MONITORING OF ENVIRONMENTAL IMPACTS OF ROADS

PIARC Technical Committee A.1 Preserving the environment
The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

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Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organizations or agencies.

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Road infrastructure projects impact the environment in many ways. The construction, operation and maintenance of infrastructures have consequences on nature, landscape development, water and air quality, noise and other environmental fields. Monitoring road impacts is essential for the identification of new issues, tracking trends and implementing appropriate mitigation actions. This report clarifies what is encompassed in the concept of monitoring. It focuses on current environmental monitoring practice and seeks to identify best practices in order to draw recommendations that can be applied in new and existing road infrastructure.

The results are based on a survey of current practice in participating countries, as well as a literature search.

The first part of this report (Chapter 3) analyses current practice in the different environmental fields. For each field, road infrastructure impacts are illustrated and monitoring practice discussed within each project phase: planning, construction, operation.

The second part of this report (Chapter 4) presents a selection of case studies illustrating best practice in different environmental fields. They illustrate how monitoring can be effectively used in a road infrastructure project.

The third part of this report (Chapter 5 et 6) discusses the contribution of monitoring in each environmental field. The environmental indicators currently in use at national and international levels are listed. Recommendations for effective monitoring are given.

Overall, it is confirmed that monitoring the environmental impacts plays a key role for reporting, assessing and mitigating the negative effects of road infrastructures. Monitoring is most effective when organized at the appropriate project stage.

All participating countries perform monitoring of impacts at different levels. Indicators used differ between countries, with however common tools for the measurement of air quality. Air quality, noise and climate are the fields receive the most frequent attention.

The legal framework is heterogeneous. There are legal obligations at different levels: local (cities), national (countries), regional (group of countries). A large number of countries are committed by international agreements (Kyoto protocol, Biodiversity convention, etc.), which bind them into carrying out some sort of monitoring. In general, national laws and international agreements related to public health issues are based on WHO guidelines. European countries show more homogeneity, through the minimal standards established by the European Council's directives.
Mitigating the environmental impact of roads is an important part of sustainable approach to transport infrastructure. The World Road Association (PIARC) has focused on this issue in the past examining best practice in the report "Social and environmental approaches to sustainable transport infrastructures" [1].

The conclusions regarding the environmental aspect of sustainable mobility underlined the mostly negative impacts of roads on the environment and the importance of mitigating these impacts. Sustainability evaluation of road transport (plans and projects) is based on methods originating from the environmental perspective such as Strategic Environmental Assessment or Environmental Impact Assessment. Few countries apply additional methods, which would give a broader view of impacts or an overall perspective on all three dimensions of sustainability. The development of such methodological instruments on the project and plan evaluation level seems to be an open field for research.

A key to assess sustainability of road transport in the long run appears to lie in the continuous collection of relevant data connected to the impacts of the road network. This monitoring of crucial indicators covering all three dimensions of sustainability is an essential requirement to analyze the progress of impacts along the life cycle of the infrastructure and to allow sustainability evaluation in the future.

Following these conclusions, the technical committee A.1 “Preserving the environment” decided for PIARC’s 2008-2011 strategic plan [2] to investigate further how the environmental impacts of roads are monitored and to conduct a review of current environmental monitoring of road impacts performed amongst the member states. The aim is to identify best practices in terms of environmental monitoring, and produce recommendations for the use by the road community.

Work topic for 2008-2011: monitoring of the environmental impacts

This report is related to issue A.1.2 “Monitoring of the environmental impacts”, of the technical committee A.1. The following list of questions is to be addressed:

• What type of monitoring is taking place in the states?
• Which environmental topics are covered?
• What is required by law? What is the legal framework?
• Which aspects of environmental monitoring fall into international laws, agreements, or supranational directives?
• To what extent are the data used, and what for? Public information, mitigation measures, mitigation plan, new policies, strategies, regulations?
• How is the monitoring taken into account in the development of future policies?
• How does it feed back into the system?
It was decided to focus on environmental monitoring of environmental impacts in the following key areas: Air and climate, noise, hazardous substances and major accidents, waste management, soil, water resources, biodiversity, landscape.

2. METHODOLOGY

The report is based on a two part survey among participating PIARC countries and a literature research through the web in English, French and German. The surveys served at identifying current practice.

The two questionnaires sent to the members of the technical committee A.1 Preserving the environment are to be found in the annexes. The first in form of a table (Appendix 1) asks participants to describe what is being monitored for each environmental topic (air quality, biodiversity, climate, etc.), differentiating the monitoring activities according to four phases in infrastructure planning:

**Phase 1:** Planning stage. Before a project receives approval, best practice demands that environmental impacts be examined. Often data is collected. Here the participants were asked to describe how the data is collected, what is being measured, where and how the data are stored.

**Phase 2:** Construction stage. During this stage, compliance reports may initiate more monitoring. What is checked at this level and how? How are the data used to feed back into the project design?

**Phase 3:** Project operation stage. Environmental monitoring during this phase may be less standard. Participants were asked to address the following questions: What is monitored? What type of data is collected and how is it used to influence further operation?

**Phase 4:** Network operation. This addresses monitoring concerning the whole network and not only a single project. This stage is better defined as a level rather than as a phase. Monitoring at this level may be more seldom or not directly related to roads but to broader environmental issues.

Following the first set of answers from the first questionnaire, a second questionnaire was established (Appendix 2) with more focused and precise questions. The topics addressed are: air, biodiversity, climate, soil and water. In a few cases the second questionnaire was accompanied with a country-specific part in order to address a special topic from that particular country.
Twenty four countries participated in the study by answering one or both questionnaires:

Australia, Austria, Canada, Cuba, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iran, Japan, Mexico, New-Zealand, Norway, Portugal, Romania, Slovakia, South-Africa, Sweden, Switzerland, UK, USA. Case studies illustrating current monitoring schemes were also provided and are presented in chapter 4.

3. OVERVIEW OF PRESENT ENVIRONMENTAL MONITORING PRACTICE

3.1. AIR, CLIMATE

3.1.1. Impacts of roads

Motorized traffic is a major source of air pollution. The main emissions include exhaust gases (nitrous oxides $\text{NO}_x$, carbon monoxide, sulphide dioxide or ozone), particulate matter and dust. Air pollution is a serious public health problem. According to the World Health Organization, air pollution is a major environmental risk to health and is estimated to cause approximately 2 million premature deaths worldwide per year [3].

In 2005, road transport was responsible for 40% of $\text{NO}_x$ emissions in Europe [4], highly damageable to health. On a larger scale, air pollutants, once released in the atmosphere, may travel, accumulate and impact ecosystems. They potentially contribute, directly or indirectly, to the increase in greenhouse gases, responsible for the global warming [5], but also to ozone pollution, ocean acidification or acid rain, among others.

In 2004 the transport sector was responsible for 23% of world energy-related greenhouse gas emissions, with about three quarters coming from road vehicles [6]. Furthermore, the total amount of greenhouse gas emissions from road transport is in constant increase and is projected to increase further in the future (see figure 1, following page).

Beyond the global climate issue and the impact of road traffic on $\text{CO}_2$ emissions, road infrastructures can impact local climate. This is mostly caused by an alteration of the local radiative balance due to a change of the surface albedo, frequently observed when an infrastructure replaces a natural area [8, 9]. This phenomenon is also known as "heat islands". Its influence is dependent on the size of the infrastructure.
3.1.2. International thresholds

Diverse emission thresholds are used. These thresholds were established as standards for preserving public health and ecosystems. Most are derived from WHO guidelines. For the EU-countries, the national policies are based on the EU-directive relative to air quality [10].

3.1.3. Monitoring practice

Emissions monitored

Monitoring of air quality is carried out by a majority of countries (17 out of the 19 countries participating in this study). As shown in figure 2, following page, most countries are monitoring the levels of pollutant gas such as carbon monoxide (CO), sulphide dioxide (SO$_2$), ozone (O$_3$) and nitrous oxides NO and NO$_2$ at some stage of the project. The monitoring of hydrocarbon (HC) and lead (Pb) is carried out in half of the countries, while the monitoring of CO$_2$ is much less common. It is noted that gas emission monitoring is not always specific to roads.

Out of the 19 countries that answered the questionnaire, 16 are monitoring at least one type of particulate matter (PM) concentration: PM10, PM2.5, SPM, or DPM. Most of the countries monitor both PM10 and PM2.5, which are the established international standards with respect to public health monitoring.

16 out of 19 countries store the data collected by monitoring programs in databanks. The Convention on Long-range Transboundary Air Pollution (LRTAP) has established...
a framework for co-operative action in Europe, setting up under the EMEP programme protocols for the collection of emission data and measurement of air quality\(^1\).

Most of the countries are committed to stabilize or reduce their greenhouse gas (GHG) emissions, in agreement with the Kyoto protocol [11]. The GHG emitted during the construction of roads are included into the national emission inventories.

**Monitoring during construction stage**

There is limited monitoring practiced during the construction stage among the participants. At this stage monitoring aims at reducing local emissions of construction equipment. Dust is a frequent problem during the construction stage, mentioned by 6 countries. Mitigation actions carried out by the countries include spraying water (e.g. in France and in Canada), tarping trucks that carry construction soil and materials, wheel washing, or forbidding the loading and unloading of trucks in the vicinity of sensitive areas (living area, large traffic road, sensitive farming).

Specifications needing air quality monitoring may be made (e.g. USA, New Zealand, Romania) in the EIA. In Mexico for instance, vehicles used during construction must comply to standard regulations to control the maximum limit of emissions. The use of filters on machines may be imposed.

\(^{1}\) http://www.emep.int
Monitoring during project operation - example of the control of mitigation efficiency in Rotterdam

Monitoring is regularly used to check the efficiency of mitigation measures. The following example from Rotterdam (NL) provides an illustration. Speed control measures were implemented on the A13 motorway in 2002 in Rotterdam as a response to concerns related to health and poor air quality for residents living in close proximity to the road. Speed limits were reduced from 120 km/h to 80 km/h along a 3.5 km stretch of the motorway and tightly enforced through a series of cameras. Monitoring showed subsequently an improvement in local air quality. NO_x emissions fell by 15-20%, PM10 by 25-30% and carbon monoxide (CO) by 21%. In terms of ancillary benefits, it was estimated that emissions of CO_2 fell by 15%; the number of accidents decreased by 60% and noise was reduced by approximately 50% [12].

Long-term monitoring

Many countries have national networks of automatic measurement stations for long-term monitoring of air quality. EUROAIRNET\(^2\) the European air quality monitoring network has a selection of high-quality air monitoring stations in Europe, based on national networks such as Hungarian Air Quality Monitoring System\(^3\), the Romanian National Network for Air Quality Monitoring\(^4\), or the Swiss National Air Pollution Monitoring Network\(^5\) (NABEL [13]). These all collect long-term measurement series of air pollutants with the aim of informing the public about the air quality situations and developments over time. In Switzerland, as an example, the monitoring network consists of monitoring stations located all over the country, representing the different typical levels of pollution. This monitoring is not specific to roads, but in Switzerland the Federal road office participates in its financing where it is pertinent to roads.

The data collected from the measurement networks are used as a basis for modeling emissions. Nearly all the participating countries project air quality trends by using models when planning new road infrastructure. This permits an estimate of long-term environmental impacts of projects. Modeling is also used for the calculation of the overall road-emission calculations.

3.1.4. Trends shown by monitoring

Long term monitoring is essential to reveal trends and measure the effectiveness of policies. The decrease of lead pollution following its ban due to public health issues is an evocative example. Lead was an additive used in gasoline to improve

\(\text{http://air-climate.eionet.europa.eu/databases/EuroAirnet/index\_html}\)
\(\text{http://www.kvvm.hu/olm/map.php?lang=en&id=Budapest}\)
\(\text{Reteaua Nationala de Monitorizare a Calitatii Aerului, URL: http://www.calitateaer.ro/}\)
\(\text{Nationale Beobachtungsnetz für Luftfremdstoffe (NABEL), URL: http://www.empa.ch/nabel/}\)
performance. Since this progressive ban since the 1970's, monitoring has shown a consequent reduction of the level of pollution in air, water, and soil (see figure 3).

![Lead air quality, 1980-2008](image)

1980 to 2008: 92% decrease in national average

**FIGURE 3 - MONITORING CLEARLY SHOWS THE DECREASE IN LEAD CONCENTRATION IN THE US SINCE LEAD WAS BANNED AS GASOLINE ADDITIVE**

**SOURCE: US-ENVIRONMENTAL PROTECTION AGENCY, EPA**

Generally monitoring of air pollution in Europe showed the influence of traffic on emissions and the decrease of pollutants following implementation of corrective legislation. With the dramatic increase of the number of combustion engine vehicles since the 1950s, concentrations of pollutants such as PM or NO\textsubscript{x} increased and became an increasingly serious public health issue. Progressive and increasingly stringent emission standards were introduced in the earlier 1990s (catalytic converters, and PM filters traps and reduced sulfur content in fuels). These standards urged the industry to find innovative solutions and develop efficient gas exhaust filters. The effectiveness of these measures was clearly shown through monitoring (see figure 4, following page), and has encouraged further standards (Euro-5 in 2010, Euro-6 in 2015) [14].

Despite these successes data from selected measuring stations in urban agglomerations close to major traffic arteries indicate that the concentration of NO\textsubscript{2} and PM10 are at or above the European air quality limits at these sites. This increase is explained by the use of diesel in urban areas and an increase of the fraction of NO\textsubscript{x} emitted as NO\textsubscript{2}. Oxidation catalysts and regenerative traps in modern diesel vehicles have been found to lead to such increases [15].
3.1.5. Use and influence of monitoring results

Monitoring is used to evaluate impacts in the EIA phase, such as potential effect of projects on local climate (Maryland, USA).

Monitoring is used to evaluate current air quality and to control immission thresholds. 12 countries out of 19 countries implement remedial action when thresholds are exceeded. The range of actions is quite large. In some countries, this action may involve public information about health hazards (e.g. Portugal and Finland). It can go from traffic regulations (e.g. Greece, Italy, Iran, Germany) to legislative actions (e.g. particulate filters imposed on cars in Denmark, or possible prosecution in Australia).

Monitoring before, during and after mitigation is important for controlling and/or improving the effectiveness of measures. During the heat wave over Europe in summer 2003, monitoring of ozone and PM concentration in southern Switzerland showed that thresholds were exceeded. As a consequence, it was decided as an experimental measure to lower speed limits on motorways from 120 to 80 km/h in order to decrease traffic emissions. Although monitoring showed a reduction of emissions, there was no reduction in immissions as regional factors, pollution from Milan area dominated. The results showed that speed reduction were not efficient at addressing the problem in this situation. [16, 17, 18].

In Athens (Greece) monitoring has shown a temperature increase up to 10°C above the surroundings [19] due to roads. Tree planting (and vegetation in general) is used
an effective mitigation action. Monitoring [20]. confirmed the effectiveness but showed also dependence on other parameters, for example building heights, or the density of building areas.

Long term data from databanks is used as an important source of information for future planning (basis for impact analysis evaluation) and future policies (analysis of trends) and associated action plans. Certain trends can only be analyzed over several years or concerning climate change over several decades. Models developed through analysis of long-term data are used to simulate the impacts of the road infrastructure.

Monitoring can also be used to identify best practice for GHG (i.e. lowest energy consumption), or to measure performance.

3.2. Noise

3.2.1. Impact of roads

Road traffic is a significant source of noise and vibrations. It is acknowledged that noise seriously effects human health and interferes with people's daily activities [21]. Elevated sound levels can cause hearing impairment, hypertension, vasoconstriction, ischemic heart disease, annoyance, bowel movements, sleep disturbance, etc. Beyond these effects, elevated noise levels can create stress, increase workplace accident rates, and stimulate aggression and other anti-social behaviors. In Europe, it is estimated that traffic noise alone is effecting the health of a third of the population, and that one in five Europeans is regularly exposed to sound levels at night that could significantly damage health. Road traffic is a major source of noise, that can cause up to 80% of the all annoyances (Norway). Noise generated by traffic also impacts fauna and ecosystems [22]. As transport volumes increase [7], impacts from noise increase, unless mitigated.

3.2.2. International thresholds

Thresholds and ways of evaluating noise are very diverse. From the answers of the questionnaires, it appears that many of the countries have their own national policies when it comes to noise.

In Europe, in order to harmonize the practice, the European Parliament and Council has issued the European Noise Directive in 2002 [23]. This directive provides the member states with a set of common measurement procedures, indicators, and limit values. The introduction of this directive allows quantitative comparisons of noise values between the countries. WHO guidelines set tight limits for noise emissions, with the aim of further lowering these limits with time.
3.2.3. Monitoring practice

Noise is a frequently monitored aspect of roads. 18 out of the 19 countries that participated in the study reported doing some kind of noise or vibration monitoring during road infrastructure projects.

Monitoring during planning stage
During the planning stage, ambient noise levels are measured or simulated. Models are used to project future noise levels. The impact of noise is analyzed as part of the Environmental impact assessment. Mitigation measures are then identified to protect residents from adverse noise impacts. In some countries, existing data from noise cadastres are completed and updated (e.g. Austria, Switzerland). Mitigation measures decided during the planning stage are mostly based on emissions models of the expected noise verified through punctual and short term monitoring. The characteristics of the mitigation means, such as the type of product and the dimension, are assessed.

Monitoring during construction stage
Monitoring of noise and vibration is a compliance tool used during the construction stage. It is used to control the effective application of the prior agreements (e.g. Canada, Austria and Switzerland) [24]. In Scotland, vibration associated with piling may be monitored if close to sensitive land uses. There, the construction noise is also often monitored when the construction work takes place in the vicinity of sensitive properties, to ensure compliance with noise limits. Other countries that may monitor noise during the construction phase include for example.

Monitoring during project operation
During project operation, the acoustic performance of the structures and materials used for noise mitigation may be assessed. In Denmark for example, the efficiency of noise screens are monitored with measurements and questionnaires. In Switzerland, the rolling noise measured by the "Close Proximity" (CPX) is used for monitoring of the different types of pavements every 5 years, as part of general pavement quality monitoring. Also in Switzerland post-project punctual monitoring is mandatory. In a few countries, like in Australia, noise monitoring during project operation is performed only if problems are identified, or valid complaints are received.

Monitoring during project operation can be used to implement new mitigation measures. In Scotland for example, traffic noise is calculated, based on the actual traffic flow. According to the results, the residential properties close to the new road infrastructure might be eligible for noise protection measures.

In Greece, monitoring of noise levels for a 6-laned highway around the city of Athens is the basis for implementation of well tailored mitigation measures. Thanks to these
measures, noise values in the vicinity of the highway have stayed within acceptable limits despite the new infrastructure (see dedicated case study in chapter 4).

**Long-term monitoring**

Long-term monitoring of noise on a network-level is becoming more common, particularly in Europe. Maps are drawn using models and sometimes measurements (essentially for specific studies). Among the 11 countries that answered this part of the questionnaire, 5 used noise maps, database, or cadastre for the long-term monitoring. In Finland for instance, approximate electronic maps of modeled noise are used, and when a project starts precise modeled maps are produced. In Sweden, noise levels calculated and measured along state roads are written in a database. In Switzerland, there is a national noise monitoring database [25] that gathers noise pollution data from the main sources, including roads. In Romania noise maps are produced and are used for action plans.

**3.2.4. Trends shown by monitoring**

Monitoring has shown the steady increase of noise emissions with the increase of traffic levels. It has been shown how lorries contribute particularly strongly to emissions. Monitoring has also shown the long term drop in efficiency of certain mitigation measures, such as porous asphalt and the need for better performing materials.

**3.2.5. Use and influence of monitoring results**

Noise monitoring has been essential for the building of noise propagation and emissions models. Without this data cost-effective models would not be possible. These models then allow cost-effective projections of noise levels of new infrastructure for the planning stage. The design of the infrastructure and the different possible mitigation measures (e.g. noise barrier lengths and heights) can be tested.

Further monitoring can be needed for validation and correction purposes. In Denmark, monitoring showed that noise was being underestimated by the propagation model in use. It proved that the model was too simple. A more complex model was then used.

Sound-propagation models cited by the participants include SoundPLAN\(^6\), Cadna-A\(^7\), or NORD96 and NORD2000. Other models for noise mapping in use within the community include Lima\(^8\) and IMMI\(^9\).

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\(^6\) http://www.soundplan.eu/
\(^7\) http://www.datakustik.com/en/
\(^8\) http://www.bksv.com/Products/EnvironmentalNoiseManagement/NoiseManagementSolutions/...NoisePredictionSoftware/7812Lima.aspx
Models provide a great advantage over traditional monitoring of noise levels for large scale analysis. Models offer a cost-effective overview that serve as a basis to test mitigation strategies to limit adverse noise levels or test effectiveness of new regulations.

In Europe, models are used to produce noise maps using a set of common indicators, enabling monitoring and comparison between countries. A website dedicated to these maps is publicly available on the web\(^\text{10}\). In a short future, a common noise model will be developed for the entire EU in order to harmonize the monitoring practice and allow reliable inter-comparisons. This in turn is a basis to prioritize noise mitigation. Models are also used to harmonize urban and road development, so as to avoid development in noise affected areas.

An example of such an overview is provided by the software SonBase in Switzerland. SonBase projects nation-wide noise levels produced by the road network. Part of the modeling is based on monitoring and measurement of basic data, such as traffic volume, geography and buildings, whereas the propagation model calculates and maps the resulting noise \([26]\). SonBase produces noise maps, which can be used to identify problematic stretches, and help with strategic choices.

In Switzerland, monitoring is used along the network to check the efficiency of noise screens and implement further corrective measures if needed \([27]\]. Switzerland uses monitoring to study the long-term changes of noise screens' noise reduction capabilities \([28]\), in order to plan when maintenance may be needed. Noise monitoring is also used to study policy outcome of traffic transfers from road to rail along two strategic roads (see case-study in chapter 4).

### 3.3. RISKS FROM HAZARDOUS SUBSTANCES

#### 3.3.1. Impact of roads

Hazardous substances can be found in road infrastructures. As an example, tar residues contain polycyclic aromatic hydrocarbons (PAHs) which can be released at high temperature. Paints used on metal structures often have heavy metal components.

Other hazardous substances may arise through accidental spillages during the construction or operational phase. Prevention plans are activated in sensitive areas.

In many countries, the monitoring of hazardous substances is integrated in water and soil monitoring.

\(^{10}\) [http://noise.eionet.europa.eu](http://noise.eionet.europa.eu)
3.3.2. International thresholds

Risks associated with the use and treatment of hazardous substances in the context of road infrastructures fall under the national laws on dangerous substances management.

On the European level new regulation has entered into force in 2007 with REACH [29] which deals with the Registration, Evaluation, Authorization and Restriction of Chemical substances. The regulation places responsibility on industry to manage risks from chemicals. The manufacturer is responsible for successful registration. REACH demands that risks be evaluated and good practices described for registration. This is done through the Derived Non Effect Level (DNEL).

As an example mastic asphalt has been registered through the concerted efforts of the industry and classified as non dangerous, but must not be transported or used at temperatures above 200°C [30].

Further regulation was adopted on March 9th 2011 by the Council of the European Union with a revision of the current Construction Products Directive [31]. New emphases will be given to the integration of a new basic requirement on sustainable use of natural resources.

Concerning the transport of hazardous substances in the operational phase, at the European level, a directive has been established on the minimum safety requirements in tunnels [32, 33], which includes safety requirements for the transport of hazardous substances.

3.3.3. Trends shown by monitoring

Monitoring of PAH’s has shown their existence in asphalt due to the use of tar up to the 1970's and highlighted potential worker health issues. On site monitoring has shown that decreased mixing temperatures decreases PAH emissions. In Switzerland, the total amount of PAH used in road infrastructures has been monitored [34]. It has shown a very heterogeneous problem, with road stretches very low PAH rates (under 5,000 ppm) and others with high rates (over 20,000 ppm), linked to previous building practices.

3.3.4. Use and influence of monitoring results

Monitoring PAH has shown the need to find site specific solutions for recycling. These can entail working at lower temperatures in order to limit PAH emissions and protect workers, limiting recycling to certain road structures or developing new recycling procedures.
Concerning the transport of hazardous substances, some countries, like Switzerland, have databanks where accidents involving dangerous goods are recorded. An example is the Gotthard Road tunnel (16.9 km), or the Great St. Bernard Tunnel (5.8 km) in Switzerland. Trucks transporting dangerous goods have to apply before being authorized to drive across the tunnel. However there is no clear differentiation between dangerous goods (from a tunnel safety perspective) and dangerous substances (from an environmental perspective).

### 3.4. WASTE MANAGEMENT

#### 3.4.1. Impact of roads

Road building is a material intensive industry. Residual materials are produced in large amounts and in various modes during maintenance and construction: earthworks, damaged pavement layers, demolition waste, sub-products of activities, etc. During road operation, sources of waste include also waste collected from bins in rest areas, and from roadsides (vegetation, diverse litter).

#### 3.4.2. International thresholds

Waste management monitoring is mentioned as being part of the environmental impact assessment in several countries (e.g. Denmark, Japan, Greece). The management of waste due to road infrastructure projects fall in many countries (e.g. Austria, Scotland), under general laws on waste management at the national level.

#### 3.4.3. Monitoring practice

**Monitoring during construction stage**

During the construction, the main source of waste materials mentioned by the participating countries is earthworks. Some countries (e.g. Austria) document the waste generated by the construction project. In Finland, an environmental report is produced stating how much land mass is taken away from the building site and disposed of in dumping areas.

Monitoring is used to reduce waste production in several countries. In Sweden, proper planning is stressed in order to avoid waste generation. In Scotland, an incentive to minimize waste in the form of a landfill tax is used. Contractors minimize waste arisings by balancing cut and fill, and by re-using or recycling materials in order to avoid the tax.

**Long-term monitoring**

During the long-term operation of the infrastructure, there is limited waste production. Several countries (e.g. Scotland, UK) record the waste produced by litter in the rest
areas, or due to maintenance activities such as replacing damaged fencing or cutting vegetation. In Switzerland, general waste statistics are published in regular reports, which include waste from infrastructure construction sites, [35]. An example of the relative amount of excavation and demolition waste for different activities is shown in figure 5.

![Figure 5 - Relative Amount of Excavation and Demolition Waste in Switzerland [35]](image)

**Figure 5 - Relative Amount of Excavation and Demolition Waste in Switzerland [35]**

X axis values in tons are shown for comparison.

### 3.4.4. Trends shown by monitoring

Trends show a growing concern with waste production and limited resources. This has enhanced the development of recycling strategies, particularly for pavement and asphalt [36]. Further monitoring of materials could enhance other recycling strategies by providing information for interested partners for the use of materials.

### 3.4.5. Influence and use of monitoring results

In Greece, in the Attica Tollway project, a recycling strategy has been put in place. A material catalogue of recycle goods was identified. The list of goods include: used mineral oils, vehicles, tyres, dangerous waste, iron elements, electrical and electronic waste, batteries. In Hungary, the amount of waste collected during maintenance work and litter picking is recorded. The data is used to control the share of dangerous waste in collected waste (340 t out of 40,500 t in 2009).

### 3.5. WATER RESOURCES

#### 3.5.1. Impact of roads

Roads impact surface and ground water mostly through runoff or through leachates out of materials used in road construction. Road runoff accumulates pollutants produced from the wear of brakes, tyres and the road surface. Road runoff is a concern for surface waters also because of hydrological stress that can be induced. After heavy
rains, the quantity of water that may be evacuated can flush out smaller river courses or provoke flooding. De-icing agents are also pollutants that impact water resources along roads in northern countries. Accidental spillage during operation or construction is also a concern and a potential impact.

3.5.2. International thresholds

Legislation is various but leans on WHO recommendations for drinking water. In Europe, the legislation on water and the environment is regulated by two directives. These directives are the directive on the protection of groundwater against pollution and deterioration [37] (also know as the groundwater directive), and the directive establishing a framework for community action in the field of water policy [38] (also known as the water framework directive). Legislation on water can set limits to water line change due to projects (France, one centimeter limit to rise in water line). A special authorization for changes in water level or water flow regime can be requested.

3.5.3. Monitoring practice

Pollutants monitored

Out of the 21 countries that answered the questionnaire, 17 carry out water quality monitoring (figure 6). 16 countries have a water pollution databank. A majority of the participating countries carry out water quality controls related to roads and road infrastructures.

A summary of the monitored pollutants is shown in figure 7, following page. The most commonly monitored pollutant is Chlorine, which is a residual of de-icing salt compounds used during road maintenance in winter. Chlorine is monitored in 9 of the participating countries. Other monitored pollutants include gasoline additives, such as lead and MTBE, but also nitrate, copper, or cadmium, which are pollutants frequently found in roadside soils and plants. Several countries monitor emissions which are not listed, including: calcium, sodium, iron, potassium, sulphate, and water pH.

All of the 18 countries answering this part of the survey carry out some kind of water resources monitoring during at least one stage of the infrastructure project.
Monitoring during planning stage

Potential impact of future infrastructure on the water resource is assessed in the planning stage. Several types of impacts are taken into account: impact on the water level, on the water quality, or on the surrounding water catchment's area and local hydrology.

Most countries evaluate the impact on water quality (e.g. Romania, Sweden, Denmark, Scotland, Switzerland), by assessing the potential pollution from for road run-off to surface and groundwater and the risks of spillage of polluting material.

Water catchment basins are sensitive areas that are monitored in several of the participating countries. In Canada and France for example, a hydro-geological study is carried out during the EIA. A mapping of the surface- and groundwater network is performed in order to assess its initial state. The sensitive areas and the water outlets are identified. The alignment of the road must avoid the freshwater catchment areas.

A project can affect the level of the water table. Many countries (e.g. Denmark, Switzerland, Finland, France) evaluate the risks of changes in water level when pertinent to the project.
Monitoring during construction stage
Participating countries, such as Finland, monitor during the construction stage surface and groundwater in order to prevent pollution against predictable and accidental spillage.

Monitoring is used to check conformity and implementation of protection measures during construction: France has developed a procedure to control the proper implementation of measures. An evaluation is done, reporting accidents, and feeds back into the system. Survey operations and conformity controls are performed. In Hungary, an observation well is made in order to monitor groundwater quality. In the USA, sediment and erosion control measures are implemented to minimize the adverse impacts to surface and groundwater. Other countries, like Austria, only monitor surface and groundwater during construction in sensitive areas.

Monitoring during project operation
Monitoring is not often done during project operation and is mostly limited to sensitive stretches with potential impact (e.g. Austria, Switzerland, Japan). Chloride accumulation due to winter road maintenance is however an issue in Nordic countries and is often monitored (see case study in chapter 4).

Monitoring of drainage systems has been used in Scotland to ensure that no flooding arises and that the design is adequate to accommodate run-off of water after rainfall events.

Long-term monitoring
Some participating countries have a national water quality monitoring program (e.g. Switzerland, Austria, Romania). Those national programs are usually not specific to roads. Some countries have a national network of measuring stations, such as Romania and France. Nordic countries, such as Finland, make a special emphasis on monitoring Sodium Chloride in groundwater on large scales.

3.5.4. Trends shown by monitoring
Monitoring has shown an increase of salinity due to de-icing agents along certain stretches in Nordic countries. It has also shown the gradual stabilization and decrease of lead and the appearance of MBTE as a new pollutant. However levels do not appear problematic. Monitoring has also shown potential accumulation of heavy metals from road runoff in river course sediments.

3.5.5. Use and influence of monitoring results
Different monitoring programs have been essential in giving a sound basis for deciding when mitigation and treatment are necessary, and to scale measures efficiently.
For instance an intensive monitoring program in Switzerland gave the needed data for the appropriate design and scaling of treatment systems. Road runoff from a 1-km motorway stretch was monitored over one year [39]. The aim was to measure pollutants and correlate them with rainfall events. Results showed for example that runoff pollution is proportional to rainfall intensity and that the maximum pollutant load occurs at the beginning of the rain event in case of heavy rain, but later in case of light rain. Such monitoring results help distinguish which part over time of road runoff needs treatment. Thence the volume of treated water can be downsized, allowing to lower costs and improve treatment efficiency. [40].

In the UK, monitoring has been used to develop a highway runoff pollution model, the Highways Agency Water Risk Assessment Tool (HAWRAT). This tool models road runoff pollution evaluating the need for a water treatment system. More details are given in a case-study in chapter 4.

The monitoring of the efficiency of different treatment systems has helped evaluating which systems perform best for which situations [41]. This kind of information is essential for road planners.

3.6. SOIL

3.6.1. Impact of roads

Road infrastructures impact soils during construction when sealing permeable surfaces or through compaction of soil by machines. Soil is also impacted during operation through dry deposits from emissions out combustion engine and pollutants produced by wheels and brakes and accidental spillage of pollutants (oil, grease, fuel when filling tanks). These pollutants deposit on the roadsides and accumulate in the soil.

3.6.2. International thresholds

Legislation is heterogeneous, if it exists at all. The legal framework for soil protection is not very developed. Only a few countries mentioned regulations linked to soil pollution (e.g. Austria and Switzerland).

In Europe, a directive establishes the framework for prevention and remedial actions to address environmental damages, including soil [42]. All European countries are obliged to implement this directive into their national laws.

3.6.3. Monitoring practice

Pollutants monitored in soils
Approximately half of the participating countries monitor in some way soil pollution.
Out of the 21 countries that answered the questionnaire, 11 stated having a specific monitoring program for soil pollution and have databanks of soil quality in 10 cases (figure 8).

The most commonly measured pollutants among the participating countries are metals such as lead, cadmium, zinc and copper. About half of the participating countries declared monitoring these pollutants. Other monitored compounds include polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and manganese.

**Monitoring during planning stage**
In Mexico and in the USA, the EIA describes the soil composition prior to the project and evaluates how it will be affected by the change of use. In Australia, acid sulphate soils, erosion, and fertility of the soil are measured prior to starting the project.

**Long-term monitoring**
Databases for long-term monitoring exist in a few countries (e.g. France and Switzerland). They are not specific to roads but contain pertinent information. One aim of the databases is to allow soil pollutant cartography and spatial analysis.

In Romania, regular measurements and evaluations are performed, especially for heavy metal pollution, and gathered in monthly reports, but are not directly correlated to roads. In Scotland, there is a focus on risk assessment of slopes adjacent to road network as part of climate change adaptation processes.

Polluted earthworks is an issue mentioned by several countries. Management plans are used in France and in Denmark, for polluted earthworks. The plan might include confining the polluted soil on-site, treatment by phytoremediation, or external storage, according to the degree of pollution.

Monitoring can focus on a specific risk. In Portugal develops monitoring programs only when the project carries a situation of high risk of soil or water contamination.

The agricultural value of the soil is one of the indicators used by the participating countries (e.g. Austria, Portugal) during the EIA in order to assess the quality of the soil and evaluate the impact of the project. Portugal identifies areas of high value, from an agricultural or ecological point of view, so as to protect them. In Scotland,
the effects of the project on soil quality are assessed via its agricultural capacity. Topsoil and subsoil protection is monitored to ensure minimal erosion during the construction.

3.6.4. Trends shown by monitoring

Monitoring has shown the accumulation of heavy metals in roadsides over time. These appear mostly stable and not to leach out over time. In Germany, the pollutant content in roadside soil material was monitored and the results published in a comprehensive study [43]. Results showed that motorways represent the road-type accompanied by the highest levels of pollutants and that soil concentrations of many substances (e.g. lead, cadmium, copper, zinc) exceeded precautionary values. Monitoring results further showed that 95% of the eluate concentrations of pollutants were below negligibility levels, thus highlighting the filtering action of roadside soils.

3.6.5. Use and influence of monitoring results

Monitoring has shown how soils can be impacted and permitted an evaluation of that impact. Soils from roadsides do not appear to be a problem as long as they are not translocated elsewhere. In Switzerland, soil pollution caused by road transport has been specifically studied [44]. Monitoring showed that the strongest pollution in soil along roads is due to the presence of lead, followed by cadmium and zinc. Monitoring also showed the effect of the ban of lead in gasoline on soil pollution, with levels declining progressively over time.

3.7. BIODIVERSITY

3.7.1. Impact of roads

Roads impact both fauna and flora. The primary effects are loss of natural habitat, barrier effects, fauna casualties, disturbance and pollution. These effects put together cause fragmentation, which is the splitting of natural habitats into smaller, more isolated patches (figure 9, following page). Habitat loss and fragmentation are the most significant threat to biodiversity [22]. Flora is impacted through the physical changes of habitat due to: gaseous emissions, salts, change in soil pH. Roads are also a vector facilitating the dispersal of non-indigenous and invasive species.

3.7.2. International thresholds

Countries have integrated international obligations (Rio convention, 1992), regional obligations (EU-directives for example) in their national legislation (e.g. national regulations, code of practice).
International treaties related to biodiversity exist, such as the Ramsar convention on wetlands (159 countries), the Bern Convention on the Conservation of European Wildlife and Natural Habitats, or the Bonn convention on Migratory Species. More recently, the Intergovernmental Platform on Biodiversity and Ecosystem Services has been set up in order to tackle changes to biodiversity. It is noted that none of the above-mentioned treaties is specific to roads.

In Europe, ambitious policies for biodiversity preservation are in place, with a scheme to monitor progress towards 2020 targets. Two directives form the European legislative framework: the Habitats Directive and the Bird Directive. Under these directives, a network of nature protection areas has been established, called Natura 2000. Natura 2000 is the centerpiece of Europe's nature and biodiversity protection.
policy. The Habitats Directive requires a precautionary principle; projects can only be permitted if there is no adverse effect on the integrity of the site.

In France, the national strategy focuses on action plans to reduce the impact of large infrastructure projects on biodiversity, for instance by restoring ecological corridors, optimizing routing and alignment, or making builders sensitive to biodiversity issues.

### 3.7.3. Monitoring practice

#### Aspects monitored

Natural habitats constitute territorial entities susceptible to react to the changes due to transport infrastructures. The observed effects on natural habitat are often complex and result from a combination of disturbances.

16 participating countries reported monitoring possible effects of roads on biodiversity and 15 countries declared having a national biodiversity program with 4 linked to roads *(figure 10).*

<table>
<thead>
<tr>
<th>Monitoring possible effects of roads on fauna</th>
<th>National biodiversity program</th>
<th>National biodiversity program linked to roads</th>
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<tbody>
<tr>
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<table>
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<tr>
<th>Monitoring methods</th>
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<table>
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<th>Observation of change behaviour, stress</th>
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<table>
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<th>Toxic emissions</th>
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<td>no</td>
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*FIGURE 10 - SUMMARY OF THE ANSWERS TO THE QUESTIONNAIRE ON BIODIVERSITY COLLECTED FROM THE 21 PARTICIPATING COUNTRIES*

It is noted that the monitoring type, the method used, and the issues raised are project-dependent. In the field of biodiversity, monitoring is usually based on species inventories made specifically for each project and is carried out by biodiversity experts.
Monitoring during planning stage
Monitoring of the impacts of roads on biodiversity is often required by national legislation in the planning stage (e.g. Mexico, Australia, Austria) and linked to the EIA process. Most countries that answered this part of the questionnaire do inventories or census of species during the planning stage or during the evaluation of the project's impact. Some like Mexico perform a quantitative and qualitative inventory of the fauna and flora species, using biodiversity databanks and field studies. In Canada, an extensive census of the fauna and flora is performed. Parameters such as habitats and species are recorded, but also migration (for example fish upstream and downstream migration), reproduction, foraging and shelter. Other countries performing a species census include Switzerland, France, or Denmark. In some countries, such as Mexico, there is an emphasis on monitoring sensitive species (rare, threatened, or endangered), which are especially at risk.

Evaluating fragmentation and impacts on fauna may include using road casualties and hunting statistics to establish main wildlife corridors (Hungary, Finland). Hungary also examines pollution in tree leaves.

Monitoring during construction stage
Monitoring during construction stage aims at protecting sensitive species. For most countries, monitoring during the construction stage depends on the agreements in the EIA. It is conditional (e.g. Switzerland, Australia) to situations with sensitive ecosystems or species, or to construction stretching over several years.

In Romania, fauna monitoring usually involves observations of the behavioral changes and stress of the species due to construction, whereas the flora monitoring involves measurements and observations of the pollutant levels, especially dust, and how the photosynthesis process is affected.

Monitoring during project operation
During the project-operation stage many countries use monitoring for the assessment of the success of mitigation measures proposed in the EIA and implemented. Austria has initiated a monitoring programme along 4 motorways to systematically evaluate the efficiency of measures (see case study n°8). Proposals for future improvement are made that can benefit other projects.

In France, an intermediate assessment is carried out after the commissioning of the project. During this assessment, compliance of the mitigation measures is controlled, and monitoring of fauna mortality is performed, with date and place of the deaths along the infrastructure. France appears to have the only standard final assessment of the project made 3 to 5 years after commissioning. Parameters such as fauna mortality, fauna passages, evolution of the natural vegetation or qualitative evolution of the habitats are monitored.
Most monitoring is project specific and defined in the EIA. It may be of vegetation development, habitat translocation, reforestation or the other mitigation measures with a focus on helping to improve future projects by improving measures design. It may be limited to a one time control or a repeated control over time. In Romania, monitoring during project-operation is defined during the planning phase, and usually involves the efficiency control of the technical solutions used for species protection and an assessment of the measures taken to limit habitat fragmentation. The project operation phase usually involves the ecological rehabilitation of surfaces used temporarily, and the measurement of significant pollutants that could affect vegetation.

In Denmark monitoring of mitigation measures and wildlife passages is not standard, but several assessments have been being carried out, on the efficiency of fauna passages across a motorway, and an inventory of conflict points between animals and traffic on state roads. In Finland, monitoring is very much project-dependent, and can include fauna monitoring, efficiency assessment of fauna underpasses, or quadrate monitoring of flora. Switzerland has set standards for the monitoring of wildlife overpasses. Follow up is required in the EIA.

Monitoring sometimes focuses on vegetation. It has been used to identify local species having a higher tolerance to salts used for winter maintenance. According to a study on the environmental impacts of spread de-icing salts in Japan [49], there is a correlation between the quantity of saline spray used on roads and the salinity of the leaves of the plants on the road verges. If the salinity of the leaves exceeds a certain value, damage is observed.

**Long-term monitoring**

Fauna casualties are a recurrent indicator measured in most countries (Denmark, Spain, Scotland, Switzerland, USA) on network and long-term basis. Different countries record wildlife casualties (e.g. UK with Scotland, USA with Maryland) and feed the information back into the mitigation design for future road improvement.

In Finland, the impacts of road infrastructure construction were monitored over six years for 2 projects. The monitored species included flora, beetles and birds. In the case of a new highway it was found that traffic-induced vibrations had a large impact on the beetle population. Bird populations were affected differently, some species benefited while other species suffered from the new highway. In the case of road upgrading scheme, no significant impact on flora, but a significant negative impact on birds, mainly due to traffic noise (*figure 11, following page*) was found.

### 3.7.4. Trends shown by monitoring

Monitoring has shown through casualty counts the increase in fragmentation as infrastructure networks grow. It has also helped to show which species are most
impacted. This depends on bio-geographical regions. Some studies have shown sensitivity towards noise among certain species. Other studies have shown the importance of roadsides as dispersal corridors. Monitoring of wildlife passage has been essential in defining appropriate design, with narrower passages showing less effectively.

### 3.7.5. Use and influence of monitoring results

Monitoring is used mostly to optimize projects. Maryland USA provides the example of a bypass project stopped during the design process when a small turtle was listed as a federally threatened species and given protection under the Endangered Species Act. Monitoring was put in place to determine the presence and movement activities of the turtle along the proposed road corridor. Monitoring results were used to develop a roadway design that meets both the needs of the turtle and its habitat, and the needs of the town’s traffic congestion problems [51]. Monitoring results were also used to implement other measures, such as purchasing lands and wetlands which support the turtle populations, providing a vegetation management strategy to create and support the preferred cover for the turtle, studying the hydrologic resources which support the wetland habitats for the turtle vegetation, and increase the publics’ understanding through teaching and learning opportunities.

In Romania, the implementation of Natura 2000 Network has resulted in monitoring construction projects. In one case (National road 19) this lead to significant design changes, such as redesigning culverts for amphibian protection and installation of protective guardrail to guide endemic amphibians (figure 12, left, following page).
Monitoring is used for efficiency control of mitigation measures. Portugal provides an example of monitoring of culvert design along a highway (figure 12, right) showing a good response from small carnivores to dry ledges.

Monitoring helped identify possible improvements, such as mounting barbed wire at the top of fences to discourage animals from climbing over fences.

3.8. LANDSCAPE

3.8.1. Impact of roads

Road infrastructures impact the landscape through cut and fills, imposive structures, such as bridges and viaducts, and by fragmentating landscape units. Often new roads are followed by new urbanisation, with ribbon development along the road. The impact of roads on cultural heritage and historical landscapes is an important concern. As a consequence, lots of efforts are made to integrate the infrastructure into the surrounding landscape. Techniques used to limit the impact include blending the infrastructure into the scenery, or compose with the surroundings in order to achieve some visual harmony.

Other impacts of roads on landscape include the impacts on archaeological and historical sites.

3.8.2. International thresholds

Landscape monitoring is not common and heterogeneous approaches have been developed. Often landscape is included in national or regional spatial development plans and legislations. At the international level, a European convention exists, the "European Landscape Convention", adopted in 2000 and ratified by 30 countries of the Council of Europe. This convention aims at the protection, management and planning of all landscapes and at raising awareness of the value of a living landscape.¹⁶

¹⁶ http://www.coe.int/EuropeanLandscapeConvention
3.8.3. Monitoring practice

Two aspects of landscape monitoring emerge from the answers: archaeological findings and landscape restoration. Landscape restoration and landscaping aesthetics is a current issue among some of the participating countries.

Monitoring during planning stage

Landscape monitoring is integrated during the planning stage in the EIA. This can take several forms. Canada monitors cultural heritage by studying scenic roads, visual landscape characteristics or agglomeration entries, and the impact of light pollution. In Scotland, the predicted effects of a scheme on the cultural heritage are evaluated, including the indirect effects on setting and on historic landscapes. There, at the recreational level, the effects of the project on paths, cycle routes and recreational areas walking and cycling routes are also evaluated. In Japan, a site survey should be conducted before construction to protect the cultural properties. In the USA, the changes to the aesthetics of an area are examined, with the possibility of using landscaping as a mitigation tool in the impacted areas.

Archaeological and historical considerations are also taken into account in different countries. Greece and Portugal have strict archaeological guidelines for excavations in order to protect the cultural heritage. Mexico requires that every project be presented for authorization to a national institute of anthropology and history in order to determine whether cultural heritage could be affected. In France, both an archaeological diagnosis and preventive excavations are done during the EIA. In Switzerland, projects are reviewed to assess the potential impact on archeological sites. If a site is impacted, it must first be fully documented and, if possible, all valuable elements saved.

In general, it appears that during the planning stage countries develop studies to analyze the landscape, identifying the sensitivities of the territories. Projects include measures to mitigate impacts. One of these measures, common in many countries, is landscaping with revegetation of affected areas by construction.

Monitoring during construction stage

Monitoring is seldom done during the construction stage. Some examples were cited such as the monitoring landscape plantings during construction in the U.S.A or monitoring the visual evolution of the landscape during project development (e.g. France, Portugal) through a photographic survey.

Monitoring during project operation

During project operation, several countries assess the effect of the infrastructure on landscape. In Austria, a post-project analysis is carried out 3 to 5 years after commissioning. In Finland, a photographic follow-up of the cultural landscape is
carried out. In France, a series of controls are made, such as assessing the conformity of the spatial development, and the usefulness of the excavation work in terms of knowledge advancement. In the USA, plantings are monitored, and replaced as necessary.

**Long-term monitoring**

Long-term monitoring is scarce. It is often carried out by spatial development authorities at the national or regional level. In France a post environmental assessment of the project is carried out. It assesses the effect of the construction on cultural heritage.

Switzerland monitors the global and local changes in landscape by measuring the evolution of the number of kilometers of roads built. The record dates back from 1972 and is based on aerial photography and topographic maps. A periodic report is produced to monitor the evolution [52]. This study is used as a general indicator on land use for policy towards better spatial planning.

The "effective mesh size" (meff) and the "effective mesh density" (seff = 1/meff) [53] [45] are suggested as a physical measure of the degree of fragmentation. The effective mesh size is an expression of the probability of two points chosen randomly in a region being connected, that is no separated by barriers such as transport infrastructure, urban areas, or natural features. The more barriers in a landscape, the lower the probability that two points will be connected, and therefore the effective mesh size. The effective mesh density represents the number of meshes per 1,000 km² of surface area. The effective mesh size would be 0 km² in an area completed covered by urban structures. It has been used as an indicator for trend analysis in Germany, Switzerland, Italy, France and Canada. The "effective mesh size" allows for comparison between regions as well as between time series. The European Environment Agency is engaged in a cross-country comparison.

**3.8.4. Trends shown by monitoring**

A study of the effective mesh size from series from 1885 to 2002 in Switzerland have shown that the effective mesh size in Switzerland has decreased by 70% since 1885 from 580 km² to 176 km². Correspondingly, the effective mesh density has increased by 230% over this time period from 1.7 meshes per 1,000 km² to 5.7 meshes per 1,000 km². Monitoring has shown the strong urban development that roads induce specially around junctions. Ribbon development has been identified as a new problem in many regions.

**3.8.5. Use and influence of monitoring results**

Photographic monitoring can help measure whether landscaping goals have been met. Monitoring provides a tool for better understanding of the interactions between
Monitoring of environmental impacts of roads and spatial development. The understanding of these interactions and dynamics need to be integrated in urban planning. Trend analysis is important for future infrastructure planning.

4. CASE STUDIES

4.1. CASE STUDY 1. MONITORING AIR AND NOISE AS A BASIS FOR POLICY IMPLEMENTATION IN SWITZERLAND [54]

4.1.1. Political background

The Swiss transport policy requires that merchandise transiting through the ecologically sensitive Alps should whenever possible be by rail instead of road. From 2019 onwards, only a maximum of 650,000 heavy goods vehicles shall cross the Swiss Alps per year. In return, Switzerland offers an efficient rail infrastructure for transalpine carriage of freights.

The main transport routes on road in the transalpine freight traffic are the Gotthard motorway (A2) and the San Bernardino motorway (A13). The monitoring of air and noise pollution along these two motorways shall show the effects of the supporting measures when the freight is shifted from road to rail.

4.1.2. Measuring concept

Six measuring stations have been placed directly beside the motorways (figure 13, following page) since 2003. These stations cover the typical geographical regions affected by the north-south traffic (Jura, midland, alpine region). Transport-specific parameters for air pollutants and noise are collected to investigate the environmental impacts of traffic, and particularly of heavy freight traffic on the motorways. The noise impact of rail along the north-south axes is monitored at two stations by the Federal Office of Transport.

In this way, the trend of the impact of (freight) traffic on noise and air pollution on the north-south axis shall be monitored. The monitoring results are included in a report of the Federal Council, published every two years.

4.1.3. Monitored parameters along the motorway

Parameters for traffic, weather, air pollution and noise are collected. Figure 14, following page shows an illustration of the data collected at an MSM-E station.
Monitoring of Environmental Impacts of Roads

Figure 13 - MSM-E Monitoring Stations Air and Noise
Motorways are shown in solid grey, railways in dashed grey

- Monitoring stations roads (A2, A13)
- Monitoring stations rail (Lötschberg, Gotthard)

Figure 14 - Example of a Measurement Station MSM-E

Meteo
- Temperature - 10m
- 2m - wind, humidity, rainfall, solarization

Air
- NOx, NO2, NO, CO, O3,
- VOC, PM10, PM2.5,
- Number and surface of particles, carbon black

Noise
- Leq (A), Lmin(A),
- Lmax(A), Lmax(LIN),
- Terz-Spectra

Traffic
- 10 categories, average v,
- Number PW, LKW
4.1.4. Key results

The monitoring of air pollutants at the MSM-E-stations in the period 2003-2008 shows that:

• because of special topography and meteorological effects, Alpine valleys are sensitive to air pollutants. For example, the same amount of nitrogen oxide emission causes a three-fold increase in the level of emissions in the Alpine region, compared to the midland;
• in 2007, heavy goods vehicles emitted in 2007 about 60% of the total NOx emissions on the A2 and A13 in the Alpine region with a share of only 10% of the total kilometres travelled;
• there are significant regional differences in air pollution; the NO2 emissions range from 25 to 65 µg/m3, while the PM10 emissions range from 12 to 32 µg/m3;
• in spite of the large regional differences, the pollutant concentration tends to decrease in the period 2003-2008;
• the thresholds for NO2 and PM10 are exceeded at all the measuring stations along the Gotthard route (A2);
• if the 2003-2008 trend continues, a further improvement of air quality can be expected. The target limits of the Ordinance on Air Pollution Control, however, will still not be met without additional measures aimed at reducing pollutant emissions.

The monitoring of noise shows that:

• the Alpine valleys are sensitive to noise propagation not only because of the topography but also because of meteorological effects (inversions);
• the annual average noise levels in the period 2003-2008 have not significantly changed. There was no reduction in noise;
• noise during the night (10 pm to 6 am) is 6 to 8 dB lower than noise during the day. Since the Noise Ordinance recommends a threshold difference of at least 10 dB between day and night, these results should be improved;
• noise in the early morning from 5 am to 6 am is mainly produced by heavy goods vehicles;
• a single heavy goods vehicle causes about as much noise as ten cars;
• on Sunday afternoons, the noise level is nearly as high as on weekdays. The noise caused by road reflects social activities;
• road surfaces and tyres have great potential to reduce road noise emissions.

4.1.5. Outlook

Based on the limited measurement time, it would be premature to draw general conclusions on trends of air pollution or noise. It will be interesting to see how cleaner motor technology (Euro norms) will be reflected in the collected data.
4.2. CASE STUDY 2. MONITORING AT THE PROJECT LEVEL - CONSTRUCTION PHASE - LISBON REGIONAL INTERIOR RING (LANDSCAPE MONITORING)

4.2.1. Overview of the project

The Lisbon metropolitan area has 2,700,000 inhabitants (it is the greatest population centre in Portugal). Daily traffic flow in the region ascends to more than 700,000 vehicles of all types. Planned since 1980 in the national road program and in the regional transports program, this project consists of an internal ring of roads that ensures connections between several roads coming to Lisbon.

The rationalization of the traffic flow, coming daily to Lisbon, will keep the heavy traffic away from the city centre.

This Ring is placed in the north of Lisbon and goes along the city limits, stretching from Algés, in the West, to Vasco da Gama Bridge, in the East.

A missing section is still to be built. It is in the construction phase. The technical characteristics are:

• 3,650 meter-long IC17/CRIL – Buraca/Pontinha section and 770 meter-long IC16 – Radial da Pontinha section

FIGURE 15 - ROAD NETWORK OF LISBON’S METROPOLITAN AREA
• 7 junctions (Buraca, Damaia, Portas de Benfica, Pedralvas, Alfornelos, Benfica (IC16), Pontinha);
• 28 restorations of local roads;
• 8 overpasses, 2 underpasses, 2 viaducts;
• 2 tunnels on IC17, of length: 1,500 m and 240 m;
• 2 tunnels on IC16 of length: 290 m and 80 m.

This section is located in a very dense urban area where there were many degraded buildings. This work gave an opportunity to rehabilitate the area and to give the population new green spaces, better accessibilities and an improve urban landscape.

4.2.2. Landscape monitoring

It was decided to implement a landscape monitoring in order to check that the landscaping measures fulfilled their goals, and adapt them where needed. During the initial phase of the project, the effects of the project on landscape were studied using visual simulations (figure 16). Subsequently, a series of important points along the alignment of the future road were identified, and a photo monitoring every three months was implemented.

![FIGURE 16 - INITIAL SITUATIONS (LEFT) AND VISUAL SIMULATIONS (RIGHT)](image)

4.2.3. Results

The result of this monitoring is a series of photos of the selected points during the entire construction phase and during the operation phase.
4.2.4. Outlook

Current results already show that the entire area is benefiting from the project. New spaces are being created with vegetation, which contribute in giving a new look to the surroundings.

The photographic monitoring will continue until all the works are finished, and during the operation phase. This will help identify places where further work is needed in order to fulfill the initial objective of improving urban landscape.

4.3. CASE STUDY 3. THE OPERATION PHASE: URBAN MOTORWAY MONITORING IN GREECE

4.3.1. The project

Attica Tollway, one of the biggest peripheral roads in Europe, constitutes an infrastructure project which has revitalized the congested area around Athens, since it is essentially a fully access-controlled Tollway within a metropolitan area. The 65 kilometer – long Tollway consists of 3 traffic lanes and an emergency lane in each direction and a high speed rail runs along its central strip. The payment of tolls is carried out via both manual (toll collectors), as well as electronic (transponders) methods.

As a new motorway in the metropolitan capital of Athens, Attica Tollway faced significant difficulties because of the complexity of constructing a motorway in a dense urban area, with limited room for expropriation and an already congested road network. In addition, the metropolitan area of Athens faced significant problems regarding air quality and noise, as a direct result of the already congested network, and hence, design and construction of the new motorway was carried out following all relevant Greek and European legislation, to ensure the greatest degree of environmental impact alleviation. It is, however, through continuous environmental post-monitoring during operation that the impacts are measured and special measures are taken, when and where necessary.

Attica Tollway has been established as one of the most environmentally-friendly motorways in Europe and Attica Tollway Operations Authority was awarded the first prize in 2008 in the IRF GRAA competition in the category of Environmental Mitigation.

4.3.2. Air quality and noise level measurements

The levels of air pollution and noise are monitored constantly by eight air-pollution measurement stations, located at key locations along the motorway, as shown in
figure 17. Reports are issued every quarter and submitted to the Ministry of Environment, showing levels and trends of air and noise pollution. For noise monitoring, in addition to permanent measuring stations, 24-hour acoustic measurements are carried out in 200 different locations every year using mobile measuring stations (figure 18).
In order to assess air quality, the following emission levels are monitored:

- Carbon monoxide (CO)
- Nitrogen monoxide (NO)
- Nitrogen dioxide (NO$_2$)
- Total volatile organic combinations (TVOC)
- Dust (PM10).

In compliance with the European Directive relative to air quality [10], Attica Tollway now monitors PM2.5 and benzene levels. Noise levels are monitored using the following parameters:

- L10 (18h)
- LAeq (08.00-20.00)
- LAeq (24h)
- Lday (07.00-19.00)
- Levening (19.00-23.00)
- Lnight (23.00-07.00)
- Lden.

### 4.3.3. Results

#### Air quality

Monitoring shows that air quality conditions have improved since the construction and operation of Attica Tollway. According to the study carried out in 2006 by the National University of Athens [55] total emissions in the metropolitan area of Athens were reduced with the operation of the Tollway. In certain areas, emission levels increased, but remained well within the levels defined by the EU (EU Directive 2008/50/EC). However, in the centre of Athens, which greatly suffered from severe congestion and high emissions, emissions were reduced, while the total change in the emissions in the greater Athens area was very small. In other words, construction of a new road did not significantly worsen living conditions, but it re-distributed traffic and relieved traffic congestion in the capital overall.

Air pollution monitoring results in 2008 and 2009 show that in general, NO$_2$ and CO values never exceed the values stated by the European Union legislation, which are 200 μg/m$^3$ and 10 mg/m$^3$, respectively. As far as PM10 are concerned, the limit of 50 μg/m$^3$ is exceeded in a few cases, but not more that 35 times per year, as stated in the relevant legislation (EU Directive 2008/50/EC).

#### Noise levels

In general, measurements fall below the limits of the relevant legislation. However, a series of noise-protection measures are taken whenever and wherever the need
rises, such as the installation of noise barriers (with a length currently exceeding 18 km), as well as the construction of buffer zones and the planting of slopes and embankments, as shown in figure 19. In addition, when complaints regarding noise levels are received, the mobile station carries out noise measurement in the area, to ensure that the quality of life and the health of the people living near the motorway is not compromised.

In recognition of its efforts in monitoring and mitigating noise-related disturbances, Attica Tollway was nominated for the “Décibel d’Or” prize in 2003, for the program "Management and reduction of Road Noise Pollution from the Operation of Attica Tollway".

Besides monitoring noise and pollution levels along the motorway, noise, pollution and vibration levels are also regularly monitored at the toll stations, to ensure a safe working environment for the toll collectors.

4.3.4. Outlook

A new road, and certainly an urban road with more than 300,000 vehicles per day such as Attica Tollway, will always have an impact on noise and air emissions. However, constant monitoring offers the opportunity to mitigate the negative effects and improve living conditions in the areas affected by the new road. Technology and research offer a great variety of solutions (noise barriers, pollution-repellent paints, planting, etc.), it is a matter of investigating and finding the solution that is most appropriate. Attica Tollway Operations Authority is dedicated to remaining a “green motorway” and is proactive with regard to bringing different solutions to possible problems that will arise, sooner or later.
4.4. **CASE STUDY 5. MONITORING AT PROJECT LEVEL: LEACHING OF POLUTANTS FROM THE SUBBASE**

4.4.1. **Context**

Since the 1990's the issue of road construction with wastes and secondary materials has led to various studies and programs aiming at clarifying its technical, economical and environmental feasibility. Indeed, alternative material placed inside road structure will be submitted, for long term periods, to mechanical and thermal stresses, soaking and drying effects, both responsible of physical and chemical changes, and infiltrations (*figure 20*). The goal of this diagnosis is to determine the state of municipal solid incinerator bottom ash (MSWIBA) as well as its close environment, after several years of service in the road structure, in the aim to assess any possible impact. For this, road inspections allow to assess the mechanical durability and the environmental impact of the MSWIBA layer, under actual conditions of use. Besides, laboratory tests, both mechanical and environmental, allow characterising these materials with respect to the present references.

![Figure 20 - Road-soil-water system](http://ofrir.lcpc.fr, carex)

4.4.2. **Description**

The studied infrastructure is an urban road build in France in 1978. MSWIBA was used in the subbase. The portion of the road made of MSWIBA is 430 m long and 10 m width. The structure of the road is presented in *table 1, following page*.

The studied waste was produced in 1978 and stored on the production site. It is a mixture of MSWI bottom ash and fly ash, as in this period, the separation between these two materials was not achieved. This material was simply prepared by means of a coarse iron removal and no ageing was carried out before use. The material was used as an unbound graded aggregate.

17 [http://ofrir.lcpc.fr, CAREX](http://ofrir.lcpc.fr, CAREX)
4.4.3. Study context

- climate: annual rainfall between 600 and 700 mm, temperature between 40.4°C and -21°C;
- hydro-geology: no water-table;
- road traffic: 12,000 vehicles/day and a bus line. No heavy lorry;
- maintenance: During winter, some de-icing operations may be carried out.

4.4.4. Indicators used in the study

Two indicators\(^{18}\) are used to characterize soil after a relatively long period of service time:

- Soil indicator (IS)
- Road effect (RE)

4.4.5. Results of the diagnosis

A diagnosis was carried out 20 years after the implementation. Results are as follow: regarding the sub-soil quality, high chromium and zinc concentrations, lower than intervention limit values of the Dutch standard [Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieubeheer, 2000. Circular on target values and intervention values for soil remediation], are observed all across the vertical profile. Chromium, nickel and zinc concentrations are clearly higher in the deepest levels of the soil than upper. This is not so regarding cadmium, copper and lead. In order to interpret better these results, they were compared to a reference soil chosen in the neighbourhood.

Heavy metal contents are low with nevertheless a slightly higher content in the upper level for copper and lead. However, all measured concentrations are lower than intervention limit values of the Dutch standard.

\(^{18}\) Detailed in Jullien and François (2005) [56]
Chemical composition and leaching behaviour:

Among the measured elements, one can see those measured during the leaching test (aluminium, cadmium, chromium, copper, iron, manganese, nickel, lead, zinc) and other like silicium, calcium, potassium and sodium. Most abundant elements are, by decreasing order, silicium (due to the presence of glass), calcium (calcium carbonate), iron (scrap), sodium and aluminium (metal) (from more than 100 to 10 g/kg), the magnesium, potassium, zinc and manganese (10 to 1 g/kg). As a whole, the solubility of this MSWI residue is low. Leaching tests were carried out according to the NF X 31-210 standard (i.e. MSWIBA authorized for road use). For all the parameters, the studied material is below the threshold values required for class-V MSWI bottom ash (allowed for road use), with the exception of loss-on-ignition (LOI). The soluble fraction is low. Total chromium, measured instead of chromium VI, is lower than the limit value required for the latter. The pH is almost neutral.

4.4.6. Conclusion

The diagnosis showed that the state of the road and its environment is, as a whole, correct. Mechanical properties correspond well to users’ requirements and no significant environmental impact on the subsoil was noticed.

4.5. CASE STUDY 6. MONITORING DURING OPERATION: SALT IN GROUNDWATER IN FINLAND

4.5.1. Context

In Finland, groundwater is a highly appreciated natural source for drinking water, and most towns have their own water plants connected to local groundwater. In winter, de-icing agents (salts) are used for maintenance on roads undergoing the highest traffic loads. De-icing is implemented according to traffic volume and safety strategies. In the Turku road district of the Finnish Road administration, salted roads represent a total length of 1,914 km, of which 150 km are located on groundwater catchments areas. These de-icing agents flow into groundwater. Monitoring of chloride in groundwater started in 1994.

Road and environmental authorities work together to evaluate the resilience of groundwater areas affected by the salting of roads. Resilience has been approached with the help of a risk assessment database.

4.5.2. Chloride level limits

The recommended upper limit for chloride content in drinking water is 250 mg/l. However, chloride levels above 25 mg/l already corrode plumbing materials and can
dissolve harmful substances from the pipes into drinking water. Thus in Finland the allowed chloride limit in groundwater is 25 mg/l.

Since natural background level for chloride is approximately 5 mg/l, it is easy to calculate the amount of salts that originated from the salting of the road. For instance, if the monitored amount of chloride is 55 mg/l, then 50 mg/l originate from roads.

The Finnish Environmental Protection Act [57] explicitly states that it is prohibited to deposit a substance in a way that makes groundwater hazardous to health (groundwater pollution prohibition). It also states that operators must have sufficient knowledge of their activities' environmental impact and risks and of ways to reduce harmful effects.

4.5.3. Monitoring

In the Turku district, chloride groundwater monitoring is conducted at observation points, which are defined in agreement with the environmental authorities. The number of measurement points change from year to year, according to need. As an example, in 2010 there are 22 measurement points, assessing 15 groundwater areas. In addition, the Finland Environment Agency performs monitoring in four other points, as part of a national monitoring programme.

Monitoring consists of taking a sample of groundwater at water table level, and measuring chloride concentration, electrical conductivity, pH and sulphate concentration. This is done twice a year for the district monitoring programme (May and October), and 4 times a year for the national monitoring programme (March, May, October and December).

4.5.4. Use of monitoring results

Monitoring results are used to predict changes in drinking water quality. They enable timely actions, for example the decision of temporarily limiting the amount of salt used in a given road portion. As a result, salts are also used more rationally, which has the effect of reducing the overall use of salt. For example, in the Turku district, an average of 19,000 tonnes of salt was annually used in the period 1988-1991, whereas in the last few years the annual quantity fell to 13,000 tonnes.

Monitoring results are used to establish a pollution risk database. It consists in assigning points to the different roads and their associated groundwater, so as to evaluate which road portion poses the highest risk with respect to groundwater chloride pollution. Areas with the highest risks are given priority for the construction of a groundwater protection infrastructure (shown in chapter 4.5.5). The higher the score, the more important it is to construct a protection. For example, 100 points
mean high pollution risk, 50 points mean low pollution risk. As mitigation is very expensive, monitoring is essential for prioritising targets.

4.5.5. Groundwater protection

The main mitigation measure used is to build protections on roadsides to prevent harmful substances from flowing into groundwater *(shown in figure 21)*. In addition to preventing the flow of salty drainage waters, they also prevent harmful substances (such as tanker accident components) from entering groundwater. To date, a total of 28.8 km of protections have been implemented in the Turku district. A schematic of the groundwater protection is shown in *figure 22*.

![Groundwater protection along a road in Finland](image1)

*FIGURE 21 - GROUNDWATER PROTECTION ALONG A ROAD IN FINLAND
LEFT: DURING THE CONSTRUCTION WORK, RIGHT: IN OPERATION*

![Cross-section of the groundwater protection](image2)

*FIGURE 22 - CROSS-SECTION OF THE GROUNDWATER PROTECTION*
4.6. CASE STUDY 7. MONITORING DURING OPERATION: HIGHWAYS AGENCY WATER RISK ASSESSMENT TOOL (HAWRAT)

4.6.1. Context

A range of soluble and sediment-bound pollutants from vehicles, road wear and road maintenance activities accumulate on the highway until a rainfall event transports them to a receiving watercourse. Previous research has indicated that pollutant concentrations in this highway runoff are generally low and often close to analytical limits of detection. However, under certain conditions, it is possible that the pollutants in highway runoff may exert an impact on the aquatic organisms in the receiving water.

The Water Framework Directive (WFD) has added new pressure on highway authorities to assess and prevent the pollution of watercourses and ground water from road surface water.

Without a robust environmental risk assessment technique, the Highways Agency (HA) could have been faced with the installation of unnecessarily complex and expensive treatment systems in order to meet WFD objectives.

4.6.2. Approach

It is not practical to thoroughly assess the ecological effect of highway runoff at each outfall as this would require monitoring which would be extensive in both the number of parameters studied and the length of the study – not least because highway runoff is intermittent and other non-highway discharges may affect aquatic ecology. Furthermore, there is no way of monitoring the effects of a new outfall before it is installed. The solution was to construct a tool which could use detailed research findings to underpin predictions of pollution risk at all existing and proposed outfalls.

Hence the focus of a Highways Agency-led research initiative, undertaken in partnership with the Environment Agency (EA), to provide underpinning monitoring data and an understanding of the nature and impacts of pollutants in highway runoff.

This research has led to the creation of the Highways Agency Water Risk Assessment Tool (HAWRAT), and will ensure that the HA meets the requirements of the Water Framework Directive (WFD).

4.6.3. Monitoring and research

The HA and the EA commissioned five research projects. The first project, carried out by the company WRc, aimed to provide monitoring data that could be used to predict
Monitoring of environmental impacts of roads

Pollutant concentrations in highway runoff were measured for over 2 years at 24 sites spread across 4 climate regions in England. Results from 280 rainfall events were collected during this period. The sites covered traffic volumes ranging from 11,000 vehicles/day to 160,000 vehicles/day. Many pollutants were identified across all of the samples but few of these occurred with sufficient regularity to be useful for making predictions. The key soluble pollutants which occurred in all of the samples were found to be copper and zinc. The key sediment-bound pollutants were copper, zinc, cadmium and certain polycyclic aromatic hydrocarbons (PAHs).

The second project, carried out by WRc and King’s College London, used field and laboratory-based controlled exposures of fish, algal and invertebrate species to establish toxicity thresholds for short-term exposure to the key soluble pollutants. An example of the research outputs is shown in figure 23 – a Species Sensitivity Distribution for cadmium.

![Species Sensitivity Distribution](image)

**FIGURE 23 - EXAMPLE OF A SPECIES SENSITIVITY DISTRIBUTION OF DATA FOR DIFFERENT ALGAL, INVERTEBRATE AND FISH SPECIES FOR CADMIUM. BLACK DOTS REPRESENT THE OBSERVED RESULTS. THE CONCENTRATION AT WHICH 5% OF THE ORGANISMS WERE AFFECTED WAS ADOPTED AS THE TOXICITY THRESHOLD.**

The third project, carried out by the University of Sheffield, used similar techniques to derive toxicity thresholds for exposure to the key sediment-bound pollutants. This project also developed a method for predicting the likelihood and extent of sediment accumulation in the receiving watercourse.
The fourth project, carried out by WRc, used these research results to build a prototype version of HAWRAT. HAWRAT reports a ‘Pass’ or ‘Fail’ status with respect to soluble copper and soluble zinc and to sediment bound copper, zinc and PAHs. Once the prototype version of HAWRAT was ready for use, the fifth project, carried out by Gifford, evaluated the tool and considered the implications for the management and operation of highways. Gifford then worked with WRc to further develop HAWRAT into a robust and practical tool.

4.6.4. Methodology

By applying internal algorithms to simulate 10 years of rainfall events, the tool calculates the corresponding average and extreme concentrations of soluble pollutants and sediment loadings. The tool then makes a comparison with the ecological toxicity thresholds in order to determine whether the discharge is acceptable or not.

The risk assessment methodology used by HAWRAT follows three basic steps:

**Step 1** calculates pollutant concentrations at end-of-pipe and considers whether these concentrations exceed the ecological toxicity thresholds.

**Step 2** calculates the in-river dilution and the resulting concentration of soluble pollutants. It again considers whether these concentrations exceed the toxicity thresholds. The potential dispersion of sediment is also considered.

**Step 3** considers the scale of mitigation required (if any) to reduce the concentration of soluble pollutants and the volume of sediments to acceptable levels.

At each stage HAWRAT reports ‘Pass’ or ‘Fail’. The steps require progressively more input, such that if a site passes at Step 1, no further time or expense need be spent gathering information for a Step 2 assessment. Furthermore, most of the input parameters can be determined by desk-study alone and only if sediment-bound pollutants are ‘Failing’ after Step 2 is a field study required.

4.6.5. Resulting tool

The Highways Agency Water Risk Assessment Tool (HAWRAT) provides a simple means of assessing the risks which highway derived pollutants pose to receiving watercourses. The tool uses a Microsoft Excel platform to determine the risk of pollution based upon a number of user entries related to characteristics of both the highway and the watercourse. A screen-shot of the user interface is shown in figure 24, following page.

The aim of the tool is to provide a quick yet reliable means of identifying the pollution risk associated with each highway outfall. The calculations built into the
Monitoring of environmental impacts of roads tool are underpinned by the joint HA/EA research. The tool is aimed at consultants and network service providers who are tasked with carrying out environmental risk assessments. HAWRAT has been designed to be user-friendly and requires only simple site specific data in order to perform a risk assessment.

4.6.6. Influence on guidance

HAWRAT produces a headline ‘Pass’ or ‘Fail’ result in addition to a series of detailed results which, primarily, are useful for determining the scale of any failure. In turn, these detailed results aid in the design of mitigation measures which can be fed back into the tool at Step 3.

All HAWRAT results are recorded on the Highways Agency Drainage Data Management System (HADDMS) and are linked to the corresponding outfall node on HADDMS. This provides a central record of the assessment which can be viewed by anyone with access to HADDMS. Figure 25, following page is a screen shot of HADDMS showing outfalls near the M3/M25 junction, each colour coded according to the degree of pollution risk associated with that outfall.

As previously detailed, the research provided the basis for the development of HAWRAT. In turn, the need to use HAWRAT in assessments of highway runoff is now written into HA guidance documents (HD45/09). Indeed, HAWRAT must be
used for such assessments. As HA and EA collaboration continued throughout the
development of HAWRAT, the assessment process and the results it produces are
endorsed by the EA.

4.6.7. Conclusions

The development of HAWRAT gives the HA a tool to determine whether highway
runoff is likely to have a significant impact on the receiving water environment and,
importantly, where it will not. In turn, this improves decision making with regard to
both the need for, and scale of, any capital works for mitigation at any given site.

There is potential for HAWRAT to be updated or recalibrated should future monitoring
demonstrate that the toxicological thresholds the model uses are inaccurate, or that
the average pollutant concentrations in highway runoff have changed.
4.7. CASE STUDY 8. MONITORING OF COMPENSATORY MEASURES ALONG HIGHWAYS IN AUSTRIA

4.7.1. Introduction

When constructing a motorway, a number of compensatory and support measures are put in place in order to mitigate or compensate the impact of the motorway on the environment. In Austria, a monitoring of selected measures is taking place, in order to check that the efficiency and purpose of each measure is satisfied. The monitoring takes place along 4 highways, that are in operation since a few years (figure 26). Following this monitoring, recommendations and guidelines for future compensatory measures are made. The state-owned infrastructure company ASFINAG has been commissioned to carry out this study.

![FIGURE 26 - MONITORED HIGHWAY SECTIONS (GREEN)](image)

4.7.2. Methodology

The monitoring project lasted for 9 months (April to December 2010). It included three major steps:

1. Collecting and sorting out available documents showing the initial status, and setting up a questionnaire (Apr.-May 2010).

The objective of this first phase is to document the size, location and functionality of the compensatory measures. The documentation is then used in order to establish a questionnaire. The aim of this questionnaire is to standardize the review of the ecological compensatory measures in the different road sections. The questionnaire, the content and the scope of the survey are set up in collaboration between ASFINAG and the federal authorities.

The compensatory measures are inspected on site. An ecological assessment is made, based on the questionnaire. The very existence of the compensatory measures is checked and their evolution in time is controlled. The success of the implemented measures are assessed and documented. Each road section is during one day simultaneously assessed by a botanist, an ecologist specialized in animals, and the project manager.


Using the knowledge that was acquired during already completed projects was one of the most important component of this project. It was made in the form of interviews with road personnel on the long-term efficiency of maintenance and on surface management. In the interviews with the road agents, the long-term maintenance of the compensatory measures was the central topic. In the interviews with the land purchase agents, the focus was on land organization.

A schematic of the compensatory measures monitoring procedure is shown in figure 27, following page.

4.7.3. Monitoring results

The results of this monitoring were processed in the form of a report (Delivery date: Dec. 2010). The report includes concrete examples, showing best practice, as well as recommendations for improvement or prevention with regard to the planning and implementation of compensatory measures. Emphasis was placed on the long-term feasibility in the maintenance of compensatory measures that are already included in the planning phase (e.g. access road, space for the use of machines, etc.). The results feed back to the system.

4.7.4. Conclusions

The monitoring of compensatory measures along 4 highways gave the opportunity to identify the type of measures that proved successful in achieving their key targets, and the measures which should be improved.

The recommendations and guidelines resulting from this monitoring will allow in the future the assessment and correction of planned compensatory measures. It will make sure they are functional, feasible and cost-efficient, thus increasing their chances of success.
It is planned to regularly repeat this procedure on selected highway portions.

4.8. CASE STUDY 9. MONITORING DURING OPERATION: THE LARGE ANIMAL REMOVAL REPORTING SYSTEM IN THE USA (LARRS)

4.8.1. Context

The state of Maryland (USA) has been actively participating in several national research projects sponsored by the Transportation Research Board under the National Cooperative Highway Research Program\(^\text{19}\). The focus of these projects has been to investigate successful methods of reducing animal vehicle collisions (AVC). The reasons are clearly identified on the human side of the equation by looking at the accumulating data from the insurance industry which documents a growing trend in property loss and injury from vehicle collisions with animals\(^\text{20}\). On the other side of

\(^\text{19}\) [www.trb.org/Publications/Blurbs/AnimalVehicle_Collision_Data_Collection_159423.aspx](http://www.trb.org/Publications/Blurbs/AnimalVehicle_Collision_Data_Collection_159423.aspx)

\(^\text{20}\) [www.statefarm.com/about/media/media_releases/20090928.asp](http://www.statefarm.com/about/media/media_releases/20090928.asp)
the equation is the need to recognize the landscape level impact that highways have on the habitat connectivity needs of wildlife populations using the land adjacent to our roadways. With growing national attention beginning to focus on this problem\textsuperscript{21}, the Maryland State Highway Administration (SHA) initiated a statewide assessment of how AVC data was being collected. It soon became apparent that we at SHA had no clear picture as to the magnitude of the problem. This realization led to the development and initiation of the Large Animal Removal Reporting System (LARRS) which standardized collection and reporting methods on a statewide level.

4.8.2. Monitoring

Since our maintenance offices were already being directed to pick up and remove carcasses from our roads it became both a simple and cost effective data collection technique to provide them with a form on which they could record route and mile point locations for each pick up within their jurisdiction. Upon returning to the maintenance facility these forms are turned over to data entry personnel who enter the information into a central LARRS data base currently located at our central Office of Maintenance. Here the data resides so that it can be accessed and, if desired, transferred into a GIS mapping system which provides a more visual interpretation of the data and greatly assists in decisions on where best to consider if mitigation strategies should be employed that might serve to reduce instances of AVC.

4.8.3. Use of monitoring results

Since data is being collected by mile point (every 0.1 highway mile or approximately 500 ft.) it becomes a simple matter of viewing accidents at the same or adjacent mile points over time in a GIS format \textit{(figure 28, following page)}. The resulting data clusters reveal accident “hot spots” where significantly numerous incidents can be portrayed. This provides SHA with a decision making tool that maximizes the cost/benefits of providing methods to warn motorists of a potential hazard or preventing animal access to the roadway. Signage is the standard method to warn motorists, but standard deer crossing signs have been employed for so long that they have become almost invisible to the motorist. New signage needs to be designed that will better inform drivers when approaching known collision “hot spots” \textit{(figure 29, following page)}. Wildlife fencing is another standard means of preventing animal access onto our roadways. However, growing concerns involving the landscape level impacts that our roads have on habitat connectivity necessitate the development of best management practices which will not only prevent access onto our roads but also lead to sites along the road where connectivity to adjacent habitats is available. This may be at existing bridge structures or smaller structures of sufficient size to allow animal passage. A Maryland State Highway research project is currently under way

\textsuperscript{21} www.deercrash.com
Moni tors of environMental iMPacts of roads

Figure 28 - aniMal collision mapping

Figure 29 - signage informing drivers when approaching known collision "Hot Spots"
which will provide information on animal usage and size of such structures. Finally, national research is being conducted on the reliability and effectiveness of advanced technology warning systems that can be deployed in unique or highly sensitive areas. Use of these systems will be expensive. The LARRS database combined with GIS mapping will be a critically important tool in determining when the cost of such a system would be justified.

4.9. CASE STUDY 9. MONITORING DURING OPERATION: ROAD MORTALITY MONITORING IN PORTUGAL

4.9.1. Context

Since Portugal joined the European Union in 1986, more than 1,000 km of highways have been constructed and a growing concern on the interaction between roads and wildlife emerged. Over the last years, an increasing number of studies have studied road mortality but these were restricted in time and space [58, 59], or focused on a few species [60] and knowledge is still scarce and fragmented. Existing crossing structures built under and over roads and highways have received increasing attention as potential valuable alternatives to restore landscape permeability for some species [61, 62]. Nevertheless, not all species use them and the knowledge of effective and affordable crossing structure designs is also limited.

In 2003, a protocol was established between BRISA Auto-Estradas de Portugal S.A. (a private company holding 1,100 kilometers of highway across Portugal, see figure 30) and the Centre of Environmental Biology of the University of Lisbon. The aim was to study the highways’ effects on wildlife in general, and in particular to monitor road mortality (road kills).

23 FCUL/CBA - BRISA PROJECT " Effectiveness of mitigation measures to prevent the negative effects of highways ", by Road Ecology Research Group - website: http://gtee.fc.ul.pt
4.9.2. Road mortality monitoring

In 2002, BRISA initiated a first wildlife mortality monitoring. This monitoring was performed by the staff in charge of the highway's safety. The staff received no training on species identification.

One year later, following the protocol between BRISA and Lisbon University, a more accurate monitoring was planned. The research team developed a wildlife guide, describing the main features for the correct identification of a species. The wildlife guide included a total of 71 species, including amphibians (6 species), reptiles (8 species), birds (28 species), and mammals (29 species). Some species were classified as threatened or vulnerable to roads. To avoid losing information, the wildlife guide was organized in a hierarchical classification that, in case of doubtful species identification, allowed the observer to assign the road-kill to the main taxonomic group (amphibians, reptiles, birds and mammals) or to a group of species (e.g. snakes, owls).

Training sessions for the BRISA staff were organized in order to explain how to use the guide and test the staff's ability to correctly identify the species or group of species (figure 31).

![Wildlife Guide Examples and Training Sessions to the BRISA Staff](COPYRIGHT: JOAQUIM PEDRO FERREIRA)

For each road-kill along the BRISA highways network, the recorded parameters are: date, species identification, and location (hectometre landmark).

In a subset of the network (276 km along A2 and A6), and until 2009, owls and carnivores have been collected to further identify sex and age and to allow the collection of tissue samples to be later used to study the genetic structure of the populations.

4.9.3. Key results

From 2002 to 2008, a total of 10,739 road-kills was recorded. Mammals were found to be the most highly impacted (69%), followed by birds (26%), reptiles (4%) and...
amphibians (0.3%). The scarcity of amphibians and reptiles is most probably a result of the low level of detection and the staff's lack of motivation to look for small-sized species.

The species groups most vulnerable to highways were found to be: owls, representing 51% of the birds (0.8 individual/km/year), carnivores (0.46 individual/km/year), lagomorphs (0.36 individual/km/year) and insectivores (Western hedgehogs -Erinaceus europaeus) (0.1 individual/km/year). The overall mortality has been increasing since 2002, a fact that highlights the importance of staff motivation to obtain more reliable data.

Temporal patterns shown by the different taxonomic groups reveal that vulnerability to roads is seasonal and species-specific mainly due to life-traits and behaviour.

Monitoring has already allowed the identification of mortality hotspots for owls and carnivores. These hotspots were identify using a low likelihood threshold (0.01%) of a road kill to occur in each 500-meter road section (see details in Malo et al., 2004 [63]). It is noted that hotspots do not seem to pose major concerns, due to the relatively low number of road-kills: 3 to 9 owls and 8 to 10 carnivores over a six year period.

4.9.4. Conclusions and outlook

As the road mortality database has grown, monitoring has become an increasingly valuable instrument for road authorities to identify road kill hotspots and accident trends. Results are used to identify places where mitigation measures are needed. The current limitation of highway road kill monitoring is the low level of detection of small-sized species.

So far, no relevant road kills of threatened species were recorded and mortality hotspots (number of roadkills/500m) appear not to raise concerns.

5. DISCUSSION

Countries participating in this report were asked to provide examples of environmental monitoring. However, confusion was often made between environmental mitigation and monitoring. For example, it is frequently thought that environmental mitigation such as setting up a water treatment plant, or planting trees along a road, is monitoring, whereas it does not meet the definition. However, regular measurement of the pollutants entering the water treatment plant, or recording the evolution of salt contents in trees would be monitoring.

In order to avoid confusion, a definition of the term "monitoring", as understood in this report, is given in chapter 6.1.
5.1. MAIN CONTRIBUTIONS AND BENEFITS OF MONITORING

Monitoring environmental impacts has an expense. However monitoring provides an essential basis of knowledge which in turn should help focus mitigation where it is needed and assure proper implementation and design. It can be a tool of cost-effectivity and help save resources by focusing them properly.

Figure 32 describes in general terms the infrastructure assessment cycle in which monitoring needs to be integrated. Data and information from monitoring programs can be used for the following purposes:

- **Detection of problems (early warning)**
  Monitoring data are used to oversee important parameters, and to trigger containment or measures in case of need. For example, if the ozone concentration exceeds a threshold value, a series of safety measures can be taken, such as enticing people to leave their cars and use public transportation.

- **Providing a sound scientific basis for mitigation policies**
  Policy development in the environmental field should be based on a comprehension of factors of influence. Monitoring can provide the scientific basis. The problem of lead emissions from vehicles and how this was solved is an excellent example, of how monitoring can feed policy.

- **Control the effectiveness of mitigation measures**
  Monitoring is often used to evaluate whether the mitigation measures meet their goals and identify best practice. For instance monitoring of wildlife passages has shown their effectiveness and multiple use by animals. Correct tailoring of measures is important to reduce costs.

- **Basis and validation of models**
  Long term monitoring is mostly used to build models, projecting the complex
influences. Monitoring data are used to compare models with real life phenomena. This is done for example in relation to noise. The modeled impact of noise barrier is tested through monitoring at a different locations.

5.2. CONTRIBUTIONS OF MONITORING IN EACH ENVIRONMENTAL DOMAIN

5.2.1. Air and climate

For air pollution and climate change, monitoring plays a key role in shaping practice. Monitoring is essential in following the evolution of pollutants over time and to control the effectivity of policies. For instance the influence of road traffic on emissions of particulate matter, nitrous oxides or carbon monoxide has been clearly identified. The introduction of catalytic converters and reduced sulphide content in fuels has contributed substantially to the reduction of these pollutants. Monitoring has clearly shown the effectivity of air emission restrictions encouraging further policies and legislations, such as enforcing tighter PM limit-values for vehicle engine emissions.

Baseline monitoring provides important data for the development of air pollution models. In return these models allow projections of emissions and immisions helpful for new infrastructure planning or for management plans.

Models derived from monitoring provide also information for policy planning. Studies of future road transport pollutant emissions in Switzerland [64], are based on projections of the evolution of vehicle fleet that feed models acquired from monitoring.

The main question in monitoring air pollutants is the question of scale. A supraregional coordination of measurement stations for long-term monitoring of air quality seems essential to reduce costs and improve data validity. The EUROAIRNET’s in Europe provides an example. Monitoring should be coordinated to represent different typical levels of pollution of all emission sources. A specific monitoring for roads only is not generally recommended.

5.2.2. Noise

Monitoring has clearly shown the relationship between traffic and noise levels, as well as fleet structure and noise. Strategic noise maps, based on monitoring results, are essential for properly targeting areas where mitigation is needed. Strategic noise maps are also an important basis for testing the effectiveness of different policies.

Monitoring of mitigation measures is necessary when controlling effectiveness of measures or comparing acoustic characteristics. Noise screens with proven acoustic properties need not be monitored till structural maintenance questions arise. Monitoring of different pavements [65] has shown the potential of low-noise pavements to reduce noise emissions. But monitoring of low-noise pavement has also shown that the noise-reduction properties diminish with time and that further research is needed.

The use of low-noise tyres also reduces noise emissions. Lower-noise tyres are already available on the market. In Europe, tyres are to receive energy labels in order to encourage consumers to choose quieter and more energy-efficient tyres. A follow-up will be necessary.

5.2.3. Waste management

As a material-intensive industry, monitoring of types and quantity of waste generated by infrastructure projects is an essential basis for any waste management practice and for encouraging recycling of materials. It is an important basis for contractors to find ways of reducing the amount of waste produced.

During construction, monitoring should be used to survey the total amount of material used. Recent research shows that the thickness of asphalt layers supporting high volume of heavy goods can be reduced by around 20% when using hard grade bitumen instead of conventional grades [66]. During road maintenance operations, monitoring can be used to show the percentage of the removed material which is recycled back into the new infrastructure. Various technologies and approaches are available which allows recycling the reclaimed pavement materials either in the same carriageway during its rehabilitation or for the construction of other pavements or platforms [67].

On the other hand, monitoring allows recording the usage of non-road-related waste in roads. Various waste materials have been used in roads for a number of years [68]. Waste used includes glass, rubber, fly ash or construction and demolition waste [69]. There exists also a potential for using new materials, such as non-biodegradable plastic from city garbage into roads. For example, polymer blend made out of littered plastic bags, PET bottles and thin film grade plastics are used for modifying bitumen in the construction of roads [70]. Using non-degradable waste in roads could contribute to reduce the amount of waste to be disposed of by the authorities. Other experiments have been carried out, such as using incinerator bottom ash as subbase in roads with low traffic in Denmark [71] or in France (detailed in a case study in chapter 4). It is noted, however, that using incinerator bottom ash can pose public health issues as well problems for recycling schemes.
When recycling waste into roads, monitoring of leachate is necessary so as to ensure the practice is safe in the long term and not creating new hazardous waste sites.

### 5.2.4. Hazardous substances

There has been little monitoring of the potential toxicity of hazardous substances found in infrastructure. This is changing with the implementation of REACH in Europe and the use of Life cycle analysis.

There is an effort in Europe to monitor the transportation of dangerous substances on roads. Attractive solutions exist, such as the "Good Route" project [72], which aims at monitoring the transport of dangerous goods on the road infrastructures at the regional level. This includes a classification of the danger and a risk analysis according to the infrastructure used. Hazardous substances management can be one part of the general risk management of roads, promoted by PIARC's Technical Committee C.3 on managing operational risks in road operations [73].

In this field as well, models can be used to analyse the risks associated with the transportation of dangerous good by roads. Such models already exist, as it has been shown in a study in Switzerland [74].

### 5.2.5. Soil

Monitoring has contributed to the assessment of the levels of pollutants in the soil, such as heavy metals, and their evolution over time. A number of long term studies on soil pollution have shown the accumulation of heavy metals and organic pollutants such as PAH, as soil acts as a filter for these substances. A recent study along two major highways has shown that heavy metal pollution in soil drops rapidly with distance to the road. Background pollution levels are reached 25 meters away from the roadside, with pollution exceeding limit levels in the closest 0.5 meter of the roadside [75]. Similar conclusions were drawn from a study on de-icing salt, which showed that 72% of the scattered salts were deposited within 3m of the road edge [49].

This knowledge has contributed to policy changes, for example in the ban on lead in gasoline, by pinpointing problems and trends.

About half of the countries participating in this study have declared not monitoring soil pollution. On a project level monitoring does not seem to be needed, as available long term studies offer better quality data. The main concern could be remobilisation of pollutants and induced leaching. Monitoring can be needed for special soil types where this question is of concern.
Countries should define pollution levels, above which action should be taken either to protect the surrounding environment or to ensure polluted soils are disposed of appropriately.

Standardised sampling and analytic methods combined with databanks for storing the collected information would provide the basis for long-term data analysis. It could also be used for recording ancillary information such as the type of soil and vegetation on site.

5.2.6 Water resources

Monitoring is aimed mostly at measuring the level of pollutants in road runoff. Extensive monitoring of pollutants and their impact on the ecology of surface waters has been done in different countries, providing a sound basis for policy and emission limits. The degree of pollution in water runoffs is directly related to the type of roads and to the traffic it undergoes. Added studies are only needed where doubts subsist or special environmental conditions are faced.

In countries prone to cold winters, large quantities of Chlorine are used for road maintenance. Chlorine dissolves in water and contributes to surface and ground water pollution. The quantity of salts spread by winter maintenance machines could be recorded along with the geographical location of the spreading vehicles in order to exactly monitor the Chlorine input to water runoffs along the road network. This option has already been tested in cities [76].

In the UK, monitoring has been used to develop a model: During 2 years, highway runoff pollution has been monitored at 24 sites across the country. Results of this large-scale monitoring allowed the development of a comprehensive software called the Highways Agency Water Risk Assessment Tool (HAWRAT). The purpose of this tool is to assess the risks which highway derived pollutants pose to receiving watercourses. HAWRAT combines a water runoff pollution model and a model that predicts the impact of the runoff on receiving rivers and streams. Details of this tool are given in a case-study in chapter 4.

Monitoring of rainfall and runoff dynamics have been a basis for assessment flooding risks and hydraulic wash out.

Project level monitoring can help design mitigation measures, such as runoff treatment. Monitoring of new types of treatment is essential for evaluating efficiency of treatment and for comparison with more traditional facilities.
5.2.7 Preservation of biodiversity

Wildlife casualties along roads are an important indicator of critical road sections with black spots needing mitigation measures. Monitoring casualties and storage of data should be organised by maintenance teams. Both biodiversity and safety issues are addressed.

Monitoring of fauna and flora is readily used in environmental impact studies, so as to adjust alignment and design take effective mitigation measures to reduce impacts. A recent comprehensive study on the impacts of road infrastructures on mammal and bird populations showed that population densities decline with proximity to the infrastructures [77]. It reinforces the importance of good planning of the infrastructures in order to identify and avoid regions more sensitive to infrastructure developments.

Monitoring is used to control the efficiency and improve design of the mitigation measures in place, such as fauna passages.

Roadsides form a very specific habitat for both flora and fauna. Until recently, biodiversity of roadsides was poorly monitored. Now it is acknowledged that many living species develop in these areas and it has become a challenge for biodiversity preservation [78]. Monitoring can help record the evolution of species in the road verges, and could be used to set biodiversity preservation targets. With invasive plants becoming ever more a problem, monitoring can be essential to control their spreading. A study on forest roads [79] shows that these facilitate the spreading of invasive plants.

5.2.8 Landscape

Landscape is the result of the interaction of different environmental factors, like geology, topography, water resources, land use, social and biological aspects. Monitoring can supply information on many levels, important to adjust the mitigation measures and to conceive different kinds of road project solutions. For example, the success of revegetation linked to some slopes contention solutions allows choosing, in similar situations, the best cost-effective solutions. Photographic surveys during project development have been used to monitor landscape evolution. An example of such monitoring is shown in chapter 4 for an infrastructure project in Portugal.

Anthropogenic fragmentation of landscapes is also an area where monitoring can play a key role. In industrialized countries, landscape fragmentation is known as a major reason for the loss of species. Monitoring of parameters such as effective mesh size, which characterize the anthropogenic penetration of landscapes from a geometric point of view is easy to use [53]. Monitoring of landscape fragmentation in Europe is currently under way [80]. Recently, research has been carried out in
order to formulate new indicators for landscape fragmentation, taken into account parameters such as population density and landscape use [81, 82].

To follow the long-term evolution of landscape over larger areas, cartographical surveys are particularly well adapted, as shown in a report on the evolution of landscape in Switzerland [52]. The method used in Switzerland could serve as reference in countries that have produced cartographical maps over time, but have not yet analysed the information. No other methodologies have been found in the survey. For monitoring future landscape evolution, countries could use already-existing high-resolution satellite pictures. Pictures could be updated every year. Latest technology products, such as 3-D maps from satellite observations, could be incorporated to landscape monitoring as they become available on the market. Monitoring landscape through satellite remote sensing also offers the possibility of following not only visible evolutions, but also changes in infrared or microwave radiation. Water resources, soil composition and usage, or agricultural practice could be monitored.

5.3. BENEFITS OF MONITORING FOR ENVIRONMENTAL POLICIES

Environmental reporting should be based on monitoring results. As we have seen in the previous chapters, there are many examples showing how monitoring has been a basis for setting environmental policies.

Monitoring is important to measure the effectiveness of environmental mitigation and policy plans. Lead concentration in the environment provides a good illustration of how monitoring and policy can interact. Firstly, monitoring showed alarming lead levels in the environment and increasing trends and a need for regulative policy. Then with the banning lead from gasoline, new policy was designed and implemented. Finally, with lead levels decreasing, the effectiveness of the new policy was confirmed. To summarize in this case, monitoring showed the need for mitigation measures, and the measure's efficiency was confirmed by the new monitoring results.

Monitoring also guides decision making. If the adopted policy does not bring the expected gain, this would show in the monitoring results. A more appropriate policy can then be established.

Speed limitation against ozone pollution in southern Switzerland is an appropriate example. Monitoring showed that ozone levels were exceeding alert thresholds. As a mitigation measure, the authorities decided to lower speed limits on local motorways in order to limit the emissions of ozone precursors. Past the ozone event, the analysis of the monitoring data showed that this measure had no significant influence on immissions of ozone, due to other factors. As a consequence, this measure was not repeated during the following ozone pollution event.
5.4. INDICATORS

The choice of indicators plays a fundamental role in monitoring. The concept of environmental monitoring requests the use of appropriate indicators in order to monitor the changes over time in a given environmental area. It appears that environmental fields benefiting from a larger degree of monitoring are also the fields which have best defined indicators. This is the case for noise or air pollution.

Well-defined indicators should express measurable physical quantities. These physical quantities are associated with defined data acquisition procedures, and standardized units. They are also easily transferable from one road infrastructure to another, and are transposable at the international level. Moreover, they offer easier modeling possibilities.

Based on WHO guidelines [83], we propose the following indicator criteria:

- The ability to predict an effect (high correlation between the indicator and an effect);
- Different indicators for different purposes;
- Easy to explain to the public (intuitively understandable);
- Avoid unnecessary breaks with current practice;
- Enforceable;
- Defined threshold values.

The main environmental indicators used on the international level in relation to roads are shown in the table, pages 73 to 75.

The indicators used for monitoring can also be used for setting eco-comparators. France, for instance, has studied environmental indicators especially designed for road infrastructures [87]. The aim was to find ways to assess the ecological impacts of a planned infrastructure, in an effort to take the environmental impact of a project in account when selecting the contractor. As a result, the eco-comparator "ECORCE" has been developed. This tool takes into account the construction and the maintenance impact on the environment. At the European level, the European Environment Agency published a list of indicators to be used within Europe [84].

5.5. MODELING

Models are regularly used in a limited number of fields: air quality, climate, and noise. These are fields where measurable physical quantities are defined. They are starting to be used in the water resource field to model road runoff.

Models are used during two different stages of the project. First during the planning stage, the aim of the modeling is to evaluate the impact of the future infrastructure.
### TABLE 2 - THE MAIN ENVIRONMENTAL INDICATORS USED ON THE INTERNATIONAL LEVEL

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<tbody>
<tr>
<td>Air</td>
<td>PM10, PM2.5, O3, NO2, SO2[^28], Traffic load</td>
<td>SO2, NO2, NOx, PM10, PM2.5, Pb, benzene, CO, Ozone</td>
<td>CO2, CH4[^29], NOx, GHG emissions</td>
<td>SOx, NOx, PM, CO, VOC, CO2, GHG emissions[^29]</td>
<td>Pb, NOx, O3, PM, SO2[^30], benzene, percentage of days with AQI[^30] &gt;100</td>
<td>Percentage loss of Ozone depleting substances</td>
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<td>Noise</td>
<td>LAeq,T, L1max, fast[^31], Lnight[^32]</td>
<td>Lden, Lnight[^31], Population exposed to different road traffic noise levels</td>
<td>Population exposure to noise, Noise abatement expenditure</td>
<td>Leq(h), L10[^34]</td>
<td>EPA superfund site designation</td>
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<tr>
<td>Hazardous</td>
<td>substances</td>
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[^26]: OECD Environmental Data Compendium, OECD environmental indicators. Not specific to road projects. http://www.oecd.org/document/49/0,3343, en_2649_34441_39011377_1_1_1_1,00.html http://www.oecd.org/findDocument/0,3354,en_2649_34441_1_119656_1_1_1,00.html http://www.oecd.org/dataoecd/7/47/24993546.pdf


[^29]: OECD, ADVANCED AIR QUALITY INDICATORS AND REPORTING, Methodological Study and Assessment, ENV/EPOC/PPC(99)9/FINAL, 1999


[^31]: As defined in WHO noise guidelines. URL: http://www.who.int/mediacentre/factsheets/fs313/en/index.html

[^32]: As defined in WHO Night noise guidelines for Europe[^83]

[^33]: As defined in European directive 2002/49/EC[^23] and explained in[^84]

[^34]: As defined by US Federal Highway Administration[^85]

## TABLE 2 - THE MAIN ENVIRONMENTAL INDICATORS USED ON THE INTERNATIONAL LEVEL

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<tr>
<th>WHO</th>
<th>EU</th>
<th>Worldbank</th>
<th>OECD</th>
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<th>CEPAL</th>
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<td>Waste management</td>
<td>Waste quantity, Toxic/ non-toxic waste</td>
<td>Waste generation, recycling rates</td>
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<tr>
<td>Soil</td>
<td>Terrestrial protected areas (Number and % of total surface area)</td>
<td>Land use, Change in land use, Degree of top-soil losses</td>
<td>Land use, Erodability factor (soil types) and NRCS rating (prime farmlands) and hydric soils</td>
<td>Protected areas (Number and % of total surface area)</td>
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<tr>
<td>Water resources</td>
<td>Numerous indicators (e.g. suspended matter, mineral oil)</td>
<td>Heavy metals, persistent hydrocarbons, materials in suspension</td>
<td>Organic water pollutant (BOD, kg/day)</td>
<td>River quality, Heavy metals in rivers, Waste water treatment, Water treatment expenditure</td>
<td>N and P loads in large rivers, sediment or turbidity, dissolved oxygen, temperature, E. coli, % impervious surface in watersheds, and biological criteria (fish and benthos)</td>
</tr>
</tbody>
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26 OECD Environmental Data Compendium, OECD environmental indicators. Not specific to road projects. [http://www.oecd.org/document/49/0,3343, en_2649_34441_39011377_1_1_1_1,00.html](http://www.oecd.org/document/49/0,3343, en_2649_34441_39011377_1_1_1_1,00.html)


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<td>Biodiversity</td>
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<td>Threatened mammal and fish species</td>
<td>Threatened or extinct species as a share of total species known,</td>
<td>Threatened species index</td>
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<td>Threatened plant species</td>
<td>Habitat alteration, Heavy metals and organic compounds in living species</td>
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<td>Forest area (sq. km, and % of land area)</td>
<td>Land conversion from natural site, Forest area</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Land cover, land use, forest fragmentation</td>
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<td></td>
<td></td>
<td></td>
<td>Loss of forest cover</td>
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</tr>
<tr>
<td>Landscape</td>
<td>Meshsize [86]</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>


[^26]: OECD Environmental Data Compendium, OECD environmental indicators. Not specific to road projects. http://www.oecd.org/document/49/0,3343, en_2649_34441_39011377_1_1_1_1,00.html

It is also the moment when mitigation measures can be designed and their influence evaluated. This is especially true for noise modeling, where the type of mitigation, as well as its location, is chosen. Using models also allows the evaluation of the long-term impact of the infrastructure.

Secondly, models are used during the network operation phase. Modeling during this phase is made to evaluate the impact of the infrastructure on a larger scale, in space or in time, or to produce infrastructure-wide monitoring maps.

Modeling feeds into monitoring at a higher level. It can reinforce innovative approaches to monitoring. For example, one could imagine combining the same model in several environmental fields. A modeling of the fleet of vehicles, associated with the state of the asphalt and a weather component could allow a network-wide monitoring of air pollution (including climate input), water pollution, and noise.

It is noted, however, that models cannot be used in every field, as physical quantities are needed for the mathematical calculations. Models should be reliable. In fields such as air or noise, models clearly are used as a basis for political decisions taken with respect to infrastructure.

It also emerged from this study that the relationship between monitoring and modeling is two-way. Monitoring data provide valuable input for models. They help fine-tune model parameters, and are needed for model validation. When modeling can replace monitoring, it allows carrying out large-scale monitoring at minimal cost. It enables a cost-effective planning of projects.

6. RECOMMENDATIONS

6.1. MONITORING

6.1.1. Goals

The aim of the environmental monitoring of road impacts can be to:

• describe how roads are impacting the environment;
• early warning system: Detect changes in the environment by comparing current and past states through trend analysis;
• assess threats, detect new environmental issues;
• give basis for planning and assessment of protection measures;
• provide input for remedial actions or optimization of processes;
• evaluate the effectiveness of mitigation measures taken;
• obtain data and information needed for transportation and environmental policy;
• offer a basis to legislation on environmental quality standards;
• measure progress towards environmental objectives.
6.1.2. Applications

Monitoring can be used on a continuous routine basis or on a discontinuous basis, short term or long term. Routine monitoring should be addressing regulatory compliance. Routine monitoring is needed for certain prevention strategies.

Ad-hoc (discontinuous) monitoring programs should be addressing questions that need data to be answered. Monitoring can be included in the environmental impact assessment.

New types mitigation or solutions need to be backed by monitoring to check their effectiveness. Mitigation used outside its normal parameters need also to be backed by monitoring.

Monitoring, for instance of certain construction sites, is also needed when the failure of implemented mitigation could have extremely expensive consequences for the human or natural environment. However it is essential that it be tied into a hierarchal decision matrix, so that alerts lead to necessary actions.

Monitoring programs or studies should have defined stakeholders that are informed of results. Stakeholders can be the road and environmental authorities responsible for checking the efficiency of mitigation or on another level, policy maker or on a yet wider level the general public. Communicating monitoring results can provide basis and support for further actions.

Figure 33, following page proposes decision criteria for the implementation of monitoring programs. Monitoring should not be done blindly with no clear goals. There are areas where sufficient data is available and further studies are not needed unless environmental or emission conditions change.

6.1.3. Use of monitoring results

Monitoring results are of fundamental importance to environmental management plans and should be able to feed into environmental policies. Published results are important for transparent public information and to justify policy choices.

Results can serve as a basis for:

- for status reports for roads and environment, and for official statistics;
- to allow a correct focus of intervention, if there is a deviation from targets or thresholds;
- to improve the efficiency of environmental mitigation measures;
FIGURE 33 - PURPOSE OF ENVIRONMENTAL MONITORING
• to strengthen and better coordinate joint solutions for transboundary environmental problems, based on similar environmental monitoring practice;
• as a strategic instrument for measuring progress on environmental objectives and on remedial actions;
• as a dynamic instrument in the drafting of environmental objectives, environmental quality standards, and quality criteria.

6.1.4. Requirements

A monitoring program should be implemented for a defined purpose only. To be successful, the goals of the monitoring program and the methods used need to be set clearly from the beginning. Data should only be collected with a clear purpose to avoid the risk of accumulating data that cannot be analysed or creating a non-exploitable databank. It should be ensured that monitoring meets the SMART criteria (Specific, Measurable, Attainable, Realistic and Timely). Monitoring needs to meet cost-efficiency. Stakeholders and an information policy should be defined at the onset. Where and how the results are going to be used should be known.

Monitoring should be planned as early as possible in the project, to allow easy implementation. It's implementation should be decided in the planning stage.

Monitoring programs should use stable measurement protocols following recognized standards that can be repeated and compared over time or carried out over long time periods providing a clear understanding of cause and effects.

6.1.5. Frequency of monitoring

The frequency of monitoring has to be assessed from project to project. As seen above, there are two basic types of monitoring: Continuous (instrument continuously running), and discontinuous (measurement campaign once a month/year, etc.). Continuous monitoring is pertinent when a high risk needs to be well contained. This is the case of water pollution risks during the construction stage for example. A discontinuous monitoring is pertinent when the risk is more limited or predictable. For example, noise levels along the road infrastructure. In this case, a monitoring at regular intervals is acceptable.

6.1.6. Cost-effectiveness

Funding should generally be included in road infrastructure budgets, where monitoring is pertinent to roads.

Monitoring programs should be planned on the basis of sound cost assessment, restricting itself to the essential data (measure as much as you need, but as little as possible). Sample size should be adjusted to needs and focus on minimum needed for statistics.
Monitoring should try to move as quickly as possible from continuous to discontinuous measurement. Monitoring cycle should reflect risk assessment and need of information.

One element for cost management is the identification and prioritization of projects requiring monitoring. Highways agencies may have many projects underway at any given time. As such, it is important to gauge the level of monitoring for each. Monitoring of projects should be wound down as the threat to the environment is minimized. Environmental risk is essentially the potential for impacts to the environment based on the type and sensitivity of natural resources on or adjacent to the construction project.

6.2. INDICATORS

It appears from this study that the following indicators can be used in most situations and provide a good basis for comparisons. They provide measurable parameters.

<table>
<thead>
<tr>
<th>TABLE 3 - INDICATORS USED AS A BASIS FOR COMPARISONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air pollution</strong></td>
</tr>
<tr>
<td>- Local Pollutants: PM, NOx, Ozone</td>
</tr>
<tr>
<td>- Traffic load monitoring (modeling of the fleet)</td>
</tr>
<tr>
<td>At the network level: - CO2 (climate), contribution</td>
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<td>of the network to the national emissions</td>
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<tr>
<td><strong>Noise</strong></td>
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<td>- Lden</td>
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<td>- Lday</td>
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<tr>
<td>- Levening</td>
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<tr>
<td>- Lnight</td>
</tr>
<tr>
<td>- Number of people disturbed by noise</td>
</tr>
<tr>
<td>- Number of houses disturbed by noise</td>
</tr>
<tr>
<td><strong>Biodiversity</strong></td>
</tr>
<tr>
<td>- Fauna: Number of wildlife casualties along roads</td>
</tr>
<tr>
<td>- Flora: Plot inventories following changes in flora</td>
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<tr>
<td>composition impacted on roadsides</td>
</tr>
<tr>
<td><strong>Landscape</strong></td>
</tr>
<tr>
<td>- Deforestation rate (area/time)</td>
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<tr>
<td>- Landscape fragmentation:</td>
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<tr>
<td>- Effective mesh size</td>
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<tr>
<td>- Effective mesh density</td>
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<tr>
<td>- Area covered by the infrastructure</td>
</tr>
<tr>
<td><strong>Water resources</strong></td>
</tr>
<tr>
<td>- Percentage of network treated</td>
</tr>
<tr>
<td>- Number of treated/untreated water evacuation points</td>
</tr>
<tr>
<td>- Pollutants in effluents: TSS, Zn, Cu,</td>
</tr>
<tr>
<td><strong>Soil</strong></td>
</tr>
<tr>
<td>- Surface of the country taken up by roads (percentage)</td>
</tr>
<tr>
<td>- Area affected by the infrastructure</td>
</tr>
</tbody>
</table>
6.3. DATA STORAGE AND AVAILABILITY

Monitoring produces a significant amount of data. Following the results from the questionnaire, it appears that the collected monitoring data are mainly kept in databanks. Archiving the data and the associated collection procedure is vital for trend recording and comparative analysis. Previous results can be recalculated and compared in the light of new findings or new data. Long-term monitoring requires good data recording.

Storage of monitoring data is therefore to be promoted in a standardised form and performed systematically.

There are several rules that can be recommended in order to build a good database. Firstly, the use of normalized data and standard parameters (commonly used in the field) are to be promoted. SI-units and good naming standards are also essential. Data should be well documented: acquisition procedure, instruments used, eventually ancillary parameters such as weather conditions or useful remarks. Finally, data integrity should be protected.

7. CONCLUSIONS

The survey shows that when member countries are monitoring environmental impacts of roads, the extent of the monitoring and the practice is very diverse. Most often monitoring is project-related. It investigates the efficiency of mitigation measures. Network level monitoring is oriented at researching the impacts of roads. However, the objectives and use of monitoring are very different. The very definition of environmental monitoring was subject to interpretation, since monitoring is often confused with mitigation.

The use of monitoring is diverse: it is used for early warning, to provide scientific basis for mitigation policies, to control the effectiveness of mitigation measures, or as basis and validation of models.

This survey shows that monitoring can be of significant value in each environmental field. Many examples show how monitoring has contributed to show trends and influenced policies.

In each road infrastructure project, the need for monitoring has to be assessed. Monitoring is needed in particular when required by law, when the mitigation techniques have not been tried and tested, its impacts have not been assessed, or when the consequences of mitigation failure is not acceptable. Monitoring should be carried out when needed, it should not be an objective in itself. It should address specific questions, drive actions and be a basis for improvements.
This survey also shows that attention should be paid to how monitoring is designed, in order to enhance costs efficiency. It appears that goals behind monitoring are not always clear and that results could be better exploited. Common indicators should be promoted as to enhance the comparison between similar projects.

Monitoring can play an important role in optimizing project cost by promoting better tailored mitigation measures. Best practice can only be identified by follow-up and effectiveness monitoring of mitigation measures.

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## GLOSSARY

<table>
<thead>
<tr>
<th><strong>Term</strong></th>
<th><strong>ENGLISH</strong></th>
<th><strong>FRANÇAIS</strong></th>
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<tbody>
<tr>
<td>EIA</td>
<td>Environmental impact assessment</td>
<td>EIE</td>
</tr>
<tr>
<td>PAH</td>
<td>Polycyclic aromatic hydrocarbon</td>
<td>HAP</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter</td>
<td>MP</td>
</tr>
<tr>
<td>SPM</td>
<td>Suspended particulate matter. Refers to general airborne particulate matter.</td>
<td>MPS</td>
</tr>
<tr>
<td>PM10</td>
<td>Particulate matter of size less than or equal to 10 microns. Also called inhalable dust, it enters the nose and mouth during normal breathing.</td>
<td>PM10</td>
</tr>
<tr>
<td>PM2.5</td>
<td>Particulate matter of size less than or equal to 2.5 microns. Also called thoracic dust, it reaches the lungs during normal breathing.</td>
<td>PM2.5</td>
</tr>
<tr>
<td>DPM</td>
<td>Diesel particulate matter. Refers to particulate matter in the size range of 0.1 micron. DPM is part of the so-called respirable dust, it penetrates into the gas exchange region of the lungs.</td>
<td>MPD</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
<td>CO</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
<td>CO₂</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrogen oxides (NO + NO₂)</td>
<td>NOₓ</td>
</tr>
<tr>
<td>NO₂</td>
<td>Nitrogen dioxide</td>
<td>NO₂</td>
</tr>
<tr>
<td>SOₓ</td>
<td>Sulphur oxides</td>
<td>SOₓ</td>
</tr>
<tr>
<td>SO₂</td>
<td>Sulphur dioxide</td>
<td>SO₂</td>
</tr>
<tr>
<td>O₃</td>
<td>Ozone</td>
<td>O₃</td>
</tr>
<tr>
<td>HC</td>
<td>Hydrocarbons</td>
<td>HC</td>
</tr>
<tr>
<td>Pb</td>
<td>Lead</td>
<td>Pb</td>
</tr>
<tr>
<td>Cd</td>
<td>Cadmium</td>
<td>Cd</td>
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<tr>
<td>Zn</td>
<td>Zinc</td>
<td>Zn</td>
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</tbody>
</table>
Monitoring of environmental impacts of roads

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Terme</th>
<th>Définition</th>
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<tbody>
<tr>
<td>Cu</td>
<td>Copper</td>
<td>Cu</td>
<td>Cuivre</td>
</tr>
<tr>
<td>Mn</td>
<td>Manganese</td>
<td>Mn</td>
<td>Manganèse</td>
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<tr>
<td>GHG</td>
<td>Greenhouse gases</td>
<td>GES</td>
<td>Gaz à effet de serre</td>
</tr>
<tr>
<td>WHO</td>
<td>World health organisation</td>
<td>OMS</td>
<td>Organisation mondiale de la santé</td>
</tr>
<tr>
<td>MTBE</td>
<td>Methyl tert-butyl ether</td>
<td>MTBE</td>
<td>Méthyl terbutyl éther</td>
</tr>
<tr>
<td>VOCs</td>
<td>Volatile organic compound</td>
<td>COV</td>
<td>Composés organiques volatils</td>
</tr>
<tr>
<td>MAH</td>
<td>Monocyclic aromatic hydrocarbons</td>
<td>HAM</td>
<td>Hydrocarbures aromatiques monocycliques</td>
</tr>
<tr>
<td>VHH</td>
<td>Volatile halogenated hydrocarbons</td>
<td>HHV</td>
<td>Hydrocarbures halogènes volatils</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Environmental monitoring is a regular, systematic collection and assessment of environmental data, using set indicators. This includes environmental compilation of changes in air, soil, water, landscape, biodiversity, noise, waste production, carbon emissions, resource consumption, etc. Monitoring can involve a long term program or a shorter study over a limited period, but with a scientific protocol that can be repeated later.</td>
<td>Suivi</td>
<td>Le suivi environnemental est la pratique qui consiste à réunir et à évaluer régulièrement et systématiquement les données relatives à l’environnement en utilisant un jeu d’indicateurs, y compris en compilant des données sur les changements survenus dans l’air, le sol, l’eau, le paysage, la biodiversité, le bruit, la production de déchets, les émissions de carbone, la consommation de ressources, etc. Le suivi peut impliquer un programme à long terme ou une étude de plus courte durée sur une période limitée, mais assortie d’un protocole scientifique pouvant être répété ultérieurement</td>
</tr>
<tr>
<td>CPX</td>
<td>Close-Proximity (CPX) is a method used to record the noise properties of a road surface.</td>
<td>CPX</td>
<td>La méthode CPX (de proximité immédiate) sert à enregistrer les propriétés d’une surface routière en matière de bruit.</td>
</tr>
</tbody>
</table>
APPENDICES

1. QUESTIONNAIRE 1

First questionnaire sent to the countries.

---

Table 1: Monitoring of environmental impacts

<table>
<thead>
<tr>
<th>Stage</th>
<th>Indicators measured</th>
<th>Type of mitigation measures</th>
<th>Indicators evaluated</th>
<th>Adaptive measures</th>
<th>Methodologies, indicators measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning stage (EIA)</td>
<td></td>
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<tr>
<td>Construction stage</td>
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<tr>
<td>Post-EIA studies</td>
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<tr>
<td>Network Operation stage - long-term monitoring of system</td>
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</tbody>
</table>

| Topic guidelines |

Generally we are seeking to gather knowledge on what is being monitored at what level and for what purpose. We would like to know what is done with the information, how does monitoring environmental impacts influence project or network design. Please do not go into details on the legal framework, cite only what seems most important. It is of interest as a justification for monitoring.

Air quality monitoring of emissions and or emissions such as NOx, Sox, HC, CO2, PM10 on project level, during construction on or at a network level. What is being monitored and how are the results used? What is modeled, what is measured?
Biodiversity
monitoring fauna and flora along roads or impacts by roads on natural habitats and wildlife corridors. What is being monitored? What indicators and/or inventories are used? What is being censused or measured?

Climate
monitoring greenhouse gases on a project or network development level. What models are being used?

Landscape
cultural heritage includes archaeology, architectural heritage as well as protected landscapes (see European landscape convention) and recreation, what impacts are measured or analysed and how? What indicators are used?

Hazardous substances
What hazardous substances are used in road building (for instance PAH)? What kind of hazardous substances could be in each stage? What environmental aspects are several impacted (water, soil, etc) with hazardous substances? How is the transport of hazardous substances being regulated and monitored (technology risks)? What indicators are measured, used?

Noise, vibrations
What is modelled, what is measured? What is regulated and or monitored at what level?

Public health
Only issues that are not integrated under noise, water, air or waste management
soil = topsoil, that is the surface that is biologically active and of agricultural relevance
How is the protection of soil taken into account in the planning and construction phase of roads? Is the amount of impacted topsoil (m2) recorded (quantitative impact)? Are there monitoring programmes or research on the problems of soil contamination along roads (heavy metals, PAH) (qualitative impact)

Water resources
How is quality and impacts measured, monitored? What indicators are used to measure quality of surface water and impacts of roads on surface water? Are hydraulic impacts measured?

Waste management
How are materials/waste from constructions sites treated? What is recycled? What is disposed of, and how? Is a balance sheet for life cycle analysis held?

Contaminated sites
Are contaminated sites monitored? What kinds of methodologies are utilized to restore contaminated sites? Do you have an interesting study case about contaminated sites on roads and what kinds of substances were involved?
2. QUESTIONNAIRE 2

Second questionnaire sent to the countries.

Following the answers gathered from the questionnaire PIARC A1.2 Monitoring of environmental impacts of roads sent on 21.01.09 to the PIARC A1.2 members, we would like to obtain more examples, descriptions or further information from your country on the topics listed below.

Any contribution or response is very interesting for us and highly appreciated.

- Country:
- Contact person:

1. Air
- Do you monitor Air Quality?
  - Yes
  - No
- Which Emissions are monitored in your country?
  - NOx
  - NO2
  - SOx
  - SO2
  - O3
  - CO
  - HC
  - CO2
  - Pb
  - PM2.5
  - PM10
- What are the pollutant thresholds?

- Are they according with international thresholds (e.g. UNECE, WHO)?
  - Yes, with
  - No
- What happens if the thresholds are exceeded around roads? Are there any obligatory measures (like speed or traffic regulation)?
- How is the monitored data used, what is their value (any influence on policy)?

- Do you have databanks?
  - Yes,
  - No
- Do you use models to calculate air quality?
  - Yes,
  - No

2. Biodiversity
- Are possible effects of roads on fauna being monitored?
  - Yes
  - No
- Does a national biodiversity monitoring program exist?

Federal roads office (FEDRO), Switzerland. Internal reference: 1375-0536
• If Yes, is the national biodiversity monitoring program linked to roads?
  □ Yes,
  □ No

• Which effects on what kind of fauna are being monitored?

<table>
<thead>
<tr>
<th></th>
<th>Game</th>
<th>fish</th>
<th>birds</th>
<th>Amphibians</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat fragmentation</td>
<td></td>
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<tr>
<td>Stress/ Noise</td>
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<td>Mortality induced by traffic</td>
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<tr>
<td>Success of habitat translocation/ reforestation</td>
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<tr>
<td>Toxic emissions</td>
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</table>

• What is the monitoring method:
  Inventory of species / data bank
  Observations on changes of behavior/stress
  Quadrature monitoring flora profile, inventory

3. Climate
• Is there a plan for emission reduction in traffic following the Kyoto protocol?
  □ Yes,
  □ No

4. Soil
• Do you have a specific monitoring program? Do you have a databank?
  □ Yes,
  □ No

• Which Emissions are monitored in your country?

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<thead>
<tr>
<th></th>
<th>Pb</th>
<th>Cd</th>
<th>Zn</th>
<th>Cu</th>
<th>Mn</th>
<th>PCB*</th>
<th>PAHs*</th>
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<td>PAHs*</td>
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• What are the thresholds?

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<th>Cu</th>
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• Are they according with international thresholds?
  □ Yes,
  □ No

• What happens if the thresholds are exceeded along roads?

* Polychlorinated biphenyls
* Polycyclic aromatic hydrocarbons
How is the monitored data used, what is its value (any influence on policy)?

What measures are taken to mitigate the effects on the soil?

5. Water

- Do you monitor Water Quality?
  - Yes
  - No

- Do you have a databank?
  - Yes
  - No

- Does your state/nation require water quality controls for roadways?
  - Yes
  - No

- Which Emissions are monitored in your country?

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<thead>
<tr>
<th>MTBE</th>
<th>NO3</th>
<th>VOCs</th>
<th>Pb</th>
<th>Cd</th>
<th>CN</th>
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<th>MAH*</th>
<th>VHHD</th>
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<th>Other</th>
</tr>
</thead>
</table>

- What are your pollutant thresholds?

<table>
<thead>
<tr>
<th>MTBE</th>
<th>NO3</th>
<th>VOCs</th>
<th>Pb</th>
<th>Cd</th>
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<th>MAH</th>
<th>VHHD</th>
<th>Cu</th>
<th>Zn</th>
<th>Other</th>
</tr>
</thead>
</table>

- Are they according with international thresholds (e.g. UNECE, WHO)?
  - Yes
  - No

- What specific chemical, physical, or biological monitoring is required for water quality facilities, streams or watersheds influenced by roads?

- How are these locations chosen?

- What is the typical duration of monitoring?

- What happens if the thresholds are exceeded?

- How does monitoring data influence decisions reached during the road project development or influence long range operational practices?

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* Monoaromatic hydrocarbons
* Volatile halogenated hydrocarbons

Federal roads office (FEDRO), Switzerland. Internal reference: 1375-0536