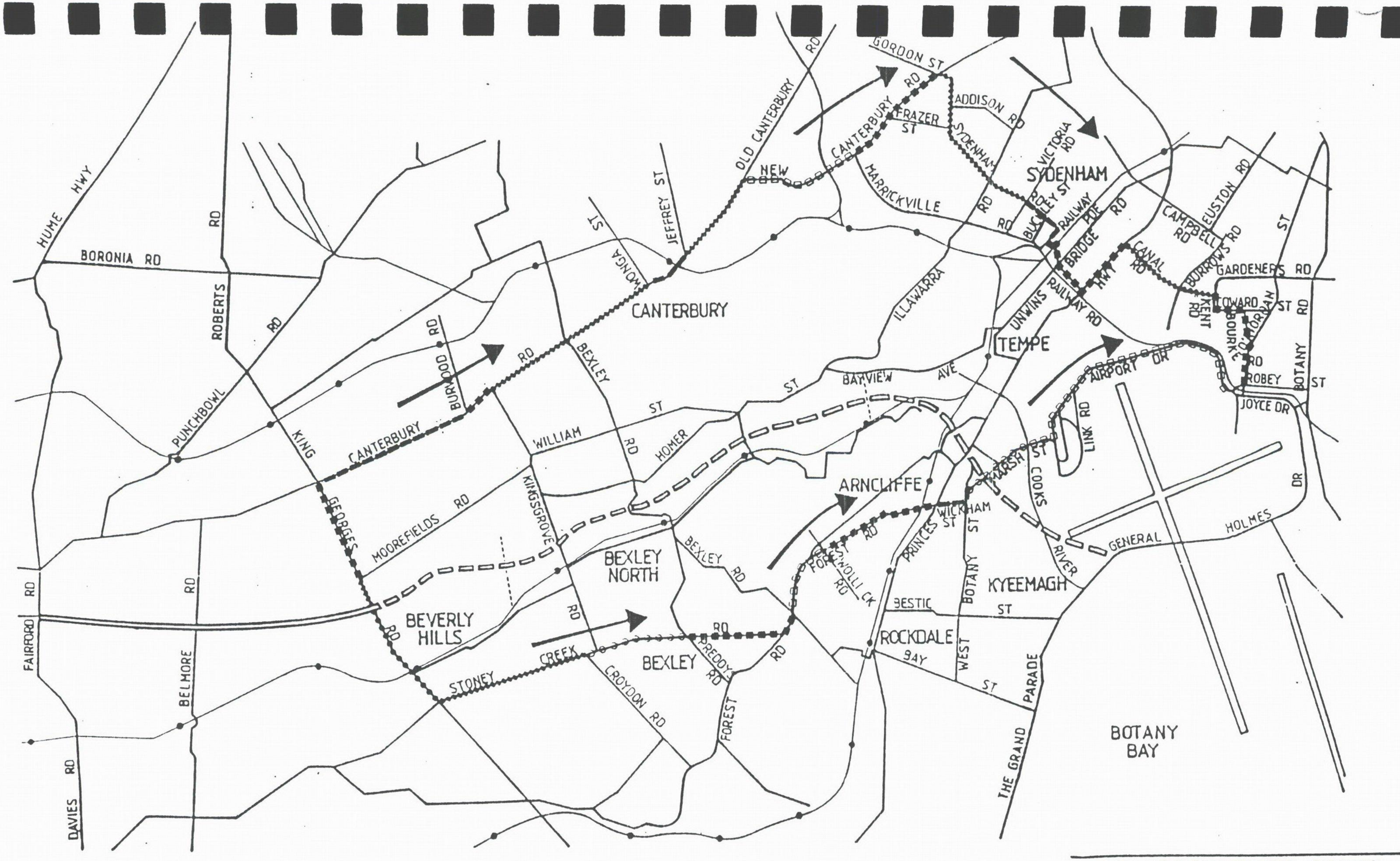

LEGEND

▪▪▪	< 20 kph	•••••	30 - 40 kph
▬▬	20 - 25 kph	□□□	40 - 50 kph
••••	25 - 30 kph	○○○	> 50 kph

1994 AM PEAK TRAVEL SPEEDS FOR ALTERNATIVE DANGEROUS GOODS ROUTES

Figure 3.3a

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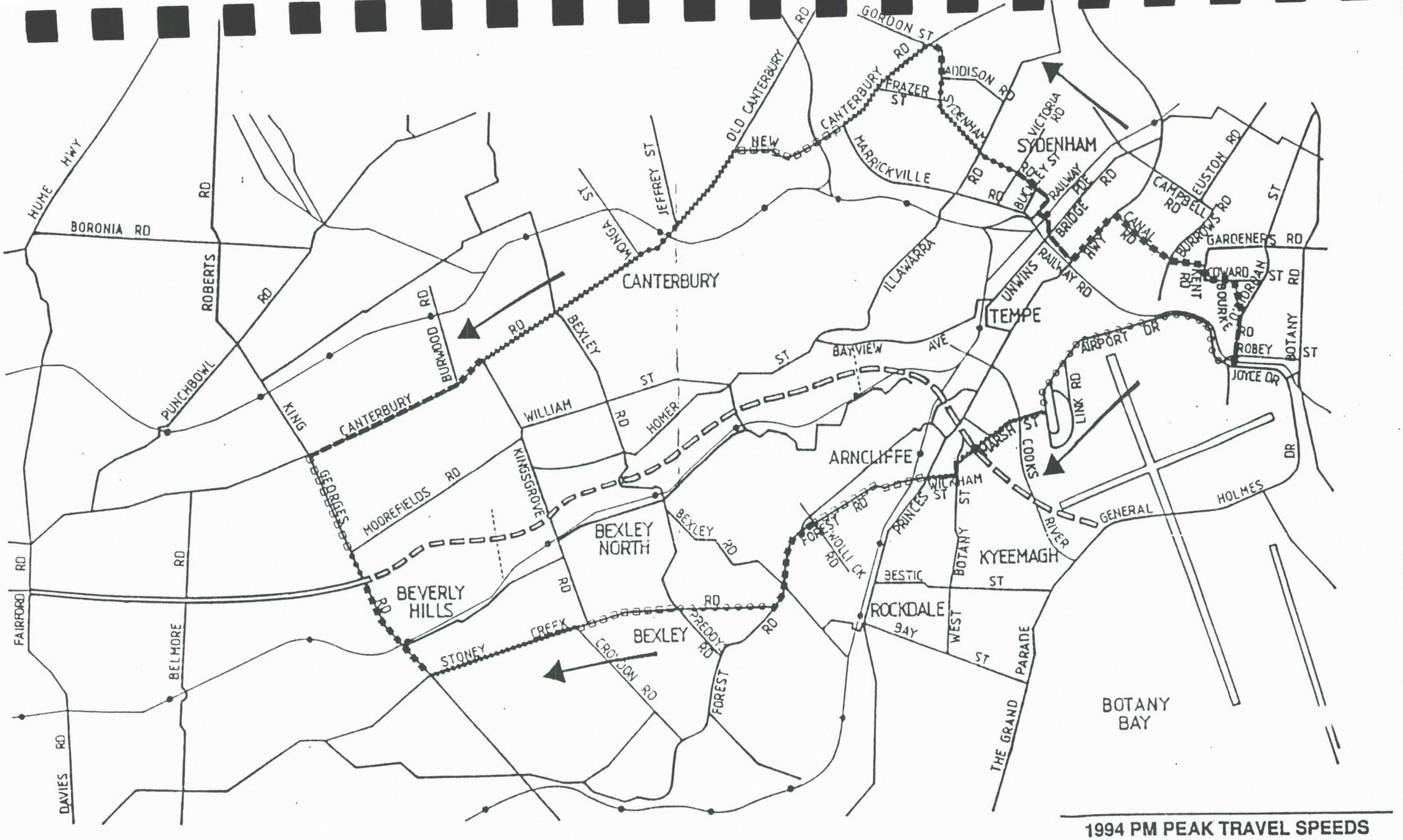


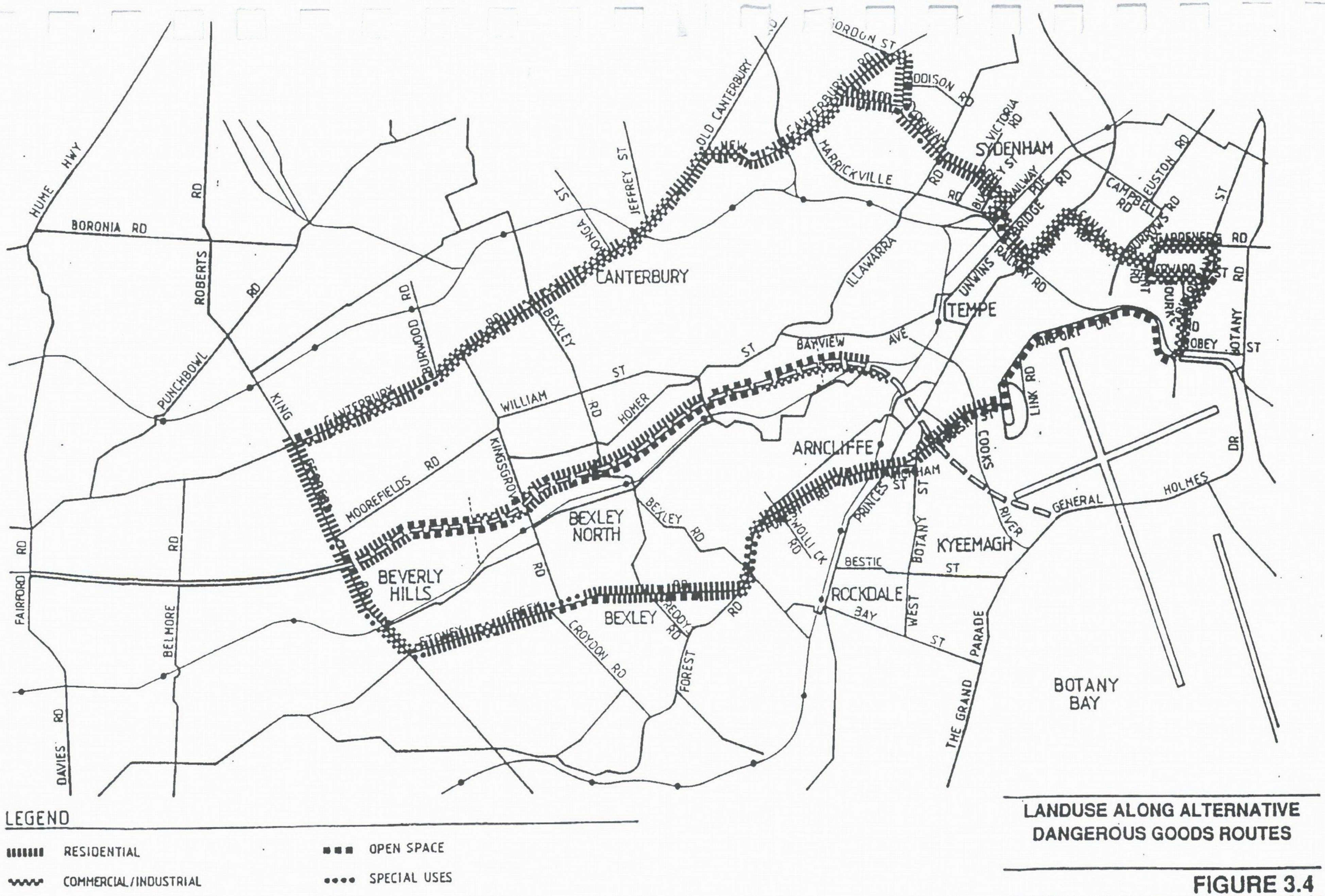
LEGEND

▪▪▪ < 20 kph	30 - 40 kph
20 - 25 kph	▢▢▢ 40 - 50 kph
•••• 25 - 30 kph	○○○ > 50 kph

1994 PM PEAK TRAVEL SPEEDS FOR ALTERNATIVE DANGEROUS GOODS ROUTES

Figure 3.3b

TEC Consulting Pty Ltd **J485**



LANDUSE ALONG ALTERNATIVE DANGEROUS GOODS ROUTES

FIGURE 3.4

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