26th Australasian Transport Research Forum
Wellington
New Zealand
1-3 October 2003

Managing the Environmental Impacts of Land Transport: A Measured Approach to Sustainability by Integrating Environmental Analysis with Urban Planning.

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ABSTRACT

Environmental effects from land transport - road and rail - can take many forms and arise from many mechanisms. Negative effects include degradation of local air and water quality, increased noise and contribution to climate change. Managing environmental quality has increasingly become the responsibility of local government, where transport activities, effects and resource management decisions are most concentrated.

Ecological sustainability implies a measure of 'capacity' within an ecosystem to absorb effects, up to an inherent threshold. Human health can be seen as an indicator. These thresholds vary by pollutant type, concentration of emissions sources and their activity, and receiving environment sensitivity for a given location. As environmental management in New Zealand is 'effects-based', the problem must be defined in order to design efficient solutions. Effective environmental management needs to target the root cause of any problem, rather than compensate for its effects.

From a "clean-sheet" study into the effects of vehicle emissions on local air quality, the New Zealand Ministry of Transport developed an approach referred to as Environmental Capacity Analysis (ECA). This is a practical analytical tool for managing the complexity of environmental effects, integrated with the routines of overall urban management. The guiding principles of ECA include: being impacts based; establishing clear targets; using a measured approach; demonstrating actual effectiveness and practicality of solutions; and being sustainable. The ECA process can be applied to any urban situation.

Once developed for a specified location, the 'ECA package' becomes a live, geo-spatially defined model of the local equilibrium between emission loading patterns and receiving environment impacts. The ECA is able to track variations in urban form and activity (traffic and other). It can also determine what mitigation strategies are required, now or in the future, to maintain threshold targets and improve performance over time. Originally designed for local air quality management, other pollution mechanisms are now included (water contaminants and greenhouse gases), in a fully integrated approach. Noise and traffic safety are further effects that may later be included.

Key Words: vehicle emissions, pollution, air quality, New Zealand, environmental capacity, transport policy.

1. INTRODUCTION

Concern over damage to the environment is a major topic nowadays. This damage can take many forms. It can arise through a wide variety of both human activities and natural mechanisms. The main environmental effects from transport are:

- Reductions in local air quality;
- Pollution of aquatic ecosystems;
- Increases in noise levels; and
- Increases in CO_2 emissions affecting climate change.

The first three effects are local, the last is global (although many regard the cause as local due to the combined effects of local behaviour patterns, in the use of energy, etc.). Currently, in New Zealand (NZ) monitoring and management of each environmental medium (air, water, etc) tends to be done separately. Because transport so often creates environmental effects across media, addressing both the effects and the media in a more measured and integrated manner has become an important issue in its own right (Ministry of Transport, 1996).

1.2 SUSTAINABLITY COMES FROM THRESHOLDS AND CAPACITY

When reference is made to environmental protection, a common byword is sustainability. This implies that the environment has a natural ability to cope with a certain 'threshold' level or concentration of pollution activity before damage arises, whether it is to natural ecosystems or human health. The thresholds vary for each of the diverse range of contaminant types. Thresholds are often formally recognised as guidelines or standards setting maximum pollutant concentrations (e.g. a maximum local air quality guideline or national environmental standard for particulates). The concept of thresholds provides the first point of reference in understanding how to approach environmental management.

1.3 MANAGEMENT 'MEASURES'

The Resource Management Act 1991 (RMA) provides the framework for environmental management in NZ. Laws governing land, air and water resources form a single piece of legislation. The RMA's purpose is to promote the sustainable management of natural and physical resources. By concentrating on the environmental effects of human activities, the RMA introduced a new approach to environmental management. This enables resource managers to use a wide range of techniques and methods to achieve environmental outcomes.

Under the RMA framework, it is necessary to define the problem before designing appropriate and effective solutions. It is unwise to implement environmental management strategies that are not thoroughly analysed, or cannot be guaranteed to work. Not only are environmental protection measures often costly to implement, but it can take a long time before they are seen to be successful. International (European Conference of Ministers of Transport, 1998) and local NZ experience has also shown that unless there are firm, clear and numerated targets for improvement, accepted by all concerned, there will be neither the necessary buy-in and adherence to the strategies required nor their successful implementation.

The RMA provides the mechanism to establish guidelines or standards for pollutant thresholds. Once a threshold is determined it provides the 'measure' against which to assess whether a pollutant problem exists.

Comparing the results of environmental monitoring against these thresholds and targets gives the all-important first measure of what the problem is, how bad it is, and how much change will be required. Alternately, if the thresholds or targets are not yet under threat, will developments through time cause them to be? Often a general objective of environmental management is to improve the quality of the environment over a period of time. The question then becomes how to set progressively more stringent targets; and how much intervention will be required to meet these.

1.4 INTEGRATED RESOURCE MANAGEMENT (IRM)

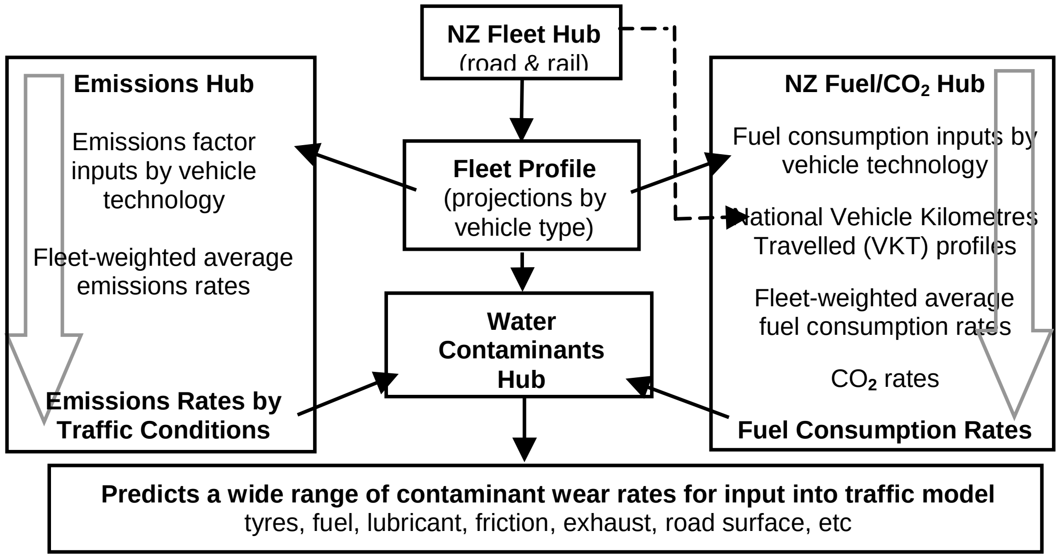
The concept of environmental thresholds or capacity originated in the 1960's. The concept of integrated resource management (IRM) joined the environmental lexicon in the 1980's. Whilst the general intent was easy to understand, putting it into workable practice has not readily followed. For existing or likely environmental problems associated with emissions, this has often been due to the inability to integrate good indicators of the impacts of the emissions with the other routines used for managing human activity and infrastructure development. This is particularly true in urban areas where emissions-producing activities are often both diverse and concentrated (by design). For environmental problems where acceptable social or environmental thresholds are exceeded ex post solutions will often involve far greater intervention (and costs) than prevention.

2. THE NEW ZEALAND VEHICLE FLEET (EXHAUST) EMISSIONS CONTROL STRATEGY (VFECS)

The Vehicle Fleet (exhaust) Emissions Control Strategy (VFECS) arose out of the need to ensure that responses to address vehicle emissions to air were appropriate for addressing the identified problem, as well as from the need for a practical means of environmental management. The aim of VFECS was to investigate the extent to which road transport contributes to local air quality problems in New Zealand. VFECS used a 'clean sheet' approach, recognising that many overseas vehicle exhaust emission strategies had, or were proving, less than effective. NZ did not necessarily want to import or adopt these strategies just because other countries used them (Ministry of Transport, 1997).

The New Zealand Vehicle Fleet Emissions Model (VFM) was developed as part of the VFECS work. The VFM , refer Figure 1 below, is a nation-wide inventory of the light and heavy vehicle road fleet, drawn from the vehicle registration database. The VFM can simultaneously calculate predictions of all emissions species of concern across all media, once these have been identified in the monitoring of the pollution in the receiving environment. These emissions measures are available to be interfaced with any traffic/geo-spatial urban model, to produce the emissions loading results by source.

Figure 1. Structure of the New Zealand Vehicle Emissions Fleet Model (VFM)



By starting from an understanding of the impacts (effects-based environmental management), it became clear that air quality problems were largely confined to the larger towns and cities. The nature of the problems varied greatly from centre to centre:

- by pollutant type;
- by extent, in exceedance of the guideline levels for air quality objective;
- by location, within the urban airshed, down to particular road corridors;
- by time within a day, by season and by other periods (long and short), with varying trends towards potential problems; and
- by source, as motor vehicles were not the only significant emissions source.

The resulting policy outcome recognised that two levels of policy approach were required:

- National level: controlled by central government, for measures that would apply beneficially to the whole of the fleet (remember, it's a mobile source, its emissions are not captive to any particular area); and

- Local level: controlled by local or regional authorities that have the statutory responsibility for air quality management, with measures that relate to local influences on the emissions loading from vehicle traffic.

At a national level, work is now being undertaken on the development of the Vehicle Emissions Policy (VEP), as announced in May 2003. Proposals include in-service screening, screening of vehicles upon import and a public education campaign.

At the local level, the VFECS study revealed that vehicle technology was only one of a number of potentially significant factors to determine the exhaust emissions output of the national or a local vehicle fleet. The local density of the road network (number of roads within a given area) and the density of the traffic within the network (or any given road link) was potentially even more significant. Traffic congestion is just one variable that can lead to actual per vehicle exhaust emission rates increasing by a factor of three. Therefore, any gains in the fleet's potential emissions performance from improved vehicle technology may be offset by uncontrolled growth in vehicle numbers and congestion. This is a factor that is becoming worse in many urban centres (Ministry of Transport, 1998f).

VFECS showed that there are many other influences, beyond just vehicle traffic, to be considered in the effective management of local air quality. The root cause is the combination of the demand for travel and the choice of vehicles for its supply, within the specific type of urban form in question. As effective environmental management needs to target the root cause of the problem, rather than just compensate for its effects, the full picture needs to be the basis for the analysis, and integrated management.

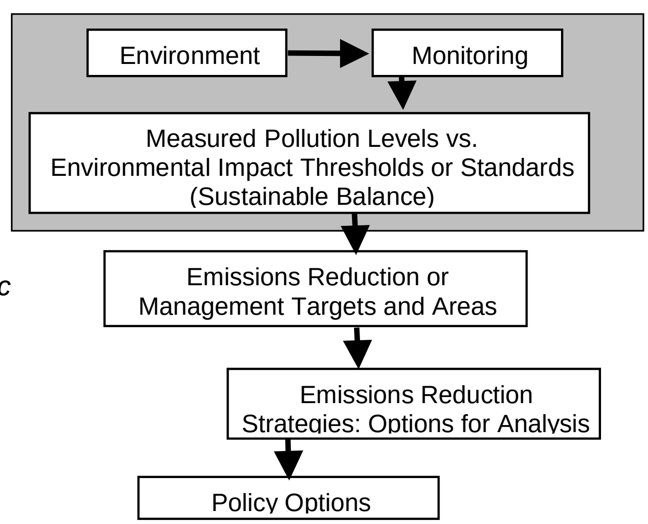
3. ENVIRONMENTAL CAPACITY ANALYSIS (ECA)

The need for the wider picture naturally led to the policy of taking the original concept of Environmental Capacity through to an analytical approach, as a working decision-making tool in the management of the urban environment. This approach provides a framework that can be readily applied to any urban form. It also provides a consistent and measured means for correlating urban form, activity and future development with the direct emissions (or contaminant) impacts on the surrounding environment. Environmental capacity analysis (ECA) can provide the means to correlate the potential effectiveness of national level policy measures with those that can be applied at local authority level, in a consistent and measured sense. Although formulated within the context of VFECS for transport-related exhaust emissions, importantly it also integrates the analysis across all air pollution sources, putting the emissions contribution of each into a consistent context (Ministry of Transport, 1998d).

The ECA 'package', once developed for a particular location, becomes a representation of the spatial and temporal nature of the features of urban design and the variety of activity that has environmental consequences. Comparing the emissions loading profiles that are produced with results from local environmental monitoring provides a measure of how close the monitored pollutant is to its capacity in the equilibrium between emission output rates, and the proximity of actual to threshold pollution levels (or targets for improvement). See Figure 2.

Figure 2. ECA Model Part 1. Defining the Problem.

The initial stage of developing the ECA process often starts with some monitoring of an environmental factor or indicator, i.e. defining the problem. This data is compared with a standard or a threshold, and a reduction determined. The various strategies for achieving the reduction can be determined and analysed. Specific policy options can then be identified.



ECA can indicate trends of effect within urban development and change, either through policies for either environmental management or for other reasons. The ultimate use is as a basis to analyse the degree of emissions reduction required and the variety of potential means to achieve the emissions reduction, within a consistent framework that reflects the actual urban situation.

3.1 URBAN MANAGEMENT INTERFACES

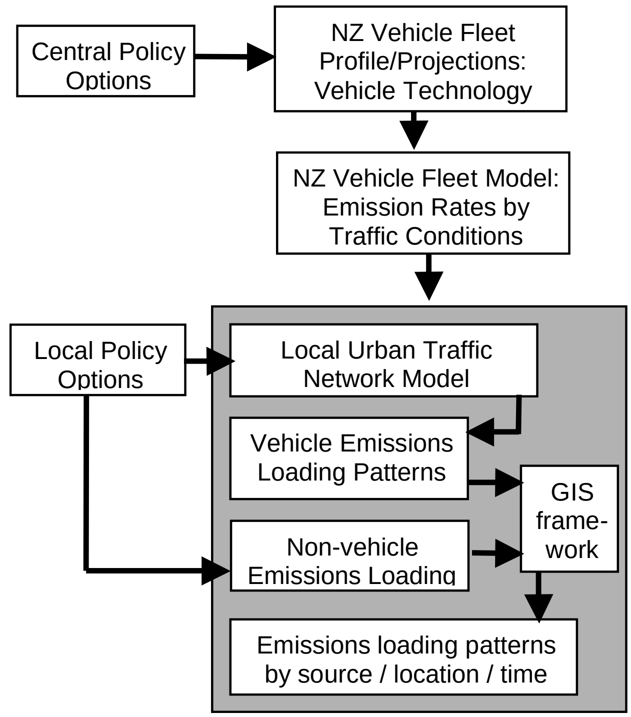
To be effective when implemented, an emissions control measure must be designed around the way in which the source is conventionally used, measured and managed. It must speak and work in the same language. Otherwise, adverse effects from the change required cannot be assessed in a consistent and comparable manner. This makes it difficult to determine the optimum level of emissions and reach an acceptable and workable trade-off.

To understand how to manage exhaust emissions there needs to be an understanding of how they are formed, not just in the process of combustion, etc., but back through to the reasons why the vehicle is being used. This includes not only the engine technology, but must include traffic management, the network design and management, and the transport planning based on trip demand. From this can be determined the factors that can be changed in a practical sense, and identify what degree of exhaust emissions reduction can be achieved. Where cost is involved, what is the marginal cost of this reduction, as not only will there be an absolute limit but also an incremental cost towards it.

For road transport, the primary interface is with the urban traffic model, which is used by road controlling authorities for design, management and projections of the network operations. These are maintained by all urban authorities, to a greater or lesser degree of detail (as needed), and form the basis for translating local travel demand patterns into vehicle traffic flows, and other network parameters. The exhaust emission indices in VFECS are characterised by the conventions used to classify road type design and traffic flow quality, so interface directly with the routine network performance indicators. Figure 3 shows how the fleet emissions data is integrated with the local traffic model.

Figure 3. ECA Model Part 2. Compiling the data into the geo-spatial framework.

Policy options can be developed to reflect the technology of the fleet at a central level, or to manage traffic or network at a local level. Altering central level policy influences the emissions rates of the fleet, depending on traffic conditions. Combining fleet and traffic management within the local authorities urban traffic model produces emissions calculations for the vehicles. When combined with information on other emissions sources, within a spatial context (the GIS), the result is a spatially referenced local emissions inventory.



Some traffic models are based on a geo-spatially defined framework, so that the actual distribution of the emissions activity can be shown, and also the disposition of the non-vehicle sources of the same pollutants in the area.

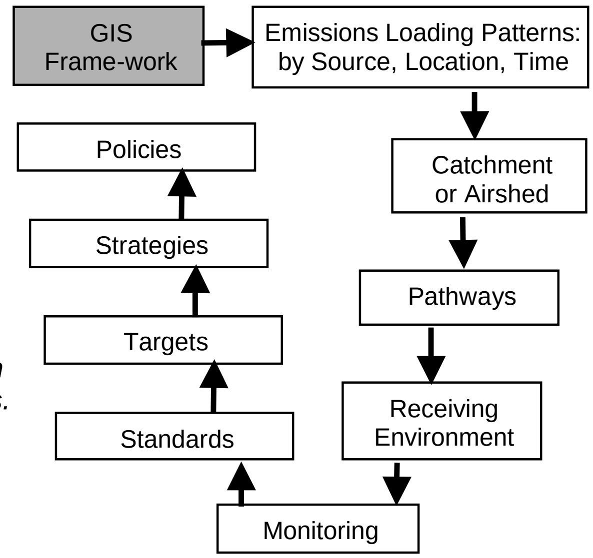
For traffic models that are not geo-defined it is a straightforward process to assign the individual network links to defined area boundaries, then have the results calculated in spreadsheet format.

A parallel emissions calculation process can also interface with the 'meshblock' (smallest statistical area) system of defining urban population and activities, to calculate the corresponding emissions output from non-vehicle sources. This becomes the basic emissions inventory. When interfaced on a common geographic information system (GIS) reference, the two systems can show the emissions loading profiles in a local spatial context and the relative quantities from each source, under regular daily patterns of behaviour. The process also provides for projections, in the emissions performance of the various source technologies. This is shown in Figure 4.

For instance, the vehicle fleet changes its composition through time, so that as technology improves, the average fleet emissions performance also improves. In the future, could the network therefore handle more traffic within the same overall emissions loading, working back from the environmental 'capacity' of the system?

Figure 4. ECA Model Part 3. A local ECA inventory is developed.

From the GIS comes the emissions loading patterns for a given area, by source type, location and time. These emissions are discharged into a defined catchment (water contaminants) or airshed(exhaust emissions) and find their way into receiving environments via both natural (streams) and built (pipes) pathways. It is often at these points that monitoring of environmental quality is undertaken, and this information is fed back into the policy making process.



3.2 OTHER ENVIRONMENTAL POLLUTANTS

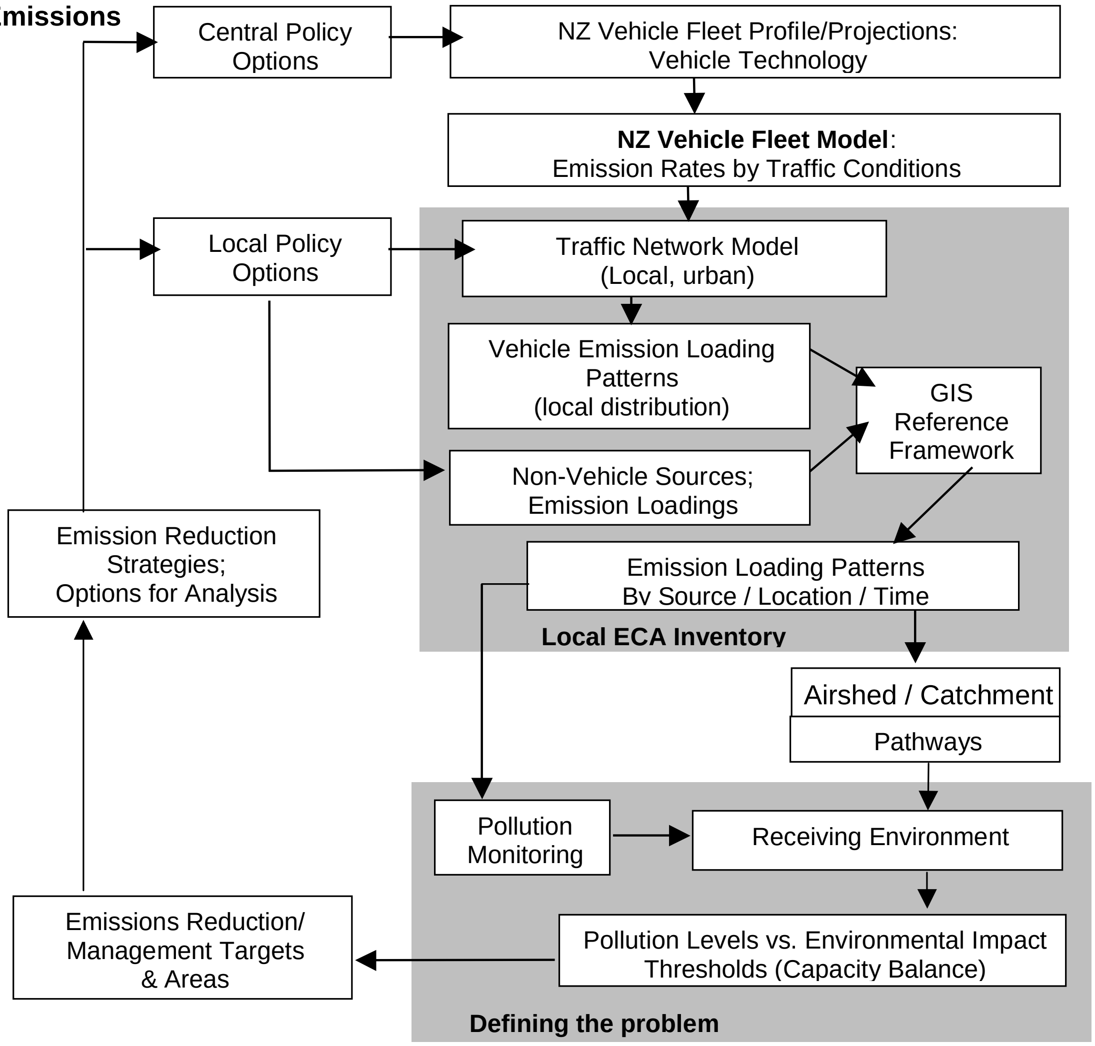
The original context of VFECS was air, but this is not the only environmental concern resulting from either road transport, or all other emissions sources. There are also potential impacts from transport on local water ecosystems and the noise nuisance (now a recognised "pollutant"), as well as the climate change implications of CO_2 and other greenhouse gases.

It is most important to understand and measure the degree to which strategies for one area of protection might interact with other objectives, co- or counter productive. This is where the term ‘integrated’ achieves its full meaning. It occurs where the analysis of contaminant emissions is not only hard-wired into the overall local urban management procedures but is also integrated across all environmental pollutants and their potential impacts, providing for their simultaneous analysis.

In applying the ECA concept, integration is also important in the on-going management process because it provides for one central database to define the situation and to be used to analyse each of the pollutant types. At present, each medium (air, water, etc) tends to be monitored and analysed separately, without the convergences and crossovers being recognised. This can result in different and inconsistent data sources being used to represent the same activity.

Figure 5 summarises the logic of full integration in this process. It is generic in its application to the environment media.

Figure 5. The Full ECA Model. Sustainable Road Transport - Integrated Environmental Management of Air, Water and Energy Consumption / CO_2 Emissions



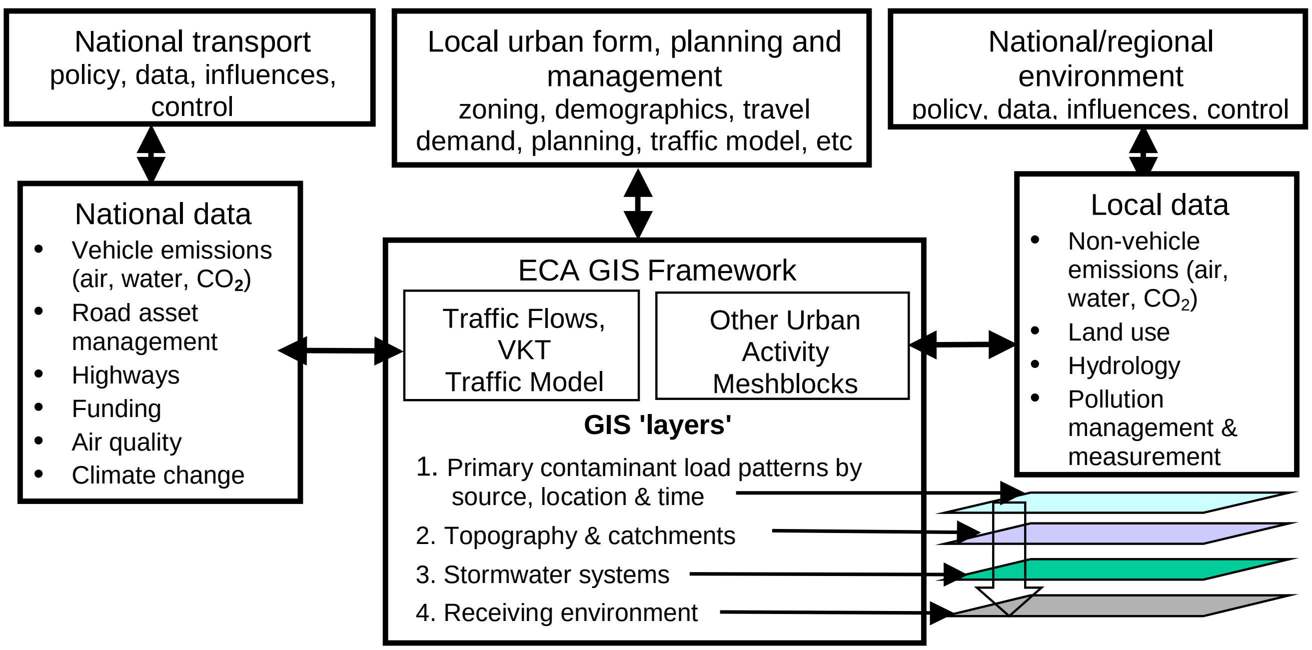
The ECA approach can also be used to identify where pollution monitoring could be targeted. It can predict where hotspots might arise from local concentrations of emissions activity and the 'pathways' the pollutants will follow. For air, this mainly involves the local meteorology and containment at ground level. For water, the pathways are represented by the local catchment topography and stormwater systems that carry the deposition to the receiving environment. In the water case, the traffic model is interfaced geographically with the layout of the catchment systems, and can show where a receiving waterway is linked "upstream" to the urban zone of the emissions activity, for the given pollutant.

The loop continues from determining the "capacity" balance, through setting targets for improvement, and then analysing the relative effectiveness of central strategies (e.g. clean up the fleet, over time, through emissions standards) versus local level strategies (e.g. reduce local bottlenecks, congestion, catchment design). As the analysis works with absolute measures, once the ECA package is set up for a city, it will automatically be calibrated and updated as a routine through other urban management data systems. It therefore becomes a living inventory of emission activity that tracks the change in loadings to the local environment.

4. WAITAKERE CITY ECA CASE STUDY

In conjunction with the Waitakere City Council (WCC), a territorial local authority in the west of the Auckland metropolitan area, the Ministry of Transport has undertaken a case study to demonstrate the validity of the ECA approach. The case study has focussed primarily on stormwater contaminants, as part of a wider research project investigating the effects of land transport-sourced contaminants on aquatic ecosystems. Following the ECA process outlined in Figure 4, the data framework for the case study looks like that in Figure 6.

Figure 6. Waitakere City Environmental Capacity Analysis Stormwater Case Study: Data Framework



An earlier case study in 1999 with the Christchurch City Council addressed the approach in the narrower context of air quality and vehicle exhaust emissions (Ministry of Transport, 2000).

Recent work on water quality issues and the perceived role of road transport in causing these issues has identified a need to better define the problem in aquatic environments, and to link any problem to the pollutant sources in the area, including vehicle traffic. Defining the relationships will enable local authorities and road controlling authorities to identify the extent to which road transport is part of the problem.

The vehicle fleet model water contaminants hub (refer Figure 1) provides an inventory framework that relates contaminant emission rates with the technology of the vehicles in the fleet, and how they operate in local traffic conditions. These are linked to the layout of the local road network to calculate the spatial distribution of emissions loadings where the contaminants originate. This is then also linked to the various pathways whereby the contaminants are deposited in the receiving environment. The end product is an integrated model that relates emissions source to environmental impact, defined around the actual configuration of the particular urban form.

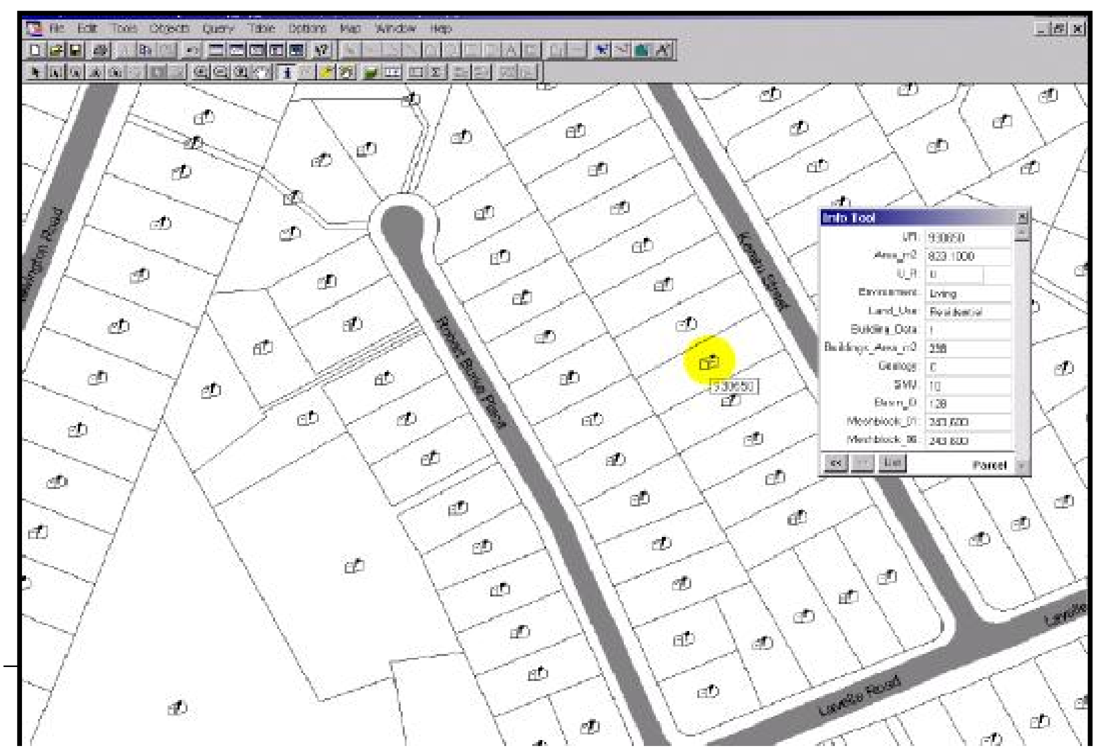
A benefit of this tool is that it draws together a huge volume of information, in a consistent and integrated way, and provides a means to examine the relative emissions contributions on a source-by-source basis and within a defined urban area. It automatically provides environmental indicators for any change in the urban form, roading and traffic activity. Below are sample data sets presented in geographic format layers from within the GIS analysis.

4.1 THE WAITAKERE CITY DATA SETS

Stormwater Information: The council area was divided initially into 33 stormwater management units (SMU) incorporating various water features such as receiving environments, covering both urban and rural areas. SMUs are larger than single stormwater catchments and can contain several receiving environments. Within each of these SMUs, the built stormwater system was plotted and local stormwater basins defined. This information layer was created by this project based on the built stormwater system, surface contours and local knowledge and data. The basins are used as an initial area basis for summing emissions activity, to correlate with the impacts defined in the eventual receiving environment. Basins contain numerous land parcels, which represent the smallest building block in a spatial emission inventory.

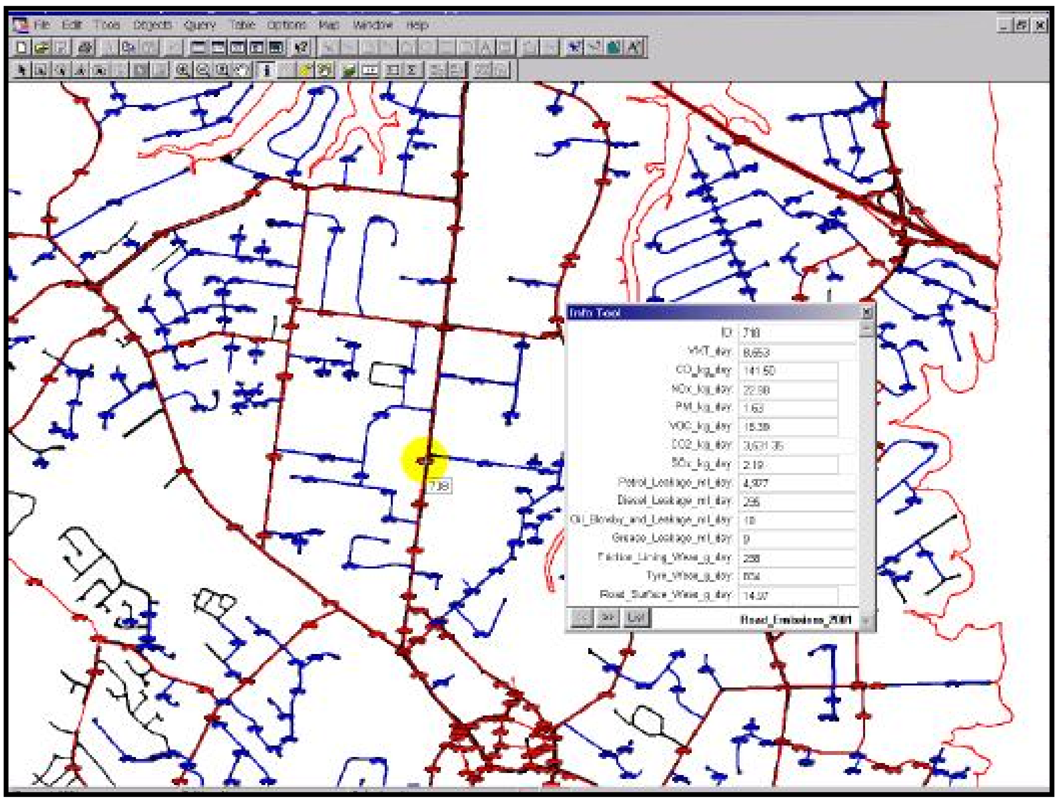
Land Parcel / Cadastral Information: At the detailed level, parcels contain address data, road corridors and land use emission sources. Information assigned to each parcel and the length of roads builds up to the calculation of area-defined runoff and emission loading. Parcel information (see pop-up box on Figure 7 below) uses council definitions and includes address and building data, geology, land-use activity, industry data and particular anomalies, etc. This local information can be correlated with national information census/statistical data based on the meshblock structures.

Figure 7. Sample of the Waitakere ECA Model showing Cadastral Data



Road Information: A layer of roading information was produced from information based on the Council's EMME2 traffic model. It represents all the road corridors in the local network and contains estimated, if not actual, traffic count data. Information points were created for each individual road link, for each direction of traffic flow, (see the pop-up box shown on Figure 8 below). This means there are two sets of road information and emissions data for each road. It also allows calculation of projected trends over time in response to urban growth and development, taking into account fleet composition, turnover and technology evolution.

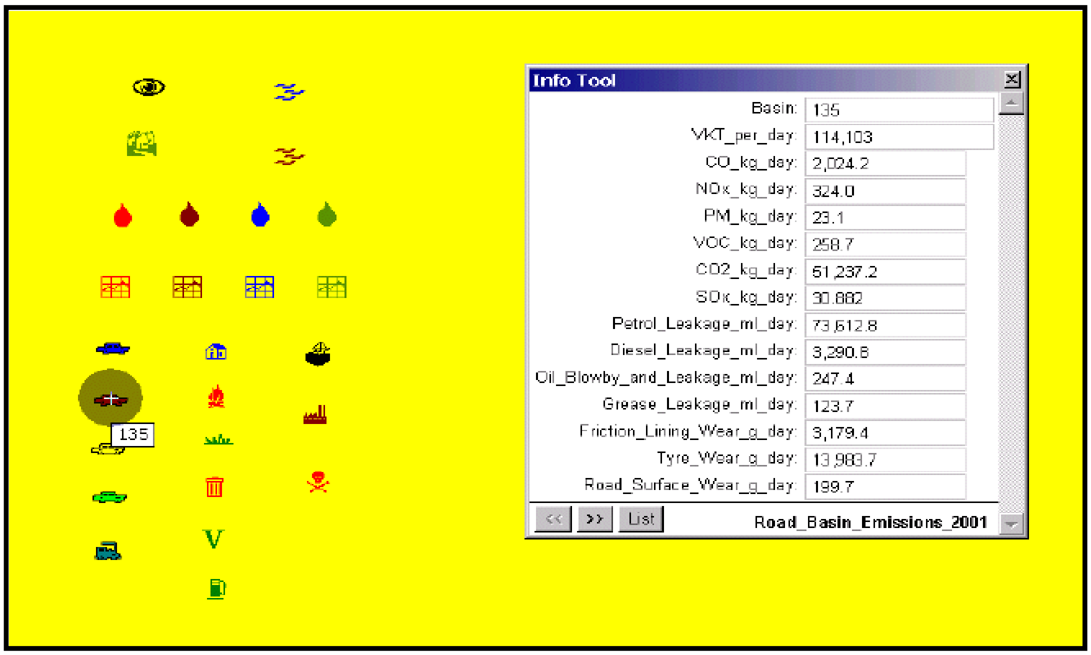
Figure 8. Sample of the Waitakere ECA Model showing Road Emissions Information Data for year 2001.



Stormwater Basin Emissions Information: For each basin, data has been summarised from the various source layers to create information points. As shown in Figure 9. each symbol represents basin information, including rain/runoff, annual contaminants for land-use types within the basin, wash-off profile, road emissions, roof runoff, home heating, domestic lawn mowing, domestic waste and volatile organic compounds (VOC), industry activity types and dangerous goods sites. This information comes from council-held data (both regional and territorial councils) and national data (e.g. statistical data regarding home heating materials used).

Figure 9. Sample of the Waitakere ECA Model showing Stormwater Basin Information for year 2001.

Each symbol reflects a set of data pertaining to the defined basin.

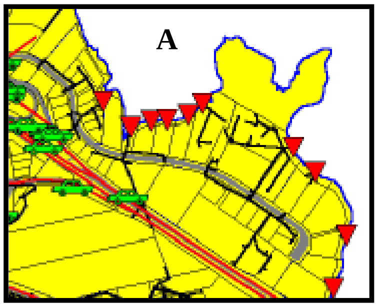


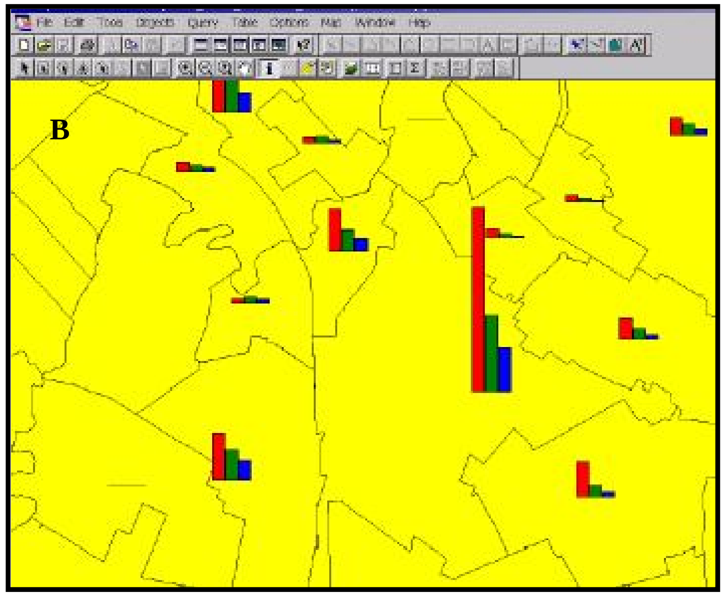
Graphic Output layers: These provide for output results from the analysis to be displayed in an easy to read, graphic format. This allows a quick, visual display of trends, area comparisons, etc. and prioritisation of issues.

Figures 10 A and B show examples of output information. Figure 10A shows the stormwater discharge points for particular basins, which can assist in identifying likely monitoring sites or sensitive receiving environments. Figure 10B shows a comparison between stormwater basins. The coloured bar graphs in this case, represent three different time periods (red, 1990; green, 2000; blue 2010) for a single contaminant loading from the basin. They may also be configured to represent different sources or different contaminants for a single basin.

Figures 10A & 10B. Samples of the Waitakere ECA Model Results Graphic Output.

A. Basin Stormwater Discharge Points (red triangles), roads, land parcels, and stormwater systems (black lines).
B. Relative basin emissions loadings for a single contaminant.





5. CONCLUSION

The ECA framework has been developed for dealing with the environmental impacts of road transport (and rail). The basic principles behind this are:

Using consistent measures for, and consistent comparison of:

- The technical design and performance characterisation of the vehicles, as a source of the emissions (and any other unwanted impact);
- How the fleet of vehicles evolves, in response to supply/market demand/policy control of their design and performance;
- How they operate, therefore perform, within the demand for transport, and associated roading/transport infrastructure; and
- The surrounding spatially defined receiving environments, therefore balance between how transport operates, the local sensitivities and resulting impacts;

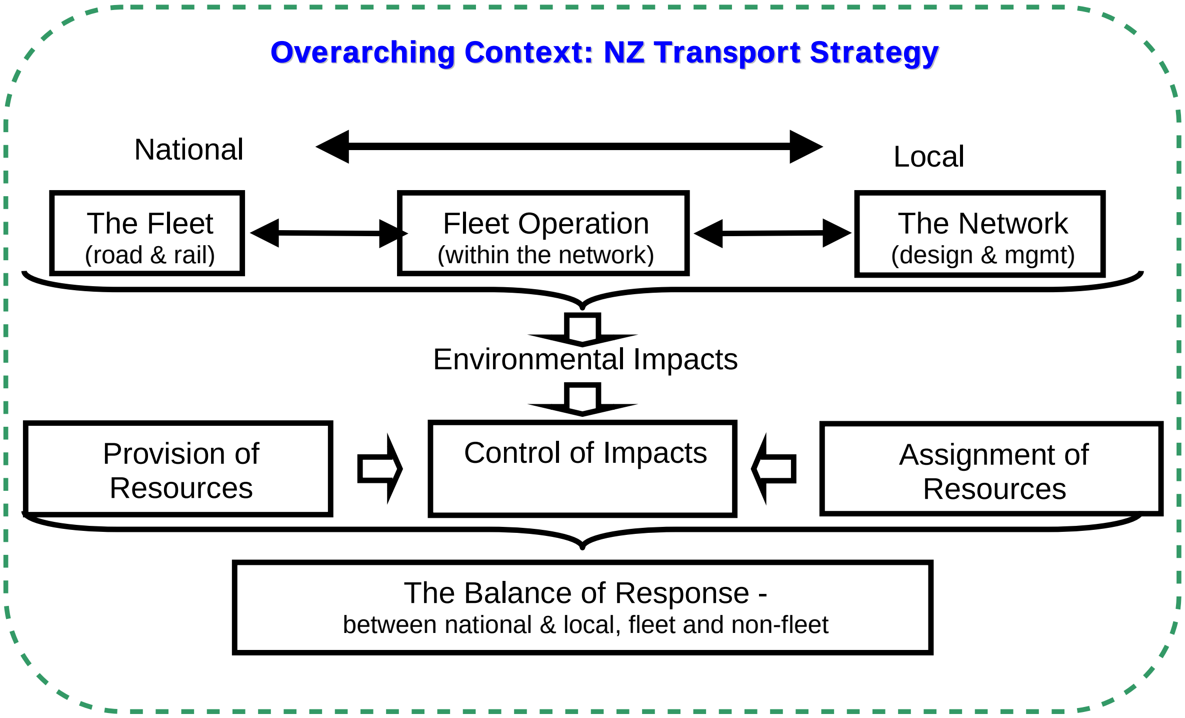
This comparison is undertaken within a framework that is integrated with existing systems for urban design and management.

The transport system should be considered in its widest sense, as an "asset". Road transport and urban systems managers should seek to manage the road transport network in terms of:

- The service it provides;
- The benefits and impacts its creates; and
- The costs that are imposed

Many of these impacts are locally defined and vary accordingly in terms of magnitude. The responses are also defined locally, to be optimal and efficient, especially in deciding how to pay for them. There is a national vs. local balance here, with the way in which transport policy / infrastructure / impacts / costs need to be dealt with. Figure 11 shows this is in a diagrammatic form.

Figure 11. The tension between national and local influences, resources and outcomes.



The logic process in the "integrated environmental management" approach could also extend beyond environmental impacts to:

- The national vehicle fleet (as a whole) - in the supply of vehicles, in terms of such as energy efficiency/CO_2 at the national level, right through to life cycle and disposal issues;
- Safety (in vehicle design) and safety management (in local traffic networks);
- Road user costs and road network maintenance; the design of electronic road user charges (E-RUC);
- Fiscal structures, based on the need to derive revenue, or influence demand/ behaviour due to local impacts/constraints imposed; and
- Congestion management

With the ultimate goal being to achieve a sustainable transport system, it should be possible to consider many, if not all, the possible (adverse) impacts of the transport system, in a measured and consistent manner. When developing the controls required, assigning the costs, and providing the resources needed, it should also be possible to address co- and counter effects within an appropriately balanced and equitable manner. Environmental Capacity Analysis, used as a means to achieve integrated urban environmental (resource) management, provides that opportunity.

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Further information on all aspects of this policy paper, as well as copies of the references above, are available at the New Zealand Ministry of Transport website at: www.transport.govt.nz.