The guides

TUNNELS MASTER FOLDER, DOCUMENT N°5: ENVIRONMENT

Resources, land, habitats and housing
Energy and climate
Sustainable development
Risk prevention
Infrastructure, transport and the sea

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Ministère de l'Écologie, du Développement durable, des Transports et du Logement

july 2011

Tunnels Study Centre (CETU)

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The tunnels master folder contains six documents:

1. Presentation - Summary (pending publication)
2. Geometry (December 1990)
3.Civil Engineering (November 1998)
4. Equipment
    4.1 Ventilation (November 2003)
    4.2 Lighting (November 2000)
    4.3 Electric power supply (pending publication)
5. Environment (july 2011)
6. Costs (pending publication)

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PREAMBLE

Environmental concerns, recognised as being in the general interest, are an excellent reason for carrying out studies at various stages in the development of infrastructure projects. In most cases, environmental studies focus on routes and not on tunnels as a case apart. However, there are a number of aspects that differentiate tunnels from other structures, the environmental impacts of which require analysis.

It was decided that these specific aspects should be discussed in a special section of the Tunnels Master Folder. Note, however, that considerations of the environmental aspects should be linked to all other project areas. The indications given in this document cannot alone provide the answers to each and every issue as, in each case, the approach has to be tailored to the characteristics specific to the project or site that strengthen the influence of any given criterion.

This document, mainly intended for contracting clients and their professional advisors, comprises:

- an introductory chapter that summarises the regulatory framework, describing the key phases in project rollout and the significance of the environmental aspect; this chapter also discusses the concepts of integration measures and impacts;
- a serie of topic-based chapter:
  - > ground settlement,
  - > structure-borne noise,
  - > air blasts,
  - > noise,
  - > air pollution,
  - > energy consumption abd the greenhouse effect,
  - > management of materials and waste,
  - > water and sanitation,
  - > natural environment,
  - > landscape and heritage,
  - > living environment and human activities.

Each of these environmental topics is dealt with under the same plan, which looks at:

- features specific to tunnels compared to open-air road construction projects,
- impacts and challenges,
- study approach,
- methods and means that can be used for impact assessments,
- measures planned with regard to these impacts,
- specific regulatory provisions,
- useful references.

This document does not cover occupational or worksite-related health and safety as both these topics refer back to specific regulations that are separate from those governing environmental issues.

1. GENERAL APPROACH AND BASIC PRINCIPLES FOR FACTORING ENVIRONMENTAL CONCERNS INTO TUNNEL CONSTRUCTION PROJECTS

1.1 REGULATORY FRAMEWORK

Environmental regulations now form a highly technical and relatively complex field that has developed significantly over the last few years, driven, in particular, by European directives and ongoing scientific and technological advances. Nowadays, they also incorporate changes introduced by the **Grenelle Environment**, which was launched in France in July 2007 to *"fight against climate change and adapt to it, protect biodiversity and all related services, contribute to creating an environment that protects health, preserve and enhance landscapes" (article 1 of law No. 2009-967 of 3 August 2009 implementing the Grenelle Environment)*.

By grouping the main legislative and regulatory provisions in a single document, the **Environmental Code** has now simplified access to current legislation in this field.

Where construction projects are concerned, in addition to sector-based responses (protection of water resources, limitation of noise pollution, etc.), it is also necessary to develop insight into the various environmental components in a highly integrated manner, and at every stage of the project, from upstream studies right through to maintenance and operation.

Following this reasoning, this chapter on regulations summarises both the basic principles guiding a owner's environmental approach, and the environmental assessment tools established by regulations to facilitate an improved integrated project approach. The regulatory aspects specific to each topic are discussed in the relevant chapters.

1.1.1 Fundamental principles of environmental protection

In adopting an **Environmental Charter**, the *French law of 1 March 2005* introduced a certain number of new fundamental rights and duties into the French Constitution. These are principles that apply to everyone, some of which deserve to be mentioned due to obligations of means and results that they can enforce. For its part, the **Environmental Code** (EC) sets out a general principle for environmental protection.

ENVIRONMENTAL CHARTER (LAW OF 1 MARCH 2005)

FUNDAMENTAL RIGHTS

- *everyone has the right to live in a balanced environment which shows due respect for health,*
- *under the conditions and within the limits defined by law, everyone has the right to access environmental information held by the public authorities, and to contribute to developing public decisions impacting on the environment.*

FUNDAMENTAL DUTIES

- *it is the duty of every person to participate in preserving and improving the environment,*
- *it is the duty of every person, under the conditions provided for by law, to foresee and avoid the occurrence of any damage which they may cause to the environment or, failing that, to limit the consequences of such damage,*
- *it is the duty of every person to contribute to repairing any damage they may cause to the environment, under the conditions defined by law,*
- *it is the duty of public policies to promote sustainable development.*

ARTICLE L110-1 (EC)

- *" I. The spaces, resources and natural environments, the sites and landscapes, the quality of air, the animal and plant species, the biological diversity and balances to which they contribute is part of the nation's common heritage."*
- *" II. Their protection, improvement, remediation, rehabilitation and management are of general public interest and support sustainable development in addressing the development and health needs of current generations without compromising the ability of future generations to meet their own needs. Under the laws that define their scope, they are based on the following principles:*
  - *> the precautionary principle, according to which, given the existing scientific and technical knowledge, the absence of certainty must not delay the adoption of effective and proportional measures designed to prevent a risk of serious and irreversible environmental damage at an economically acceptable cost,*
  - *> principle of preventive and corrective action to rectify damage to the environment, by priority at the source, using the best available technologies at an economically acceptable cost,*
  - *> polluter pays principle, according to which the costs of pollution prevention and reduction measures and the fight against pollution have to be borne by the polluter,*
  - *> principle of participation, according to which everyone can access environmental information, including that relating to hazardous substances and activities, and the public participates in the process of developing projects with a significant impact on the environment or land-use planning. "*
- *" III. The sustainable development objective, such as described in II, consistently and concomitantly meets five outcomes ;*
  - *> the fight against climate change;*
  - *> the preservation of biodiversity, environments and resources;*
  - *> social cohesion and solidarity between regions and generations;*
  - *> development of the inherent potential of each and every human being;*
  - *> a development dynamic based on production methods and responsible consumption. "*
- *" IV. Agenda 21 is a territorial project for sustainable development. "*

These environmental concerns affect everyone, especially public owners, particularly in terms of land-use planning works or projects subject to authorisation or approval *(art. L122-1 EC)*.

The penalties and sanctions relating to non-compliance with environmental procedures or to negative impacts (e.g. accidental river pollution) are generally specified in the relevant legislative texts. Under *Community Directive 2004/35/CE, Law No. 2008-757 of 1 August 2008* relating to environmental liability specifies the notion of liability in terms of the prevention and remedying of environmental harm, focusing in particular on certain cases of serious ecological harm. It gives substance to the obligation to make good the harm, based on the polluter pays principle, targeting a return to the pre-harm condition. The ecological harm involved concerns damage to the condition of soils, water, and protected natural habitats and species.

1.1.2 Environmental assessment tools

1.1.2.1 Environmental impact study

The impact study is the rule for all works, structures or land planning projects undertaken by a public authority or requiring an authorisation or a decision of approval. When all the works planned in the corresponding programme are executed simultaneously, the impact study must cover the whole programme. In the case of staggered execution, the impact study for each operating phase must contain an assessment of the cumulated impacts for the whole programme.

The scope of this project environmental assessment document can be summarised in the following *Table*:

With regard to tunnel development operations, which are not specified in Annexes I to IV of the decree, and therefore not automatically exempted from the impact study nor subject to the impact notice, the financial limit of € 1.9 M, tax inclusive, applies to all the expenses planned for the land development (tunnel alone) or the works programme (the tunnel is part of a more comprehensive road operation), including when the tunnel is subject to renovations that are staggered in space or time. The works programme corresponds to a set of operations governed by separate authorisations and related by a functional link.

These provisions are pending amendment under the Grenelle II law of 12 July 2010 that introduces reforms to environmental impact studies. While the exact methods of this reform are subject to decree, the proposed reform aims, in particular, through a more effective incorporation of European directive 85/337/EC of 27 June 1985, to specify the scope of the impact study, to take better account of environmental sensitivity criteria and cumulative project impacts, to guarantee the effectiveness of the study's planned measures and to extend the reach of rights involving public participation and information.

Scope of the impact studies (decree of 12 October 1977 + annexes)		
Projects for works, structures, land-use planning		
Subject to impact study	Subject to impact notice	Exempted from the impact study
Depending on the nature of the project and/or the technical thresholds specified in annex III* of the decree	Categories shown in Annex IV* of the decree	Maintenance and major repairs
Projects whose amount is greater than or equal to € 1,900,000, tax included		Categories shown in Annexes I* and II* of the decree
		Projects whose amount is below € 1,900,000, excluding the operations listed in Annex III* of the decree

* *annexes I to IV included in articles R122.5 à R122.9 EC*

The content of the impact study is specified in article *R122.3 EC.*

CONTENT OF THE ENVIRONMENTAL IMPACT STUDY (ART. R122.3 EC)

I. The content of the impact study shall relate to the scope of the planned developments and works and to their foreseeable environmental impacts.

II. The impact study presents in turn:

1. *a analysis of the initial status of the site and its environment, focusing mainly on natural resources and spaces - natural, agricultural, forested, maritime or leisure - affected by the development work or structure;*
2. *an analysis of the project's direct and indirect, temporary and permanent impacts on the environment and, in particular, on fauna and flora, sites and landscapes, soil, water, air, climate, natural environments and biological balances, the protection of property and cultural heritage and, where necessary, on neighbours' convenience (noise, vibrations, odours, light emissions) or on public sanitation, hygiene, health and safety;*
3. *the reasons why, with respect to environmental concerns in particular, the proposed project was selected from among the parties considered and described;*
4. *the measures planned by the owner or the petitioner in order to eliminate, reduce and, where possible, counteract the project's harmful consequences on health and the environment, together with an estimate of the related expenses;*
5. *an analysis of the methods used to evaluate the project's environmental impacts listing any technical or scientific difficulties encountered when producing this evaluation;*
6. *for transport infrastructures, the impact study also includes an analysis of the collective costs for pollution and nuisances as well as of the resulting benefits for communitie together with an assessment of energy consumption generated by project operation, particularly due to any travel it either causes or helps to avoid.*

III. A non-technical summary of the study is drafted In order to facilitate public awareness of the information contained therein.

IV. When all the works planned in the programme are to be executed simultaneously, the impact study shall cover the whole programme. For staggered execution, the impact study for each operating phase shall contain an assessment of all programme impacts.

The impact study is not an administrative document or a procedure, but a documentary component in a file, inserted into an authorisation procedure or an administrative works approval, or into a public inquiry that may be part of such a procedure. It is a basic tool for informing and educating the public and, therefore, has to be drafted in a clear and understandable manner (this requires the preparation of a non-technical summary).

With regard to tunnel projects, special attention has to be given to the health section of the impact study, in terms of both the overall programme and the tunnel itself, given the potential for impacts in the execution or operating phases, in particular, relating to:

- tunnel drilling operation: storage, transport and the use of explosives, structure-borne noise (impact on surface-level homes and activities), air blasts (impact of blasting operations), etc.
- noise emissions (transport of rubble, worksite machinery, blasting, traffic during the operating phase, etc.),
- pollutant emissions within the tunnel and their impacts outside the tunnel (tunnel portals, additional openings in the tunnel structure, extraction vents),
- possible impacts on water resources (hydrological regime, water quality).

1.1.2.2 Other environmental assessments

Water Act impact study

In most cases, tunnel drilling works are likely to impact on water and aquatic environments during both the construction phase (discharge of wastewater from tunnel drilling works, draining of roads for worksite vehicles, of product and plant storage areas, etc.) and the operating phase (drainage of underground waters, collection and discharge of tunnel rinsing waters, etc.). Accordingly, they will generally be subject to the approvals or declarations procedure established by the *Water Act of 3 January 1992*.
The decision on whether to exempt the project from this approvals or declarations scheme shall be assessed by systematically comparing the project or the works programme at every stage in its execution (worksite operations, siting of structures, maintenance and operation) against the specific classification established by law (*decree of 29 March 1993 amended by the decree of 17 July 2006 – see art. R214.1 EC*). The project appraisal procedure under the Water Act requires an assessment of project-related water impacts.

WATER ACT APPRAISAL SCHEME AND WORKS PROGRAMME

The corresponding studies and documents shall cover all facilities or equipment operated or planned by the petitioner, which have the potential to impact on water and aquatic environments due to their proximity or connectivity with the facility subject to approval (art.2 procedure decree). If several structures, facilities or categories of works or activity have to be executed by the same person, at the same site, it will only be necessary to submit a single approval application covering all these facilities (art. R214.42 EC). A single survey is carried out and a single order gives an overall ruling and sets the recommendations provided for under Art.13 of the procedure decree (art. 214.15 and 16, R214.35 and 39 EC). This shall always be the case for a group of structures, facilities, works or activities that depend on a given person, a given operation or a given company and concerning the same aquatic environment, whenever this group exceeds the threshold set by the classification of the operations or activities subject to authorisation, while these structures, facilities, works or activities, executed simultaneously or successively, taken separately, lie below the classification threshold (art.10 decree procedure).

This impact study shall make it possible to meet the general objectives for balanced management of the water resource, the general principles (*art. L 211.1 CE*) of which are summarised below.

GENERAL PRINCIPLES FOR BALANCED AND SUSTAINABLE MANAGEMENT OF THE WATER RESOURCE (ART. L211.1 EC)

A balanced and sustainable management of the water resource is designed to:

1. *Prevent flooding and protect aquatic ecosystems, sites and wetlands; wetlands means any land, used or not, that are generally flooded or saturated with freshwater, saltwater or brackish water on a permanent or temporary basis; any vegetation is dominated by wetland plants during at least part of the year;*

2. *Protect water resources and the fight against pollution deriving from spillages, run-offs, discharges, direct or indirect deposition of materials of all sorts and, more generally, from any event likely to induce or increase damage to water resources by modifying their physical, chemical, biological or bacteriological characteristics, whether for surface water, groundwater or seawater within regional water boundaries;*

3. *Restore the quality of these waters and their recovery,*

4. *Develop, mobilise, create and protect the water resource;*

5. *Develop water as an economic resource and, in particular, in order to develop the production of electricity from a renewable source and the distribution of this resource.*

6. *Promote efficient, sparing and sustainable use of the water resource.*

7. *Re-establish ecological continuity within drainage basins.*

Above all, balanced management shall make it possible to meet requirements in terms of health, public sanitation, civil safety and the supply of potable water. It shall also provide for meeting or reconciling, during the diverse range of uses, activities or works, the following requirements:

1. *biological life in the receiving environment, especially finfish and shellfish;*

2. *conservation and free flow of waters and protection against flooding;*

3. *farming, fishing and marine cultures, freshwater fishing, industry, energy production, in particular to ensure the safety of the electricity grid, transportation services, tourism, protection of sites, water sports and leisure activities and all other lawfully performed human activities.*

The *Water Framework Directive of 23 October 2000*, incorporated into the 30 December 2006 law on water and aquatic environments, makes important changes to the guideline on the approach to objectives, including the following objectives in particular:

- no degradation of water resources, since 2000,
- achievement of good ecological status and good chemical status in all water bodies by 2015,
- good ecological potential and good chemical status in man-made or heavily modified water bodies by 2015.

The content of the approval application (*art. R214.6*) or declaration (*art. R214.32*) to be submitted by the petitioner is set out below:

THA WATER ACT AUTHORISATION OR DECLARATION FILE "LOI SUR L'EAU"

1. *Name and address of the applicant,*

2. *The location on which the facility, structure, works or activity have to be executed,*

3. *The nature, substance, volume and purpose of the planned structure, facility, works or activity, together with their related classification heading(s),*

4. *A document (impact document):*
   - *indicating the direct and indirect, temporary and permanent project impacts on the water resource, aquatic environment, run-off, water level and quality, including run-off, based on the implemented procedures, the works or activity execution methods, the operation of structures or facilities, the nature, source, and volume of assigned or used waters taking account of seasonal and weather-related variations;*
   - *including an assessment of project impacts on one or more Natura 2000 sites, with regard to the conservation aims for these sites. The content of the Natura 2000 impact assessment is defined in article R. 414-23 and may be limited to the presentation and summary defined in section I of article R. 414-23, whenever this preliminary analysis concludes on the absence of a significant impact on any Natura 2000 site;*
   - *outlining, where necessary, why the project is compatible with the master plan or the water management and development plan and its part in meeting the objectives listed in article L211-1 of the Environmental Code as well as the water quality objectives covered by article D. 211-10;*
   - *specifying whether there are any planned corrective or countervailing measures;*

5. *Planned monitoring means and, for hazardous operations, response measures in the event of an incident or accident;*

6. *Diagrams, plans or maps that assist the understanding of file documents, particularly those mentioned in 3 and 4.*

Natura 2000 impact assessment

The term Natura 2000 refers to a European network of protected areas consisting in Special Protection Areas and Special Conservation Areas. In these areas, member states undertake to maintain the relevant habitats and species in a favourable conservation status.
At the same time as this network was being set up, a special environmental assessment process governed by administrative approval or authorisation schemes was established for projects likely to have a significant impact on these sites.
The corresponding scope is defined by *article L 414.4 EC* and has been subject to recent amendments. French *law No. 2008-757 of 1 August 2008* relating to environmental liability established a system national and local lists aimed at subjecting a greater number of projects to an impact assessment. A decree dated 9 April 2010 (*article R. 414-19 EC*) set the corresponding national list. In particular, this list reproduces the categories already subject to an impact assessment in the previous arrangement; in particular:

- works and projects subject to a study or an impact notice under *articles L.122-1 to L.122-3 EC and articles R.122-1 to R.122-16 EC*;
- facilities, structures, works and activities subject to authorisation or declaration under *articles L. 214-1 to L. 214-11 EC* (Water Act review scheme).

The local authorities will decide on local lists supplementing this decree based on the existing local challenges while a second decree is planned to further extend the system to cover projects currently not governed by other regulations.
The technical content of this impact assessment is specified (art. R414.23 EC) below::

NATURA 2000 IMPACT ASSESSMENT

I. - In all cases the assessment contains:

1° A simplified presentation of the planning document, or a description of the programme, project, event or intervention, accompanied by a map showing the land or marine area that could be impacted and the Natura 2000 sites likely to be affected by these impacts; a detailed site plan is included when works, structures or developments are to be executed within the boundaries of a Natura 2000 site;

2° A summary presentation of the reasons why the planning document, programme, project, event or intervention may or may not impact on one or more Natura 2000 sites; if so, this summary will list which Natura 2000 sites are likely to be affected, in view of the nature and scope of the planning document, programme, project, event or intervention, its location on a Natura 2000 site or the distance separating it from said Natura 2000 site(s), the topography, drainage pattern, operation of ecosystems, characteristics of the Natura 2000 site(s) and of their conservation aims.

II.- If there is a likelihood of one or more Natura 2000 sites being impacted, the file will also contain an analysis of the temporary or permanent, direct or indirect impacts that the planning document, programme, project, event or intervention could have, either individually or due to impacts cumulated with those of other planning documents, programmes, projects, events or interventions run by the local authority responsible for approving the planning document, the owner, the petitioner or the organiser, on the conservation status of the natural habitats and species that warranted the site(s) designation.

III.- If the analysis referred to in II reports that the planning document, programme, project, event or intervention, during or after their execution or during the planning document's period of validity, are likely to have substantial harmful effects on the conservation status of the natural habitats and species that warranted the site(s) designation, the file will contain a summary of the measures to be implemented aimed at eliminating or limiting these harmful effects.

IV. - When, despite the measures planned in III, there are remaining substantial harmful effects on the conservation status of the natural habitats and species that warranted the site(s) designation, the assessment will also:

1° Describe any possible alternative solutions, giving the reasons why the selected solution is the only one possible together with the details providing the grounds for approval of the planning document, or execution of the project programme, or event, under the conditions set out in VII and VIII of article L. 414-4;

2° Describe the measures planned to counteract any harmful effects that the measures planned in III cannot eliminate. These countervailing measures provide an effective and proportionate means of counteracting the damage to the conservation aims for the relevant Natura 2000 site(s) as well as to maintaining the overall consistency of the Natura 2000 network. These countervailing measures are deployed according to a schedule that enables continuity in the ability of the Natura 2000 network to ensure the conservation of natural habitats and species. When these countervailing measures are spread out over time and space, they involve a global approach, making it possible to ensure this continuity;

3° An estimate of the corresponding costs and procedures for managing the countervailing measures; planning documents are covered by the authority responsible for their approval, programmes, projects and interventions are covered by the client or the recipient petitioner, while events are covered by the recipient organiser.

The impact study, impact notice or Water Act impact document can serve as the Natura 2000 impact assessment provided that they meet the recommendations of the impact assessment scheme specified above. In this case, the impact assessment supplements, but does not replace, the "natural environment" section of the impact study, impact notice or Water Act impact document, as it focuses solely on natural habitats and species of Community interest.

CAUTION: as pointed out in the french circular of 5 October 2004 relating to Natura 2000 impact assessments, this assessment include some specific features in relation to impact studies:

- it targets natural habitats and species of Community interest;
- the damaging nature of the impact has to be determined based on the environmental features and conditions specific to the relevant site, in view of the conservation/ restoration objectives defined in the assessment's objectives document;
- imperative reasons of overriding public interest have to be strongly motivated; public interest alone is not sufficient reason to warrant its execution;
- any countervailing measures, chiefly aimed at ensuring the overall consistency of the Natura 2000 network, shall:
  > cover the same biogeographic region;
  > aim to cover to the same degree the habitats and species facing harmful effects;
  > maintain ecological functions as they are shown in the ecological data (standard data form, objectives document) meeting site selection criteria;
  > clearly define management targets and procedures to ensure that, at any point in project roll-out, these countervailing measures can play an effective role in maintaining the consistency of the Natura 2000 network.

1.1.2.3 Environmental report (LOTI)

Article 14 of La Loi d'Orientation des Transports Intérieurs (French Domestic Transport Guidelines Act (LOTI law)) of 30 December 1982 introduced the principle of major infrastructure project assessments based on uniform criteria that assimilate the impacts of external transport effects mainly concerning the environment and health and safety, and that can be used to make comparisons within a given transport mode and between different modes or combinations of modes. When these operations are supported by public funding, a report on the economic and social results is published no later than 5 years after their commissioning. The term "report on economic and social results" should not lead to the exclusion of the environmental considerations contained in the report commissioned by the LOTI.
Prime examples of major transport infrastructure projects that will have to be reviewed in a report (in the sense of the *LOTI implementing decree No. 84-617 of 17 July 1984*):

- creation of 2x2-lane expressway with length over 25 km,
- major transport infrastructure projects costing 83 million Euros or more.

Where works are project-managed by communes, departments, regions and their consortiums, the report will also cover projects for new roads over 15 km in length and that are subject to an environmental impact study.

For State-managed projects, the Bianco circular of 15 December 1992 clarified the information that is required for a LOTI report, in particular, all the data in the environmental report. These items are specified in the box below and can therefore be tracked by the client local authorities.

WHY HAVE A POST-EXECUTION ENVIRONMENTAL REPORT?

The environmental report is drafted one year after commissioning, and then again after between 3 and 5 years, and meets several specific aims:

- *check the effective execution of the environmental measures planned in relation to the various undertakings (particularly as part of State undertakings files, for State-managed projects)*
- *evaluate the infrastructure's actual impacts, foreseen or not,*
- *explain the disparities between predicted and actual impacts, and propose corrective measures where applicable,*
- *build on feedback from other similar studies,*
- *present the information to the public.*

Note that the Grenelle II law of 12 July 2010 strengthened the system designed to ensure the enforceability of environmental measures.
The decision by the competent authority that authorises the petitioner or client to execute the project sets out the measures to be taken by the petitioner or the owner. These measures are designed to prevent, reduce and, where possible, counteract the project's significant adverse effects on the environment or human health, and also define the relevant monitoring procedures. Sworn in or authorised agents will now be able to control the application of these measures, any time, by visiting the relevant locations in particular.

1.1.3 Apparaising projects requiring the opinion of the environmental authority

In accordance with the provisions of decree No. 2009-496 of 30 April 2009 and of the implementing circular of 3 September 2009, projects subject to an impact study, whatever the owner, will require an opinion from the environmental authority.

The environmental authority is the:

- General Council for the Environment and Sustainable Development, for projects managed by the Ministry of Ecology, Sustainable Development, Transport and Housing (MEDDTL), for its delocalised departments or public institutions and, for projects requiring a ruling by the MEDDTL or taken based on a report by the State minister,

- General Commissariat for Sustainable Development (CGDD), for other projects governed by a national ruling (other than the MEDDTL),
- Regional Prefect, in all other cases.

The opinion issued by the environmental authority covers both the quality of the impact study and the way in which the project factors in environmental concerns. It includes an analysis of project context, the full nature of the impact study, its quality, the relevancy of the data it contains, how the project takes account of environmental concerns, and, most importantly, the relevance and sufficiency of the measures planned to prevent, limit or even counteract said impacts.

This opinion is issued no later than two months after acknowledgement of receipt of a file deemed acceptable (complete and reliable). This file is attached to the public inquiry file, and published on the Internet (website of the authority responsible for seeking this opinion).

It is therefore important to integrate these deadlines (permissibility of the file followed by the opinion of the environmental authority) into the overall schedule for the planned operation. Setting up this environmental authority opinion procedure should help to improve the technical quality of the impact studies. It should be remembered that the petitioner can ask the authority responsible for project approval to specify which information needs to be included in the impact study (art R122-2 of the Environmental Code, relating to the preliminary focus request). We strongly encourage the implementation of this preliminary focus as far upstream of the studies as possible.

1.2 FROM ENVIRONMENTAL STUDIES UP TO ORGANISATION OF THE WORKS

1.2.1 Linkage between environmental and project development studies

Environmental studies are conducted alongside the various project development studies according to a continuous and iterative process; the permissibility of the impacts dictates whether studies will be conducted on the selected assumptions. On the national network, the development, appraisal, approval and assessment procedures for road investment operations are defined by the circular of 7 January 2008. The main steps and endpoints are summarised in *Table 1*.

In chapters 2 to 12, which cover the various environmental topics, the steps in the study and execution approach have been deliberately simplified with respect to the roll-out presented in this table. Henceforth, only three phases will be referred to:
- **Upstream studies** i.e. all the studies preceding the public inquiry,
- **Design studies**,
- **Execution**

These various phases incorporate considerations relating to the operating phase, during which the reports referred to in Table 1 are published.

Upstream studies group:

- **Opportunity studies:** all major transport infrastructure projects are subject to debate over their economic, social and environmental interest. During this opportunity study, all the main infrastructure functions are studied under a multimodal approach.

- **Studies preceding the public inquiry**, referred to as preliminary studies under the law governing the public sector project management – the MOP law: these studies provide input for the public inquiry file and have two key chronological steps:
  - > comparison of options during which the various alternatives are studied. Note that this study must be based on residual impacts, and must therefore integrate any mitigating measures. Some impacts are non-reducible (e.g. the disappearance of a rare biotope) while others are easier to extend (e.g. protecting neighbouring populations against noise). Obviously, this analysis also has to factor in any of the project's potentially positive impacts, especially where tunnels are concerned, which generally impact positively on surface-level activities.
  - > study of the proposed option used to establish the impact study, and that will make up the technical support file for the inquiry preceding the Declaration of Public Interest. On completing the study phase for the proposed option, the level of detail should be sufficient to enable the client to define the operation's preliminary assessment.

	Phase	Productions	Environmental assessments
Upstream studies	Opportunity studies	Opportunity study file	Environmental section of the opportunity study file
		French National Commission for Public Debate (CNDP) referral file	Environmental section of the referral file
		Public debate or consultation file	Environmental section of the public debate file
	Preceding the public inquiry studies (or preliminary studies under the law relating to public sector project management -the MOP law)	Preliminary studies file	Environmental section of the preliminary studies file
		Publix inquiry file	Environmental impact study Water Act file (if project is adequately defined) Natura 2000 impact file (if required)
	Finalisation du programme (au sens de la loi relative à la maîtrise d'ouvrage publique dite loi MOP)	Declaration of public interest	Environmental section of the programme State undertaking file
		Operation programme	
		State undertaking file	
Design studies	Finalising of the preliminary design	Preliminary design file	Environmental section of the preliminary design file
	Detailed design	Project file	Environmental section of the project file
		Other regulatory files	Water Act file (if not prepared at the inquiry stage) Natura 2000 impact file (in the event of major changes)
Execution	Execution of the works	Tender documents	Organisational framework for the Environmental Assurance Plan *(see chapter 1.2.5)*
Operation	Reports and assessments	LOTI report	Environmental LOTI report

Table 1 : environment of the main steps in project production

These studies generally provide input to the public inquiry aiming to gauge public opinion on the planned infrastructure, i.e. demonstrate the public interest through consultation, gather the public opinion, determine the option to be studied and decide on the related support measures in the owner's undertakings file. This culminates in the Declaration of Public Interest (DUP) and paves the way for project execution.

There are two studies at the **Design studies** stage:

- **preliminary design**: this is finalised based on the operation characteristics that are of proven public interest, the owner's undertakings and the validated programme that formalises the technical response. It is used to adopt the baseline cost and to align the programme with the margin.
- **project studies:** used to make a detailed study of the structure and its cost such as will be defined at the time of awarding the contract.

Lastly, there is the effective **execution** of the project. This is preceded by the preparation the Tender documents (DCE).

New partnership arrangements, in particular those that involve public-private funding, or that involve the construction consortium very early on as from the preliminary design stage do not alter the principle breaking the process down into three main phases.

1.2.2 Defining and steering the impact study

The impact study's baseline objectives are:

- to optimise project design with regard to environmental concerns,
- to provide the owner with decision-making support,
- to provide the administrative authority with insight on the decision to be made,
- to inform the public and involve it in the decision-making process.

This document is drawn up **under the sole responsibility of the owner**, who has to validate every aspect. This responsibility comprises several levels:

- definition of the structure's technical and functional requirements, jointly with the environmental aspects,
- definition of the technical content and general organisation of the environmental studies to be performed,
- setting of targets (specific to the owner, in addition to those

required by law),
- checking the achievement of targets and obligations of results,
- technical alternatives to be studied and reasons for the choices made, particularly in environmental terms,
- relevance and efficacy of the proposed mitigating and countervailing measures (integrating the basic principles of precaution and prevention at source),
- tracking of impacts and any adjustments to the recorded impacts.

It is important, therefore, to ensure effective steering of the environmental studies, by clearly framing the order with respect to the operational plan (beyond a simple statement of the notional content of the impact study) and by conducting strict monitoring and control of the resulting services.

KEY POINTS OF STUDY EXECUTION

When framing the order, it is advisable to specify:
- *study areas, tailored to the various environmental topics and the scope of the potential impacts,*
- *timescales to be taken account of, integrating the various project execution phases, the immediate and delayed impacts in the fairly long term, the way in which the study area may develop independently of the project,*
- *main challenges that need to be properly understood,*
- *sources of known and useful information,*
- *recommended methods of investigation and analysis, tailored to fit the challenges, at the level of definition of the studies,*
- *human and organisational means to be deployed,*
- *nature of the service delivery.*

Control and validation of the delivered services. Special attention must be paid to:
- *conformity to the technical content based on regulatory requirements,*
- *conformity of the studies to the order,*
- *stringency of the methods used and presentation of their limitations,*
- *inter-disciplinarity and objectivity of the resulting analyses,*
- *legibility and readability of the file in terms of public readership,*
- *relevance of the impacts and measures analysis.*

PRELIMINARY CONSULTATION FOR PROJECTS COVERING WORKS, DEVELOPMENTS AND STRUCTURES RUN BY THE STATE AND LOCAL AUTHORITIES

A circular issued by the French prime minister on 5 October 2004 restated the interest and need for a preliminary design consultation prior to their submission for public inquiry.

For projects involving the State and its public institutions, the consultation is notionally conducted at a decentralised level, led by the prefect of the department where the operation is located. For certain projects where the Declaration of Public Interest is declared by Council of State decree or where the permit is delivered by a central authority, an official consultation between State departments is conducted at this level. The consultation has to begin upstream of the project development process, based on procedures to be defined according to project scope, complexity and challenges. This can be rolled out in two phases:
- *a dialogue phase, begun as soon as the needs have been identified and study scope defined, thus making it possible to detail any noteworthy sensitivities and challenges,*
- *a more formalized consultation phase, during development of public inquiry file and finalisation of the environmental impact study file.*

For both these phases, State departments are consulted separately, making sure to leave sufficient time for them to examine the received documents and issue information or opinions. It is important that the State administrations have made all their necessary decisions on the project before it is submitted to a public inquiry. Special attention must be given to the consultation with environmental departments, given the magnitude of the project's substantive (control over impacts) and legal issues and the organisation of the corresponding studies.

For local authority projects, it is strongly advised to consult State departments in situ, due to concerns over legal certainty and control over project deadlines.

The consultation principle has since been reinforced by its incorporation into the Environmental Code (article L.121-16) under the Grenelle II law: " Failing more specific provisions planned [...] by the special legislative provisions applicable to the project, the project manager [...] can, where necessary at the request of the competent authority responsible for taking the decision, proceed with a consultation prior to the public inquiry that involves the public during the project development phase [...]."

1.2.3 Project consultation

The performance of an effective consultation and information process at the various stages of the project is absolutely vital:
- local actors (local authorities, associations, etc.) hold a substantial amount of data that is useful to project design and the environmental approach; it is therefore essential to establish a meaningful dialogue with these actors at the data mining stage,
- some project aspects may require approval from local authorities (French Water Police, French Fisheries Police, Architect from the "Bâtiments de France", Site Committee, etc.).

Environmental studies generally form a keystone element of project communication and consultation, given the substantive issues and interests of local actors. As such, it is only logical that they should generally form the core of the local consultation process and administrative appraisal procedures (inter-departmental consultation, public inquiry), **or even of disputes** (on the form and/or content).

1.2.4 Public consultation

The public consultation is a key element in the project design and general roll-out. In addition to the public inquiry procedures established by law and that meet a highly restrictive scope, the owner can also launch a local consultation on its own initiative, in a variety of ways (public meetings, questionnaires, etc.). This dialogue with people in the field is vital to:

- identifying the sources of relevant data,
- understanding the challenges and local sensitivities,
- collecting opinions on any planned alternatives,
- ensuring the transparency of project roll-out, and of the recorded impacts.

PUBLIC INQUIRIES

The inquiry preceding the Declaration of Public Interest (DUP) governed by Article L11-1 of the French expropriation code, covers operations requiring the implementation of expropriation procedures.

French law 83-630 of 12 July 1983 (Bouchardeau law), since codified in Articles L123-1 et seq. of the Environmental Code, extended the scope of the public inquiries, and created a second type of public inquiry that depending on their nature and importance, concerns developments, structures and works likely to have an environmental impact, together with the related land planning documents

PROJECT DECLARATION

French law 2002-276 of 27 February 2002 relating to local democracy amended the public inquiry scheme by requiring public sector owners to issue a project declaration on the operation's general interest. This declaration, to be taken by the State authority or legislative body of the local authority responsible for the project, follows the inquiry procedure itself.
The project declaration states the purpose of operation as it is shown in the inquiry file, and contains the reasons and considerations that underpin its public interest status.
The project declaration takes into account the impact study, the opinion of the State administrative authority dealing with environmental matters and the result of the public consultation. Where necessary, it indicates the nature of and reasons for the main amendments made to the project based on the public consultation results, but without altering its general economy.

No work permit may be delivered without a project declaration. If the project declaration is not issued within one year of the completion of the inquiry, execution of the operation will depend on the performance of a new inquiry.

The declaration will cease to have effect if the works are not begun within a period of five years as from publication of the project declaration. Provided there are no changes in the legal and factual circumstances, the declaration's period of validity may be extended one time for the same period (5 years) with no new inquiry, under a project declaration made in the same manner as the initial declaration and before expiration of the 5-year deadline (Art. L126-1 of the EC).

1.2.5 Environmental organisation of the works

The construction phase may turn out to be most critical phase in terms of environmental impacts if the appropriate preventive measures are not taken. It is important that tender documents and tender procedures (proposal content and selection criteria) should include detailed technical specifications on the environmental plan.

The Public Procurement Code integrates a certain number of provisions in terms of environmental issues and sustainable development.

PUBLIC PROCUREMENT AND ENVIRONMENT CODE (EXTRACTS)

Article 5: obligation for owners to take account of sustainable development concerns when defining needs,

Article 6: option for owners to define environmental requirements in their technical specifications (references to ecolabels allocated by independent bodies),

Article 14: option for owners to integrate environmental conditions of execution into the notice of a competitive public tender or the tender regulations,

Article 45: option for owners to investigate the applicants' knowledge in terms of environmental protection, based on an assessment of their technical abilities,

Article 50: possibility of options, including for the environmental plan (provided that the options have been clearly authorised by the owner under the tender),

Article 53: option for owners to integrate and weight (rank) the environmental criterion in all tender selection criteria.

To ensure that environmental issues are taken into account effectively, tender documents should also include a SOPAE (1) (Organisational Framework for the Environmental Quality Assurance Plan), which is then approved by the client in the same way as the other contract documents. The SOPAE should direct the contractor towards a clear-cut set of commitments (human and equipment means put into action, internal and external controls carried out, procedures for incidents, environmental performance, etc.), that will be formalised in its Environmental Quality Assurance Plan (2) (PAE).

The contractor who has been awarded the contract (the preferred bidder) puts the PAE together during the works preparation phase. This document describes the sensitivities and limitations of the sites through which the works pass and states the means actually set up by the contractor to ensure compliance with the client's targets.

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(1) Or SOPRE (Organisational framework for the Environmental Compliance Plan)
(2) Or PRE : Environmental Compliance Plan

This plan is subject to approval by the professional advisor prior to starting the works. The professional advisor's environmental officer is responsible for its monitoring and enforcement.

As soon as it has submitted its tender, the contractor designates an environmental officer, who is separate from project production, and whose presence on the worksite ensures compliance with environmental requirements.

1.3 ENVIRONMENTAL IMPACTS AND INSERTION MEASURES

1.3.1 Environmental impacts

The Environmental impact study shall contain "An analysis of the project's **direct and indirect**, **temporary and permanent** impacts on the environment and, in particular, on the fauna and flora, sites and landscapes, soil, water, air, climate, natural environments and biological balances, the protection of property and cultural heritage and, where necessary, on neighbours' convenience (noise, vibrations, odours, light emissions) or on public sanitation, hygiene, health and safety" (*art. R122.3 EC*).
A direct impact reflects the project's immediate outcomes in space and time. An indirect impact results from a cause and effect relationship that has its origins in a direct impact. An indirect impact may involve areas located some distance away from the project itself, or materialise some time later. Examples of this category would be the drying up of a groundwater catchment area or its drainage due to the presence of the tunnel.
In addition to the notions direct and indirect, temporary and permanent impacts, additional notions are sometimes added such as **induced impacts** and **cumulated impacts**:

- induced impact: impact generated by a development action made possible or timely by project execution such as the redevelopment of a village centre or a traffic deviation authorised by tunnel project;
- cumulated impact: impact generated by cumulative basic impacts such as the general nuisance caused to the local population during the construction phase or cumulated nuisances (modification of traffic plans, circulation of worksite machinery, airborne dust, noise and vibrations, etc.).

Remark: the impact studies' reform proposal currently aims to optimise the integration of cumulated impacts into projects for a given client..

1.3.2 Insertion measures

The impact study shall specify *"The measures planned by the client or the petitioner in order to eliminate, reduce and, where possible, counteract the project's harmful consequences on health and the environment, together with an estimate of the related expenses" (art. R122.3 EC).*
With regard to the regulations governing impact studies, there are three types of measure that the owner is required to implement according to the foreseeable impacts of its project:

- **prevention or elimination measures:** measures designed to prevent or eliminate an impact (e.g. choice of an appropriate season so as to prevent disturbing the fauna during the works);
- **limitation measures:** measures designed to limit an impact which is has proved impossible to eliminate, at the place and time where it occurs (e.g. construction of buildings for the control and settlement of wastewater from the platform wastewater collection network prior to its discharge to the receiving environment);
- **mitigation measures or countervailing measures:** measures designed to mitigate (as a last resort) any harmful effects that can be neither eliminated nor limited, by setting up a counteracting measure on a similar area, not necessarily at the same location (e.g. creation of a wetland area to replace a similar area located within the project boundaries).

The definition and formalised deployment of countervailing measures supposes upstream assessment of the legal scheme (land management and/or control in particular), funding procedures (investment and management) and long-term sustainability of the measure's effectiveness (competent manager, appropriate and tracked funding).

In addition to the regulatory requirements, the owner can also contribute to the deployment of project support activities led by other actors (e.g. development of a platform and an exploratory route for a site).

2. GROUND SETTLEMENT

Tunnel excavations generate ground movements that can result in relatively major disturbance in the tunnel's surrounding environment.

Ground response to excavation works depends primarily on the geology and the geomechanical characteristics of the surrounding material, and also on hydrogeological conditions, works execution methods (excavation and support structures) as well as the structure's depth and dimensions. The nature and mode of the foundations, and the distance separating the structure from neighbouring buildings also has to be taken into account in order to assess the structure's potential impact. A typical unfavourable setting would be the excavation of a tunnel at a shallow depth in an urban location.

Ground response to excavation works and the description of the phenomena leading to the appearance of surface ground settlement were discussed exhaustively in the document *Civil engineering in the Tunnels Master File [1]*. Here, we go into greater detail on the issue of the environmental impact and, therefore, the risk of damage linked to the vulnerability of the neighbouring structures. As such, this chapter can be compared with the chapters on "structure-borne noise" (*see chapter 3*) and "air blasts" (*see chapter 4*), for which there is a similar study process.

Cut-and-cover sections are covered under the issue of open-air construction projects and are not addressed here.

2.1 TUNNEL EXCAVATIONS AND GROUND SETTLEMENT

2.1.1 Physical mechanism relating to tunnel excavation

Tunnel excavations involve the decompression of the ground around the edge of the excavation, which results in a modification of the stress status. This deconfinement generates movements in the direction of excavation. Underground volume losses (convergence of side walls and extrusion of the rock face) have a knock-on effect on the wall thus creating a settlement basin on the surface: this is known as immediate ground settlement generated simultaneously with the advancement of the excavation face. This is a 3-dimensional basin that changes in response to the gradual advancement of the front. Although it is usually centred on the structure's axis, it may be offset by inhomogeneities in the surrounding land.

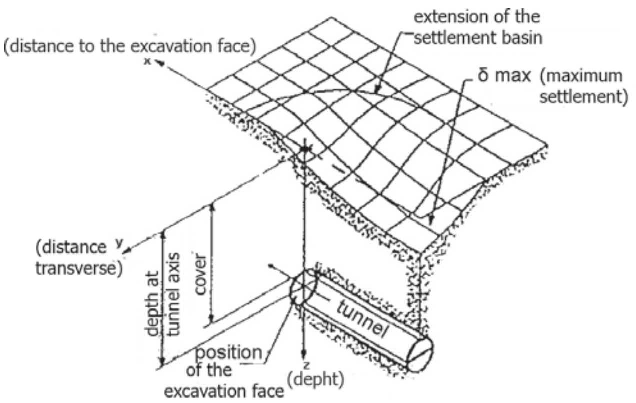

Illustration 1: three-dimensional settlement basin (source: AFTES)

2.1.2 Land and excavation methods

The site's geological, hydrogeological and geotechnical setting is a key element in determining the ground response to excavation. From this perspective, control over the stability and displacement of the rock face is essential to controlling surface ground settlement.

Mechanised excavation methods using a tunnel boring machine can meet these requirements at shallow urban locations. Caution should still be taken over the risk of creating sinkholes as the front advances. Total control over confinement is required to counter this risk. Conventional excavation methods may also be defined with the same ground settlement limitation objectives. However, experience has shown that only below-ground interventions ahead of the tunnel face are capable of modifying the final balance of the structure: once the face has passed through a given section, any form of below-ground intervention (strengthening of standard support structures or closure of the section using rigid surfacing) is generally insufficient.

2.1.3 Consolidation by ground water drawdown

Tunnel excavations can also drain aquifers by a process of ground-water drawdown that may result in soil consolidation (time-related change relating to the dissipation of excess pore pressure): this is also known as delayed ground settlement. Where high-permeability soils are concerned (colluvial deposits, sands and gravels), this consolidation-related ground settlement (dewatering) is generally of low amplitude and occurs rapidly. With low-permeability soils (clays), consolidation-related ground settlement may continue over several months.

Today, road tunnels in urban locations are systematically water-proofed. When total impermeability is achieved, post-construction refilling of groundwater generally leads to a return to the previous balanced situation, thereby helping to stabilise delayed deformations (excluding the soil's own creep characteristics).

During the operating phase, surface ground settlement can only be caused by a changed in the site's hydrogeological status.

2.2 IMPACTS AND CHALLENGES RELATING TO GROUND SETTLEMENT

2.2.1 Geotechnical influence area

The geotechnical influence area (ZIG), defined in standard NF P 94-500, [2]) is the volume of soil within which there is interaction between the structure and the environment. The shape and scope of this ZIG for tunnels at shallow depths is shown diagrammatically in illustration 2. The immediate ground settlement due to the actual excavation is located directly above the tunnel (usually in a basin stretching 50 to 100 m on either side of the tunnel).

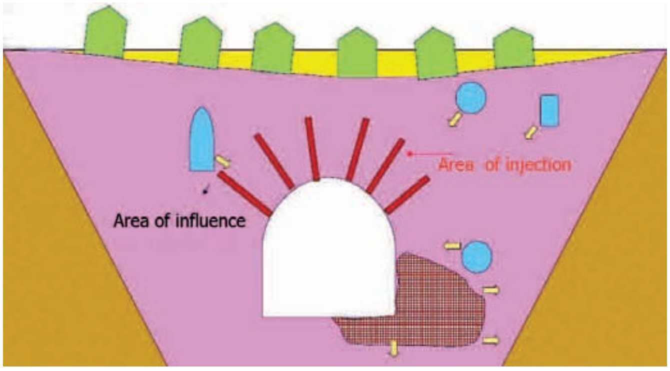

Illustration 2: geotechnical influence area (in pink) for a shallow tunnel (source: CETU)

Delayed ground settlement (consolidation) causes relatively uniform movement over a wider area corresponding to the drainage area.

2.2.2 Structural vulnerability

The impacts relating to ground settlement consist in the appearance of damage to neighbouring structures, such as buildings, structures, networks, development to land or property, located in the ZIG. The *recommendations of GT 16 - AFTES relating to "ground settlement linked to the excavation of underground structures" [3]* lists three categories of damage:

- architectural damage, that affects visual aspects;
- functional damage, that affects usage (faulty operation of doors and windows, lifts being out-of-true, etc.);
- structural damage, that affects the actual stability of the structure.

From a theoretical standpoint, surface structures are mainly sensitive to differential ground settlement between supports. The appearance of total ground settlement caused, for example, by consolidation generally has a low impact on structures. Nevertheless, if there is wide-scale total ground settlement (of the centimetre to decimetre order), the heterogeneities in the overlying soil are materialised by localised differential settlement.

2.3 STUDY APPROACH

The study approach specific to civil engineering topics (ground settlement, vibrations and air blasts) can be broken down into five technical phases. Throughout the project, the owner can also inform the local population on the project's foreseeable impacts and the measures taken during tunnel excavations. As such, it is up to the owner to set the level of damage that it deems acceptable following the consultatione.

<table>
<tr><th colspan="3">Successive technical phases</th><th>Study phase</th><th>Person responsible</th></tr>
<tr><td rowspan="2">(1) determination of excavation impacts</td><td rowspan="2">(2) initial status</td><td rowspan="2">(3) assessment of building vulnerability</td><td>upstream studies</td><td>owner</td></tr>
<tr><td rowspan="2">design studies</td><td rowspan="2">owner and professional advisor</td></tr>
<tr><td colspan="3">(4) determination of contractual control thresholds and definition of ground surveys</td></tr>
<tr><td colspan="3">(5) performance of ground surveys and description of the decision making chain</td><td>execution</td><td>owner, professional advisor and construction companies</td></tr>
</table>

Table 2: study approach applicable to civil engineering topics relating to the construction of tunnels

The 5 technical phases are described below:

(1) Determination of excavation impacts
This phase aims to identify foreseeable settlement basins based on the characteristics of both the soil and the planned excavation methods.

(2) Initial status report
This consists in drawing up an inventory of neighbouring structures that are likely to be impacted by the excavation, specifying their initial status and preparing a typological classification of the structures. This step produces a preliminary assessment of their overall ability to tolerate the deformations.

(3) Assessment of building vulnerability
This phase covers the:

- assessment of the mechanical stresses suffered by the buildings in the field displacement generated by the excavation,
- determination of permissibility thresholds, which are based on the levels of damage that can be tolerated by the buildings, separately from the estimate of expected settlement.

(4) Determination of contractual control thresholds and definition of ground surveys
Two contractual control thresholds are generally defined:

- alert threshold - threshold beyond which the method has to be adjusted,
- cut-off threshold - absolute threshold that must not be exceeded to avoid endangering the buildings.

Defining ground surveys above the structures to be protected makes it possible to check at the time of building the structure that the limit values (surface ground settlement, xyz displacements of the building, etc.) have not been reached.

(5) Implementation of ground surveys and description of the decision-making chain
Conducting ground surveys provides data on soil behaviour during excavation work, enables validation of the methods used to estimate ground settlement and adjustment of support structures with regard to control thresholds, aiming to achieve fast response times from the actors based on a clearly defined decision-making chain.

The way these technical phases link up with project roll-out as per the "Upstream studies, Design studies and Execution" schema is described below.

2.3.1 Upstream studies

The initial status has to be established as of the upstream studies phase even if, at the beginning, it only takes the form of a simple survey. If technical details on the precise definition of the project are occasionally lacking, this initial status will be refined and updated as the studies progress.

Coupled with the determination of excavation impacts, the preliminary data on the initial status gives a first idea of the stresses likely to affect the buildings. These data give indications on the feasibility of the excavation and the choice of method with respect to the thresholds derived from feedback from other, similar construction projects, pending the results of specific studies carried out at the design stage. They also guide the choice of preferred option.

At this stage, the studies, although only partial, have to establish the structure's feasibility i.e. check whether there is a method that will keep ground settlement within the limits of the acceptable values, while maintaining a large safety margin in order to compensate for the lack of accurate geotechnical and structural data. In some cases, it may be necessary to conduct more detailed settlement studies as from the upstream study phase.

2.3.2 Design studies

The thresholds for permissible surface ground settlement during tunnel excavations are set simultaneously with the determination of the structure's dimensions, with which they frequently interfere. Study design phases should lead to the setting of specific thresholds for each structure impacted by the project (at the very least per group of structures based on the typological classification mentioned in the initial inventory phase).

The resulting control thresholds and the adjustment principles for the related excavation methods, determined at the project stage, are contractualised at the contract stage.

On completion of the design studies, some uncertainties always remain concerning the nature, characteristics and behaviour of the land crossed through and on the actual behaviour of the built structures. While the design methods have to incorporate the identified uncertainties as best as possible, the residual risks also have to be given special attention.

2.3.3 Execution

The quality of the ground surveys and the actors' response times are all factors in successful protection of the buildings involved. The owner is advised to conduct a preventive procedure (see box) on a systematic basis.

The works contract has to be drafted in such a way that the contractor is aware of and can forward-plan for the residual risks, and thus be able to adjust survey and excavation methods where necessary during the works stage.

PREVENTIVE PROCEDURE

Carried out prior to starting the works, this corresponds to a joint investigation carried out in the presence of all the parties involved. The owner requests, as a preventive measure, the designation of a legal expert, missioned to:

- *look at all the information on the planned works;*
- *obtain a list of the construction firms who will be executing the works together with their insurance policies;*
- *visit the sites, describe them, specifying their condition (degradations, dilapidation, maintenance shortfalls);*
- *describe the condition of the subsurface;*
- *provide the court with the data needed to make a comparison of the condition of the buildings before and after the works;*
- *issue an opinion on any risks of destabilising existing structures and on the measures to be taken.*

Once they have completed their observations, the legal expert draws up a report containing all their observations. A copy of this report is sent to each party and to the court. When issues arise during project roll-out, the expert's mission generally provides for them returning to the site to observe and record any damage, identify the causes, make recommendations, estimate the cost of the rehabilitation works or the measures to be taken and provide any information that would assist the court in its ruling on possible liabilities.

2.4 ASSESSMENT METHODS AND MEANS

This chapter describes the available methods and tools for each successive technical phase as defined in *Chapter 2.3*. The content of each of these phases varies depending both on the progress status of the studies and the related challenges.

2.4.1 Determining excavation impacts

Describing the stresses acting on neighbouring structures involves evaluating foreseeable massif displacements during the excavation. *AFTES recommendations [3]* review the list of usable methods. *Section III of the Tunnels Master File "Civil engineering" [1]*, states:

"There are a certain number of methods that provide a simple estimate of surface-level ground settlement generated by tunnel excavations. These methods are generally based on a process with the following steps:

- assessment of volume losses generated by the tunnel excavation (losses dues to extrusion of the rock face, wall convergence, incorrect filling of the annular space behind the skirt of a tunnel boring machine);
- assessment of the part of these losses affecting the surface (for shallow tunnels, the general assumption is for a full transmission of the surface volume lost);
- choice of the shape of the settlement basin and determination of its width based on the tunnel's geometric characteristics (dimensions, depth) and the nature of the soil;
- calculation of the depth of this basin in order to ensure a volume at the surface that equals that of the losses taken into account."

Input data concerns the geology, the structure's excavation-support method, the project's geometric definition (structural dimensions, roofing). Output data on the description of the expected settlement basin concerns:

- width (emprise of the potential risks), depth (maximum total settlement) and slope (maximum differential settlement) taken on a transverse section through the structure's axis;
- theoretical longitudinal curve for settlement.

The above-mentioned methods apply to the determination of "immediate" ground settlement that occurs simultaneously with advancement of the excavation face (but whose effects may be felt on the surface over time). These empirical or semi-empirical methods are very useful during the upstream study phases and provide orders of size that can then be compared against the results of more sophisticated computations of the displacements in the tunnel environment, mainly using the finished elements method, during the design study phase.

In some cases, delayed ground settlement may appear after completion of the works, particularly in fine-grained soils where consolidation may result from the tunnel excavations.

2.4.2 Initial status analysis

The Initial status analysis is based on a survey phase that characterises both the site's geological, hydrogeological and geotechnical setting (see section II of the *Tunnels Master File "Civil engineering" [1]*) and the diagnostic of neighbouring structures (buildings and structures located within the geotechnical influence area of the tunnel).
This second point consists in collecting data on the structure and any sensitive networks, and in gathering archive documents and technical expert reports, possibly accompanied by a topographic survey.
The summary of all this data is used to assign the structure and networks a typological classification, where possible linking this to a breakdown into uniform areas that also integrate the geotechnical data. This classification is based on the following data on the structure to be protected:

- nature and function,
- dimensions, materials and design method (masonry, reinforced concrete, etc.),
- foundation mode,
- age and current status (based on a qualification of pre-existing damage),

and provides a preliminary assessment of the structures' overall ability to withstand deformation.

For example, the following Table illustrates the typological classification established for the excavation of the second tube of the Toulon tunnel.

Nature and fonction	Building structure	Building condition
1 – building intended primarily for public use or housing a large business	A – stone or rubble masonry, wood or metal flooring	1 – building shows no structural disorder
2 – building intended primarily for residential use	B – reinforced concrete and modern masonry with a high intertia value	2 – building shows some signs of structural disorders
3 – building intended for artisanal or industrial use	C – reinforced concrete and modern masonry with a low interia value	3 – buildings showing signifiant structural disorders

Table 3: example of a typological building classification; a public building made of reinforced concrete showing no disorder would be classified 1B1

The investigation endpoint:

- determines the baseline status of the structures summarised in engineering data sheets,
- gives a few pointers towards one or more appropriate technical solutions together with the related risks.

This initial inventory differs from the preventive procedure (see box in chapter 2.3.3), which the owner has to carry out prior to the works.

2.4.3 Assessing structural vulnerability

2.4.3.1 Evaluation mechanical stresses acting on the structures

Determining structural responses to stresses generated by ground movements following tunnel excavations consists in evaluating both the displacements and the expected stresses on the structure when it is placed in the required foundation-level displacement field.

Several approaches can be planned:

- analytical approaches to simplified configurations;
- numerical approaches of the "finished element" type, when there is a high risk and the results of the simplified approach appear insufficient, particularly in view of observations made on similar cases.

A sensitivity study will also have to be carried out to determine:

- the basin's shape and depth, which depends on the geotechnical parameters, on the confinement pressure during excavation with a tunnel boring machine and on the standard profiles for excavation-support structures using conventional methods;
- the basin's position in relation to the structure (influence of geology on the theoretical basin).

Based on input data (ground settlement basin, building baseline status), this phase provides for establishing a qualification of the impact of the planned works by determining the expected structural displacements and mechanical stresses.
While the modelling phases are generally conducted separately, complex cases may require the soil-structure interaction (influence of structural stiffness on the required displacements) to be taken into account.

2.4.3.2 Determining permissibility thresholds

A permissibility threshold corresponds to a limiting stress condition for a structure beyond which it will no longer be possible to meet at least one of the required performance criteria. These include:

- serviceability limit states (SLS), which correspond to a load spectrum beyond which one of the structure's functions is no longer assured. This is referred to as architectural damage below the SLS, and functional damage above the SLS.
- ultimate limit states (ULS), which correspond to a load spectrum, any overrun of which would impact on the structure itself. Above the ELU, this is referred to as structural damage.

For example, AFTES *[3]* proposes a damage qualification for masonry work based on observed cracking. These values are not appropriate for use with other types of structure.

2.4.4 Determining contractual oversight thresholds and defining ground surveys

2.4.4.1 Determining contractual project oversight thresholds

Acceptable foundation-level displacements are quantified, taking account of the baseline status of the structures and their permissibility threshold.

Contractual project oversight thresholds are determined based on these acceptable displacements and incorporate a safety margin. They are characterised by total and differential ground settlement, and apply either to the whole project or vary according to geographic sections or areas. To recap, two contractual project oversight thresholds are usually identified (*see 2.3*):

- alert threshold,
- cut-off threshold.

Project oversight as the excavation proceeds is based on total ground settlement forecasts (behind the face). These forecasts are based on the data measured very early on ahead of the face and extrapolated for the area behind the face using theoretical longitudinal settlement curves. These forecasts are compared against the contractual thresholds in order to decide whether to strengthen or reduce the pre-linings or confinement and possibly adjust the speed at which tunnel sections are completed.

This project oversight method requires very fast response times on the part of all the actors involved (construction companies and professional advisor in particular) who have to be continually predicting expected settlements and rapidly drawing operational conclusions. If such response times cannot be guaranteed, there will have to be a greater safety margin.

2.4.4.2 Defining ground surveys

Excavation monitoring normally requires underground inspections in order to:

- evaluate immediate safety: knowledge of the excavation's stability status,
- check support structures: check on whether the support structures meet the planned deformation requirements and any adjustments,
- determine actual soil behaviour: understanding of the actual behaviour of the rocks in the wall area surrounding the excavation,
- improve predictions: fine-tuning of the selected model throughout the project.

In particular, underground monitoring of excavations makes it possible to evaluate the initial movements (convergence in walls and extrusion of the rock face) responsible for generating potential surface disturbance. To find out more about the different measurement means and operating methods, please refer to section IV "*Inspections during the works" in the Tunnels Master File "Civil engineering*" *[1]*.

Alongside the underground monitoring of excavations, it will be necessary to carry out:

- measurements of surface-level vertical ground settlement: these free-field measurements represent the ground settlement basin;
- ground surveys of sensitive structures: evaluation of displacements in three spatial directions;
- survey of neighbouring underground structures: convergence, levelling, monitoring of cracks;
- piezometric monitoring of the site.

Standard methods use topographic measures made with automated theodolites. Structures can also be monitored using tilt sensors on vertical building walls (inversion), of the crackmetres, electrolevel beam sensors, etc.

The definition of ground surveys has to comply with several basic rules:

- site behaviour has to be established prior to starting the works: pre-existing ground movement, daily cycles linked to temperature, traffic, etc.
- the whole surface of the estimated basins has to be covered to a sufficient density in order to obtain their transverse and longitudinal shapes,
- care must be taken to ensure the complementarity of the monitoring measures for buildings and surface areas,
- the measurement frequency must be appropriate to the sensitivity of the structures and the project's progress status.

The table below gives an example of the identified building classifications used to define the level of monitoring to be planned.

Classification	Definition of actions to be planned
class 0	buildings and structures for which the diagnostic and aquired data is not sufficient to estimate the risk: continue the investigations that would enable stepping up from class 1 to 3
class 1	buildings and structures with a low estimated risk: no specfic action needs to be defined apart from a regular visual inspection
class 2	Buildings and structures requiring the setting up of a monitoring system: definition of specific instrumentation
class 3	Buildings and structures requiring the execution of preliminary buttressing works: definition and estimate of buttressing works and definition of specific instrumentation

Table 4: example of a structural classification to be used in the definition of ground surveys

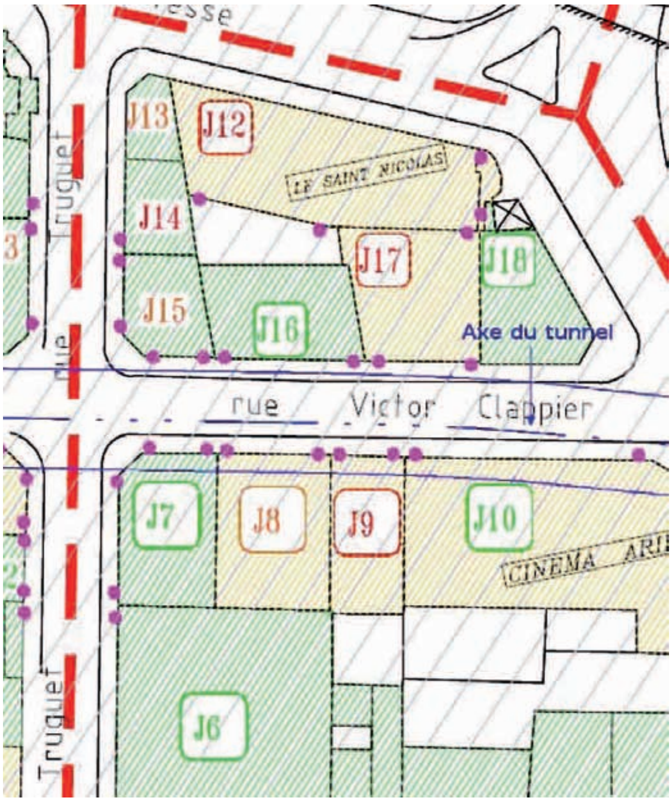

Illustration 3: map showing the structures involved during excavation of the Toulon tunnel. Label colours indicate the condition of the buildings (as per the model in column 3 of Table 3) while the classification is illustrated by the colour of the built surface area (as per the model in Table 4). Ground survey points are shown in violet. les points d'auscultation.

2.4.5 Ground surveys and description of the decision-making chain

It is recommended that ground surveys be carried out under the same contract as that covering the underground works. The works manager is therefore also responsible for the ground surveys. They have the necessary means for steering their works project at all times.

It is also advisable to make sure that the contractor responsible for the works has a clearly defined decision-making chain, especially regarding the settlement issue. In particular, the contractor can define intermediate and supplementary thresholds in addition to the contract project oversight thresholds in order to ensure graduation action with the identified actors.

2.5 IMPACT LIMITATION MEASURES

The settlement phenomenon is irreversible; any deformation that occurs during excavations is final. The measures selected to limit the impacts on structures aim to limit the phenomenon's amplitude or structural vulnerabilities.
These limiting measures have to be determined during the design study stage:

- limit immediate ground settlement, through the choice of excavation method,
- limit delayed ground settlement, using methods to limit soil permeability..

2.5.1 Immediate ground settlement

Tunnels excavated using a tunnel boring machine generally allow greater control over the settlement phenomenon than more conventional methods.
At sensitive sites, the tunnel boring machines used necessarily work with confined faces. The main limiting measures for ground settlement are:

- quality project oversight via control over the confinement pressure at the rock face and over the volumes of excavated rock,
- definition of over-digging adjusted to fit the expected soil behaviour (skirt conicity) and the treatment of this over-digging (quality of the injections behind the stone arches).

To limit ground settlement at urban locations, conventional excavation methods can still be used provided that precautions are taken when defining standard profiles for excavation-support structures:

- excavation phasing for the section (full section or divided section),
- installation of rigid roof supports as close as possible to the rock face at both the top and the bottom,
- installation of pre-linings around the edges of the excavation (forepoling ahead of the rock face) and face confinement via long bolting.

Project oversight has to allow for adjusting standard profiles to fit the observed behaviour.

Whatever the chosen method, ground settlement can also be limited by treating soils ahead of the rock face in order to improve their mechanical properties and/or limit their permeability (injections, jet-grouting or freezing). The injections do have a measurable impact on the environment and may result in the long-term alteration of the physico-chemical parameters of groundwater in contact with the treated soils (see *AFTES recommendations on soil injections [4]*). Despite the above-mentioned measures, ground settlement may still be significant and require the use of compensation grouting. This involves compensating for ground settlement in real-time during the excavation. These techniques are delicate and difficult to control and are reserved for use in certain geological settings.
Furthermore, when the structural permissibility threshold is deemed too low, the relevant structures may be reinforced. This is a delicate operation that requires detailed knowledge of their structural operation.

2.5.2 Delayed ground settlement

Delayed ground settlement is limited by injecting sealant into the soils. These injections have to be made prior to beginning the excavation work, either from the surface or from the tunnel during its excavation (see *AFTES recommendations on injections [4]*)

2.6 REGULATORY PROVISIONS RELATING TO PERMISSIBLE GROUND SETTLEMENT

From a strictly regulatory point of view, there are no specific laws governing ground settlement.
However, for information purposes, some legislative texts address the issue of limiting values for structural deformation and foundation movement:

- informative annex in Eurocode 7: annex H *"Limiting values of structural deformation and foundation movement" [5]*;
- Belgian standard NBN B 03-003 *"Structural deformation -Limiting values of deformation – Buildings" [6]*.

The values indicated in these legislative texts are the thresholds derived from feedback on similar structures. They are used at the upstream studies stage to provide a preliminary estimate of the structures' overall ability to withstand deformation. A specific study is required at the design study stage.

2.7 USEFUL REFERENCES

[1] Dossier pilote des tunnels "Génie Civil" / CETU / 1998.

[2] Norme NF P 94-500, missions d'ingénierie géotechnique : classifications et spécifications / 2006.

[3] Tassements liés au creusement des ouvrages en souterrain, (Tunnels et Ouvrages Souterrains n° 132) / recommandation de l'Association Française des Travaux en Souterrain (AFTES) / 1995.

[4] La conception et la réalisation des travaux d'injection des sols et des roches, (Tunnels et Ouvrages Souterrains n° 194-195) / recommandation de l'Association Française des Travaux en Souterrain (AFTES) / 2006.

[5] Norme NF EN 1997-1, Eurocode 7 : Calcul géotechnique" – Partie 1 : "règles générales et annexe H "Valeurs limites des déformations des structures et des mouvements des fondations" / 2005.

[6] Norme belge NBN B 03-003, déformation des structures, valeurs limites de déformation – bâtiments / 2002.

3. STRUCTURE-BORNE NOISE

The term "structure-borne noise" refers to vibrations generated by waves travelling through the ground. These differ significantly from airwaves that travel through the air, which are studied in the following chapter.
During the operating phase, vibrations are generated solely by vehicle traffic and the operation of tunnel equipment such as fans or pumps, and are generally of relatively minor importance.

During the works phase, structure-borne noise is generated by mine blasting or the use of mechanical machinery.

These are the only vibrations that are discussed in this document, in particular concerning the case of a tunnel excavated via blasting, given that the studies are similar whichever excavation method is used (rock breaker, partial face tunnelling machine, dynamic compaction machinery, vibrodrive drill, tunnel boring machine, etc.).

The construction of cut-and-cover sections is not covered as this involves open-air work projects.

3.1 TUNNEL EXCAVATIONS AND STRUCTURE-BORNE NOISE

There are a range of different underground excavation techniques that generate varying levels of structure-borne noise. Blast excavations generate vibrations of a very short time-frame (a few seconds) with each advancing step. The use of partial face tunnelling or tunnel boring machines results in vibrations of a lower amplitude but that are continuous over time leading to a risk of structural "fatigue".

Generally speaking, blast excavations require the highest level of vigilance regarding structure-borne noise. Use of this method must therefore be assessed in view of both technical and environmental constraints.

The use of explosives in tunnels is more problematic than in the open air work site due to the confined nature of the area to be excavated. The only way out for excavation material is via the rock face. Drilling and firing patterns plans therefore define several zones on the rock face in which to clear this material.

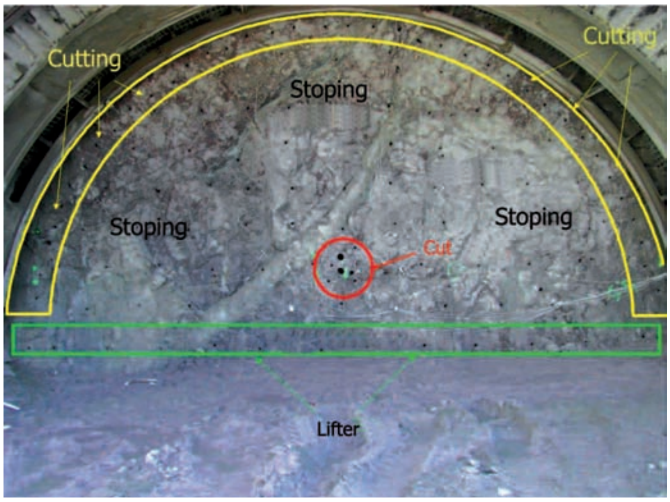

Photo 1: marking out of the various zones of the firing plan for the Lioran tunnel (source: LRPC - Clermont-Ferrand)

These zones, illustrated in photo 1, are usually referred to as:

- Cut: this is the first stage in the firing order; it facilitates the expulsion of rock by creating a cavity that is then used to clear the other zones;
- Stoping: this denotes the ground to be excavated around the cut;
- Cutting and lifter: They designate the outlines of the section to be excavated.

Drilling and firing patterns specify the quantities of explosive, their location and the start time for each detonator for each zone.

Part of the explosive energy used to fragment and mine the rock matrix is propagated and dissipated throughout the surrounding environment in the form of vibratory air and structure-borne waves (see chapter 4) that are dampened with distance.

3.2 REGULATORY PROVISIONS RELATING TO PERMISSIBLE GROUND SETTLEMENT

The impacts relating to vibrations are:

- **damage to structures:** this concerns both buildings and more specific civil engineering structures or even the natural environment via caves or cliffs,
- **damage to sensitive equipment** or the disturbance to their operation (computer equipment, measuring devices, production chain, etc.),
- **inconvenience caused to exposed persons**.

These impacts are identical to those caused by air blasts. The difference involves the structural load mode as, in this case, the incoming the point of entry of the vibrations is via the foundations.

Moreover, the tunnel itself is one of the structures likely to suffer damage. Works on existing structures (tunnel lining, excavation of galleries or safety recesses, etc.) therefore require a certain level of vigilance (e.g. risk of falling masonry blocks in the neighbouring tube that is in operation). Vibrations can also hinder the setting of fresh concrete at the worksites.

The actual vibratory parameter to be evaluated, which is compared to contractual limitations, depends on the structure under study, i.e.:

- speed for a building,
- displacement for a bridge deck,
- acceleration for computer equipment.

The standard base quantity is nevertheless the speed v, which is used to determine the acceleration or displacement respectively by differentiation or integration. Speed v is obtained:
• either by direct measurement using speed sensor,
• or by integrating the signal from an accelerometer.

Table 5 shows the vibration speed threshold values actually recorded in the public works domain according to the type of building to be protected.
These values were proposed by the Comité Français pour les Techniques Routiéres in its guide *Terrassements à l'explosif dans les travaux routiers [7]. This document states that "these values, relating to unfiltered signals, apply to the track with the fastest speed and not to the combined speeds of all three tracks. The choice of a value, within these extremely large ranges, depends on:*
• the frequencies of vibrations that can only be determined following measurement. The thresholds must be particularly stringent as this involves low frequencies,
• the condition of the building to be protected and its behaviour recorded after measurement,
• the functionality requirements of the structure to be protected, which have to be assessed by the building's manager."

Structures to be protected	Seuils constatés dans la pratique (mm/s)
residential housing, buildings using traditional masonry techniques	2 to 15 with a standard value of 10
historical monuments, damaged structures	1 to 10 with a standard value of 5
structures in reinforced concrete (excl. fresh concrete), retaining walls, metal structures, pylons, etc.	15 to 70
underground structures excl. the manager's special requirements	20 to 100
structures under a manager with specific requirements (SNCF, EDF, GDF, etc.)	to be defined with the managing service
sensitive equipment (electronics, computing, PLCs, alarms, etc.)	to be defined according to manufacturers' requirements
unstable units	to be defined as a part of a specific stability study

Table 5: permissible vibration thresholds according to receiver (source: Terrassements à l'explosif dans les tavaux routiers / CFTR Technical Guide / January 2002)

3.3 STUDY APPROACH

This process follows the same reasoning as for the ground settlement study (*see 2.3*), with the structural stresses in this case deriving from the vibrations:

(1) Determination of excavation impacts,
(2) Initial status report,
(3) Assessment of the structures' vulnerability,
(4) Determination of contractual control thresholds and definition of ground surveys,
(5) Implementation of ground surveys and description of the decision-making chain.

The following paragraphs describe the features specific to vibrations during the course of the studies.

3.3.1 Upstream studies

At the upstream studies phase, this involves assessing the site's level of sensitivity in order to guide the selection of alternative route as well as the method of excavation, which can also lead to the approval/refusal of the "blast excavation" option.

This assessment is based on an **Initial status analysis (2) (*see chapter 3.4.1*) with regard to the expected effects of the excavation (1)** and also on the geological data, field ground surveys and the identification of which receivers are sensitive to vibrations.

3.3.2 Design studies

A more accurate **determination of excavation impacts (1)** is based on the determination of a damping pattern used to evaluate how vibrations propagate through the soil. This study is based on the firing tests (*see chapter 3.4.2*).

The firing tests also make it possible to analyse how the **structures respond (3)** to pulsed stresses.

Permissible vibration thresholds (3) for a structure also have to be defined or set at the design studies stage, notwithstanding the above. This determination of permissible thresholds is followed by the **definition of ground surveys (4)** required directly opposite the buildings in order to check at the time of construction that the vibration limit values have not been reached.

Control thresholds (4), which are inferred from the permissible thresholds, are used to define the maximum charges to be implemented when designing the firing plans.

All the parts making up the vibrations study and, in particular:

- site damping pattern determined by the firing tests,
- listing, location and description of any buildings and areas sensitive to vibrations in the vicinity of the worksite,
- control thresholds,

come under the owner's responsibility, and must be shown in the contract documents.

3.3.3 Execution

At the very beginning of the project, the vibrations study may be supplemented by a verification of the damping pattern by real-life firings, referred to as test firings. As with ground settlements, the owner is advised to conduct a preventive procedure.

During the works, control consists in adapting the firing plan according to geological observations and survey results.

3.4 ASSESSMENT METHODS AND MEANS

3.4.1 Initial status analysis

The Initial status analysis is based on the same principles as those for the "Settlement" topic.

Specifically, the main vibration-sensitive structures must be identified. This usually concerns structures like single-family homes or apartment buildings, industrial buildings, bridges and overbridges, technical galleries and drains, road or railway tunnels. This can also involve natural sites (cliffs, caves, etc.)

The equipment inside these buildings or facilities also has to be taken into consideration.

As the risks are directly related to proximity, experience has shown that it is best to draw up an inventory for an area covering a 200-m strip around the project's central axis at the least. Beyond this distance, and excluding special configurations, vibration amplitudes are generally insignificant.

3.4.2 Determining excavation impacts based on firing tests

Annex 4.7 of section 4 of the civil engineering master file: "Study and control of ground shaking relating to the use of explosives" [1] sets out the main principles relating to firing tests. It is referred to several times in this chapter.

"The main objective of firing tests carried out during drilling operations is to establish a vibration damping pattern according to distance, while that of test firings is to ensure the feasibility of the planned technical provisions by full-scale testing of an actual firing plan [...]at the given site." [1]

"The firing test consists in detonating in boreholes explosive charges of increasing size, arranged at different levels. The vibration speeds generated by these blocked mine explosives are recorded at various points in the sensitive environment at increasing distances. These recordings are analysed in order to establish a damping pattern of for vibration speeds..." [1]

To characterise the transmission of vibrations from the source up to the point of survey, the damping pattern for velocity according to firing-sensor distance weighted by the instantaneous unit load in the general form:

$V = K (D/Q^{½})^{-α}$ avec :

- V particle velocity in mm/s,
- K site constant or coefficient,
- α slope of the regression line in a log-log diagram,
- D firing-sensor distance (in m),
- Q quantity of explosive by number of firing caps (in g).

This pattern has to be updated continuously in order to factor in all the available measurements and make it possible to evaluate the dispersion of results, which is inevitable given the large number of parameters controlling the emission of vibrations, their transmission through the soil and their reception at the point of survey.

An objective comparison of the results (per firing and per sensor) requires the determination of a *Chapot-type law [8]* where the coefficient α is set at 1.8, which generally gives a value K of between 3 and 12. This simplification requires a certain amount of caution as it is not appropriate to every case. The comparison of the level of induced vibrations is therefore based solely on the site coefficient K.

This gives:

- mean law (K_{moy}, α=1,8) that generally describes the propagation of vibrations within the wall;
- maximum law (K_{max}, α=1,8) that illustrates the dispersion of measurements around the mean law above.

In terms of compliance with vibration thresholds and to ensure safety, the maximum law should be followed to determine the permissible explosive charges for a given firing, taking account of the distance from the structures to be protected.

"It is not standard practice to carry out preliminary tests for non-explosive mechanical earthworks means as this type of equipment has generally been selected by the contractor responsible for works execution. However, reference can be made to simplified damping curves (see illustration 4), that give the critical distances for the main equipment." [1]

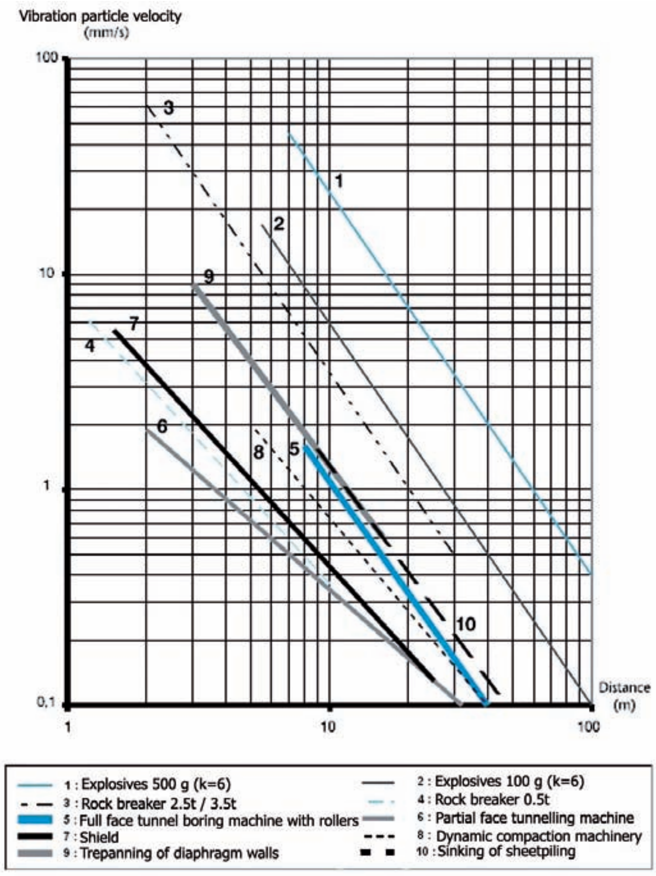

Illustration 4: magitude of the vibrations emitted by the public works equipement (source: Tunnels Master Folder, civil engineering, excavation procedures and support structures/CETU)

3.4.3 Assessing structural vulnerability

"Permissibility thresholds depend on both the type of stress (pulsed stress for blasting, continuous stress for mechanized excavation), structural characteristics (building materials, state of disrepair, type of foundation), the quality of the foundation block and the structure's intended use.[...]

Initially, the AFTES recommendations [9] can help make the assessment; these mainly target standard residential buildings:

- *v < 10 mm/s, low probability of damage,*
- *10 mm/s < v < 30 mm/s, requires good control; increased probability of claims,*
- *v > 30 mm/s, not recommended in populated areas".[1]*

3.4.4 Determining contractual control thresholds and defining ground surveys

3.4.4.1 Determining contractual thresholds

Control consists in adapting excavation methods or drilling and firing plans in the event that thresholds are exceeded. To recap, two contractual control thresholds are usually identified (*see 2.3*):

- alert threshold,
- cut-off threshold.

In the case of vibrations, we also speak about thresholds of control which practises it are slightly lower to permissible vibration thresholds for buildings.

The damping pattern helps to determine which unit charges can be used in the firing plans in order to maintain compliance with the established thresholds.

The maximum permissible thresholds for non-explosive mechanical earthworks machinery are generally lower in order to factor in the continuous nature of the oscillation or the repetitive nature of the pulse that increases the probability of damage. The studies therefore help to define equipment specifications (generally as a power value) or the minimum use distances for an equipment with given characteristics.

3.4.4.2 Defining ground surveys

Excavation monitoring procedures usually require the use of a data channel set up in the field to:

- ensure that vibration criteria are complied with at all times and that the works are carried out safely with respect to the environment,
- refine the forecasts by updating the damping pattern where necessary.

An in-the-field data channel comprises sealed sensors on sensitive sites, connected to a device that records or provides direct display of the results.

The instruments must be matched to receivers according to their degree of sensitivity. Vibration data are collected in three spatial directions.

To meet these requirements, a control plan detailing the necessary instrumentation and the location of measurement points is drawn up. This involves placing vibration sensors preferably at the base of the foundations for previously selected sensitive structures. This choice may be based on joint ground surveys of the condition of neighbouring buildings carried out prior to starting the works or on the presence of sensitive equipment or activities.

3.4.5 Carrying out ground surveys and describing the decision-making chain

As with ground settlement, it is recommended that ground surveys should be carried out under the same contract as the works contract. The works manager is also responsible for the ground surveys. They have the necessary means for controlling their works project at all times.

The decisions to be taken during the project mainly concern adaptations of firing plans and, where necessary, updating of the damping pattern.

3.5 IMPACT LIMITATION MEASURES

As with air blasts or ground settlement, it is vital to conduct a preliminary information and explanation procedure with local population.

There are specific worksite measures that can help to reduce vibration levels. The principal potential measures when:

- blasting: a comprehensive revision of the firing plan
  - > chronology of blast detonations,
  - > time between blasts,
  - > blast value,
  - > nature of the drilling, etc.
- using mechanical machinery: accommodation of the time and nature of the work (period duration, power adjustment, etc.).

In addition to reducing vibrations at source, the inconvenience caused to local population can be limited by tailoring the works phasing (excavation approach direction, etc.) and setting time slots that fit in with the activity of local population. The definition of set firing times can apply where sensitive activities or equipment are involved.
Lastly, specific measures can be taken in the vicinity of an underground structure in operation i.e. temporary traffic stoppages

3.6 REGULATORY OR NORMATIVE PROVISIONS

Although the regulations governing vibrations are fairly broad-based, the owner nevertheless has to take account of compliance with third-party rights and control worksite-related vibration phenomena.

The General Administrative Terms of Contract for the Works (C.C.A.G.T.) refers to the use of explosives in article 31-11 (*use of explosives*) of chapter IV (*execution of the works*). The contractor is responsible for making sure every precaution is taken with regard to neighbouring structures and buildings.

Leaflet No. 69 of the General Technical Terms of Contract (C.C.T.P.), currently at the drafting stage, states in the article on *"Environmental protection during the works project"* that it is *"advisable to prevent, limit or control the creation of nuisances [...] so as to limit the environmental impacts. The C.C.T.P. defines the contractual requirements with regard to environmental limitations and gives all the necessary details for taking these into account during execution of the works. This generally means having to deal with the following issues […] limitation of nuisances caused by noise, air blasts and vibrations."*

The courts refer to the two legislative texts shown below:

- *circular of 23 July 1986* relating to mechanical vibrations emitted by facilities classified for environmental protection,
- *order of 22 September 1994* supported by *circular No. 96-52 of 2 July 1996* relating to the operation of mines and the facilities for the initial processing of quarried materials.

Lastly, the measurement of vibrations and evaluation of responses by buildings, sensitive equipment and occupants are governed by *standard NF E90-020 of July 2007*.

3.7 USEFUL REFERENCES

1] Annexe 4.7 de la section 4 du dossier pilote Génie civil : étude et contrôle des ébranlements liés à l'utilisation des explosifs / CETU / 1998.

[7] Terrassements à l'explosif dans les travaux routiers / Guide technique CFTR / 2002.

[8] Étude de vibrations provoquées par les explosifs dans les massifs rocheux / Rapport de recherche du LCPC N°105 / 1981 / Pierre Chapot.

[9] Étude des effets sismiques de l'explosif / recommandation de l'Association Française des Travaux en Souterrain (AFTES) / 1982 (update 2007).

[10] Effets de vibrations dues à des tirs de mines sur du béton aux jeunes âges / Thèse d'Anne Denoyelle de l'ENSM de Paris / 28 juin 1996.

[11] Tirs en masse et vibrations / édition EGICO / 1994 / Bruno Froment.

4. AIR BLASTS

The term "air blasts" describes the shockwave transmitted through the air when detonating mine charges. This phenomenon therefore only affects the tunnel construction phase where excavations are performed using explosives. Generally speaking, any explosion generates an air blast wave whose intensity depends on the volume of gas emitted and the emission velocity. Underground firings are characterised by low-level containment of detonations, a long firing sequence and propagation of the shockwave in the direction of the axis of the excavated tube. These particularities require a specific study of these phenomena of a strong, but localised, intensity.

For a long time, this topic was dealt with in association with that of noise and measured as such resulting in an underestimation of its actual impact, which is reflected by the vibration of structures according to a specific regime that affects the raised parts of buildings.

The special case of the use of explosives for the construction of cut-and-cover sections is not covered as this involves open-air work projects.

4.1 UNDERGROUND FIRINGS AND AIR BLASTS

Detonating an explosive charge involves a chemical reaction that converts a solid body into a gas at very high speeds (1 kg of explosive is converted into approx. 800 l of gas). These gases expand firstly inside the rock, splitting and displacing it, and then in the air, generating an airborne shockwave within a short distance of the firing, referred to as a "blast wave". A few metres beyond the explosive charges, this wave travels at the speed of sound (340 m/s), generating alternate areas of air compression and decompression (*see illustration 5*).

The high-velocity displacement of quarried materials (a few tens of m/s) also generates a similar blast wave but with a lower starting frequency.

All these waves, called N-waves, are characterised by an initial blast component at audible frequencies that corresponds to densification of the gas (ambient air and gas from the firing) in a reduced volume concentrated immediately behind the wave front. The concentration of gas molecules in this area causes their depletion in the area behind, thus creating an area of depression affecting a larger volume, with the pressure gradually returning to its initial value. This area of depression is characterised by low, inaudible frequencies. These phenomena are similar to those associated with a lightning strike or a sonic boom.

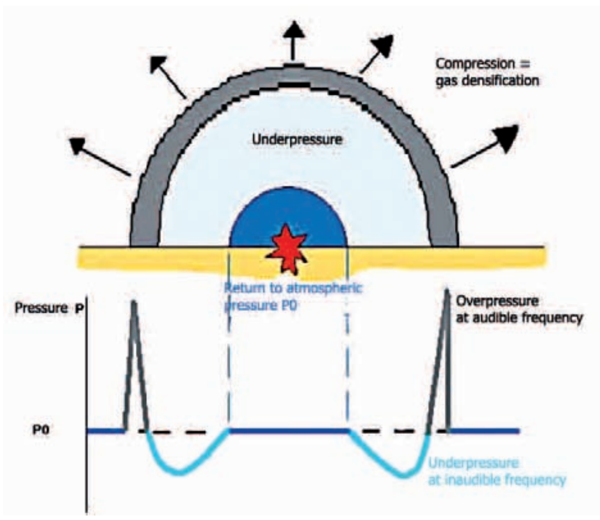

Illustration 5: propagation of N-waves (source : LRPC de Clermont-Ferrand)

The frequency of these waves diminishes with increasing distance from the explosive charge, concentring beyond a few tens of metres in the inaudible ultrasound range (frequencies between 1 and 20 Hz).

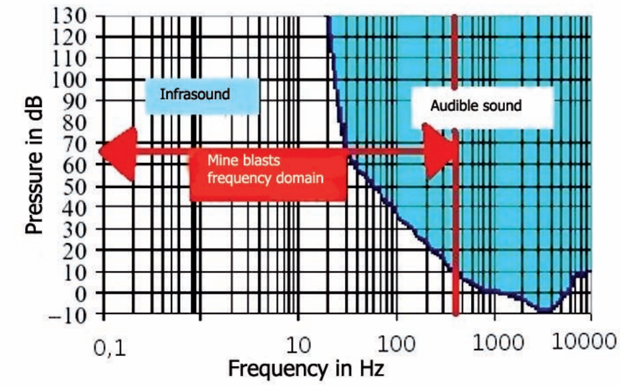

Illustration 6: lower audibility limit (source : Fletcher et Munson)

The features specific to underground blasts are:

- low containment of explosive charges that promotes high-velocity emissions of gas into the atmosphere and the displacement of quarried materials: the charges are placed a few tens of centimetres from the front compared to a few tens of decimetres for aerial blasts;
- high specific explosive charge that generates a large volume of gas per cubic metre of quarried rock (approx. 1 kg explosive per m3 against 0.4 kg for aerial blasts);
- initial propagation along the axis of the tunnel thus concentrating the blast in a preferred direction, with very low attenuation inside the tube ("canon" effect);
- long firing sequence marked by a succession of waves over a period of 5 to 8 seconds against 1 second for aerial blasts: this heightens the discomfort of local population.

When the successive fronts of this shockwave reach a building, they generate vibrations affecting light objects at height that escalate with the increasing intensity of the phenomenon (firstly ceiling lights, objects that are hanging or placed on a surface, followed by partitions and light ceilings, wooden and then concrete floors, structural frames, etc.). These shockwaves are likely to cause inconvenience and alarm to exposed local population; in some cases they may even damage certain structural elements. This airwave, the main energy of which is inaudible, is generally perceived by local population as a vibration.

4.2 IMPACTS AND CHALLENGES RELATING TO AIR BLASTS

The impacts relating to air blasts are similar to those caused by ground vibrations. This therefore mainly concerns damage to structures and sensitive equipment as well as the inconvenience caused to local population.

The difference lies in the way structures are subjected to stress with, in this case, the point of entry for vibrations being walls and, in general, all building components at height rather than the foundations.

The standard physical unit is the Pascal (Pa), which has the disadvantage of varying over a wide scale when describing similar impact phenomena (see table 6). To overcome this drawback, a logarithmic scale expressed in decibels is normally used, although this does also lead to confusion with noise measurements.

The blast measurement is expressed in mathematic decibels according to the equation:

$P_{dBL} = 20 \log (P_{pa} / P_0)$ with P_0 arbitrary reference pressure equal to 2.10^{-5} Pa et P_{pa} pressure measured in Pascals.

This unit, which is not weighted for frequency and calculated based on a non-averaged pulsed signal is rated dBL or dBF. This rating limits the confusion with noise measurements corresponding to the time-averaged values that are frequency-weighted according to the hearing acuity of the human ear. These are rated dBA or dBC depending on the selected weighting.

Table 6 shows the progressive impact of air blasts according to intensity expressed in Pa and dBL.

Pressure in dBL	Pressure en Pa	Observed impacts or applicable thresholds
<100	<2	imperceptible air blast
112	8	appearnce of the first complaints
120	20	complaints become more numerous, windows start to shake and hanging lights start to swing
125	35	threshold recommended by the "quarry" order of 22/09/94
130	63	USBM (United States Bureau of Mines) damage thresholds, perceptible shaking of floors
135	112	superficial damages (falling plaster, displacement of tiles)
140	200	breakage of the most fragile windows
145	350	internationally recognised threshold for the exposure of unprotected persons

Tableau 6: impact of air blasts according to intensity (source: LRPC de Clermont-Ferrand)

4.3 STUDY APPROACH

The study approach is very similar to that for ground settlement and structure-borne noise and is based on the five technical steps below:

(1) Determination of excavation impacts,
(2) Initial status,
(3) Assessment of building vulnerability,
(4) Determination of contractual control thresholds and definition of ground surveys,
(5) Implementation of ground surveys and description of the decision-making chain.

However, the impact of air blasts has only recently started to be incorporated into studies, which means that there are only a few projects that include a full study approach to these phenomena from upstream phases up to works execution.

Unlike ground-borne vibrations that can be modelled from individual explosive charges fired during the studies, there is no comparable source for air blasts. Emission conditions cannot be recreated at a reduced scale. The **initial status (2)** therefore plays a decisive role given the inability to make a real-life assessment of the stresses to which the buildings will be subjected.

4.3.1 Upstream studies

Based on an analysis of the site and its environment, upstream studies are used to estimate the risk and assess the related impacts on the works *(see chapter 4.4.1).*

This study phase directs the choice of excavation method.

4.3.2 Design studies

The **permissible blast thresholds (3)** for a structure are then set at the design studies phase. These permissible thresholds are used to determine the **control thresholds (4)**. This is followed by the **definition of the ground surveys (4)** that will be required.

The control thresholds are given in the CCTP.

4.3.3 Execution

As with any topic likely to have an impact on structures, the owner is advised to carry out a preventive procedure.

Air blast studies may be supplemented by full-scale test firings at the very beginning of the works project.

During the project, control consists in adapting the firing plan according to survey results.

4.4 ASSESSMENT METHODS AND MEANS

4.4.1 Risk estimate based on the site inventory

The risk estimate is based on a site analysis and inventory of the structures, sensitive equipment and persons likely to be exposed. The criteria to be taken account of are:

- distance to the tunnel portal and relative position with respect to the tunnel axis: the area of sensitivity generally extends from the portal out to 200 to 500 m, with an outlet cone of approx. 30° in flat ground,
- land topography and occupation plus surrounding vegetation,
- sensitivity of receivers to impacts caused by air blasts which are analysed according to the nature of the receivers with regard to the following aspects:
  - > buildings: type of construction, wall surfaces, floor spans, etc.
  - > sensitive equipment: type of equipment, operating mode, insulation system, etc.
  - > people: type of activity, period of absence, etc.

These criteria are used to define empirically and on expert appraisal, areas of decreasing probability of risks.

Empirical propagation models do exist but they depend on highly variable local factors that make it difficult to use them in the absence of in situ measurements of the actual source. The growing number of measures will no doubt lead to the future availability of more reliable forecasting models, in a field where such data has only recently started to be taken account of and which has so far received only limited feedback.

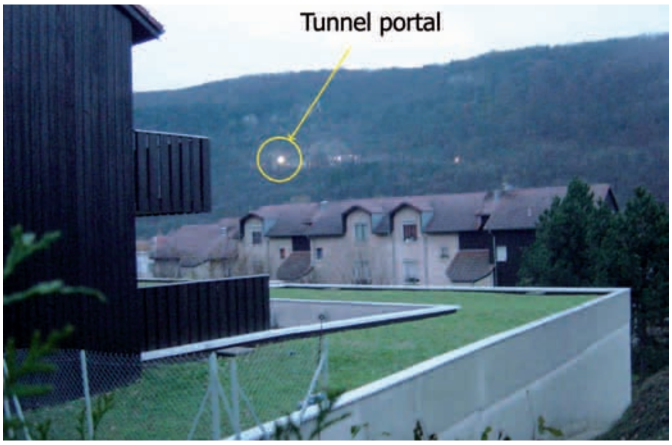

Photo 2: site with an unfavourable topography with a tunnel in the middle of the hillside and surrounding rocky cliffs (source : LRPC in Clermont-Ferrand)

4.4.2 Assessing structural vulnerability

This involves setting absolute thresholds for the various structures that it has been possible to identify, including sensitive equipment and the presence of local population. This work is carried out by an expert in air blasts. *Table 6* gives an idea of the scale of possible values.

4.4.3 Determining contractual control thresholds and defining ground surveys

Permissibility thresholds are used to determine control thresholds with an integrated safety margin. Works control is therefore based on the control of air blasts derived from analysis and adjustment of the blasting plan. These thresholds are set at the same time as the definition of ground surveys.

4.4.4 Carrying out ground surveys

During the project, air blast measurements are used to track whether the selected forecasts are appropriate or whether they need to be adjusted.

The air blasts measurement is taken using "low frequency" microphones which are synchronised with the 3-way sensors in order to measure the vibrations. The measurement procedure is described in standard ISO7196:1995 (not NF). This joint vibration/ air blast measurement helps to define the relative share of energy transferred to structures via ground or air, the related shockwaves travelling at greatly varying velocities (a few thousands of m/s in soil against a few hundred in air -*see illustration* 7-).

Sonometres used solely to measure noise cannot be used to characterise air blasts, where the main energy transmission occurs in the infrasound range.

The purpose of making synchronous vibration and air blast measurements is to identify the main source of the vibrations affecting all or part of a structure, so as to define the technical provisions providing for compliance with the vibration thresholds set in order to control this impact or to factor in complaints from local population. This process is required in cases of numerous or continuing complaints while the measured vibrations affecting the foundations are low or even attenuated (for more information on this measurement and control aspect, please refer to the topic "structure-borne noise").

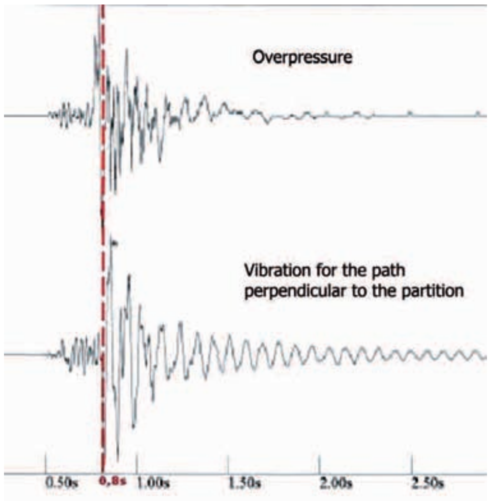

Illustration 7: air blast and vibration measurement taken by a sealed sensor in the middle of a brick partition 120 m from a 500 kg mine blast at the Cressy-on-Somme test site. The airwave generates maximum vibration levels. The ground-borne vibrations are located at between 0.5 and 0.8 s, while the airwave follows at between 0.8 and 1.5 s. The vibration of the partition after 1.5 s corresponds to its free damping phase to its specific frequency (source: LRPC in Clermont-Ferrand).

4.5 IMPACT LIMITATION MEASURES

Air blasts mainly cause inconvenience, and therefore require a preliminary information and explanation initiative targeting local population. The inconvenience will be received more sympathetically if people are correctly informed in advance.

This initial approach must be sustained throughout the works by means of continuous communication campaigns focusing on the control measures implemented through direct contact with local population and the processing of any claims.

Beyond the information initiative, specific project measures can also help to reduce air blast levels. These measures are built around two principles: limitation of energy generated by the source and dissipation of the energy produced. On this last point, while there are energy dissipation systems their sizing is poorly understood at the present time due to lack of experience.

These principles help to limit air blasts at the level of the exposed areas; the main possible measures for their application are given below:

- action at the source, by adjusting the parameters of the firing plans while making sure that the reduction in air blasts does not result in an increase in ground-borne vibrations, via:
  - > compliance with a minimum packing,
  - > optimisation of the specific charge so as to avoid overloading the blast,
  - > limitation of the total quantity of explosives,
  - > appropriate primer sequence.

- action during propagation in the tube and at its exit in order to:
  - > disrupt the gas flow: start of the lateral galleries;
  - > absorb energy via mechanical work: heavy obstacles with a certain degree of freedom such as wall of hanging beams;
  - > deviate the preferred emission axis: earthen bund at the tunnel portal.

Most of these provisions require heavy-duty implementation and remain of limited effectiveness at the current stage of understanding of these phenomena. Furthermore, limiting air blasts means phasing the works appropriately (excavation approach direction, emergency galleries that can create an obstacle helping to disrupt gas flows, etc.) and setting blasting time slots that fit in with activity of the local population so as to limit inconvenience and the exposure of sensitive equipment.

4.6 REGULATORY OR NORMATIVE PROVISIONS

At present there are no regulatory texts dealing specifically with this phenomenon. The regulatory or normative provisions are common to structure-borne noise issues (*see chapter 3.6*).

4.7 USEFUL REFERENCES

[7] Terrassements à l'explosif dans les travaux routiers / Guide technique CFTR / 2002.

[12] La surpression aérienne / TIRS - Applications et implications - Les techniques de l'industrie minérale - n° 14 / juin 2002 / Alain Blanchier.

[13] Limites d'exposition aux infrasons et aux ultrasons - Étude bibliographique / INRS-Hygiène et sécurité du travail - Cahiers de notes documentaires / 2ème trimestre 2006 / Jacques Chatillon.

5. NOISE

There are two main types of noise pollution generated by a tunnel or cut-and-cover section during the operating phase:

- a concentration of noise emissions at the level of the area around the tunnel portals,
- noise generated by use of mechanical ventilation systems.

The tunnel construction phase often employs heavy-duty technical excavation processes, with the localised and occasionally long-term presence of noisy equipment in addition to continuous traffic of construction machinery, which are all adverse factors in terms of the creation of noise pollution.

Where users are concerned, although travelling through a closed, highly reflective environment generates a significant increase in noise inside passenger compartments, the reduced exposure times, the resulting levels that are well below the danger thresholds and the individual vehicle performance do not justify the introduction of special limitation measures. This chapter only discusses noise impacts outside tunnels

5.1 SPECIFIC FEATURES OF TUNNELS RELATING TO NOISE

5.1.1 Traffic-related noise

A tunnel or cut-and-cover section significantly reduces the noise levels along the road it contains. Except in some very specific cases (e.g. openwork structures), the sound energy radiating along the length of the structure can be ignored. Conversely, a tunnel or cut-and-cover section forms a wave guide where noise is only slightly attenuated with distance. The highly reflective tunnel walls encourage reverberations. A large part of the energy emitted by vehicles circulating in the tube is therefore radiated towards the tunnel portals, with the portal geometry being a decisive factor in the direction of radiation.

Due to this reverberated field, a vehicle, or even a fleet of vehicles, can be identified outside in the vicinity of the portals, even at considerable distances from the receiver. Vehicles exiting a tunnel also generate a sudden increase in noise in portals' immediate surroundings.

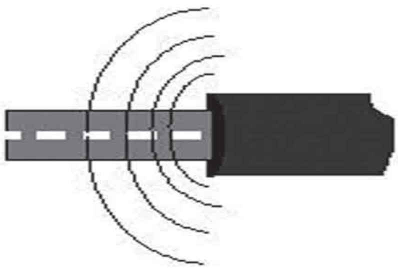

Illustration 8: hemispherical radiation of noise from a tunnel portal (source: CETE de Lyon)

Some cut-and-cover sections may have special openings designed for the purposes of ventilation, lighting or landscape views. Noise waves can then travel through these openings. Therefore, the sound energy radiated along the length of the tunnel can no longer be ignored. This reduces the external sound-damping effect along the length of the tunnel. It may even be significantly reduced when these openings represent a surface area exceeding 10% of the total surface area. Evaluations of the impact of these structures have to take account of this effect if they are to avoid underestimating noise levels. This case also concerns structures whose walls have a reduced attenuation index. This last case is rare given the construction techniques used.

Photo 3: external view of an openwork cut-and-cover section along the Gave de Pau (source: http://www.midi-pyrenees.equipement.gouv.fr)

5.1.2 Acoustic emissions linked to ventilation equipment

Ventilation equipment in tunnels acts as an acoustic source with a potential to cause noise pollution. This includes:

- jet fans: placed in the link section of the tunnel, they are use to maintain and increase the airflow along the length of the tunnel;
- extraction or blowing fans placed in ventilation plants.

In both cases, this involves axial fans that can be fitted with silencers at the flow input and/or output. Centrifugal fans, which are usually quieter than axial fans, are used very rarely for road tunnel ventilation, mainly due to their footprint.

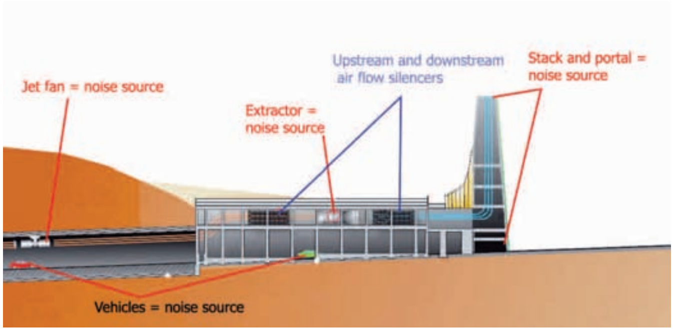

Illustration 9: noise emission sources and acoustic devices (source: EPA Works Approval Application for the EastLink Tunnels/ Australia)

The noise emitted by these ventilation systems has three sources: electrical, aerodynamic and mechanical. Generally speaking, a fan's sound power level will depend on fan type, blade characteristics, airflow rate, total pressure and engine rotation speed.

The noise generated by these systems may be superimposed on the traffic noise at the tunnel portals. It is also emitted through extraction bays or stacks located at the ends or along the length of the tunnel, and forming a series of point noise sources.

There is a formula that describes the order of magnitude of the sound power of a centrifugal fan:
Lw = 63 + 20 log PT + 10 log qv (empirical formula in standard use) with PT, total fan pressure in mm CE (water column) and qv, fan flow in m^3/s.

Photo 4: stack at the Croix Rousse tunnel opening onto Croix Rousse plateau (source: CETE de Lyon)

The frequency content i.e. the spectrum of the noise emitted by the ventilation systems is marked by the presence of frequency peaks relating to the number of blades and the engine rotation speed (*see illustration 10*). It is different from the spectrum for traffic noise. The fundamental frequency (FPP) is determined from the following formula:
FPP = number of blades x rotation frequency

These noise aggravation peaks can be observed if the background noise does not completely cover the noise dynamics of the aeraulics system.

The data on sound power, per octave band or 1/3 octave, as a function of engine rotation speed is supplied by the ventilation system manufacturer.

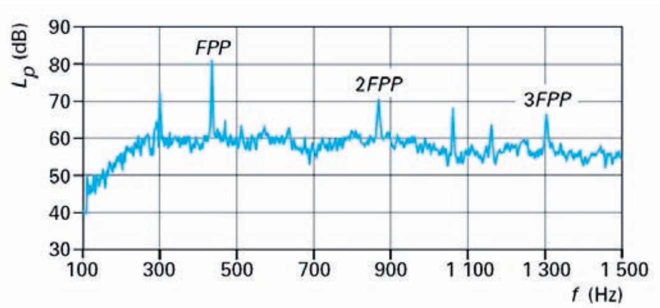

Illustration 10: narrow spectral bands for a 9-blade fan rotating at 2893 tr/min. Note the FPP frequency noise aggravation peaks, the fundamental frequency, and the FPP multiple harmonics (source : Le bruit des ventilateurs – T.Vincent – www.mssmat.ecp.fr)

5.1.3 Noise during the construction phase

In addition to the noise generated by any road construction project, tunnels involves specific noise relating to:

- excavation/earthworks techniques: use of drilling machinery, tunnel boring machines, explosives, driving of sheet piles, etc.
- extraction of large quantities of material, that may require heavy traffic of vehicles to evacuate rubble and debris,
- ventilation of tunnel tubes: drilling tunnels may require the night-time use of noisy ventilation systems to evacuate dust and other gases,
- location and duration of the construction project: sites for civil engineering works require the setting up of specific stations (concrete mixing plants, pumping stations, etc.) that may be present for periods of several weeks.

5.2 IMPACTS AND CHALLENGES RELATING TO NOISE

Noise levels are evaluated using time-averaged values that are frequency-weighted according to the hearing acuity of the human ear. The weighting used most often to estimate the discomfort is the dB(A). Audible sounds lie in the range above 0 dB(A) which marks the hearing threshold. The discomfort relating to high noise levels is a subjective concept that is felt differently depending on the individual. There is no sound scale capable of giving an absolute score.

The presence of tunnel portals, extraction stacks or ventilation plants near to areas that are sensitive to noise (at urban locations, or where there are residential or sensitive buildings in the immediate vicinity) is likely to increase both the exposure and the discomfort. During the operating phase, the noise levels generated by these sources are sufficiently low to avoid the generation of short-term physiological impacts (damage to hearing).

E.g. the increase in traffic-related noise due to the presence of tunnel portals lies between 5 and 9 dB(A). The point nature of the sources also limits the impacts for the first tens of metres.

The spectrum for noise generated by ventilation equipment is dominated by noise aggravation peaks at certain frequencies that cause greater discomfort than broadband noise (open air roads for example) of the same intensity. These sources that may be masked during the day by ambient noise can appear during calmer periods, particularly during the night, if they continue to operate at high levels. In general though, this type of equipment operates at lower levels during the night (the lighter traffic flow does not require ventilation). There are also effective technical solutions technical designed to limit noise pollution.

Noise impacts during the construction phase are largely similar to those of a conventional public works project, **to which must be added noise generated by worksite ventilation systems**; these impacts cease on completion of the works. Some means used in the construction of this type of structure (heavy excavation machinery, mining, long-term work projects, etc.) require higher levels of caution in order to limit the effects.

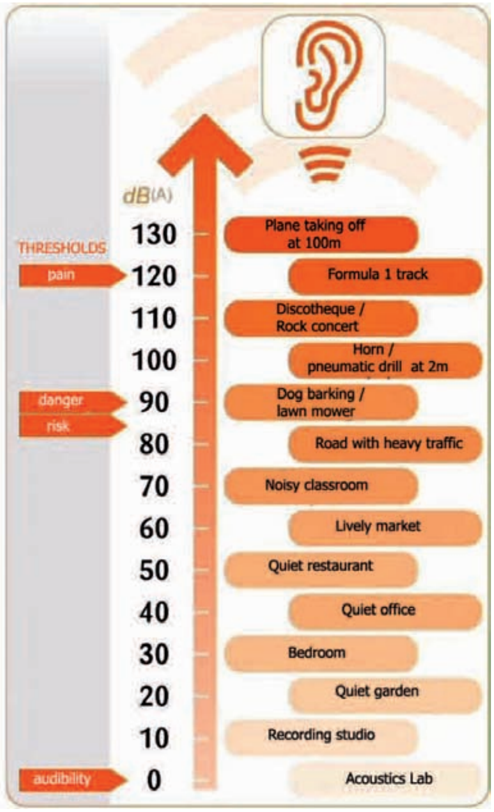

Illustration 11: noise scale (source : Bruitparif)

5.3 STUDY APPROACH TO NOISE POLLUTION

The study approach is based on the regulations set out in the Environmental Code (*see chapter 5.6*) and relating to the fight against the noise generated by inland transport infrastructures. Listed below are a few special features or watch-points specific to tunnels.

5.3.1 Upstream studies

When comparing options, particular care and attention has to be taken with options dealing with the positioning of tunnel portals. A simplified calculation of the noise footprint at the level of these portals can be made in order to estimate which populations are likely to be impacted. Any change in the position of, or the extension of, the tunnel exit could have significant repercussions on the project.

The studies must plan countervailing measures (source-level protections or wall insulation) in the event that the noise levels generated by the project exceed the regulatory targets defined according to initial noise levels, the nature of the exposed structures and the period (day or night).

The studies also include summaries of the health impacts relating to the noise (with no specific element relating to tunnels).

5.3.2 Design studies

Specific studies may be planned on the geometry of tunnel portals or their treatment with absorbent materials (*see chapter 5.4.2*). It is also at this stage of the studies that the dimensions of soundproofing systems for ventilation systems are decided upon.

In terms of forward planning for particularly sensitive construction projects, the owner can commission a specific study on noise impacts designed to optimise the layout of the worksite and any related roads. This may also define the noise thresholds that must be complied with at the walls of exposed buildings. These thresholds can be applied either as noise levels to be observed during "regulatory" periods (6h-22h during the day and 22h-6h at night) or by adapting these periods to the rhythm of the construction works. They can also be expressed as noise aggravation levels that must not be exceeded during these same periods.

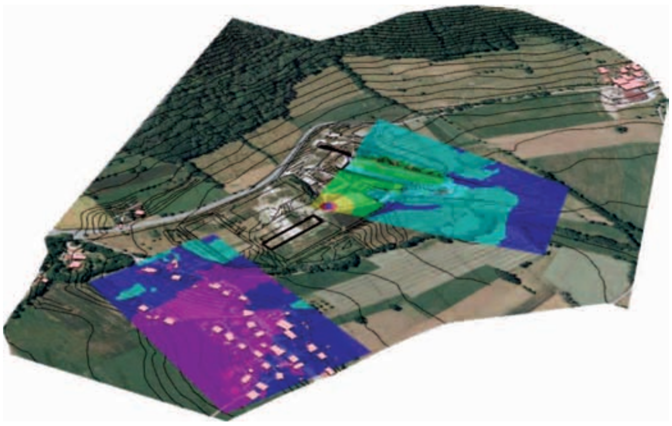

Illustration 12: noise mapping of the construction site for the Mont-Sion tunnel (north portal) on the A41; map produced using OASIS software jointly developed by CSTB and Bouygues TP (source: CSTB)

5.3.3 Execution

No specific studies are planned during the works phase. Care will simply be taken to deploy the means for limiting foreseeable worksite impacts.

If noise thresholds have been defined, then their implementation must be accompanied by a continuous monitoring process (sonometres placed in the walls of buildings or at the peripheral worksite boundary) designed to measure these indicators and alert the client to any overruns. A separate noise measurement coupled with an assessment of the sound power emitted by worksite vehicles or facilities can be made via sampling (short-term measurement). These can be used to provide further data on these sources. These values should be compared against the manufacturer's data (manufacturer labelling as per the "machines" directive 98/37/CE).

5.4 NOISE ASSESSMENT METHODS AND MEANS

5.4.1 Characterising the initial status and appraisal components for the noise status

Characterising the initial status should make it possible to weigh up noise-related challenges and provide a "snapshot" of the sound environment. Various components may provide input for:

- listing of noise-sensitive buildings: residential buildings, healthcare establishments and schools, etc.
- noise level measurement campaign (as per standard NFS 31-085) sectioning areas of concern for the project: this kind of campaign helps to characterise the sound environment and can be used to set future models,
- modelling of the main sources: the aim here is to produce a map at the scale of the project area, according to French regulatory indicators $Leq_{(6h-22h)}$ for daytime et $Leq_{(22h-6h)}$ for night-time.

The design office mandated by the owner may supplement its studies with data on road noise classification and on European strategic mapping, if the relevant area is covered.

5.4.2 Numerical models and mock-ups

Table No.7 shows a representative panel of the methods that can be used or adapted to estimate tunnel-generated road noise. In most cases, the acoustic engineering models complying with *standard NF 31-133* (*see chapter 5.6*) can be used to integrate this type of structure and to meet expectations in terms of upstream studies.

In some special cases, such as the detailed study of the impact of tunnel portal geometry, it may be possible to employ an advanced finished element analysis. In practice, however, this option is rarely used.

The other methods are given for illustration only, and are no longer in actual use.

5.4.2.1 Modelling road noise at tunnel portals

Except in the case of highly detailed models that are rarely put into practice (finished element methods for boundaries or volumes), the noise radiated at tunnel portals is assimilated with that from one or more equivalent sources located at the end of each tube. In particular, the method proposed in the Guide du Bruit des Transports Terrestres *(Ministry des Transports, 1980 - document pending review- [14])* can be used as a basis.

Model type	Advantages	Disadvantages	Cost	Scope
Method of the type " noise guide"[14]	• simple to implement, "manual" methods	• highly simplified approaches, not adapted to complex sites at small scales	low	used seldom or not at all for present-day studies
Acoustic engineering models	• fairly easy to implement, simple statistics use, option of factoring in ground relief and certain obstacles, in addition to soil properties • large-scale mapping • option of modelling air vents (point sources)	• simplified modelling of tunnels • not a true 3D representation • modelling of equivalent sources at tunnel exits	average	• the method used most often at all study stages • satisfactory accuracy given the stakes
"Research" models (finished boundary elements)	• accuracy • option of modelling systems with a complex geometry (tunnel entries)	• high investment in time and computational resources • limited availability; requires a high level of expertise	high	used seldom at present given the stakes (low) and cost
Physicals models (mock-up)	• accurate representation of the environment	• difficult to implement • limited scope for interaction	very high	reserved for extremely in-depth studies; used very rarely these days

Table 7: advantages and disadvantages of the various methods for modelling acoustic propagation (source: CETE de lyon)

By extending Huygens theorem, the acoustic field between the end of the tunnel and a distance of approximately one to three times its width is assimilated into a progressive diffuse-field. The field radiated by the tunnel portal is therefore represented by a dummy point source placed at the centre of the tube portal and characterised by a power L_w estimated by:

$L_w = L_{wm}$ -10 log(A/S)

where L_{wm} is the power level emitted by the traffic per metre of road, A is the equivalent tunnel absorption area (average absorption coefficient of the walls x surface area of the walls) per unit of length and S is the surface area of the tunnel cross-section. The propagation rules for a point source thus apply to this equivalent source, i.e. the geometric spreading law that cuts the level by 6 dB by doubling the distance to the source.

It should be stressed that these laws do not take account of either tunnel portal geometry or their more or less pronounced directivity.

5.4.2.2 Modelling of the sound power radiated by ventilation systems

The data on fan sound power is supplied by the manufacturers in the form of a power spectrum as a function of fan speeds or operating flows.

This power will be attenuated depending on the length of the ventilation ducts and silencers fixed to the air channel. This gives the power radiated at the level of the air vents, considered as point sources. These sources can be added to the propagation models and their impact superimposed on that of other sources. Accurate knowledge of the day-to-day operating speed of the ventilation systems can prove useful in identifying possible conditions for source-generated noise aggravation (night-time operation in particular).

5.5 IMPACT LIMITATION MEASURES

5.5.1 Limiting traffic-related noise during the operating phase

Generally speaking, the effectiveness of acoustic attenuation measures always increases when they are applied either at or as close as possible to the source. This means having to control the acoustic energy before it begins to propagate and spread naturally, thereby impacting on larger areas.

5.5.1.1 The distancing principle

Before planning any physical protection system, the choice of route and, in particular, the distance separating tunnel portals from sensitive areas makes it possible to limit population exposure at an upstream stage of the project. For point sources, the noise decrease achieved by doubling the distance is 6 dB against 3 dB for a linear source such as a road.

5.5.1.2 Action on vehicle speed

Acting on vehicle speed makes it possible to cut the biggest element of traffic noise (tyre-road surface contact) in relation to engine noise at speeds above 50 km/h for passenger vehicles and 60 km/h for HGVs.

	Gain in dB following a reduction speed		
Reduction	Fairly silent road surface	Standard road surface	Noisy road surface
50 to 30 km/h	2,5	3,4	3,9
70 to 50 km/h	2,3	2,8	2,8
90 to 70 km/h	1,9	2,1	2,2
110 to 90 km/h	1,6	1,7	1,8

Table 8: estimated decrease in road source emissions according to the reduction in speed and type of surfacing (source: Guide for l'élaboration des Plans de Prévention du bruit dans l'environnement – CERTU - 2008)

The effect of cutting vehicle speed by 10 km/h results in a drop in noise levels of approx. 1 dB. However, this gain depends on the initial speed and the quality of the surfacing. The effect is therefore more marked at low speeds and on a noisy road surface.

5.5.1.3 Modulating flow

The emitted acoustic energy is proportional to the traffic flow. In terms of noise levels, this observation can be illustrated by the following equation:

$L_{eq\ (Q\ vehicles)} = L_{eq\ (1\ vehicle)} + 10\log(Q)$

where Leq is the equivalent noise level and Q is the trafic flow.

All other things being equal (traffic makeup and dynamics) doubling the traffic or dividing it by half therefore gives a deviation of + or -3 dB. The challenge will be 1 dB for a 30 % deviation in Q and 0.5 dB for 10 %.

In the case of some particularly long tunnels, the act of imposing minimum safety distances between vehicles will act on traffic flows and, therefore, on noise.

5.5.1.4 Action on HGV traffic

The equivalence between noise emissions by passenger vehicles and HGVs varies between 4 (slope < 2% on motorways) and 20 (slope > 6% on urban roads), with a mean of around 10. Measures designed to cut back or limit HGV traffic can therefore reduce noise levels significantly. A distinction should be made between periods of day and night traffic.

5.5.1.5 Choice of surfacing

There are two main types of acoustic road surface:

- thin, very thin, and ultrathin asphalt surfacing: these are characterised by a low grain size and thickness. The low grain size makes it possible to reduce contact noise and allows a gain of several dB in relation to a conventional asphalt mix, when they are in good working condition. Their use is compatible with the limitations applying to tunnels and cut-and-cover sections. They are most useful at tunnel portals, within the first tens of metres on either side of the tunnels ends;
- draining asphalt surfacing with acoustical properties: the porous structure partly absorbs acoustic energy and cuts traffic noise. The technical instruction (annexed to circular No. 2000-63) of 25 August 2000 states that: "*draining wearing courses are prohibited within tunnels more than 50 m from the ends. If such a wearing course is used in the tunnel approaches, the change shall be made in a covered area so as not to create a singularity in terms of skid resistance or spray at the tunnel entrance or exit in the event of rain.*"

The noise reduction linked to the use of a specific bituminous mixture, draining or otherwise, varies according to the technique used. This can reach 7 to 8 dB (A) in the open air and in tunnels compared with a conventional road surfacing technique. The way in which the surface is laid down is of key importance as variances of several decibels have been recorded with surfaces produced using the same techniques. The choice or source of aggregates and surfacing temperature are factors that can explain these results.

The acoustic performance of any bituminous mixture varies widely depending on its condition. The loss in efficiency of these surfacing is generally about 0.5 dB/year. These properties alter more rapidly under conditions of heavy HGV traffic, extreme weather conditions or by routes that augment road surface constraints.

5.5.1.6 Use of specific protection mechanisms

Changes in tunnel geometry can have a major impact on its radiated sound.

This may involve artificially lengthening the tube (see photo 5). This extension acts as a noise mitigation tunnel that can reduce the noise affecting buildings located directly opposite the tunnel end by several decibels. It also increases the distance from the source. The shape of this extension also impacts on directivity, i.e. the preferred directions of sound radiation. The architectural shape must not encourage sound reflections towards built areas.

Photo 5: tunnel portal extended by a tube – A43 motorway in Maurienne (Orelle) – Apart from its landscaping advantage, this type of solution can be used to offset the emission source by a few tens of metres (source: CETE Lyon)

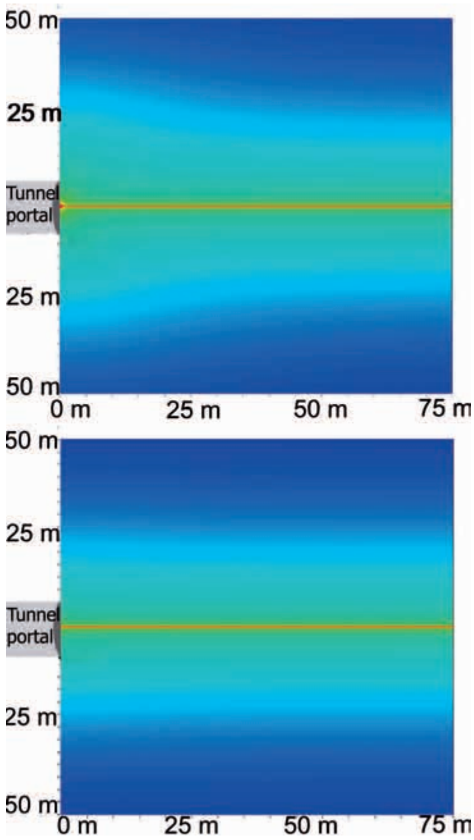

Illustration 13: noise footprint for a tunnel portal equated with a point source – top, cladded with reflective materials; bottom, cladded with porous materials. The sound radiation emitted by the tunnel portal modifies the acoustic field in the first tens of metres. Usually, beyond 25 m, the reverberated field is overlain by the direct field generated by the infrastructure (source: CETE Lyon)

Fitting the ends of the tunnel with absorbing cladding (see illustration No. 13) also helps to attenuate the emitted sound energy. Extensions can be cladded in order to enhance their performance and limit reflections on any facing buildings. If there are no extensions, this absorbing cladding can be fitted inside the tunnel over a distance of approx. two to three times the tunnel diameter (*Woehner, 1992, [15]*). Cladding the inside of the tunnel along its full length, which would represent a major investment, would not provide any worthwhile additional improvement.

Specifically, cladding tunnel ends can result in a potential noise reduction of up to 10 dB(A), i.e. a ten-fold decrease in sound energy. The cladding around a tunnel portal is at its most effective within a radius of a few tens of metres around the portal. Outside this perimeter, the noise emitted by the uncovered infrastructure starts to dominate.

Photo 6: absorbing acoustic facings on the A43 in the Maurienne valley (source: CETE Lyon)

Absorbing materials are generally the same as those used to make acoustic screens. They are designed to withstand weather-related and mechanical constraints inherent to road infrastructures. The most popular choices are particles or wood fibers bonded with cement and mineral wool silencers covered with perforated metal panels. In all cases, it is essential to ensure that the proposed materials are compatible with the fire performance requirements that apply to tunnels. As with screens, the sound-absorption capability of these materials is evaluated according to *standards IN 1793-1 and 1793-2*.

Lastly, phonic checkerboards made of baffles of absorbent materials extending from the tunnel, provide a useful solution for cutting noise emissions.

Photo 7: a phonic checkerboard (source: Les écrans acoustiques – Guide CERTU - 2007 - [16])Illustration 14 : atténuation obtenue à l'aide d'un damier phonique (source : Les écrans acoustiques – Guide CERTU - 2007 - [16])

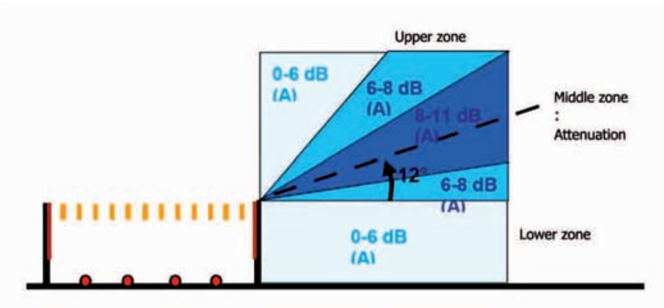

Illustration 14: attenuation obtained using a phonic checkerboard (source: Les écrans acoustiques – Guide CERTU - 2007 - [16])

5.5.2 Reducing noise generated by ventilation systems

There are several possible systems and recommendations to be considered.

The noise generated by ventilation systems using ceiling jet fans located above the traffic flow exits via the portals and raises the issue of traffic noise at tunnel portals. The noise can be reduced however, that involves fitting sound absorbers upstream and/or downstream of the jet fans.

These sound absorbers are linear silencers, i.e. absorbing mineral wool cladding covering the silencer panels fitted on either side of the jet fans. System performance depends on the thickness of the absorbing material and, above all, on the length of the silencers. The companies marketing these systems usually offer complete pre-sized solutions that factor in the effect of the silencers when measuring sound power.

Where ventilation systems that use one or more ventilation plants are concerned, in the first instance and where feasible, facilities should be located as far as possible from the noise-sensitive areas. The distance from these sources is particularly effective as they can be rapidly assimilated with the point sources characterised by geometric spreading of -6 dB by doubling the distance under conditions of uniform propagation (unaffected by the vent or a temperature gradient).

Fitting sound absorbers is an effective solution when application of the distance principle is not enough. This involves sound absorbers known as baffles or "sound traps": in this case, panels of absorbing materials are placed in the circuit at evenly spaced intervals to guarantee sufficient flow. They are sized according to damping requirements. Sound absorber performance varies with frequency. Generally speaking, their performance increases with frequency up to a cut-off frequency after which the performance level starts to drop off.

This performance curve depends on the geometry of the sound absorber and the related absorbing material. The system has to be sized according to the noise spectrum requiring attenuation.

It is also important to optimise system dimensions. The fans have an optimal operating speed that guarantees maximum flow with minimum flow turbulence and, therefore, minimum noise levels. This means sizing the units appropriately upstream in the process according to requirements to ensure use of optimal rotation speeds whenever possible. Poorly adjusted rotations speeds (too low or too high) may cause vibrations in some system components, thus generating additional noise.

Lastly, in cases where stacks are only used intermittently to remove smoke from tunnels, covers could be fitted over the vent apertures in order to limit any propagation of traffic noise from these shafts.

5.5.3 Noise reducing measures and impacts during the construction phase

In addition to the regulatory requirements, mainly concerning information to the general public, the following measures can be planned on a case-by-case basis:

- Management of worksite vehicle traffic plans provides important leverage in cases where there is heavy traffic of lorries evacuating construction materials. This point needs to be considered before beginning the works. This additional traffic on network roads extends the size of area affected by noise. The aim is to develop traffic plans that by-pass dense residential areas or sensitive buildings. When the challenges concerning noise exposure (urban environments particular) are sufficiently important, it is advised to carry out a specific study (modelling of noise levels) in order to evaluate the impacts. This study will use indicators that take account of different daytime periods.
- A noise level monitoring system could be proposed. This would involve measuring the noise generated by the worksite and the particularly noisy stations at several different locations. The owner can set thresholds (in terms of average levels and, especially, noise aggravation levels).
- When selecting contractors, the owner decide whether to opt for a vehicle fleet and worksite equipment with reduced noise levels by referring to the requirements of *European directive 2000/14/CE*, which was incorporated into French law by the *Interministerial order of 18 March 2002*. The aim is to encourage use of the latest technologies and equipment where they generate less noise.

When using explosives, part of the blasting energy is converted into sound energy in the low frequencies field. Although the human ear is naturally protected against infrasounds and low frequencies, the resulting discomfort requires the deployment of information measures at the very least, and temporary evacuations in the most extreme cases (*see chapter 4*). It is difficult to attenuate low frequency waves by means other than distancing them.

5.6 REGULATIONS

While France has an impressive arsenal of regulations and standards governing noise issues, there are no laws specifically relating to tunnels or cut-and-cover sections. Accordingly, the applicable references are provided by the legislation on inland transport infrastructures.

5.6.1 Environmental Code

The Environmental Code incorporates the main body of noise regulations. In particular, it reproduces the information contain in *law No. 92-1444 of 31 December 1992*, codified in *articles L571-9 and L571-10*.

Article L571-9 of the Environmental Code requires that the noise generated by transport infrastructure projects has to be taken account of. *Article L571-10* requires the noise classification of certain transport infrastructures. These classification procedures are specified in *articles R571-32 to R571-43* as well as in the *interministerial order of 30 May 1996*. The latter also specifies noise insulation systems to be planned for residential buildings affected by the noise from inland roads.
Articles R571-44 to R571-52 of the Environmental Code require each owner to take the necessary measures to limit the noise generated by inland transport infrastructure projects. The *order of 5 May 1995* relating to road infrastructure noise sets the regulatory thresholds to be complied with when creating a road infrastructure.

Articles L122-1 to L122-3 of the Environmental Code require the inclusion of a section "health impacts of noise" in the impact studies.

Lastly, the regulations governing inland transport infrastructures do not provide clear guidance on the issue of noise generated by ventilation systems. Although they do not cover noise "*generated by transport infrastructures and related traffic*", the regulations on neighbourhood noise, and *articles R1334-30 to R1334-37 of the Public Health Code* in particular, can nevertheless be used as a basis for setting noise thresholds (for noise aggravation in particular).

5.6.2 Standards

These mainly include:

- *standards NF S 31-010 and 110, "Characterisation and measurement of environmental noise"*, that cover, respectively:
  - > special measurement methods (*AFNOR December 1996*),
  - > basic quantities and general appraisal methods (*AFNOR November 2005*),
- *standard NF S 31-085, "Characterisation and measurement of road traffic noise" (AFNOR November 2002)*,
- *standards NF S 31-131 and 132, "predicting inland transport noise*" that covers:
  - > technical software descriptions (*AFNOR August 2004*),
  - > prediction method typology (*AFNOR December 1997*),
- *standard NF S 31-133, "inland transport infrastructure noise, calculation of sound attenuation during propagation in the outside environment, including weather effects" (AFNOR February 2007)*,
- *standards NF IN 1793-1, 2 and 3 relating to "road traffic noise limitation systems, test method for determining acoustic performance" (AFNOR November 1997)* that cover, respectively:
  - > intrinsic features relating to noise absorption,
  - > intrinsic features relating to insulation against airborne noise,
  - > standardised traffic sound spectrum.
- *standards NF IN 1794-1 and 2 relating to "road traffic noise limitation systems, non-acoustic performance" (AFNOR March 2004)* that cover, respectively:
  - > mechanical performance and requirements in terms of stability,
  - > general safety and environmental requirements.

5.6.3 Special case of the construction phase

Article L571-9 of the Environmental Code refers back to published decrees for the specific case of infrastructure projects. This concerns *decrees No. 95-22 of 9 January 1995 and No. 95-408 of 18 April 1995*.

These decrees have been incorporated into *the Environmental Code and the Public Health Code*. *Article R571-50 of the Environmental Code* states that "*prior to beginning any construction project, […] the owner shall send the prefect […] all the necessary and useful information on the nature of the project, its forecast duration, the expected noise levels and the measures taken to limit this noise. The relevant authorities shall receive this information no later than one month before the start of the project […]. The prefect can […] stipulate […] special worksite operating measures, particularly in terms of entry points and timetables*."

If worksites can exceed the commonly allowed noise aggravation limits, *article R1337-6 of the Public Health Code* states, "*those who […] fail to comply with the conditions of production or use of plant and equipment [as part of worksite operation] set by the competent authorities, or who fail to take the appropriate noise limitation measures, or who exhibit abnormally noise behaviour are punishable by fine*".

5.7 USEFUL REFERENCES

[14] Guide du bruit et des transports terrestres, prévision des niveaux sonores / ministère des transports / 1980.

[15] Sound Propagation at Tunnel Openings / Noise Control Engineering Journal / 1992 / Woehner H.

[16] Les écrans acoustiques, guide de conception et de réalisation / édition CERTU / 2007.

[17] Bruit et études routières, manuel du chef de projet / édition CERTU-SETRA / 2001.

[18] Bruit des chantiers de construction des infrastructures de transports terrestres / édition SETRA / pending publication.

6. AIR POLLUTION

The total quantity of pollutant emissions generated by road tunnels during the operating phase is identical to that generated by any road. It is proportional to the number of vehicles and the distance covered, and remains the same, tunnel or no tunnel. Tunnel impacts on emission volumes are therefore limited to the outcomes of a possible change in driving conditions (i.e. speed limits). Conversely, tunnels do have an effect on concentration levels, as they generate more localised pollutant discharges.

During the construction phase, the principal characteristic impacts to be taken account of when designing a tunnel are the gas discharged during blasting operations, exhaust gases from machinery and lorries and airborne dust from excavation works and the transport of materials.

The information presented below mainly concerns extracts from the methodological guide to "*Environmental studies for road projects*", *"air" and "health" sections, the specific case of tunnels*, published in 2011 [19]. The special case of cut-and-cover sections is not dealt with separately as it does not introduce any significant specific features in relation to those of tunnels.

6.1 TUNNELS AND AIR POLLUTION

6.1.1 A two-fold issue: indoor and outdoor air

Pollutants emitted within tunnels are discharged at certain specific points, thus generating an overconcentration of pollutants in a localised environment:

- at tunnel portals, natural emission discharge points in the absence of any specific system (*see photo 8*);
- at additional openings in tunnel structure, where present;
- at extraction vents or stacks if these exist.

Despite these exchanges with the outside environment, tunnels remain confined spaces where gas emissions can reach levels that are toxic to the health of users in the event of high concentrations inside the tunnel. Airborne dust may also affect the visibility and safety of these same users.

The issue of air pollution relating to tunnels therefore concerns both inside and outside air.

Photo 8: Uriol tunnel on the A51 motorway (source: CETU)

6.1.2 Regular ventilation

This document does not discuss ventilation issues in the event of fire. This topic, which is governed by very specific legislation, is dealt with in detail in the "Ventilation" Master File (CETU, November 2003 [20]).
Apart from its vital role during fires, ventilation guarantees acceptable pollution levels under normal operating conditions:

- inside tunnels, by increasing the dilution emitted pollutants,
- outside tunnels, as a direct result of optimised dilution within tunnels.

Technically speaking, there are three types of ventilation:

- natural ventilation: piston effects and turbulence generated by traffic and weather conditions,
- longitudinal mechanical ventilation: air masses are driven through the tunnel towards the outside, with no introduction of fresh air other than via one of the two portals, waste air being evacuated directly by the other portal; the longitudinal system is sometimes supplemented by point extraction systems known as massive extraction systems,
- transversal mechanical ventilation: injection and/or extraction of air at regular intervals along the tunnel via ventilation ducts.

Illustration 15: longitudinal system - the arrows represent the direction of airflow (source: CETU)

Illustration 16: transversal system - the arrows represent the direction of airflow with fresh air in blue and waste air in red (source: CETU)

Increasingly frequently now, efforts to find ways of controlling longitudinal air currents in the event of fire are leading operators to supplement transversal ventilation facilities with jet fans or injectors. These jet fans or injectors can be used for regular ventilation thereby bring the issue back to longitudinal ventilation (exchange of air solely via the portals) if the extraction system is inactive.

Studies on how tunnels impact on air quality require data on the location of discharge points, which are closely linked to the type of ventilation system used. The following general principles can, therefore, be selected; the distribution assumptions for emissions between portals will apply whenever the duration is sufficiently long to cover the conditions of varied airflow influences.

In most cases, tunnels of less than 300 metres in length have no mechanical ventilation, relying solely on natural ventilation. Pollutant discharges for a one-way tube can therefore be considered as being located entirely at the tunnel portals, driven by the piston effect. Discharges for two-way traffic in a single tube are distributed evenly between the two portals.

Longitudinal systems are often chosen for tunnels with one-way traffic and a length of more than 300 metres. Discharges may then be considered to be localised at vehicle exits, unless extraction stacks are used to maintain acceptable pollution levels in the tunnel. If transversal ventilation is used the same simplifying assumption can be made, with the natural piston effect dictating the direction of airflow inside the tunnel.

Tunnels of over 300 metres in length with two-way traffic generally use transversal ventilation systems. However, whichever ventilation system is planned, the simplifying assumption is that discharges are distributed evenly between the two portals (provided that there are no extraction systems planned for regular ventilation).

The above-mentioned principles present a highly simplified approach. For any detailed study of ventilation systems, please refer to the technical order annexed to interministerial *circular 2000-63 of 25 August 2000 and to the "Ventilation" Master File [20]*.

6.1.3 Pollutants in tunnels

In addition to the differences in regulatory levels for air in tunnels and air in outdoor environments (*see chapter 6.6*), there are also differences in terminology. In tunnels, the term "smoke" is generally used to designate particulate pollution. The latter is not measured directly but is based on opacity values, expressed as m^{-1}. Opacity describes the attenuation of a light flow crossing an air column. It is very difficult to establish a match rule between particulate matter concentrations and opacity.

Another feature of pollutants in tunnels is the behaviour of nitrogen oxides which differs widely between areas inside tunnels and at their outside edges. Inside tunnels, nitrogen monoxide has the highest concentration due to limited oxidation. In its recommendations of 14 December 1998, the Conseil Supérieur d'Hygiène Publique de France (CSHPF) recommends using the following concentration ratio: $NO/NO_2 = 10$. However, recent studies (*[21]*) have shown that this ratio is trending downwards, as technologies for the post-treatment of exhaust gases encourage nitrogen dioxide emissions.

Outside tunnels, the concentration ratio NO_2/NO_x increases with distance from the discharge point. The Centre d'Enseignement et de Recherche sur l'environnement Atmosphérique (CEREA) has developed a simplified computation model for this ratio. The modelling method is described in detail in the report *"Estimation de ratios moyens de NO_2/NOx au voisinage du débouché d'un tunnel en tranchée en milieu urbain" (CEREA, 2004).*

6.1.4 Air pollution during the tunnel construction phase

During the construction phase, tunnels have no features that are significantly different from those found in open-air road construction projects. The main adverse effect relates to airborne dust generated by the traffic of worksite machinery or by excavation works.
Tunnels do have one specific feature, however, in the use of explosives in confined spaces.

The resulting adverse effects mainly concern noise and vibrations. Gases produced during firing programmes include ammonia (NH_3) and carbon monoxide (CO).

Photo 9: worksite at the North portal of the Lioran tunnel (source: CETU)

6.2 IMPACTS AND CHALLENGES RELATING TO AIR POLLUTION

Generally speaking, the impacts of atmospheric pollution come in several forms:

- impacts on human health ranging from an increase in respiratory infections up to an impact on mortality,
- impacts on plant life and farm yields,
- damage to heritage due to corrosion and soiling,
- contribution to the greenhouse effect.

The atmospheric pollution relating to an operational tunnel is that generated by the flow of traffic along it. A tunnel therefore results in local pollutant discharges at its portals and, where applicable, at the level of any additional discharge outlets planned in the tunnel.
Outside of these zones, tunnels actually reduce the external environmental pollution generated by the traffic flowing through it..

Accordingly, permanent tunnel impacts include:

- within-tunnel concentrations that are higher than in the open air due to confinement,
- external decrease in pollutant concentrations along the tunnel opposite from the discharge points;
- external increase in pollutant concentrations in the vicinity of entities neighbouring discharge points;
- health impact that can be analysed in relation to increases and decreases in the above-mentioned concentrations.

Tunnels generally form a section of a road construction project, that itself represents only a part of total road network being evaluated. If a tunnel is likely to generate pollution in areas where no roads are present, this would indicate a negative impact. But in the first instance, the covered section of a tunnel provides protection in relation to a road that would otherwise be built in the open air. And in the second instance, the project that contains the planned tunnel may reduce pollution exposure significantly along the freed up routes.

A tunnel may also be accompanied by an increase or decrease in the contribution to the greenhouse effect, based on changes in traffic flow related to its commissioning and Corresponding changes in the levels of emitted CO_2.

During the construction phase, the impacts in terms of atmospheric pollution mainly concern those relating to exhaust gases from worksite machinery and lorries, and airborne dust generated by excavation works and the transport of materials. These impacts are temporary and disappear on completion of the construction works. However, tunnel construction projects can extend over significant periods. As regards the use of explosives and the resulting discharge of gases, these do not require any particular precautions other than those that cover the safety of worksite personnel.

6.3 "AIR AND HEALTH" STUDY APPROACH

Article L122-3 of the Environmental code states that all projects requiring an impact study have to draw up a health impact study and submit the measures planned in order to eliminate, reduce and, where possible, counteract any damage caused by the tunnel in terms of health and the environment.

The content of the "air quality and health" section of a road project study is specified in *the methodological note on evaluating the health impacts of air pollution in road construction impact studies (CERTU and SETRA, February 2005 [23]).* This provides for a content that varies according to the study level required, which is itself subject to the traffic data for the planned infrastructure and the consideration of the exposed population (*see table 9*).

The expected content principally concerns the operating phase. No specific study is required for aspects relating to the construction phase. Care must nevertheless be taken to draw up a detailed initial status report (*see chapter 6.4*) and to specify the list of foreseeable project worksite impacts and their related means of limitation (*see chapter 6.5*).

T: traffic level expected by the time of the project study (based on uniform section of over 1 km) d: population density in the study band (en hab / km²)	T≤ 10 000 veh/d ou T≤ 1 000 uvp/h	10 000 < T ≤ 25 000 veh/d ou 1 000 < T ≤ 2 500 uvp/h	25 000 < T ≤ 50 000 veh/d ou 2 500 < T ≤ 5 000 uvp/h	T > 50 000 veh/d ou T > 5 000 uvp/h
no buildingd	IV	IV	III	III
d < 2000	II si $L_{project}$ > 50 km ou III si $L_{project}$ ≤ 50 km	II	II	I
2 000 < d < 10 000	III si $L_{project}$ ≤ 25 km ou II si $L_{project}$ > 25 km	II	II	I
d ≥ 10 000	III si $L_{project}$ ≤ 5 km ou II si $L_{project}$ > 5 km	II	I	I

Table 9: definition of required "air and health" study levels (source: methodological note on evaluating the health impacts of air pollution in road construction impact studies [23])

6.3.1 Upstream studies

6.3.1.1 Opportunity studies

At the opportunity study phase, the topic of air quality and tunnels has to be addressed as part of a project presentation and a discussion of the expected phenomena. Occasionally, air quality challenges require more than the submission of general data. In this case, a simplified study can be planned based on the sequence of steps given below:

- calculation and distribution of pollutant emissions at tunnel portals: at this stage, this calculation, made using the tools presented in *chapter 6.4.2*, covers a limited number of pollutants (nitrogen oxides, particulate matter and benzene). Emissions at a tunnel portal can be considered as being equal 50% of the emissions calculated for covered section of the road except in cases of a single, one-way tube, where the all emissions are discharged by vehicles at the tunnel portal.
- factoring in of dilution data: if there is no such data, air can be taken to be exiting the tunnel at a speed of approx. 3 m/s, which gives a tunnel exit airflow of Q = 3 x S, where S is the tunnel cross-section. The concentration of discharge C_0 at a tunnel portal for a given pollutant is: C_0 (µg/m³) = Emissions (µg/s) / Q (m³/s). If the concentration C_0 is greater than the recommended concentration for air inside tunnels (*see chapter 6.6*), this would trigger operation of the mechanical ventilation system. in this case, the concentration of the discharge C_0 can be taken as being equal to the recommende threshold. Concentrations may then be estimated using simplified calculation tool presented in *chapter 6.4.3*.
- assessment of tunnel sensitivity: a tunnel's potential sensitivity can be assessed by investigating the level of background pollution, the overconcentration due to the tunnel, the overconcentration due to the open-air section of the road and regulatory thresholds. The simplified study approach proposed here makes no claims to reflect particularly specific situations in terms of weather or traffic. In common with this approach, the regulatory thresholds to be selected are the quality objectives based on an annual average.

This simplified study is always based on unfavourable assumptions that maximise the tunnel's impact. During later study phases:

- the calculation will be progressively refined as incoming data furthers insight into the project and the site;
- where necessary, measures will be taken to ensure there is no overrun of the permissible concentrations in ambient air in the vicinity of the buildings closest to the project site.

6.3.1.2 Studies prior to the public investigation: comparison of options

The comparison of options phase is designed to highlight which of the proposed routes would minimise impacts on air quality. The study level (*see Table 9*) has a direct bearing on this phase. For example, the calculation of an index of population exposure gaseous pollution (IPP) should be made for level I and II studies but not for levels III and IV. For the latter, a simplified study can still be used such as proposed earlier for the opportunity study phase.

Fo level I and II studies, the following points are adressed:

- calculation and distribution of pollutant emissions at tunnel portals: this is performed in the same way as for the opportunity study but with an extended of pollutants (nitrogen oxides, carbon monoxide, volatile organic compounds, benzene, particulate matter contained in exhaust gases, sulphur dioxide, nickel and cadmium);
- calculation of gaseous pollutant dispersion: the increase in the average annual concentration that risks being generated by the tunnel in its immediate surroundings is modelled using specific tools (*see chapter 6.4.3*).
- comparison of options using an indicator for population exposure to gaseous pollution (IPP): this IPP is determined by cross-matching population data with data for benzene

concentrations (*see chapter 6.4.4*). If benzene cannot be used to discriminate between the various options, nitrogen dioxide could be used as well. Once the IPP component has been computed for a tunnel, it then has to be integrated in the overall IPP relating to the whole project (tunnel and open-air route), on the study area. Once the IPP has been computed for each option, the option with the lowest IPP is the one that minimises the tunnel's impact in terms of the human health impacts due to gaseous pollution.

6.3.1.3 Studies prior to the public investigation : study of the proposed option

The study of the proposed option requires an assessment of the tunnel's likely impacts. Adverse effects have to be explained, together with the measures designed to remedy them.

For types III and IV studies, the presence of a tunnel does not require any particular study.

For type II studies, the aim is to estimate the concentrations likely to be reached in presence of the tunnel, and to compare these values against the regulatory thresholds set by the Air Act. This will require computing for dispersion. The process is the same as that for the previous study phase. The only differences are the necessity to take account of background pollution in order to obtain an absolute level of concentration. It is preferable to use models that can factor in chemical reactions between nitrogen oxides. Once the portal architecture and location has been accurately identified, a mock-up model can be planned. This is generally the case when covering existing roads.

Photo 10: modelling on a mock-up (source : CETU)

Type I studies require an assessment of health risks. This leads to the selection of a more detailed list of pollutants that may include, in particular, volatile organic compounds (acrolein, acetaldehyde, benzene, formaldehyde, 1,3-butadiene, etc.), benzo(a)pyrene, sulphur dioxide, nitrogen dioxide, particulate matter and heavy metals (chrome, nickel, cadmium, arsenic, mercury, barium, etc.).

If there are any indications that the tunnel may lead to an unacceptable deterioration in air quality in the vicinity of one of its portals, impact limitation measures may be planned, similar to those discussed in Chapter 6.5. If it has been decided to use an extraction stack, then this is the moment to conduct a feasibility study on its installation (possibility of finding a suitable installation location, magnitude of the quantities to be extracted in order to return to acceptable impact levels, etc.).

6.3.2 Design studies

This phase of the project does not generally require more than a few additional elements in relation to certain points studied during the preceding phases. At the very most, if as mentioned previously it has been planned to use an extraction stack, its detail study will be carried out at the project phase, once the route has been clearly defined. This particular study will use a fine-scale model that is capable of factoring in extremely local impacts.

6.3.3 Execution

During the works phase, care must be taken to deploy the means for limiting any foreseeable project impacts (*see chapter 6.5*).

Lastly, the monitoring of changes in air quality at strategic locations in the tunnel's surrounding environment can be planned during both the construction and operating phases.

6.4 ASSESSMENTS METHODS AND MEANS

This chapter presents the available methods and tools according to a sequence of four technical steps that generally include an air quality study:

- characterisation of the initial status,
- determination of the emission quantities discharged by the tunnel,
- modelling of pollutant dispersion,
- health study.

The content of each of these steps varies depending on the progress of the studies and the challenges. While the operating phase study for a tunnel project may require the implementation of all four of these technical steps, the construction phase study does not generally need anything more than the characterisation of the initial status supplemented by an analysis of foreseeable project impacts and their related means of limitation.

6.4.1 Initial status report

The initial status report has to qualify the challenges, evaluate sensitivities and define constraints in the absence of any development project, and then use this report as a baseline status against which to study the project's impacts.

As regards air quality with respect to tunnel development projects, the initial status report focuses on the areas surrounding the location of portals and, where necessary, those around ventilation plants. In 2009, CERTU published a methodological guideline for drawing up an initial status report: *études d'impact d'infrastructures routières, volets "air et santé", état initial et recueil de données [24]*. This guide details all the available information that is essential to this study phase.

Table 10 provides an indicative list of the available studies and tools, together with the organisations that have useful data for establishing the initial status report.

6.4.2 Calculating emissions

COPERT's is the most widely used methodology for road construction projects that do not involve a tunnel. For the specific case of tunnels, the emission data proposed by CETU and AIPCR are generally more relevant although they have the disadvantage of being updated less frequently than the COPERT data. For these reasons, at the preliminary studies phase, Copert's methodology is deemed adequate, even when tunnels are involved.

6.4.2.1 Copert Method

The latest version of the Copert method is given in the Copert 4 report published by the *Agence Européenne d'Environnement* in August 2007. The report provides a database of unitary emission factors that depend on vehicle type, fuelling system, engine cylinder capacity and the date of entry into service. These emission factors were determined based on average speed values taken from the measurements made by several European laboratories using precise kinematic cycles. There are dedicated tools designed to implement this methodology.

Components	Organisation or data resources
Air quality	• Associations Agréées de Surveillance de la Qualité de l'Air (AASQA) • documents such as: Regional Air quality Plans (PRQA) or future Regional Schemes for Climate, Air and Energy, Plans for Protection of the Atmosphere (PPA), Urban Mobility Plans (PDU) or even Urban Zone Road Network Files (DVA) • **if data is lacking, setting up of specific in situ measurement campaigns**
Soil quality (soil pollution due to fall-out of particulate matter)	• Institut National de Recherche Agronomique, Chambres d'Agriculture or DREAL (Regional directorates for the Environment, Town planning and Housing) • **if data is lacking, setting up of specific in situ measurement campaigns**
Meteorology	• Météo France
Ground occupation, irregularities and topography	• IGN and INSEE databases • Corine Land Cover databases
Listing of pollutant emissions	• AASQA, DREAL and CITEPA (Centre Interprofessionnel Technique d'Études de la Pollution Atmosphérique)
Health data	• ARS (Regional Health Agencies), ORS (Regional Health Observatories) and CIRE (Interregionales Epidemiology Units).

Table 10: data useful for establishing the initial status of air quality (source: CETU)

6.4.2.2 Artemis method method

The European Artemis project (Assessment and reliability of transport emission models and inventory systems) has devised a new method for calculating emissions. Input parameters are no longer based on a simple average speed, but on a "traffic status" approach that links data on the environment (urban, countryside) road category (motorway, expressway, average road, local network, etc.), traffic conditions (fluid, saturated, etc.), speed limits and traffic level. At this stage, there are no simplified tools for implementing Artemis.

6.4.2.3 Tunnels Study Centre (CETU) method

This method is described in the document *"Calcul des émissions de polluants des véhicules automobiles en tunnel" of April 2002,* available from the CETU. The data used are taken from studies carried out as part of various European programmes and specific measurements commissioned from INRETS by CETU. A new version is scheduled in 2011.

6.4.2.4 Method for calculating emissions by World Road Association (PIARC)

This method, which is very similar to that of CETU, is explained in the guide *"Road Tunnels: Vehicle Emissions and Air Demand for Ventilation"* by PIARC (Worl Road Association). It is updated on a regular basis.

6.4.3 Calculating pollutant dispersion

The study of pollution dispersion is a major step towards evaluating a tunnel's environmental impact. The challenge is to describe the field of concentrations within the impacted area outside the tunnel, where pollution levels may exceed the thresholds set by the Air act. The modelling process is based on four key steps:

- accurate definition of study specifications and the choice of modelling tool,
- collection of input data: orography, ground occupation, meteorology, emissions,
- computation of pollutant dispersion and possibly of pollutant conversions,
- use of the results.

In contrast to most of the usual sources, tunnel portals involve a certain amount of horizontal movement. Run-off is complex and is characterised by the relationship between discharge velocity and a characteristic wind speed. To this feature is added the usual phenomena of atmospheric dispersion.

Before deciding on a model, it is necessary to define the required level of precision. This makes it essential to have clearly defined objectives; certain points here merit careful identification:

- targeted pollutants: gas or particulate matter, primary pollutants that do not interact with other components, or secondary pollutants;
- nature of the sources taken into account: ventilation stack, tunnel portal, etc.
- spatial scale: scope of the computational domain, which may vary by a few hundreds of metres around the source (local scale) to a few tens of kilometres (urban scale);
- level of detail of the site description (presence of obstacles or buildings, complexity of relief, assessment of any surface irregularities);
- timeframe: analysis of the chronic pollution levels and/or analysis of the worst possible scenario for one or more pollutant sources.

6.4.3.1 Numerical models and mock-ups

Several types of model can be used to achieve some or all of these results. They are presented and compared in *table 11*.

6.4.3.2 Simplified estimation

Rough estimations of concentrations can also be made using a simplified estimate technique. Collating the results from aeraulic mock-ups makes it possible to determine the characteristic values for decreasing concentrations according to the distance to the tunnel portal and the direction in relation to the tunnel axis. These data are summarised in *illustration 17*.

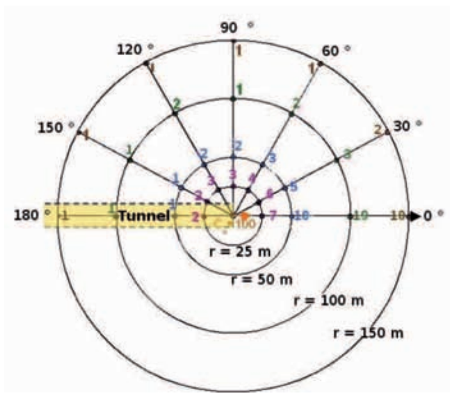

Illustration 17: decrease in concentrations, 3 metres above ground, in a tunnel portal environment (top view): for a discharge with a concentration of 100 µg/m³, the concentration in a direction of 30° at 100 m is no more than 3 µg/m³ to which is added the local background concentration (sources: CETU)

Type of model	Advantages	Disadvantages	Cost	Scope
conventional gaussian	• simple to implement • simple statistical analysis • rapid computation times	• very simplified approach, not suitable for small-scale complex sites; chemistry not taken into account • not suitable for near field	low	global studies
sophisticated gaussian	• simple to implement • simple statistical analysis • option of factoring in relief and some obstacles in near field, possible to take chemistry into account • moderate computation times	• simplified approach • problems in cases of highly complex topography (cliffs, etc.) • limitations in near field	low	recommended for studies preliminary to the Declaration of Public Interest
lagrangian	• fairly rapid computation times	• possible but complex to take the chemistry into account	average	used rarely at present for tunnel portals
eulerian (CFD)	• option of processing complex run-off patterns, possible to take chemistry into account	• difficult to put into practise • tricky to use	high	reserved for cases where the architecture and positioning of tunnel portals are accurately known
mock-up	• option of processing complex run-off patterns; reliable results	• difficult to put into practise, chemistry not taken into account	very high	reserved for highly detailed studies

Table 11: advantages and disadvantages of the various methods for modelling atmospheric pollution (source: CETU)

This lowering of concentrations only applies to passive pollutants and, therefore, excludes nitrogen monoxide or nitrogen dioxide taken alone. The reasoning for the latter has to be based on total nitrogen oxides. Once the concentration in total nitrogen oxides has been determined to the marked calculation point, the method *Estimating average NO_2/NO_x ratios in the vicinity of a cut-and-cover tunnel exit in an urban environment [22]* makes it possible to evaluate NO_2 concentrations.

Ratio NO_2/NO_x	Distance d at the tunnel portal			
Angle θ in relation to the tunnel axis	25 m	50 m	100 m	150 m
0°	0,23	0,25	0,31	0,47
30°	0,29	0,48	0,64	0,71
60°	0,34	0,55	0,68	0,72
90°	0,34	0,55	0,67	0,72
120°	0,34	0,51	0,65	0,71
150°	0,28	0,43	0,60	0,71
180°	0,22	0,25	0,44	0,69

Table 12: NO_2/NO_x ratio forvarious values of the pair (d,θ) for a large conurbation (sources: CEREA and CETU)

The CEREA method gives an order of size for the ratio NO_2/NO_x as an annual average. This means first characterising the situation in question i.e.:

- large conurbation with a high level of background pollution in nitrogen oxides,
- average sized town with low nitrogen oxide pollution.

Next, the values for the NO_2/NO_x ratio are given, always according to the distance at the tunnel portal and the direction in relation to the tunnel axis. For instance, *table 12* lists the values for the case of a "large conurbation".

6.4.4 Health study

The content of the health study varies according to the required level of detail (*see table 9*). It is specified by the *methodological guideline on how to evaluate the health impacts of air pollution as part of road construction impact studies [23]* and by general information on the relationship between pollution and health up to the preparation of a health risks assessment (ERS) according to a formalised procedure (*see "guide to analysing the health components of an impact study ", INVS [25]*)

An interim evaluation tool that supplements the ERS, referred to as the population pollution exposure indicator (IPP), provides a means of comparing the options and their related tunnels. The calculation involves multiplying, at each point in the study area, the additional concentration attributable to the tunnel by the number of people present, and then by adding up all the points for the study area. This calculation requires the figures for the additional concentration attributable to the tunnel and the population number; after which, it is fairly simple to average the results for the dispersion model used by interpolation and GIS tools.

Benzene should be selected for the IPP calculation due to both its classification by the World Health Organisation as a pollutant that is "carcinogenic to humans" and it priority status established by the National Health and Environment Plan. Nitrogen dioxide can also provide relevant support in determining IPP insofar as this pollutant is highly representative of road pollution.

6.5 IMPACT LIMITATION MEASURES

Even though they are referred to in the operating and construction phases, it is further upstream at the studies phase that impact limiting measures have to be researched, although they are only implemented at a later date.

6.5.1 Constructionn phase

The measures listed in *table 13* can be considered when seeking to limit temporary impacts of the construction phase. In addition and generally speaking, it is a good idea to set up appropriate timeframes together with a communication and information initiative targeting the local population in the vicinity of the tunnel.

Current practices for spraying worksite paths to prevent airborne dust clouds are mainly empirical. Under the voluntary undertaking agreement of 25 March 2009 concerning actors involved in the design, execution and maintenance of road infrastructures, thoroughfares and urban areas, earthworks contractors are committed to establishing recommendations to members of the profession aimed at reducing water consumption.

Impacts	Possible measures
Dispersion of dust during implementation operations on natural dry soil (earthworks, circulation of lorries and machinery on the worksite)	• fix the dust with water and spray worksite routes • carry out preventive spraying if the weather conditions are favourable to the phenomenon (dry and windy) • control any run-off caused by spraying the spraying operations
Dispersion during operations on finished materials (repairing of concrete, sawing of concrete or bitumen, etc.)	• set up a worksite quality approach aimed at limiting repairs • humidify the work area, where possible in advance • install a suction device or at least a deflector to limit the dispersion of airborne dust in the environment
Dispersion of pulverulent products	• store products in areas sheltered from wind; make sure transfer precautions are complied with
Dispersion of dust generated by equipment and storage areas	• carefully select the equipment locations or materials storage areas according to dominant winds and the sensitivity neighbouring entities
Dispersion of potentially polluting products	• protect storage areas (signalling, traffic control) • monitor storage conditions (identification and integrity of containers, compliance with safety instructions during product transfers)
Dispersion of dust during operations involving the transfer, loading and unloading of materials	• take account of weather conditions • cover lorries with tarpaulins and define relevant routes • make sure that care is taken over unloading operations • comply with the area marked out for loading – unloading operations
Emissions of smoke and dust	• check equipment that generates dust and smoke • check for the presence of dust and smoke filtration systems • install covers over some storage areas where necessary (finished products, dry and windy weather)
Exhaust gases emitted by worksite machinery and equipment	• ensure maintenance and servicing of equipment and machinery
Release of odours relating to the implementation of certain products or the execution of certain works	• take account of weather conditions (wind) and of the proximity of the local population • inform neighbouring entities of the duration of the works (leaktightness, surfacing, etc.) and of the use of strong-smelling products (paint, etc.)

Table 13: possible measures for limiting the impacts of atmospheric pollution during the tunnel construction phase

6.5.2 Operating phase

The measures that can be used to limit a project's negative impacts during the operating phase are:

- upstream thinking on how to optimise the positioning of tunnel portals,
- traffic management measures aimed at preventing road congestion and optimising vehicle speeds; pollutant emissions are minimal at speeds of approx. 60 to 70 km/h,
- good management of the ventilation system linked to the measured pollution levels,
- extraction systems designed to limit pollutant emission via the portals when these are located in highly sensitive areas,
- treatment of waste.

Regarding the last two points, the report *"MANAGING AIR OUTSIDE OF TUNNELS" (Arnold Ten - Counsel at Law, Adj. Professor of Engineering [26])* states that less than 1% of the several thousands of tunnels existing worldwide are equipped with an dedicated pollution extraction system and less than 0.01% have a waste treatment system.

Photo 11: ventilation unit UV2 in the Toulon tunnel (source : CETU)

At the end of an extraction system there is generally a stack, known as a ventilation or extraction stack. These stacks may be located at some point along the length of the tunnel or at its ends. In urban environments, it is sometimes necessary to design fairly high stacks in order to ensure raising plumes to heights that will limit any impacts. Stack height and discharge velocities have to be studied in order to ensure optimum dispersion.

While the treatment of waste is often seen as an attractive option for limiting adverse outcomes, it is nearly always of limited value for a high-impact implementation. Such techniques may provide useful support solutions knowing, however, that using one or more extraction stacks, without treatment, still provides for effective reduction of the impact of discharges including in the most severe cases.

The air treatment technique proposed in tunnels differs from that used in the open air where nitrogen oxides are targeted preferentially, especially using "Denitrifying" screens. While this technique is also being trialled in tunnels, the main focus is on the treatment of particulate matter using filtration systems. However, at present, there are few tunnels worldwide equipped with such systems. There are probably no more than sixty or so, three quarters of which are in Japan, eight in Norway and only one in France (since 2010 in the Mont-Blanc tunnel). In over 90% of cases, filtration systems are used alone with no treatment of gaseous effluents. Filtration systems are used most often in Norway and Japan in order to improve visibility inside tunnels, which can be reduced by the presence of particulate matter. Treatment systems are rarely used solely for environmental purposes, except in a few special cases and in particular for recent projects where gaseous pollutants are also targeted.

The document "*Le traitement de l'air des Tunnels routiers : état des connaissances sur les études et les réalisations" [27]* gives further information on air treatment techniques.

6.6 REGULATORY PROVISIONS RELATING TO AIR POLLUTION

The regulatory framework for air quality derives from l*aw on air and the rational use of energy (LAURE) of 30 December 1996* incorporated into the *Environmental code*. This makes it mandatory to conduct studies on how infrastructure projects impact on health and air quality (*article L122-3 of the Environmental code*).

The content of the studies to be performed as part of road construction projects is set out in a *methodological guideline on how to evaluate the health impacts of air pollution as part of road construction impact studies [23]*.

The regulatory permissible levels for pollutants in ambient air, and therefore at the edges of tunnels are set by decree. The corresponding levels are not given in this document as they are subject to change. They can, however, be viewed on the websites of the Associations Agrées de Surveillance de la Qulaité de l'Air (e.g. Airparif). The pollutants currently governed by law are:

- nitrogen dioxide,
- sulphur dioxide,
- lead,
- benzene,
- ozone,
- particulate matter,
- carbon monoxide,
- heavy metals: arsenic, cadmium and nickel,
- benzo(a)pyrene.

Lastly, there is no single, specific law governing conditions inside tunnels. The values listed in *table 14* are taken from *French circular 99.329 of 8 June 1999 issued by the Ministry of Health, the technical order annexed to the circular of 25 August 2000 and CETU recommendations*. Only three pollutants are mentioned. As exposure times in underground structures are generally short, limit values are calculated based on short durations, or even expressed as an instantaneous threshold figure.

During the construction phase, the regulations governing Facilities classified for *environmental protection* (ICPE) apply to specific facilities (concrete mixing plant, stations for treating sludge generated by tunnel boring machines, etc.), while that covering worksite machinery, *decree No. 2000-1302 of 26 December 2000* implements an acceptance procedure for engines designed to be mounted on off-road mobile machinery, prior to the marketing of said engines.

Pollutant	Parameter	Observation period	regulatory or recommended level		reference
carbon monoxide	en situation d'accident, en tout point du tunnel	instantaneous value	150 ppm	[171 mg/m^3]	technical order of 25/08/00
	teneur moyenne sur toute la longueur de l'ouvrage	15 minutes	90 ppm	[103 mg/m^3]	circular of08/06/99
		30 minutes	50 ppm	[57 mg/m^3]	
nitrogen dioxide	teneur moyenne sur toute la longueur de l'ouvrage	15 minutes	0,4 ppm	[752 µg/m^3]	circular of 08/06/99
opacity	en situation d'accident, en tout point du tunnel	instantaneous value	9.10^{-3} m^{-1}	/	technical order of 25/08/00
	en situation normale, en tout point du tunnel	instantaneous value	5.10^{-3} m^{-1}	/	CETU recommandation

Table 14: regulatory or recommended levels inside tunnels (source: CETU)

6.7 USEFUL REFERENCES

[19] Les études d'environnement dans les projets routiers, volets "air et santé", le cas spécifique des tunnels / CETU / 2011.

[20] Dossier pilote des tunnels "Ventilation" / CETU / 2003.

[21] Émissions de dioxyde d'azote de véhicules diesel, Impact des technologies de post-traitement sur les émissions de dioxyde d'azote de véhicules diesel et aspects sanitaires associés / Avis de l'Afsset et rapport d'expertise collective / AFSSET / 2009.

[22] Estimation de ratios moyens de NO_2/NOx au voisinage du débouché d'un tunnel en tranchée en milieu urbain (2004-19) / CEREA, Stéphanie Lacour / 2004.

[23] Note méthodologique sur l'évaluation des effets sur la santé de la pollution de l'air dans les études d'impact routières / CERTU et SETRA / 2005.

[24] Les études d'impact d'infrastructures routières, volets "air et santé", état initial et recueil de données / CERTU / 2009.

[25] Guide pour l'analyse du volet sanitaire des étude d'impacts / Institut de veille sanitaire / 2000.

[26] MANAGING AIR OUTSIDE OF TUNNELS / Arnold Dix - Counsel at Law, Adj. Professor of Engineering / 2006.

[27] Le traitement de l'air des tunnels routiers : état des connaissances sur les études et les réalisations / CETU / 2010.

7. ENERGY CONSUMPTION AND THE GREENHOUSE EFFECT

The Centre Interprofessionnel Technique d'Étude de la Pollution Atmospherique (CITEPA) states, *"given that carbon dioxide (CO2) is a by-product of combustion and that, at present, no system exists for collecting this gas from combustion plants, emissions remain in line with levels of fossil fuel consumption. CO2 emissions linked to fuel consumption represents about 95% of total emissions [28]."*

Fossil fuel consumption is therefore closely associated with the emission of greenhouse gases. The contribution of electrical energy to the greenhouse effect is more difficult to interpret as it depends on the production sectors (hydroelectricity, nuclear, etc.). Avoiding the discussion over which production sector is the most relevant, this chapter will mainly address the notion of energy consumption, taking the approach that, in terms of the greenhouse effect, it is the reduction of consumption levels that really counts irrespective of which energy source is considered.

As such, the commitments issuing from the Grenelle Environment are clear. "*As of now, France has to set itself on course to make a four-fold cut in greenhouse gas emissions by 2050 [...]. This means having to think of a completely new model for development that also reduces our energy needs. The 2020 target set by the European Council i.e. a 20% cut in greenhouse gas emissions, or 30% in the event of commitments by other industrialised countries, a 20% reduction in energy consumption, and raising the share of renewable energies in overall energy consumption to 20%, lies on a radical path for improving energy efficiency.*"

7.1 SPECIFIC FEATURES OF TUNNELS IN RELATION TO ENERGY

7.1.1 Operational phase

Tunnel operation is based on the operation of specific equipment such as ventilation, lighting, signalling, video surveillance, etc. that contributes to the structure's safety. The type of equipment needed varies with each tunnel and the related safety requirements: not all tunnels contain all the equipment cited. All this equipment represents sources of energy consumption, mainly in terms of ventilation and lighting. Nearly all the corresponding equipment is operated using electric power.

7.1.1.1 Ventilation

Ventilation covers several different aspects:

- **Sanitary ventilation** that operates during varying time periods during the day depending on the tunnel, at differing speeds, and during a greater or lesser number of days over the year;
- **Smoke ventilation** whose operation remains exceptional and is limited to regular tests or actual fires;
- **Emergency exit ventilation** which, in standard mode, renews the air supply to emergency exits and, in the event of fire, is used to overpressure them; exits may be ventilated either by fans that supply several offset exits in technical rooms, or each exit can be ventilated locally by a dedicated system. Lastly, it is possible to have a system that separates regular operation (renewal of the air supply to exits) from accident-related operation (overpressurising);
- **Ventilation** designed to renew the air supply and air-condition the various **technical rooms**.

7.1.1.2 Lighting

Lighting includes:

- **Safety lighting**: this low power lighting has to stay on even during power cuts. It is generally operated by the “reduced night” mode of the basic lighting system;
- **Evacuation lighting**: this low power lighting has to stay on at all times and enable the signalling of the emergency pedestrian evacuation route;
- **Basic lighting**: along the whole length of the tunnel, of a power level lower than that of the strong lighting; short tunnels do not contain any basic lighting; it operates during both night and day according to three modes: “day”, “night” and “reduced night”;
- **Strong lighting**: this requires high power input during daytime all year round:
  - > at tunnel entrances to help drivers adjust their eyes to the lower light levels in the tunnel,
  - > at tunnel exits, where necessary, to counteract risks of glare.

The need for strong lighting therefore varies according to the amount of sunlight and the speed of entry into the tunnel. At the moment, most facilities operate with two lighting levels that depend only on sunlight levels i.e. sunny days and overcast days. Research and experiments are currently ongoing aimed at developing a way of controlling lighting using a system of continuous variation. The stated aim is to link energy consumption to user requirements by using a servo-controlled system that automatically adjusts lighting levels according to sunlight conditions and traffic speed. There has already been some progress made by optimising the layout plan for lighting devices and their power levels.

7.1.1.3 Other safety equipment

Generally speaking, the most energy-intensive equipment is the basic and strong lighting systems, together with ventilation (*see Table 15*).

Other safety equipment (PLCs, cameras, automatic incident detection, barriers, signalling, marker lights, overpressurising of the fire-fighting network, etc.) generally operates at lower power levels but, for the most part, on a continuous basis.

Power budget	Regular power budget	Backup power supply, UPS(s)
Basic lighting	24	8
Strong lighting	135	0
Operation of regular and smoke ventilation	540	0
Misc.	142	62
Total power (regular + backup)	771	70

Table 15: power demand budget (in kVA) for the Lioran tunnel , length 1,515 metres: smoke extraction has a very high installed capacity (this observation does not concern consumption though as, fortunately, smoke extraction systems only operate on very rare occasions while equipment backed up by UPS are supplied 24/24, 365 days a year)

7.1.1.4 Pumping

Building a tunnel in a water catchment area or a drainage blanket may require regular pumping operations to evacuate the water inflows, and thus involves the consumption of energy. "*Although pumping facilities have high installed capacities, the quantities of water that need to be evacuated are usually fairly low meaning that pumps are only used infrequently. For structures with pumping facilities, the related energy consumption is lower than that of regular ventilation.*" *[29]*

7.1.2 Construction phase

The tunnel building phase associates energy consumption in the form of lighting, ventilation and pumping systems.

Features of tunnel construction projects specific to energy consumption may also concern the use of special machinery for excavations (tunnel boring machines, partial face tunnelling machines, etc.) and the transport of rubble. This energy consumption is accompanied by a lower, less visible energy consumption i.e. the energy used upstream to manufacture the elements of the tunnel and their transport.

As such, the use of steel and concrete is highly unfavourable as their manufacture is extremely energy-intensive.

A consistent analysis of energy consumption would therefore warrant being based on a Life Cycle Analysis (LCA) of the structure. This method is designed to assess the potential environmental impacts of a product or activity, from the extraction of natural resources up to disposal and elimination at the end-of-life stage. In practical terms, incoming and outgoing flows of materials and energy are inventoried at each stage of the life cycle. This is followed by an assessment of the environmental impacts of each flow. In particular, this makes it possible to separate out energy consumption figures (excluding the traffic in the tunnel).

At present, there is no regulatory requirement to carry out a LCA for tunnel projects. At the most, some preliminary studies have been carried out as part of research programmes. This is the case at CETU where the first results, to be viewed with extreme caution given the innovative and experimental nature of applying a LCA to tunnel construction, would appear to indicate that the construction phase has a significant effect in terms of energy consumption, even taking account of the long operating period of around a hundred years. In this calculation, operation covers only equipment and not the traffic transiting through the tunnel. This research merits further investigation.

7.2 IMPACTS ET CHALLENGES RELATING TO ENERGY CONSUMPTION AND THE GREENHOUSE EFFECT

Efforts to find ways of limiting energy consumption come under the umbrella of a national commitment in the form of the Grenelle Environment, and a European commitment in the form of the energy-climate plan. These efforts are also closely allied to the issues of global warming and greenhouse gas emissions. It is for these reasons that they are considered a key challenge.

Aside from its environmental impact, the issue of energy consumption also has to be considered alongside that of costs. Energy has a cost so limiting consumption also represents a means by which the owner and the tunnel operator can cut costs (*see table 16*).

Lastly, given the increasing number of concerns over environmental issues, using a project to innovate and drive advances in these areas can raise a project's profile favourably with users and the local population.

Type of tunnel	Annual operating and electricity costs, tax inc.
Two-way intercity tunnel (L = 0.35 km)	€ 13,303 (196 304 kWh)
Two-way intercity tunnel (L = 1.4 km)	€ 14,790
Two-way intercity tunnel (L = 4.8 km)	€ 145,700 (2 118 000 kWh)
Motorway intercity tunnel with two one-way tubes (L = 0.8 km)	€ 52,124 (819 782 kWh)
Motorway intercity tunnel with two one-way tubes (L = 3.2 km)	€ 101,337 (1 659 363 kWh)
Motorway urban tunnel with two one-way tubes (L = 0.9 km)	€ 43,500
Motorway urban tunnel with two one-way tubes (L = 1.4 km)	€ 121,761 (1 794 595 kWh)
Motorway urban tunnel with two one-way tubes (L = 2.5 km)	€ 134,500
Urban tunnels with two one-way tubes with a cumulated tube length of 18.2 km	€ 904,000
Two-way cross-border tunnel (L=12.9 km)	€ 1,264,383 (16 504 143 kWh)

Table 16: examples of operating costs and electricity consumption (source: CETU [29])

7.3 STUDY APPROACH

Several major technical choices impact on energy consumption although project constraints do not leave much room for manoeuver. This is the case when deciding on the excavation method, which is closely linked to the site's geotechnical constraints, to the vacuation of rubble and to the potential for the reuse of this rubble.

These key choices are made at the upstream studies stage. They also apply to tunnel equipment e.g.
- the number of ventilation plants,
- the number of electricity supply outlets (whether there is an outlet at each portal, intermediate outlets),
- lighting principles: interaction of the choice of road surface with the lighting,
- etc.

Therefore, it is a good idea to start researching orders of size for electricity consumption right from the upstream phase of the project. Eventually, LCA type approaches will have to be multiplied provide data on total end-to-end energy consumtion for each major technical choice.

At present, in-depth thinking on energy consumption is only begun at the Design studies phase with the implementation of power balances. The main aim being to put a size on the electricity supply systems to be installed. To take this further, it is also useful to try and determine what the power consumption level is actually likely to be and then try to find ways of limiting this through the choice of equipment and the main options for network architecture (electricity, ventilation and lighting in particular).

7.4 ASSESSMENT METHODS AND MEANS

7.4.1 Lifecycle analysis

Most of the topics addressed in this document have impacts at local levels, in the direct and immediate environment of the tunnel (noise, contamination of water resources impacted by the tunnel project, pollution air at tunnel portals, vibrations, etc.). The lifecycle analysis (LCA), already discussed in chapter 7.1.2, does not meet these very local concerns: water and air pollution are only integrated through global emission reports. It does, however, make it possible to factor in the overall impact on the environment. It is therefore particularly suitable for topics such as energy consumption or greenhouse gas emissions (GGE). Concerning GGE, the lifecycle analysis is based on the same principles as more widely known method of the Carbon Footprint®.

To perform an LCA it is necessary to have a copy of the environmental report for the various materials used. This may be obtained through Environmental and Health Statements (FDES).

The LCA tools is standardised to international level, in particular through *standards ISO 14040 and ISO 14044 (see chapter 7.6).*

7.4.2 Power budget and monitoring of equipment operation

The sizing of electric power facilities is based on a power budget. This consists firstly in determining the power input required to operate each individual piece of equipment. Next, the total power is calculated by adding together the power requirements for equipment likely to be operating simultaneously. The installed capacity is therefore often of vital importance and sized to cover rare events.

Efficient energy use means firstly being aware of its consumption. It is therefore vital when planning a facility to allow for the monitoring of consumption by each family of equipment. The plans should therefore include a general low-voltage panel with a separate set of busbars for each station that is to be monitored together with a meter on each busbar.

This monitoring system should be supplemented by monitoring of equipment operating periods and times and their response to the sensors conditioning their operation (luminance meter for strong lighting, pollution sensor for ventilation systems, etc.). Setting up this type of tool is the only effective way of identifying the most energy-intensive stations and leading considerations of how best to make them more energy-efficient.

Although control over consumption is often a question of good sense, as mentioned above, this still requires the use of monitoring tools.

Among the rules of good sense, it is a good idea to check the operating settings for the various systems and equipment. For example, there is no point in setting air-conditioning at 21°C if 25°C will suffice. Sometimes, it is better not to turn air-conditioning on at all but, rather, focus on renewing air using mechanical, or even natural means. This does not, however, mean going too far the other way and ignoring the equipment's conditions of operation: lifetimes for leaktight lead batteries (data for 20°C) are halved if the ambient temperature reaches 25°C.

The choice of equipment and technology may also be informed by energy concerns e.g.

- the choice of lighting technology: symmetrical or counter beam,
- the choice of lamps: high-pressure sodium or fluorescent.

When choosing source types, one important criterion is the "lumen/watt" ratio (the higher the ratio the brighter the lamp per 1 Watt of energy consumption). This ratio is usually greater than 100 lumens/Watt for sources used in tunnels. Note that, currently, LED sources have a lumen/watt ratio of approx. 70 lumens/Watt.

The various equipment found in tunnels have very different lifetimes. These may vary from a few years (electronic and IT equipment) to several tens of years (electromechanical equipment). It is therefore essential to take careful consideration of an equipment's energy consumption, lifetime and end-of-life (recycling). The Table below indicates the lifetimes for several types of equipment. The values show are averages adapted to fit the case of tunnels i.e. averages that can vary widely in either direction. Lastly, the equipment operating conditions and the stresses acting on them also impact strongly on the related lifetimes.

The choice of equipment can quickly become very technical. It is not always necessary to target a specific product when drafting contracts. The simplest approach is to consider the issue in terms of performance, by defining minimum yields for instance.

Under the provisions of Article 53 of the French Public Procurement Code, bid selection criteria may be based on environmental considerations and, therefore, focus on energy consumption in particular. These "*criteria and their weighting or ranking are indicated in the notice of a competitive public tender or in the tender documents*".

The environmental protection criterion must be clearly specified so as to avoid giving rise to a discretionary power.

Family	Sub-assembly	Average lifetime in years	Remark(s)
Electricity supply / distribution	Cells 20 KV	25	
	Transformers	30	
	Cables	30	
Backup power supply	Generator	25	Révisions intermédiaires
	UPS	15	
	Leaktight lead battery	5	
	Nickel-cadmium battery	20	
Lighting	Luminaires	20	
	Cables ducts	20	
	Junction boxes	20	
Ventilation	Jet fans	15	Révisions intermédiaires
	Ventilation plants	25	Y compris équipements annexes (registres, insonorisation)
Pumps	Pumps	20	
Centralised Technical management	Pollution sensors	10 à 15	Suivant le type d'équipement
	Brightness sensors	15	
	PLCs	10	Peuvent être obsolètes au bout de 5 à 6 ans
CCTV	Cameras	15	Peuvent être obsolètes au bout de 8 à 10 ans
	Display screen	10	
Signalling	Counting loops	10	
	Fixed message panels	20	
	Variable message panels	15	
Telephony	Tunnel tel. stations	15	
	Central exchange hub	25	
Radio retransmission	Radiating cable	20	
	Emitters	15	
	Antennae	20	

Table 17: lifetimes for several types of equipment (source: CETU [30])

7.6 REGULATORY OR NORMATIVE PROVISIONS

Energy consumption is one of the topics that has to be addressed in the impact study for a road infrastructure project. *Article L122-3 of the Environmental* code states that "*[...] for transport infrastructures, the impact study includes an analysis of the collective costs for pollutions and disturbances as well as of the potential benefits for local communities together with an assessment of the energy consumption generated by project execution, particularly in terms of any displacements it may cause or prevent*".

The commitments made under Grenelle Environment and the ensuing laws specifically target energy consumption. The aim of the *French programming Law No. 2009-967 of 3 August 2009* relating to implementation of the Grenelle Environment is to ensure "*a new sustainable development model that respects the environment and is combined with a reduction in the consumption of energy, water and other natural resources*". Accordingly, it targets areas such as construction and transport in general without targeting structures such as tunnels in particular.

Lastly, note a few standards relating to the lifecycle analysis:

- *standard ISO 14040* "Environmental management - Lifecycle analysis - Principles and frameworks" that describes the main characteristics of the LCA and the good practices governing the performance of such studies;
- *standard ISO 14044* "Environmental management - Lifecycle analysis – requirement and guidelines" that specifies the requirements and provides the guidelines for performing a LCA;
- *standard NF P01-010* that deals with the characteristics of construction products and Environmental and Health Statements (FDES) that specify the implementation conditions for construction products;
- *standard NF P01-020* that highlights the main points of the French consensus in terms of the environmental quality of buildings.

7.7 USEFUL REFERENCES

[28] Émissions dans l'air en France, substances relatives à l'accroissement de l'effet de serre / CITEPA / update 2009.

[29] Guide pour la maîtrise des coûts de fonctionnement des tunnels routiers / CETU / 2005.

[30] L'instruction technique pour la surveillance et l'entretien des ouvrages d'art (ITSOA), fascicule 40 / CETU / 2011.

[31] Guide de la fourniture de l'énergie électrique en tunnel / CETU / 2002.

8. MANAGEMENT OF MATERIALS AND WASTE

Tunnel excavations or the implementation of cut-and-cover sections generate large quantities of excavation materials. To these materials can be added all the waste generally associated with such works plus other waste specific to tunnels or cut-and-cover sections.

Once the operating phase has begun, waste products are mainly related to the renewal of equipment and to renovation or maintenance works. This therefore generates highly variable types and volumes of waste.
One of the basic building blocks of the effective management of this waste and materials is the limitation of their production at source, which can mean:

- eco-design of the structures,
- reasoned choice of products that are less harmful to the environment.

Forward-planning the management of excavated materials generally enables upstream identification of technical solutions favouring their reuse and/or recovery together with an idea of the related costs. As such, the project study phase plays a key role in providing a meaningful diagnostic that is useful in optimising the planning of project roll-out.

In February 2007, Workgroup No. 35 at AFTES (Association Française des Tunnels et de l'Espace Souterrain) published in the *revue Tunnels et Ouvrages Souterrains No. 199 a recommendation on the management and reclamation of excavation materials [32].* This recommendation deals in particular with regulatory aspects, and general principles for the management and reclamation of materials. Some parts of this chapter on rubble refer to these findings under the heading "GT35".

8.1 MATERIALS AND WASTE PRODUCTS INSIDE TUNNELS

8.1.1 Excavation materials during the construction phase

On average, tunnel construction worksites generate, for each tube, approx. 100 m^3/ml of rubble, i.e. approx. 200 to 250 tonnes per metre.

This rubble varies in makeup and can be partly reused elsewhere on the worksite. Some rubble may be suitable for making aggregates of concrete or other material for use as embankments.

The part reused on the worksite does not generally constitute waste as, according to article L541-1 of the Environmental code, waste means "*any substance or object, or more generally any personal property, which the owner has discarded or is intending or required to discard.*"

8.1.2 Contractor waste during the construction phase

During the construction phase, contractors generate waste specific to their activities. The nature of this waste varies depending on the worksite phase. The following can be cited in particular:

- during surfacing operations: concrete, paint, etc.
- during installation of the equipment: steel, electricity cables, etc.
- during the excavation, contractor waste can be mixed up with excavation materials with:
  - > the presence of a fluidising agent or, respectively, bentonite for excavations using a tunnel boring machine that uses either earth pressure or mud pressure,
  - > the presence of pieces of explosive, detonators, steel and iron for excavations using explosives; these same explosives contain nitrates that are likely to seep into the natural environment at a later date.

8.1.3 Waste during the operating phase

One of the specific features of tunnels is the equipment they contain:

- electrical equipment for ventilation and lighting in particular: electric power supply, electrical cabinets, transformers and batteries, cable ducts, cables, etc.
- computer equipment,
- electronic radio and video equipment,
- operating and safety equipment (signalling, ventilation, lighting, etc.).

This equipment represents a source of waste during renewal.

A distinction can be made between standard operation and large-scale renovation operations.

In standard operation, the two most important waste stations are light sources (changed every 3 to 4 years) and UPS batteries (changed roughly every 5 to 6 years).

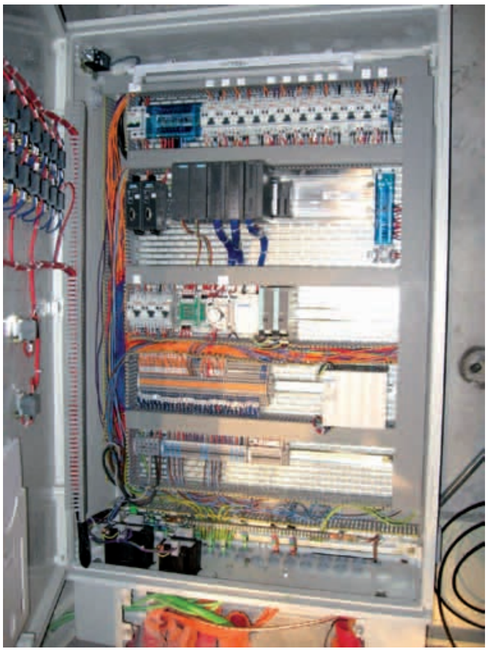

Photo 12: electrical cabinet in Lioran tunnel (source: CETU)

Heavy renovation operations can generate particularly large volumes waste. This waste can vary widely, from bituminous mixtures for road surfacing to a whole variety of other materials and products (metals, concrete, synthetic materials, light bulbs, etc.) whenever equipment is involved (see example in chapter 8.5.2). Given the number of possible situations, it is impossible to give a complete list of waste types and volumes. Where heavy renovations are concerned, this involves all equipment.

Photo 13: cabling tubes in the Lioran tunnel (source: CETU)

A noter que les équipements que l'on trouve en tunnel se retrouvent pour beaucoup dans de nombreux domaines industriels (alimentation électrique, éclairage, télésurveillance, contrôle-commande centralisé, etc.). De fait, le retraitement de ces équipements fait l'objet de textes spécifiques.

Enfin, il est à noter le cas particulier des transformateurs au PCB (polychlorobiphényle) qui font l'objet d'un plan national d'élimination en date du 26 février 2003. Ce dernier prévoit l'élimination des appareils contenant du PCB au plus tard le 31 décembre 2010.

8.1.4 Conclusion on tunnel-related waste

Note that the equipment found in tunnels can be found in many other industrial domains (electricity supply, lighting, CCTV, centralised control-command, etc.). The reprocessing of this equipment is therefore governed by specific legislation.

Lastly, note the special case of transformers containing PCB (polychlorinated biphenyl) that are governed by the national disposal plan of 26 February 2003. The latter provides for the disposal of PCB-containing devices no later than 31 December.

8.2 IMPACTS AND CHALLENGES RELATING TO WASTE MANAGEMENT

Waste can be classified in three categories:

- inert waste, which "*does not decompose, does not burn and does not produce any other physical or chemical reaction, is not biodegradable and does not cause the deterioration of any other materials with which they may come into contact, in any way likely to cause environmental pollution or to have an adverse effect on human health" (European directive 1999/31/CE of 26 April 1999)*,
- non-hazardous waste: waste that is neither inert nor hazardous for the environment or human health,
- hazardous waste, which contains substances that can endanger the environment or human health.

Whether the tunnel is in the construction or the operating phase, the production of this waste is mainly related to the notion of the works.
During the construction phase, the main challenges facing the issue of excavation materials are:

- valorization and recycling,
- storage in excess material areas,
- routing to a storage facility.

The designer's primary aim will be to produce materials that can be reused for the project. When this is not possible, the owner is responsible for bringing together all the actors involved in use of the excavation rubble. In all cases, a rapid reuse solution is sought in order to limit the volumes and the storage periods in temporary depots.

Note that excavation materials must not considered inert whenever they have been marked by excavation techniques (presence of a fluidising agent, pieces of explosive, detonators, nitrates, etc.) and required special treatments before use.

Under the *voluntary undertaking agreement of 25 March 2009* concerning actors involved in the design, execution and maintenance of road infrastructures, thoroughfares and urban areas, earthworks contractors have been set the target of reusing or recovering, by 2020, 100% of the natural geological materials excavated on the worksite and preventing the use of borrow pits or quarries external to the projects.

For other construction-related waste, the main challenges are the valorization, treatment and disposal.

During the operating phase, waste management and revalorization are dealt with under a process that is not new in itself. However, given the roles and responsibilities of each of the actors, it is important that this process is implemented alongside the very first study phases for the planned works.

The notion of responsibility is related to that of waste producer. Waste may depend upon the nature of the works project and contract, i.e.:

- residues generated by the tunnel and its design, which come under the owner's responsibility, the management of which can be contracted to the company;
- waste generated by the contractor when building a tunnel or maintenance works commissioned by a owner. These waste operations (scraps, packaging, etc.) are generally considered to be the contractor's responsibility. Although, in this case, the responsibility is shared to a lesser degree, it is not exclusive.

Article L541-2 of the Environmental code stipulates: *"any producer or holder of waste is responsible for the management of said waste up to its disposal or final revalorization, even when the waste is transferred to a third party for treatment".* This article indicates that the notion of ownership is not decisive when defining responsibility: the notions producer and holder also have to be considered; all the parties to the construction contract are therefore concerned and are required to be involved in waste disposal operations. These responsibilities are recapped in the *circular of 15 February 2000 (Ministries for Ecology and Equipment)* relating to the planning of worksite waste management for buildings and public works.

Owners are responsible for planning the necessary means, especially in terms of contracts and funding, in order to entrust waste management activities to other companies.

8.3 STUDY APPROACH

This chapter does not discuss tunnel renovation or maintenance works that, depending on their nature, may produce highly diverse waste products according to the type of equipment being removed.

What can be said about these works, however, is that it is essential that the owner carries out a preliminary diagnostic that, even before issuing the tender, clearly identifies the quantities and type of equipment to be removed and that the contractor is going to encounter on-site when executing the works. Equipment locations must be shown on an indicative plan, together with the corresponding quantities. This preliminary identification is extremely useful, as contractors will be able to use it to make attractive bids. Waste quantities and families should be identified in a file annexed to the special technical specifications, and will be deemed a contract document.

As regards tunnel construction projects, which are the subject of this chapter, upstream study phases will focus on the management of excavation materials given the large volumes involved.

8.3.1 Upstream studies

8.3.1.1 Opportunity study

At this very upstream stage, efforts to take account of waste management are concentrated on the issue of excavation materials and their reuse. This means assessing the type, quality and quantity of these materials with regard to:

- the forecast geological and geotechnical cross-section describing the materials' intrinsic properties,
- the interaction between the planned excavation method and its impact on the quality of the extracted material (material shape, grain size, physical-chemical properties, mechanical characteristics, etc.),
- the data on earlier use of similar materials in the region.

8.3.1.2 Studies prior to the public investigation

The geotechnical surveys are used to refine the analysis and provide the following data for each material encountered:

- excavated volumes,
- possible types of application according to the materials' intrinsic features compared against standardised classifications *(see Annex III of GT35, [32])*

- the impact of each of the possible extraction methods:
  - > the characteristics of the materials after extraction and the remaining options for use,
  - > the additional treatments likely to improve these characteristics,
- the possible extraction rates and related material transport modes.

For this study phase, GT 35 *[32]* recommends the implementation of the following three points in particular:

- "*a methodological comparative analysis of extraction/ potential uses, that spotlights the advantages and disadvantages linked to each method according to the expected challenges in terms of use, costs and environmental policy,*
- *definition of valorization targets for materials deriving from the tunnel's geological deposit, based on the project's chosen excavation option, and the actual integration of these objectives into the project as well as in the Departmental Quarries Plan policy ,*
- *a note giving the reasons for the choices made in terms of valorization of the deposit, and that incorporates the storage and transport aspects."*

This is also the stage at which efforts should be made to identify possible storage areas in which to house excess materials that it will not be possible to reuse.

8.3.2 Design studies

All the required geotechnical surveys are carried out. This data should provide for a full definition of the organization of the work concerning rubble, storage and reuse of materials. The GT 35 *[32]* recommends:

- "*define and specify possible and planned uses for each part of the terrain, based on the selected classification criteria,*
- *schedule the management of the materials as part of the project itself and/or as part of the regional material resources context, by integrating the logistics and transport aspects,*
- *define the selected execution methods making up the excavation sequence (excavation, mucking out,* **treatment***) also giving the class of materials obtained,*
- *Specify material storage areas and conditions by integrating the regulatory constraints*".

Concerning this last point, care must be taken to avoid storing materials in the bottom of valleys where leaching by rainwater and run-off could have an adverse affect on the natural environment (one example of this would be materials containing nitrates following the use of explosives). Similarly, such materials should not be reused in a drainage basin.

8.3.3 Execution phase

8.3.3.1 Prior to execution: consultation of businesses

The tender documents will be used to contractualise some of the upstream analysis results. Any option proposed by the contractor will have to address the issue of rubble valorization at a level of detail that is at least equal to that of the solution studied during the project (PRO).

For worksite waste other than excavation materials, the owner and prime contractor may based their approach on a contract agreement integrating a Waste Disposal Organisation and Monitoring Plan[(1)] (SOSED, *see chapter 8.4.2*).

Waste management may be one of the contract's conditions of execution, for instance, by:

- requirement to recover a certain percentage of the waste produced by the works, via the SOSED (the owner can then require green waste to be crushed in situ, to be used as compost),
- defining the sorting conditions on the worksite.

Under the provisions of *article 53 of the French Public Procurement Code*, tender selection criteria may be based on environmental considerations and, therefore, on waste management in particular. These "*criteria and their weighting or ranking are provided in a notice of a competitive public tender or in the tender documents*".

The environmental protection criterion must be clearly specified so as to avoid giving rise to a discretionary power. This may involve taking account of the following in the tender analysis:

- percentage of waste used or recycled (minimisation of the percentage taken to a landfill site),
- technical value of the SOSED.

8.3.3.2 During project execution

During project execution, it will be necessary to check the implementation of the recommendations defined during the studies and in the contract and, where necessary, to respond rapidly to any deviations and unforeseen events.

(1) There is also the SOGED (Organisational framework for waste management and disposal)

The recommendation by AFTES GT 35 clearly explains the kind of action that has to be carried out for excavation materials during the works phase. The main points of the recommendation are given below:

- **validation tests** aiming to establish the conformity of the characteristics evaluated during the studies phase in relation to those of the materials actually encountered on site;
- **suitability tests**, i.e. a campaign for checking and adjusting the production chain in order to ensure that it supplies materials with characteristics conform to those required for reuse;
- **selection of materials during progress and surveys**: these measures are designed to continuously quantify the deviation between the materials encountered on site and the planned materials so as to plan ahead and tailor treatments to real-life conditions;
- **optimisation of equipment**: the equipment used during the extraction and mucking out phase have a significant impact sensible on material properties. Their use therefore has to be monitored and, where possible, adapted to fit local variations in characteristics;
- **organisation of transport and storage of mucking out products**:
  > during underground handling operations: the mucking out sequence may include treatment phases that can cause transhipment operations. These will have to result in the provision of temporary storage locations.
  > during surface handling operations: the surface area of worksite footprints is a key factor. Surface organisation shall allow for:
    - adaptability to variations in extraction rates,
    - sorting of the recoverable part of the materials,
    - separation of different materials and their storage prior to recovery.
- **treatment of materials**:
  > materials should be sorted as soon as they are extracted, and foreign bodies (additives, metal parts, etc.) disposed of,
  > facilities have to be proportional to the size of the worksite, controlled and adjusted in real-time according to the ambient conditions.
- **quantitative monitoring**: this involves making regular assessments of the quantities of materials produced and requests for reuse so as to anticipate any procurement issues at the worksite conducting the recovery process;
- **placing in an excess materials zone**: a fraction of the materials (the smallest possible fraction) will not be suitable for reuse and will have to be warehoused. Both before and during the works, it will be important to check that the areas planned for this purpose are of sufficient size. Before being warehoused, the materials will eventually have to undergo additional treatments.

8.4 WASTE MANAGEMENT, METHODS AND TOOLS

8.4.1 Tracking slips

Waste tracking slips ensure that waste can be traced back to its source. The waste tracking slips come under the principle of manufacturer liability and provide evidence of the waste's disposal. This makes them targets for the various actors in waste disposal sectors (manufacturer, carrier, collector and disposal specialist). Although these tracking slips are only mandatory for hazardous waste and waste containing asbestos, it is strongly recommended to use them for all worksite waste products.

Examples of tracking slips can be downloaded from the Internet (Cerfa 12571 type form).

8.4.2 Waste disposal organisation and monitoring plan (SOSED)

The technical organisation of waste management on a worksite is represented by a SOSED. This is the document that specifies in detail the measures taken to ensure effective waste management, the list of waste encountered on the site up to the tracking procedures for their disposal.

The SOSED therefore provides a waste management reference document for use by all worksite actors.

Generally speaking, the oner is responsible for asking contractors to propose this type of document in their offer, based on a predefined framework included in the tender documents.

A SOSED should provide a detailed examination of the following points:

- waste production prevention methods,
- methods for preventing the mixing of waste on the worksite and, therefore, the sorting carried out, specifying:
  - > methods used to separate waste at the level of the workstations,
  - > description of waste skips, big-bags, containment bins and any other container according to waste type,
  - > planned waste storage areas and the means of access,
  - > importance of on-site sorting,
  - > signage used,
- the facilities for waste recovery, treatment and disposal according to waste type:
  - > facilities will be sought with respect to local opportunities, making sure to focus efforts on facilities in the reuse and recovery sector,
  - > the method for evacuating waste to these facilities: road (type of lorry), river or rail transport, together with the frequency of evacuation will all have to be specified;
- means for waste inspection and traceability:
  - > It is advised to include plans for one waste tracking slip (BSD) for each type of waste and transport method;
  - > The procedures for forwarding information to the owner's assistants have to be defined;
  - > the human means implemented in order to monitor performance of the SOSED have to be specified:
    - It is advisable for each contractor to designate a "waste management manager", who will be present on-site on a regular or permanent basis, who will be able to answer any questions from workers or other owner representatives,
    - the workers shall be made aware of the waste management issue and shall know how to recognise the different types of waste.

The SOSED is then finalised in the contract and subject to final review at the time of preparing the worksite in order to coordinate the various contractors.

8.4.3 "Each waste product has its solution"

Table 18 presents a rapid overview of the sectors that may be able to use the waste and rubble, according to the degree of danger that they involve. Note that only final waste is permitted in waste storage facilities (ISD).

Waste classified according to type is governed by specific regulations and can be recovered by a number of different sectors.

	Hazardous waste	Non-hazardous waste	Inert waste	Cost
waste disposal	X	X	X	variable
recycling		X	X	amortised (1)
class I ISD	X			very expensive (225 to 1250 €/tonne)
class II ISD		X		expensive (50 to 150 €/tonne)
class III ISD			X	low (5 to 50 €/tonne)

Table 18: rapid overview of the main possible sectors according to the degree of danger of the waste products (source: CETE Lyon)

In order to help professionals and private individuals deal with their waste management, ADEME (Agence de l'Environnement et de la Maîtrise de l'Énergie) provides on its website technical data sheets that are specific to each family of waste and identify solutions for their recovery (***http://www.ademe.fr*** – *heading "A chaque déchet, des solutions"*).

This chapter illustrates the type of information available through two examples:

- cables, which come under non-ferrous metal waste,
- electrical and electronic equipment.

8.4.3.1 Non-ferrous metal waste

Cable scraps, which are not covered by any specific regulations, are listed in the category non-ferrous metal waste as their main component is copper and they are covered by a plastic sheath. Generally speaking, cable waste is deemed non-hazardous, except in cases where they have been soiled by a hazardous material.

This waste has a fairly high market value. High volumes are collected in a grouping or sorting facility, and then sent to crusher units that separate metals from plastics. The metals may then be routed towards foundries for recycling.

Lastly, the SINOE (Système d'information et d'observation de l'environnement) database at ADEME (***http://www.sinoe.org/***) has information on how to locate sites that accept cable waste.

(1) In cases where the recycled waste is taken back onto the worksite as a basic material

8.4.3.2 Waste electrical and electronic equipment (WEEE)

Tunnels are equipped with electrical equipment designed to ensure the comfort and safety of users. Therefore, some waste relating to renovation, servicing or maintenance operations may be included in the category of Waste electrical and electronic equipment (WEEE). This concerns equipment with an operating voltage of under 1000 volts (AC) shown in one of the ten product categories shown in the annex to *article R.543-172 of the Environmental code* and specified in an *opinion to manufacturers of electrical and electronic equipment issued by the Ministry of Ecology (JORF of 26/10/05)*.

Concerned by article R.543-172 EC	Not concerned by article R.543-172 EC
Electronic safety equipment, fire alarm systems, smoke detectors, CCTV, light bulbs and lighting equipment	Distribution and command equipment (electrical panels, socket outlets, switches), cables and cable sheathing

Table 19: Waste electrical and electronic equipment (source: CETE Lyon)

Although, for the most part, WEEE are not classified as hazardous waste they can be made of or contain components such as asbestos or PCBs thus leading them to be classified as hazardous waste.

Professional WEEE deriving from products marketed after **13 August 2005** are subject to specific provisions set by *articles R.543-172 et seq. of the Environmental code*. These articles require manufacturers to set up and deploy selective management sectors.

These manufacturers are required to organise and finance removal and treatment, unless they have agreed otherwise with users in the equipment sales contract. In this last case, the equipment sales contract has to set out the terms and conditions requiring users to dispose of all or part of the waste from this equipment.

The holder will be able to contact the manufacturers or their respective trade organisations in order to get information on the network of pick-up points available to it together with the practical arrangements for access.

The collection and treatment of professional WEEE deriving from products put onto the market before **13 August 2005** is the responsibility of the user, unless they have agreed otherwise with the manufacturers. The holder therefore has to use the services of a company specialising in the collection and treatment of such waste.

These provisions involve the selective sorting of WEEE on or downstream of the renovation or maintenance site, and their direction towards suitable disposal sectors capable of meeting the following in particular:

- special treatment recommendations (preliminary decontamination of some equipment: nickel-cadmium accumulators, mercury in lamps, etc.),
- ambitious reclamation rates set by the regulations (up to 80% of the average weight for each device, 50% of which goes to material recycling and/or reuse).

Under the projects, owners will have to integrate the related management costs by giving project supervisors and contractors the means with which to organise their disposal. They can based these efforts on a guide published by TERRA (*How to evaluate the quality of the services for grouping and treatment of waste electrical and electronic equipment - Guide TERRA - ELEN, the MINEFI and SCRELEC [33]*).

Currently, the metals recycling sector drains a large part of the total supply of waste electrical equipment at end-of-life. Some WEEE are of interest to operators for resale on the secondary market. These WEEE mainly include equipment from electronic technologies such as telecommunications equipment, PLCs, etc. They can also involve large-scale facilities like cells or transformers.

Lastly, the SINOE database at ADEME ***(http://www.sinoe.org/)*** has information on how to locate sites open to the WEEE.

8.4.4 Waste management planning tools

At local scale, there are three waste management planning tools:

- BTP departmental waste management plan,
- departmental scheme for the disposal of household and other similar waste,
- regional scheme for the disposal of special industrial waste.

8.5 EXAMPLES OF THE IMPLEMENTATION OF WASTE TREATMENT OPERATIONS

8.5.1 Examples of systems to be deployed on a worksite

Tunnel construction projects are likely to produce large quantities of waste consisting of:

- relatively homogenous materials (soil and rubble),
- more varied waste generated by the contractors.

Sorting this waste for reclamation or specific treatment at a later date poses several problems, so (according to the available space) it is preferable to organise an on-site separate waste collection system that prevents upstream mixing of waste.

Table 20 illustrates the various possible forms of storing and sorting these various waste materials according to type. The phases for removal of these products by an approved contractor shall be subject to the issue and archiving of a tracking slip. This is mandatory for class I waste and recommended in all other cases. This slip specifies, in particular, the type and weight of the removed waste.

Lastly, some waste stored temporarily on the worksite may be hazardous and a potential source of accidental contamination. This type of waste involves the setting up of accident prevention means (*see table 21*).

Type of waste	On-site storage method	Evacuation / treatment
Used oils	Special drums or containment trays, sheltered from the weather	Removal and treatment by company specialising in waste recovery
Filters and greasy rags	Drum for class I solid waste, sheltered from the weather	Removal and treatment by company specialising in waste recovery.
Batteries / ink cartridges	Cardboard box for batteries and box for ink cartridges	Evacuation to a specific waste recovery area
Household waste	Closed plastic waste containers marked by type of waste (plastic, paper, glass, other household waste)	Collection by the services of the Commune, the Community of Communes or the syndicate responsible for the collection of household waste
Worksite waste i.e. wood, metal, plastic, polyane, etc.	Class 2 waste containers. No burning	Removal and treatment by company specialising in waste recovery (followed by recycling or storage in a storage facility for non-hazardous waste or incineration)
Excavation materials	Temporary storage at tunnel portals	Sorting to separate inert /non-inert waste Reuse on-site or evacuation to a storage facility for inert waste or evacuation to a treatment plant
Inert materials other than those from the excavation (iron-free concrete, debris, etc.)	Storage in a specific container	Reuse on-site or evacuation to a storage facility for inert waste

Table 20: organisation of worksite waste management (source: CETU, based on the Environmental Protection Plan for the Bois de Peu tunnel)

Accident	Actions	Means
Leak	Make leaktight (by taking precautions with respect to product type)	Workshop equipment, anti-pollution kit. Anti-pollution kits are available in primary and secondary facilities.
	Optimise confinement of liquids	Earth, sawdust, kit anti-pollution roll
	Maximise the recovery of the products	Sawdust, absorbent powder, recovery of contaminated soil
	Block all points of communication with groundwater, waterways, rainwater circuits	Block all evacuation points using the anti-pollution kit roll
	Identify the product 's path from the spillage point	

Table 21: emergency response means (source: CETU, based on the Environmental Protection Plan for the Bois de Peu tunnel)

8.5.2 Safety works on the Maurice Lemaire tunnel in Sainte-Marie-aux-Mines in the Haut-Rhin

The following information was taken in part from an article published in the review *Travaux n°855 – Septembre 2008 [34] (pp39-46,Thiboud A., Tournery H. et Duteil A).*

The safety works for the Maurice Lemaire tunnel included the recycling of 1,374 ventilation boxes with a unit weight of 20 tonnes i.e. nearly 30,000 tonnes of prefabricated reinforced concrete.

The ventilation boxes (*see photo 14*) dated from the 1970s and were designed to inject fresh air along the whole length of the tunnel, and also to extract smoke in the event of fire. The ventilation system had become obsolete due to changes in the regulations.

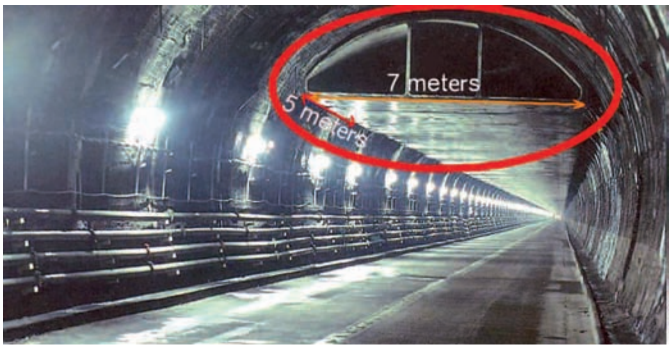

Photo 14: ventilation box (source: Thiboud A, Tournery H. and Duteil A, Works No. 855 – September 2008, [34])

During the impact studies, in addition to reuse of the excavation materials from the side gallery (200,000 m³), the owner, Autoroutes Paris Rhin Rhône, decided to add a clause in the specifications for the civil engineering works tender containing an obligation to recycle the 30,000 tonnes of reinforced concrete contained in the boxes.

The disassembly works necessitated setting up a groundwork unit at the worksite responsible for:

- finding an area in which to store, clean and dismantle the boxes, and store the resulting materials prior to their reuse,
- making the area viable and secure,
- setting up a cleaning and processing unit,
- designing, building and testing a tool removing the components,
- Developing transport units and obtaining the permits required for the convoy.

A specific tool comprising a motorised gantry with two side platforms was used to dismantle and transferthe boxes to a storage area. The latter was leaktight in order to recover any rainwater that may have been contaminated by the boxes.

A hangar was built (*see photo 15*) to shelter a metal component treatment unit, a high-pressure rinsing track for the boxes and a treatment-decontamination unit of the rinsing waters.

Photo 15: treatment unit (source: Thiboud A, Tourney H. et Duteil A, Travaux n°855 – September 2008, [34])

The evacuated boxes showed evidence of dust deposits due to vehicle traffic during the operating period. They therefore had to be cleaned prior to recycling in two phases:

- a first phase in which the insides of the boxes were cleaned manually and using high-pressure jets; seals and metal parts were removed and cleaned separately;
- a second phase of automated rinsing.

On completion of the two phases, the boxes underwent a quality check that involved a specific inert waste test.

The cleaned components were removed from the storage areas, placed in another special area and broken down into chunks measuring less than 80 cm using excavators equipped with hydraulic rock breakers (*see photo 16*). The resulting materials were then crushed using a crusher equipped with an electromagnet conveyor belt used to separate out metal and concrete components. These were then collected by a loading machine and placed, temporarily, windrow fashion at a height of 6 m in order to protect the local population against noise during the works. The rest of the materials were stored on-site pending their later reuse. All the materials (metal, concrete, etc.) were tracked throughout the whole process up to their processing. Products that could not be processed were directed towards specialised waste treatment plants.

Photo 16: crushing operation (source: Thiboud A., Tournery H. et Duteil A., Travaux n°855 – September 2008, [34])

The various handling operations were performed by specially adapted stackers. Platform logistics and organisation were performed by the contractor.

8.6 REGULATORY PROVISIONS

8.6.1 General principles

All the legislation on waste management is incorporated into *Book V of the Environmental code (prevention of pollution, risks and nuisances), title IV.*
These provisions aim to (*article L541-1*):

- "*as a matter of priority, prevent or reduce waste production and its harmfulness, in particular, by acting on the design, manufacture and distribution of substances and products and by encouraging recycling, as well as by reducing overall impacts of resource use and improving the efficiency of such use;*
- *the ranking of waste treatment methods consists in prioritising, in the following order: preparation for re-use, recycling, any other means of recovery, and, in particular, energy recovery and disposal;*
- *make sure that waste management is performed without endangering human health or harming the environment, in particular, without creating any risks for water, air, soil, plants or wildlife, without causing any noise or olfactory nuisances and without affecting landscapes and sites of special interest;*
- *organise the transport of waste, limiting this in terms of distance and volumes;*
- *make sure that the public are informed of any environmental and/or public health impacts that may be generated by production and waste management operations, subject to confidentiality regulations provided by law, as well as of any measures intended to prevent or counteract the harmful impacts.*"

The regulatory framework governing waste management is based on the polluter pays principle (article L110-1 para. 3 of the Environmental code) "according to which the polluter should bear the costs of any measures designed to prevent and limit and fight against pollution". As such, waste storage is subject to the general tax on polluting activities, which is paid by the owner.

8.6.2 Specific legislation according to waste type

To find out about these specific regulations, it is advisable to use the tools made available to sector professionals, such as the technical data sheets specific to each family of waste proposed by ADEME on its website (***http://www.ademe.fr*** - tab "A chaque déchet, des solutions").

For the specific regulations relating to excavation materials, the recommendation of GT 35 provides all of the necessary references. An example of these regulations is given in *table 22.*

Code (decree n° 2002-540)	Description	Restrictions
17 01 01	Concrete	Sorted construction and demolition waste only (1)
17 01 07	Mixture of concrete, bricks, tiles and ceramics	Sorted construction and demolition waste only (1)
17 03 02	Bituminous mixtures	Only after testing to check for the absence of tar
17 05 04	Earth and stones (including rubble)	Excluding topsoil and peat; for earth and stones from contaminated sites, only after performing a preliminary acceptance procedure
17 06 05	Construction materials containing asbestos	Only asbestos waste relating to inert materials (cement-asbestos, etc.) that are still whole

Tableau 22 : extract from the list of construction and demolition waste that can be admitted to inert waste storage facilities without prior testing (annex 1 of the order of 15 March 2006 issued by the minister for ecology and sustainable development, fixing the list of inert waste types allowed in inert waste storage facilities and the related operating conditions for these facilities)

(1) Sorted construction and demolition waste shown in this list and containing a small quantity of other types of material such as metals, plastics, plaster, organic substances , wood, rubber, etc. may also be admitted to the facility.

8.7 USEFUL REFERENCES

[32] *Recommandation sur la gestion et la valorisation des matériaux d'excavation / revue Tunnels et Ouvrages Souterrains n°199 / GT n°35 de l'AFTES / 2007.*

[33] *Comment évaluer la qualité des prestations de regroupement et de traitement des déchets d'équipements électriques et électroniques / Guide TERRA pour le compte d'ELEN, du MINEFI, de la FIEEC et de SCRELEC / 2003.*

[34] *Travaux de sécurisation du tunnel Maurice Lemaire à Sainte-Marie-aux-Mines (68) / revue Travaux n°855 (pp39-46) / Thiboud A., Tournery H. et Duteil A / 2008.*

[35] *Gestion et valorisation des matériaux d'excavation de tunnels, analyse comparative de trois grands projets / J. Burdin, C. Thalmann, C. Carron, L. Brino / 2005.*

9. WATER AND SANITATION

The creation of underground structures like tunnels and cut-and-cover sections can create disturbances that modify the natural conditions of the water cycle, especially in terms of the underground part of the cycle. Changes in a sector's hydrological conditions may impact on water tables and springs, as well as on related ecosystems such as wetlands, stream flow, farming, and also on the tunnel's long-term sustainability. The tunnel's impacts on run-off are directly linked to its position in relation to the water table and/or run-offs and, more generally, to the nature of the hydrogeological setting.

Disturbances of the water cycle may occur during the building of tunnels and their use and maintenance. All these potential disturbances are:

- quantitative in terms of the changes in run-off of underground and / or surface waters,
- qualitative in terms of the alteration of the water's natural physico-chemical properties, particularly during discharge of drainage waters into the natural environment or by the bacteriological alteration of waters due to the presence of suspended matter.

Forecasting these impacts and estimating which remedial measures need to be implemented requires an in-depth understanding of the underground and surface run-off within the project's scope of impact.

9.1 SPECIFIC FEATURES OF TUNNELS IN RELATION TO THE WATER CYCLE

9.1.1 An impact area that is difficult to determine

In contrast to surface transport infrastructures where the impact on the water cycle can be easily predicted using appropriate studies, it may be more difficult to predict the effects of underground structures, particularly in fissured or discontinuous environments. In karst environments, tunnel-related impacts may have a knock-on effect on springs at a distance of several kilometres.

The studies should provide data on the tunnel's prospective hydrogeological setting, the hydraulic relationships between groundwater and surface waters, the overall operation of the aquifer system and all the characteristics of the hydrological and hydrogeological drainage basins.

9.1.2 Disturbance of surface and underground run-offs

Underground structures in areas of water-bearing strata cause interim drainage that is generally limited to the construction phase, although it can occasionally become permanent. This may generate an aquifer drawdown that can have an effect that extends for some way, particularly in the case of interstitial porosity aquifers.

Depending on its orientation in relation to underground run-offs, the structure can also act as a barrage - lowering the water table downstream and/or increasing the piezometric level upstream. This barrage risk is mainly linked to the execution of cut-and-cover sections.

It is therefore vital to make a detailed study, within the project's scope of impact, of the areas where groundwater interacts directly or indirectly with the formation of water resources.

In areas of fissures and karsts, impacts are point-based, located at the level of outlets and are difficult to predict.

Thus, in the limestone regions of the Savoie, studies have shown that the drying up of springs in the Montagne du Chat was directly related to the creation of underground structures in the area. Also, during the same period as the works, disturbances such as excessive water turbidity and a lowering of water levels were observed, although there was no direct evidence that this resulted from the building of underground structures (*Université de Savoie, 1992, specific hydrogeological study in the Aiguebelette sector*).

9.1.3 Worksite waters loaded with particulate matter

During the construction phase, there may be very high volumes of water to be treated. These waters are heavily loaded with suspended matter, far more than is the case for an open-air worksite. They may show temperatures, pH and occasionally nitrate concentrations (due to the use of explosives) that are incompatible with the natural environment. This therefore results in setting up plants for treating heavily contaminated worksite waters.

9.1.4 Pollutant-loaded discharges during rinsing phases

During the operating phase, water contamination due to underground structures is similar to that found in open-air transport infrastructures and refers back to road drainage techniques.

Photo 17: rinsing operation in the Fourvière tunnel in Lyon (source: CETU)

One of the specific features of underground structures is the absence of any precipitation run-off on road lanes. Pollutant loads due to vehicle traffic are equivalent to those found on open-air roads with similar traffic conditions. However, pollutant discharge in tunnels is mainly concentrated on rinsing operations, which results in fairly high substance concentrations.

9.2 CHALLENGES AND IMPACTS RELATING TO WATER

The protection of water resources and aquatic ecosystems is a keystone environmental policy challenge in both France, through the *2006 law on Water and aquatic environments (LEMA)*, and Europe, through the *2000 Water Framework Directive (DCE).* One of the central aims of these policies is to meet requirements covering the chemical and ecological status of environments and maintain the use of water resources.

Where projects involving the construction of underground tunnels are concerned, an awareness of the challenges relating to water requires careful thinking at each stage of project progress, together with increasingly detailed knowledge of the study area.

The purpose is to meet the general principles governing the protection, non-degradation and preservation of water resources and aquatic environments. This makes it vital to know, during both the construction and operating phases, exactly how the planned underground structures are likely to impact on water resources and all other aquatic environments. It is also essential to identify water uses within the broader study area (supply of potable water, fishing, agro-foods, irrigation, industry, etc.).

9.2.1 Construction phase

During the construction phase, in alluvial environments, there may be a short-term impact on the underground water flow resulting from pumping operations or tapping of underground waters leading to a temporary drying up of springs, wells and wetlands. As the consequences on aquatic environments can be irreversible, construction processes have to be aligned with the recommendations on the protection of groundwater and surface waters.

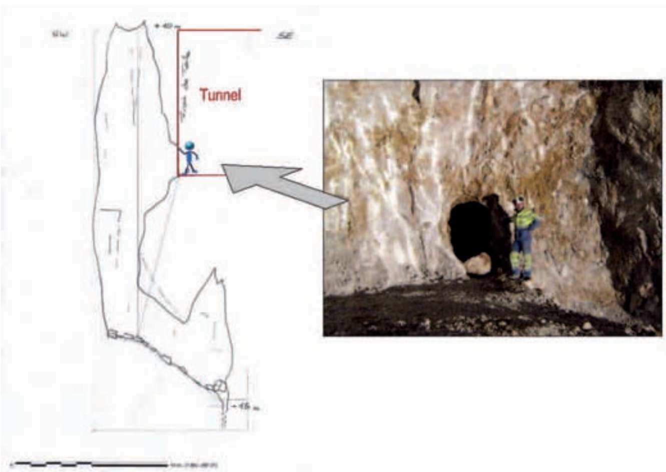

Photo 18: openning of a karst at the front face during excavation Bois de Peu tunnel (source: CETU)

In environments of fissures and karsts (*see photo 18*), encounters with water inflows during tunnel excavations can alter underground run-off by creating a new man-made outlet. This phenomenon may be irreversible and can result in the drying up of springs and a drop in water levels that reduces stream and river flow.

In addition to the quantitative aspects mentioned above, project roll-out also requires that special attention is given to aquatic environments and water quality.
Degradations in the quality of water and aquatic environments can be caused by:

- worksite facilities with:
  - > areas of worksite facilities and product storage,
  - > machinery workshops,
  - > parking areas for various vehicles and machinery,
  - > areas for cleaning and refuelling machinery,
  - > material storage areas,
  - > worksite roads,
  - > washrooms;
- temporary discharges such as:
  - > discharges contaminated by the scouring of the sectors (suspended matter in particular),
  - > discharge from rock drainage,
  - > discharge from washrooms,
  - > discharge of rinsing waters (equipment, machinery, treatment areas);
- material storage areas (due to the storage of rubble rich in nitrates that can result from the use of explosives).

The setting up of an effective worksite organisation, with rigorous monitoring of an Environmental Assurance Plan, helps to control a large part of these potential impacts during the construction phase.

The volume of materials excavated when building underground tunnels requires special attention. The management plan for these materials and their temporary storage area has to be defined by taking account of the nature of the rubble, of the possible solubility of some rocks and of any areas where the soils have been contaminated previously by human activities. Storage areas should not be placed in areas that have water-related restrictions such as wetlands, water catchment protection areas, NATURA 2000 area (relating to water), major rivers, etc.

Generally speaking, management of water pollution requires the deployment of suitable means including, in particular, the implementation of temporary facilities to treat rock drainage waters and platform waters in areas where there is frequent traffic of worksite machinery. These temporary facilities will have to be correctly sized and designed to withstand extreme weather.

9.2.2 Operating phase

Driving a tunnel through a water table may result in permanent changes to underground run-off, particularly if regular pumping operations have to be carried out to lower the level of the water table.

These changes may have a knock-on effect on groundwater, spring and waterway flows. Nevertheless, the hydrogeological studies carried out upstream of the study approach can be used to set up a structure that limits hydraulic disturbances within the rock and ensures the preservation of aquifer resources. The studies may even include the development of a deterministic numerical model that can be use to provide a detailed quantification of the tunnel's impact on underground run-off and to test the performance of the technical solutions proposed to remedy these impacts (*see chapter 9.4*).

In fissured environments, the impact of durable water inflows encountered during the works phase can involve alteration of water flows and their discharge outside the tunnel into the natural environment (temperature and mineralisation). Only the qualitative impact can be dealt with under the technical water drainage provisions (*see chapter 9.5*).

Photo 19: water inflow in a tunnel during winter (source : CETU)

Periodic rinsing of the walls of underground structures may also contaminate the collected water with organic substances (petrol, fuels, etc.), heavy metals and rinsing water additives (detergents). A system for collecting, evacuating and treating rinsing water has to be sized so as to comply with the general principles governing protection of water resources and aquatic environments (*see chapter 9.5*).

The dimensions of the road drainage network have to be suitable for collecting and retaining any accidental pollution resulting from road spillages. Special attention will have to be paid to the dimensions of the temporary drainage network to ensure it can withstand major hydrological events such as flooding.

9.3 STUDY APPROACH

At each stage of an underground tunnel project, study content should make it possible to effectively factor in the challenges relating to water issues i.e.:

- compliance with a good chemical, biological, bacteriological and ecological status of water bodies,
- evaluation of the main project impacts on the degradation of the chemical, biological and bacteriological quality of water due to discharges and on the degradation of the physical environment due to changes in stream patterns.

All the data and information on water collected at the various stages of the project will be integrated into a Geographic Information System (SIG).

9.3.1 Upstream studies

9.3.1.1 Opportunity study

At this stage, the aim is to detail the environmental challenges linked to the water sector in the wider study area of the underground tunnel project (*see table 23*).

This means collecting existing data and information in order to outline the impact scope of the underground structures and any related facilities. The impact scope designates the area in which impacts on water and aquatic environments (surface and Groundwater) may occur. These impacts may have an indirect effect. If the available data and information are not deemed sufficient at this stage in the project, further field surveys may be planned.

Objectifves	End points	Organisation or data resources
(1) further insight into the hydrological and hydrogeological setting of the wider study area	maps and geological and hydrogeological cross-sections	maps by the BRGM (Bureau de Recherches Géologiques et Minières) and database (InfoTerreTM)
	delimitation of large aquifers and location of water tables (map of water bodies and piezometry)	database and documents issued by the Agences de l'Eau (BD SANDRE) and DREAL
(2) locate and identify water uses	location of water catchment protection boundaries for for Potable Water Supply (AEP) and their declaration of public utility	data and database of the DDT (Direction Départementale des Territoires) and other services involved in water policing
	waterway category quality	Database of ONEMA (Office National de l'Eau et des Milieux Aquatiques) and DREAL
	location of wetlands and of regulated nature areas linked to the presence of water (ZNIEFF, NATURA 2000, etc.)	DREAL database
(3) identify the main challenges and limitations linked to the water domain	general recommendations in the SDAGE (Master Plan for Water Development and Management)	Agences de l'Eau
	local recommendations if there is a SAGE (Water Development and Management Plan), river or water table contract action programmes	documents by the Agences de l'Eau, General Councils and DREAL

Table 23: useful data on the water domain for the performance of an opportunity study (source: CETE Lyon)

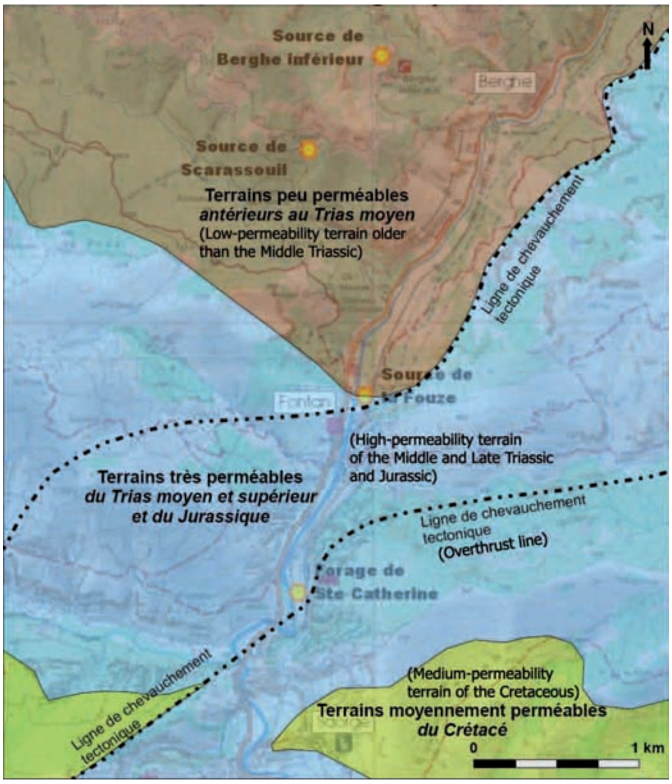

Illustration 18: hydrogeological data for a tunnel by-passing the village of Fontan in the Alpes-Maritimes (source: CETU)

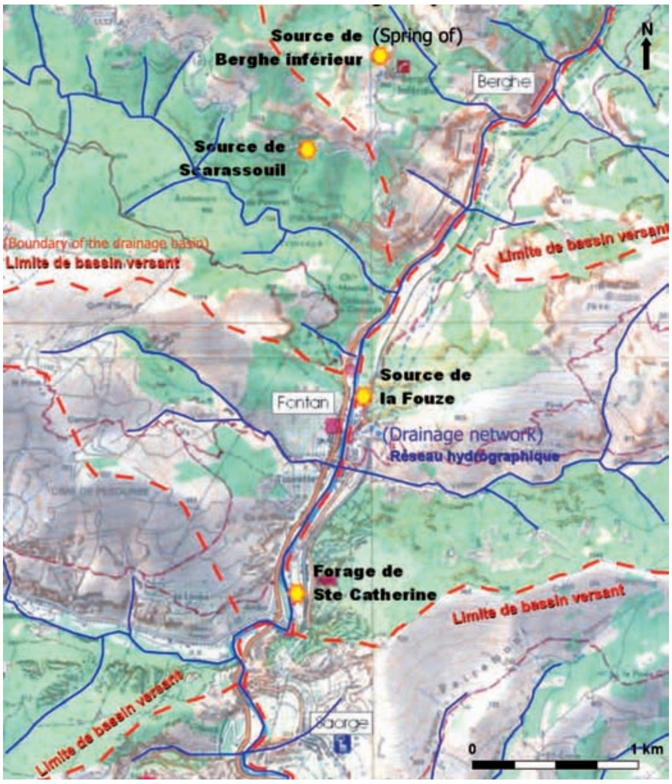

Illustration 19: hydrographic network and marking of the sources for a tunnel by-passing the village of Fontan in the Alpes-Maritimes (source: CETU)

9.3.1.2 Studies prior to the public investigation

The three objectives targeted during the opportunity study are still relevant and their control can be further refined.

Thus, furthering insight into **the hydrological and hydrogeological setting of the wider study area (1)**, involves:

- extending the collection of data to cover all data on the nature and properties of the subsurface (documents taken from university research, public and private design offices, etc.) and carrying out the additional investigations required for the project,
- making a 3-D model of the geological and hydrogeological structure of the study area based on the results of project field surveys and investigations (geology, geotechnical, hydrology and hydrogeology),
- quantifying the water balance based on the relationship between water tables and rivers, on the knowledge of the hydraulic regimes and of the environmental hydrodynamic properties as well as on a determination of the morpho-dynamic characteristics of all the relevant drainage basins.

The location and identification of water uses (2) will be supplemented by information on:

- the location of alternative water resources (identified reservation or area of potential exploitation) using documents issued by the Agences de l'Eau, DREAL, the General Councils, etc.
- the location of areas of aqua farming, swimming, leisure and water sports, irrigation, etc. using documents issued by French Water Bodies (DREAL, DDT, Agences de l'Eau, local authorities, associations, etc.).

The identification of challenges and limitations relating to water (3) will be supplemented by a characterisation of the water bodies in the wider project area and, in particular, by a data search targeting data relating to the chemical and ecological quality of these waters.

There are still two other objectives specific to this study phase i.e. the quantification of impacts and the proposal for measures in response to these impacts. The expected study content designed to cover these two objectives is detailed in *table 24*.

Objectifves	End points	Organisation or data resources
(4) quantify the impacts of project options on water and aquatic environments	quantitative assessment of health risks	search for measurement stations in the wider study area (BD SANDRE) field measurements under the project and modelling
	assessment of project impacts on water and aquatic environments	hydrological functionning (surface water and groundwater) of the study area likely to be impacted hydrodynamic functionning of water and aquatic environments hydrological modelling (surface water and groundwater)
(5) propose impact limitation measures	drainage guidelines for the operational phase	choice of a strategy that is tailored to the setting: • definition of objectives, • location of treatment facilities and any discharges
	temporary measures in the construction phase for the management of natural waters and effluents	choice of a strategy that is tailored to the setting: • definition of objectives, • location of treatment facilities and any discharges
	• solutions for preserving the supply of water resources and outstanding natural environments related to water • solutions for preserving wetland functionalities	inventory of wetlands and other outstanding environments likely to be impacted by project

Table 24: phase for the comparison of options and determination of impact limitation measures (source: CETE Lyon)

This stage of the process is characterised by the implementation of several field investigations and studies, a partial list of which is given in *chapter 9.4*. The performance of all these studies should provide solid insight into the dynamics of the water cycle and aquatic environments associated with the study area so as to quantify the impact of the underground structures.

9.3.2 Design studeis

This involves specifying all the measures *(see chapter 9.5)*, i.e. fine-tuning them to a greater level of accuracy given that the project is now more precisely positioned. Any changes stemming from the public inquiry and the tender process are also integrated at this stage. When a significant amount of time has elapsed since the public inquiry, the data collected during earlier project phase should be updated.

The phase also aims to carry out specific detail studies, particularly with respect to the "Water Act" impact file (*see chapter 1.1.2.2*) and the other regulatory procedures preceding the works (including the "Water Act" approval-declaration scheme).

9.3.3 Execution

In the same way as for all the other environmental topics, care will be taken during the works phase to deploy the means for limiting the foreseeable project impacts and ensuring their effectiveness. The latter could be tracked by monitoring the flow rates and quality of any waters likely to be impacted by the project works.

Measures	Purpose of the studies
relating to upkeep of uses and environments	• estimate of the cost of the corresponding environmental measures • set up of **campaigns to monitor** changes in the environment and in the effectiveness of the measures
relating to road drainage	• final layout and sizing of the structures designed to collect, regulate and treat waters and that have to meet specific efficacy targets, maps and cross-sections of buildings and descriptions of handling equipment • management methods for hydraulic and drainage structures and management of any by- products • monitoring programme on the sustainability and efficiency of the measures
relating to the construction phase - management of natural waters and effluents	• implementation of crisis management and prevention measures during the construction phase and corresponding specifications for control of risks of pollution (suspended matter, chemical or organic substances) and soil erosion in addition to the protection of sensitive aquatic habitats and species and the rehabilitation of the corresponding environments

Table 25: integration of measures at the design studies stage (source: CETE Lyon)

9.4 ASSESSMENTS METHODS AND MEANS

Knowledge of the hydrogeological functioning and setting within the project's scope of impact often involves the deployment of specific methods and means. This mainly involves determining the conditions at the boundaries of the study area where there are resource supply zones, run-off and transfer zones as well as outlet points or zones. The variability in physico-chemical phenomena will be estimated for at least one water cycle.

This will involve using a whole range of hydrogeology tools, from surveys to predictions. The use of these tools and the desired level of detail will have to be adjusted according to the project, the hydrological and hydrogeological setting and the water-related challenges identified in the wider study area.

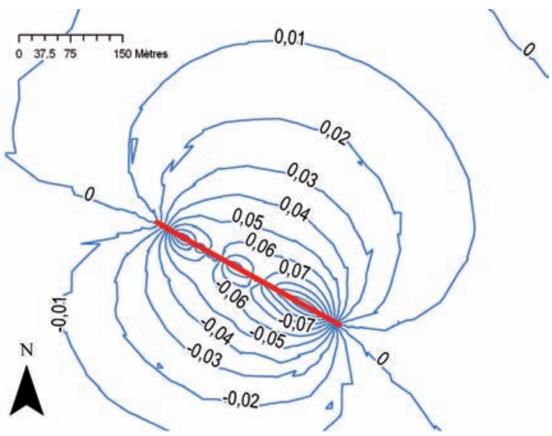

Illustration 20: result of a deterministic model illustrating a plan view of the area of impact of an underground structure i.e. the differences in hydraulic potential (unit given in metres) between the status disturbed by the tunnel and natural underground run-off. The tunnel is shown in red. The difference upstream is positive, and downstream negative. (source: HYDROGEAP and CETE Lyon)

For an environment with interstitial porosity (alluvial environment), the following can be cited:

- geological and geophysical surveys;
- deployment of a network of piezometres coupled with monitoring of changes in water levels,
- piezometres with localised measurement of hydrodynamic parameters,
- in situ measurements of the hydrodynamic parameters of porous environment (permeability and storage coefficient),
- measurements of the physico-chemical parameters of water,
- numerical modelling of underground run-off and possibly of solute mass transport. Models will be graded according to context and challenges.

For a fissured environment, the above-mentioned tools can apply. Additional tools designed especially for use in fissured and karst environments can also be used i.e.:

- inventories of surface and spring water losses,
- geomorphological surface measurements,
- monitoring of variations in spring flow and continuous recording of physico-chemical parameters (e.g. temperature and water conductivity),
- fissurisation measurements,
- tracer tests,
- speleological surveys (limestone environments).

Depending on the type, these tools can be used to establish a full initial status report on the study area, and also to estimate project impacts in respect of the way in which the tunnel may alter the natural hydrological functioning.

9.5 IMPACT LIMITATION MEASURES

With regard to the potential impacts, it is generally advisable to opt for a prevention strategy, before resorting to any limitation or countervailing measures. To be fully effective, this strategy obviously has to be implemented as far upstream as possible in the technical design process and be based on a sufficiently detailed knowledge of the study area.

Table 26 presents some limitation measures, based on impact type, to be implemented to mitigate any impacts that the prevention strategy has not been able to eliminate.

Type of impact		Limitation measures
Construction phase	qualitative (physical-chemical properties of water and bacteriology)	• positioning of polluting activities outside areas of natural sensitivity, of areas with high vulnerability of surface waters and groundwater, outside the catchment area protection boundaries , outside areas of potential flooding, • collection and treatment of worksite waters prior to their discharge in the natural environment (filter and basin mainly for treating suspended matter and nitrates where excavations have used explosives), • collection and treatment of rock drainage waters with a quality that differs from those of the receiver environment (temperature and mineralisation), • leakproofing of product storage areas, parking areas and machine maintenance areas and discharge control areas
	quantitative (disturbances/ alterations of run-offs)	• reasoned management of pumped worksite water (surface and underground) and therefore limitation of the quantity of water tapped/ drained in relation to the quantity of water that can be renewed by rain, • reduction of water inlet flows in galleries (sealing, injection).
Operation phase	qualitative (physical-chemical properties of water and bacteriology)	• maintain a separate network so that rock drainage water is not contaminated by an accidental pollution or by rinsing water, • collection and treatment of platform waters prior to discharge, including the rinsing waters.
	quantitative (disturbances/ alterations of run-offs)	• prevent drops in the piezometric level over large surface areas (for underground structures in cut-and-cover sections), • maintain run-off in the karst networks crossed by the structure, • maintain a balance between drained and renewable water within the aquifer.

Table 26: impact limitation measures (source: CETE Lyon)

In an operational tunnel, the general principle is to set up two independent networks:

- one network for collecting water run-off from roads (rain, rinsing of sidewalls) to which may be added, where necessary, liquids from accidental spillages,
- one network for collecting rock drainage waters.

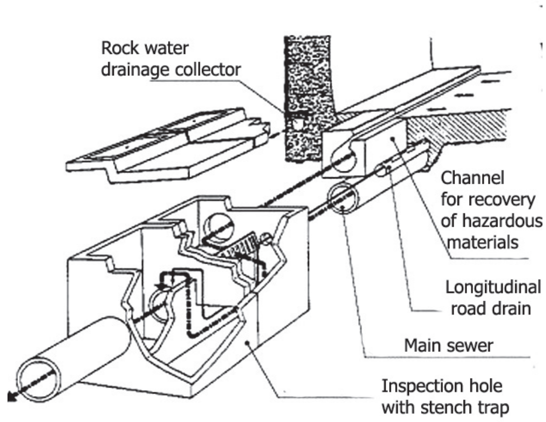

Illustration 21: tunnel drainage principle intended to prevent the propagation of spillages of hazardous liquid goods following an accident (source: CETU)

This principle is detailed in the *Tunnels Master File, civil engineering, section 7: sewerage, drainage and various networks (Technical Guide) / CETU / 1998 [36].*

Photo 20: treatment basin at the Modane decline as part of the works on the Lyon Turin rail link (source: CETU)

9.6 REGULATORY PROVISIONS

In terms of environmental protection legislation, the *2006 Law on water and aquatic environments (LEMA)*, codified, and the *European water framework directive (DCE)* are the most important legislation applying to underground structures.

The purpose of this legislation is to protect groundwater and surface waters against any harmful effects in terms of both quality and quantity.

The main useful regulatory references are listed below:

- *Directive No. 2000/60/CE of the European Parliament and the Council of 23 October 2000* setting out the framework for Community water policy;
- *European Union Council Directive No. 98/83/CE of 3 November 1998* relating to the quality of water used for human consumption;
- *Directive 2006/118/CE of the European Parliament and the Council of 12 December 2006* on the protection of groundwater against pollution and degradation;
- *Circular No. 2005-12 of 28 July 2005* relating to the definition of "good status" and to the constitution of guidelines for fresh surface waters (streams and rivers, water bodies), in application of European directive 2000/60/ CE of 23 October 2000;
- *Circular issued by the Water Directorate/Ministry of Ecology No. 426 of 24 July 2002* relating to implementation of decree No. 2002-202 of 13 February 2002 amending or creating the sections 2.5.0, 2.5.2, 2.5.4 and 2.5.5 of the "Water Act" classification and of the three orders of general recommendations for operations subject to declaration under these sections;
- *Circular CE 2006/18 relating to the definition of the "good status" for groundwater, in application of directive 2000/60/CE of 23 October 2000 issued by the European Parliament and the Council* setting out the framework for Community water policy, together with the definition of provisional values-thresholds to be applied during the transition phase;
- *Public Health Code (legislative part) - Book II - Protection of Health and the Environment - Title II, Health Safety water and food, Chapter 1: Potable water (articles L1321-1 to L1321-10)*;
- *Environmental Code (legislative part) - Book II - Physical Environments - Title I: Water and aquatic environments (articles L.210-1), Chapter I: General scheme and resource management resource (articles L.211-1 to L211-13)*;
- *Environmental Code (legislative part) - Book IV - Fauna and flora - Titre III, Freshwater fishing and management*

fish resources, Chapter II: Preservation of aquatic environments and protection of fishing heritage

- Section 2: Protection of fish and their habitat (articles L.432-2 and L.432-3);

- *Environmental Code (regulatory part) – Book II - Physical environments - Title I, Water and aquatic environments, Chapter IV: Activities, facilities and use, Section 1 Procedures for approvals or declarations - Sub-section 1 - Scope (Articles R214-1 to R214-5);*
- *Decree No. 2001-1220 of 20 December 2001* relating to water intended for human consumption, excluding natural mineral waters;
- *Decree No. 2007-135 of 30 January 2007* stating the criteria for defining and determining the boundaries of the wetlands mentioned in article L. 211-1 of the Environmental code.

9.7 USEFUL REFERENCES

Technical guides

[36] Dossier pilote des tunnels, génie civil, section 7 : assainissement, drainage et réseaux divers (Guide technique) / CETU / 1998.

[37] Prise en compte de la directive cadre eau et des enjeux liés à l'eau et aux milieux aquatiques dans l'élaboration des projets routiers (Guide technique) / SETRA / pending to publication in 2010.

[38] Pollution d'origine routière - Conception des ouvrages de traitement des eaux (Guide technique, 83 p) / SETRA / 2008.

[39] Chantiers routiers et préservation du milieu aquatique - Management environnemental et solutions techniques (Guide technique, 120 p) / SETRA / 2007.

[40] Dossier pilote des tunnels, génie civil, section 2 : géologie - hydrogéologie - géotechnique (Guide technique) / CETU / 1998.

[41] Assainissement routier (Guide technique, 92 p) / SETRA / 2006.

[42] Drainage routier (Guide technique, 91 p) / SETRA / 2006.

Documents on environmental knowledge

[43] Guide méthodologique de caractérisation initiale des masses d'eau souterraine / BRGM / 2003.

[44] Pollution et impact d'eaux de ruissellement de chaussées (109 p) / Édition LCPC, Nantes, (109 p) / LEGRET / 2001.

Technical documents on investigation methods

[45] Apport des techniques pétrolières de forage et diagraphie à la reconnaissance des grands ouvrages souterrains : les mesures hydrogéologiques et leur utilisation dans le cadre des études de tunnels / revue Tunnels et ouvrages souterrains, n°184 / AFTES / 2004.

[46] Hydrogéologie (460 p) / Édition Presses de l'Université du Québec, Montréal / BANTON et BANGOY / 1997.

[47] Hydrogéologie quantitative (215 p) / Ed. Masson, Paris / MARSILY GHISLAIN DE / 1981.

10. THE NATURAL ENVIRONMENT

The fragmentation of the landscape, and division of areas into several separate isolated entities is one of the primary causes of adverse effects on biodiversity. Road transport infrastructures are responsible for a large part of this fragmentation. They isolate land areas and cut through ecological corridors.

Building tunnels is one way of limiting this fragmentation and preventing breaks in any biological corridors. Tunnel crossings also contribute to reducing infrastructure-related noise, air and light pollution and preventing risks of collisions with wildlife on the route in question. The adverse effects of a tunnel on the natural environment are mainly felt during the construction phase. These adverse effects are active primarily at the tunnel portals, and are less evident during the structure's operating phase.

10.1 SPECIFIC FEATURES OF TUNNELS IN RELATION TO THE NATURAL ENVIRONEMENT

During the operating phase, aside from some local effects in the vicinity of the tunnel portals, tunnels generally provide a means of avoiding sensitive natural habitats on the surface, and therefore limit the corresponding direct impacts. This does not, however, exclude the possibility of indirect impacts on some environments, caused, for instance, by changes in underground run-off flows leading to a drying out of wetlands.

Nevertheless, the construction phase has the potential to cause considerable disturbance (noise, vibrations, diverse forms of pollution, etc.) to natural land and aquatic environments located close to the tunnel portals, wells (if any), traffic routes for vehicles and machinery and storage areas.

In the specific case of a cut-and-cover section, the destruction and then rehabilitation of the environment covering the section will have a major impact on the natural environment as the act of opening up the section effectively involves the total destruction of the habitats there and of some or all of the plant and animal life they shelter. Generally speaking, the in situ restoration of the destroyed environments never fully compensates for this major impact.

10.2 IMPACTS AND CHALLENGES RELATING TO THE NATURAL ENVIRONEMENT

10.2.1 During the construction phase

There are a number of impacts relating to the construction phase. These are illustrated in *table 27*. Some of them will mark the landscapes and the ecosystems they cross through for many years. It is difficult to make a preliminary assessment of these impacts as in many cases the available upstream data on project progress and technical constraints is simply not sufficient.

Emphasis should be placed though on two particularly sensitive potential impacts that may occur during the construction phase: loss of habitats and degradation of aquatic environments.

The first impact mainly concerns the construction of cut-and-cover sections, the opening up of which will impact along the whole of the relevant length of road. This contrasts with tunnel construction works which have very limited impacts on the plants, wildlife and natural environments of the sites protected by the tunnel's route. The second concerns all types of underground structure. The construction-related impacts of a tunnel or a cut-and-cover section may have a wide range of damaging consequences on these sensitive environments (pollution due to spillage of fines or other products, aquifer drawdowns, changes to hydraulic flows of small waterways, disturbance of species, etc.). Therefore, it may be recommended to carry out works execution under "dry" conditions, i.e. separated from groundwater, by the implementation of measures specific (*see chapter 10.5*).

Impact	Limitation measures
Destruction of habitat	**Total or partial destruction of one or more habitats** during earthworks, clearing operations, equipment deposits and loans, spraying of concrete on walls, creation of thresholds for the passage of machinery, etc.: **this destruction is irreparable whenever the project has a bearing on the environment.**
Destruction of individuals of an animal or plant species	**Direct destruction of individuals in adult form** (destruction of nesting places, or of adults hidden in the soil, etc.) or larval form (insect eggs, fish larvae) and indirect due to major reworking of the soil during the construction phase which can create attractive areas for some species that then become deadly traps (ephemeral ponds for amphibians for example).
Degradation of habitat and decline in the resource	• **Degradation of one or more habitats at a given moment in time,** followed by a post-works period of healing of the environment that varies according to the environment concerned: this variable healing process is sensitive to the issue of invasive plants that rapidly colonise the disturbed areas. • **Consumption of space** that may create adverse conditions for the availability both of the food resource as well as of resources in term of breeding sites and wintering grounds. • **Potential impacts on environmental water levels** (drying out of wetlands, alteration to run-offs, aquifer drawdown, etc.)
Diffuse pollution in waterways and wetlands	**Emission of suspended matter** with possible impacts on the quality of grass beds and fish spawning areas due to blockages, degradation of the trophic resource for aquatic species.
Disturbance	• **Disturbance of species during periods of movement** or during **breeding and over-wintering periods.** • **Impacts due to noise and vibrations:** disturbance of bat colonies.

Table 27: impacts on the natural environment during the construction phase (source: CETE Lyon)

10.2.2 Operating phase

There are few if any impacts relating to the operational phases of tunnel projects. In practise, tunnels or cut-and-cover sections avoid the fragmentation of habitats, one of the primary causes of harm to biodiversity. Here, the infrastructure no longer represents a "barrier" to the movement of wildlife and the dispersion of plant life.

Moreover, tunnel crossings also avert or limit the scope of any countervailing operations for the surface redevelopment of farmland which can have major impacts on natural environments (hedge clearance, drainage, etc.) if they are not carried out in a satisfactory manner.

Generally speaking, any negative impacts during the operating phase will be limited solely to areas immediately surrounding tunnel portals and relating to the impacts observed with open-air road infrastructures. At the very most, the lighting specific to the portals can attract insects, thus disturbing their circadian rhythms (set of chrono-biological behaviour over a 24-hour period) and increasing mortality by predation.

10.3 STUDY APPROACH

The full study approach is summarised in *table 28*. Note that the diagnostic methods used have to take account of two very important aspects:

- species and their habitats,
- landscape ecology that explains the ecological functionning of the areas crossed (scenic corridor, ecological continuums and corridors, "green corridor" and "blue corridor").

Note that at this stage, it will not generally be possible to separate the approach relating specifically to tunnels from that applied to the road infrastructure as a whole. The following information is not therefore specific to tunnels.

10.3.1 Upstream studies

The description of the initial status, the evaluation and the ranking of challenges is performed in a stepwise fashion, with the approach becoming gradually more detailed and comprehensive as the studies progress. The first step, at the time of the opportunity studies, is to identify key major challenges such as outstanding natural spaces with regulatory protection. The latter merit an avoidance tactic and careful thinking on how best to position tunnel portals or, at the very least, increase the technical and regulatory complexity of the project, as well as driving up costs due to the need for the deployment of large-scale limitation and/or compensatory measures.

The preliminary studies will then be used to detail the challenges, potential impacts, the reasons for selecting a given option from among all the other planned options together with the mitigating measures of the selected solution.

Study area boundaries also have to be tailored to the study progress status (which becomes increasingly restricted with further clarification of the project definition). This study area factors in the ecological features specific to each habitat or species likely to be impacted by the project. It is vital that field inventories take account of the biological cycles of the relevant species and, therefore, cover a favourable period, generally based on an annual cycle.

Projects likely to impact on a Natura 2000 site shall be subject to a specific study, referred to as an impact study (*see chapter 1.1.2.2*). The impact study mainly assesses the project's impact on the conservation status of the natural habitats and species for which the site was designated.

During the upstream phase, it is also important to anticipate requirements regarding the preparation and submission of applications requesting exemption from the protection measures covering protected species. An exemption request will have to be filed during the design phase in the event of the capture/ transfer or destruction of a protected species or of its breeding or resting grounds. This will have to be conducted jointly with DREAL departments prior to a central level review by the National Council for the Protection of Nature (CNPN). This application shall be based on detailed and accurate inventories of wildlife and plant species carried out during the upstream phase.

Step	Natural environment approach		
	Specific objectives	Tools	Working scale
Opportunity studies	• Identify, rank and map the challenges • Seek to avoid testing challenges in the positioning of tunnels portals and the chosen route	• Analysis of regional ecological networks , green corridors and blue corridors • Identification of sensitive natural spaces (regulatory zonings) and species protected under the 1976 law • Contact with administrations and bodies involved in this issue • Bibliographic search • Simplified mapping (ground occupation, natural environments) of the challenges	1/100 000 to 1/50 000
Studies prior to the public investigation	• Determine the boundaries of the study area • Develop the main development principles • Refine keystone challenges • Evaluate the Natura 2000 impact • Forward-plan protected species exemption files • Define insertion measures, • Propose limiting or countervailing measures	• Analysis of ecological corridors (photointerpretation and field inventories) • Full inventories of protected animal and plant species (presence / absence, abundance, occupation of space, critical areas) • Inventory of habitats (typology, surface area, conservation status) • Inventory and determination of wetland boundaries. • Mapping of limitations	1/25 000 to 1/5 000
Pre-project et project	• Refine the proposals • Place equipment accurately • Prepare the Water Act File and protected species exemption file • Define specific deployment means for countervailing measures	• Field validation of the insertion measures • Additional inventories • Consultation • Definition of the procedures for measurement and monitoring of the measures, the structure and its equipment	1/5 000 to 1/1 000
Works	• Prevent any accidental pollution and destructions of sensitive environment.	• Definition of the contractor's environmental specifications • Worksite monitoring and inspection	
Operation	• Check the enforceability and sustainability of the measures • Analyse the actual real-life impact	• Definition of monitoring indicators and determination of protocols	

Table 28: overview of study roll-out and consideration of the natural environment (source: CETE Lyon)

10.3.2 Project stage

Specific, supplementary studies are implemented during the design phase, with the following key aims:

- updating of the list of habitats and species likely to be impacted aimed at further elaboration of the project;
- a more detailed mapping of the habitats and species sensitive to the project, with an accurate identification and location of protected species and habitats, together with their protection rating;
- proposals for specific mitigating measures, concerning both the operating and construction phases (schedule, sectors to be avoided, special deployment measures for certain works, etc.). Special attention needs to be paid to the operational definition of any countervailing measures (land control, funding for acquisition and management, management convention, tracking of the measurement enforceability, etc.) that must not just remain a simple commitment in principle;
- definition of the environmental specifications for the contractors who are to be entrusted with execution of the works;
- preparation of the operation's environmental monitoring and of any related reports: in particular, this involves drafting the report on major infrastructure projects provided for in article 14 of the French Domestic Transport Guideline Act (LOTI). The latter will consist in tracking any changes linked to development, with a special focus on:
  - > changes to the plants and wildlife of natural habitats,
  - > species monitoring (disappearance, reduction, appearance),
  - > tracking of the measures' enforceability,
  - > changes in the ecology of the landscape and in fragmentation.

Generally speaking, it is during this design phase that the project reaches a level of definition that makes it possible to deal appropriately with certain impacts, therefore calling for the finalising of the following files:

- "Water Act" file containing the project's impact study,
- Files containing requests for exemption from the protection measures for protected species.

10.4.1 Assessing initial status

The first step, at the time of the opportunity study, is to draw up an initial status report that involves collecting all the available data on the natural environment and on protected species together with any data relating to the green and blue corridors defined in *articles L371-1 to L371-6 of the Environmental code.*

At this stage, the study area is large and covers all functional landscape areas: drainage basin, geological entity, etc.

The next step, at the stage of the studies conducted prior to the public investigation, is defined by time and means constraints designed to ensure a relevant, high-quality initial status report - an essential condition for a successful impact study. The methods will have to be implemented stepwise, firstly by processing the data that is already available and contacting the various competent bodies, and then by carrying out vital inventories and field surveys. It is advised to base the approach on:

- bibliographic data (ZNIEFF inventories -Natural areas of Ecological, Plant and Wildlife Interest-, ZICO -Important Bird Conservation Areas-, Natura 2000, red lists of threatened species, guides and atlases, earlier studies, local nature reviews, university research papers, etc.): inventoried or regulated areas can usually be accessed directly with GIS data on DREAL websites;
- Any person or organisation likely to have information on natural environments: administrations (DREAL, DDT), local authorities, nature associations, ONCFS -Office National de la Chasse et de la Faune Sauvage-, ONF -Office National de la Forêt-, ONEMA, fédérations de pêche, de chasse, etc.
- field survey - in order to produce a detailed map of all the relevant natural habitats and to located protected species.

Note that when drawing up an initial status report, the choice of season is paramount. Several plant species are not visible, and therefore cannot be identified, at certain times of year. The best dates vary depending on altitude and the nature of the environment. Wildlife observation seasons also vary widely. These depend on which groups are under study and the site (*see table 29*)

Service phase	Forecast intervention periods and durations													
	Year n-1			Year n										
months	*10*	*11*	*12*	*01*	*02*	*03*	*04*	*05*	*06*	*07*	*08*	*09*	*10*	*11*
Characterisation of the waterway														
Inventory of wetlands														
Inventory of protected flora and habitats														
Inventory of butterflies														
Inventory of mammals														
Castor														
Otter														
Large mammals (deer, wild board, etc.)														
Other mammals														
Inventory of amphibians and reptiles														
Amphibiens														
Reptiles														
Inventory of insects														
Inventory of molluscs														
Inventory of fishes and shellfishes														
Shelfishes														
fishes														
Inventory of birds														
Migrating birds														
Nesting birds														
Hibernating birds														

Table 29: Example of a forecast schedule of intervention periods for field surveys designed to establish an initial status report of the natural environment. Green boxes show favourable periods. Dark green periods are more favourable than light green periods. (source: CETE Lyon)

10.4.2 Methods for assessing impacts on the natural environment

Methods for assessing impacts on the natural environment are often qualitative and based on expert appraisals, with the option of quantifying some impacts, such as the surface areas impacted, the length of the recalibrated waterways or the numbers of the impacted populations. It is also possible to use more complex models in order to describe the dispersion conditions for some species.

Table 30 proposes a method for ranking the challenges relating to the natural environment.

Impact	Description of the impact
Low	• Absence of outstanding natural habitats such as those referred to in annex 2 of the Habitat Directive, absence of ZNIEFF, • Absence of outstanding animal or plant species • No breaks in the ecological corridor
Average	• Project area lies on outstanding habitats such as type 2 Znieff or a wildlife reserve • Presence of species considered rare at departmental or regional scale
Strong	• Project area lies on outstanding habitats at national scale (type 1 Znieff, SNE –Sensitive Natural Environment - , ZICO important bird conservation area, conservation sites, etc.) • Project area lies on wetlands of national or regional importance, sensitive to changes in their water supply • Presence species considered rare at departmental scale or of a number of rare species at local scale, species included on the red list
Major	• Project area lies on outstanding habitats at national scale (type 1 Znieff, SNE –Sensitive Natural Environment - , ZICO important bird conservation area, conservation sites, etc.) • Project area lies on wetlands of national or regional importance, sensitive to changes in their water supply • Presence species considered rare at departmental scale or of a number of rare species at local scale, species included on the red list

Table 30: permissible regulatory ranking of sensitivity and vulnerability levels of species and natural habitats in relation to an infrastructure project (CETE Lyon)

10.5 IMPACT LIMITATION MEASURES

Initially, efforts should focus on determining prevention or elimination measures as these will aim to eliminate harmful effects by by-passing any challenging areas. For instance, this can mean modifying the positioning of the portals in order to avoid a wetland area, or choosing the season that is best suited to the works (e.g. outside the breeding season for a given species).

Additional limitation measures will consist in adjusting project characteristics in order to mitigate a potential impact on the site. This involves measures acting within the project sector, carried out before or after the works, such as installing basins for the control and treatment of water prior to discharge to a sensitive environment. These measures may also include dry execution of the works in order to limit the impact on aquatic environments. In this case, the works would be sealed off from groundwater, by setting up chambers or leakproof structures that will prevent any aquifer drawdown. It must also be stressed that the presence of deep confined bodies of water undergoing recharge, even when their roof is located well below the base of the excavation, may require the adoption of special works execution provisions, such as the installation of discharge wells.

As a last resort, countervailing measures can be considered aimed at counteracting any harmful effects that can be neither eliminated nor sufficiently limited. These measures introduce counterparties on a similar area, at the level or outside the impacted site. This can involve the creation of a substitutive wetland in order to compensate for the loss of another wetland area elsewhere, or the creation of new animal movement corridors, or the acquisition and management of a threatened natural environment of interest. Generally implemented outside the project boundaries, these measures have to be defined in highly operational terms in order to give every guarantee of their effective implementation. Special attention should be paid to the definition of a clear set of objectives with regard to the desired compensatory effect, the control of the relevant land area, the partnerships to be proposed, the management by one or more competent bodies, the funding and sustainability of management means.

Protection or conservation measures may also be implemented in cases involving species or areas that are identified as having heritage status under article L411-1 of the French Environmental Code. Accordingly, the owner shall first submit exemption request to the supervising ministry. As the submission of these requests does not guarantee an approval, it is advisable to refrain where possible.

Lastly, in other cases, the owner can take part in optional operations, on its own initiative and not in response to regulatory requirements.

This provides an opportunity to use the project to enhance the protection of nature. These support measures are generally designed to optimise a project's positive impacts and control any induced impacts. This can mean creating and setting up environmental observatories or contributing to the ecological rehabilitation of any nearby mines.

10.6 REGULATORY PROVISIONS

10.6.1 European directives

At the level of European regulations, three directives can be cited:

- *Directive 79/409/CEE* of 2 April 1979, amended, concerning the conservation of wild birds, referred to as the "Birds" directive,
- *Directive No. 92/43/CEE* of 21/05/92 "Habitats-Fauna-Flora", concerning the conservation of wildlife and natural habitats, referred to as the "Habitats" directive,
- *Directive No. 2000/60/CE* of 23 October 2000 setting out the framework for Community water policy.

Annexes I (natural habitats of Community interest) and II (animal and plant species of Community interest) to the "Habitats" directive list the habitats and species whose protection requires the designation of a Special Area of Conservation (SAC). Some of these habitats or species have priority ranking. The SACs, coupled with the Special Areas of Protection (SAP) designated under the "Birds" directive, together form the Natura 2000 network.

Articles 12 (animal species) and 13 (plant species) of the *Habitats directive* requires setting up a system both inside and outside the Natura 2000 network that provides stringent protection of the threatened species cited in annex IV.

The "Birds" and "Habitats" directives apply through their incorporation into French law, mainly under A*rticles L414-4 et seq. of the Environmental code*. These regulations require the execution of an impact study (*art. R414.23 EC*) for projects or programmes whose execution is likely to have a major impact on a Natura 2000 site. *Environmental circular DNP/SDEN 2004-1 of 5 October 2004* states the expected endpoints of this impact assessment.

The originality of this scheme lies in the fact that, some cases will require the European Commission to have announced its decision on the planned countervailing measures.

10.6.2 French law

The general framework is set by:

- *Law No. 76-629 of 10 July 1976* relating to the protection of nature (implementing decree No. 77-1141 of 12 October 1977 amended by decree No. 93-245 of 25 February 1993),
- *Law No. 94-477 of 10 June 1994* relating to the diversity biological framework agreement (decree publishing Convention No. 95-140 of 6 February 1995, which entered into force on 29 September 1995).
- Moreover, *circular No. 96-21 of 11 March 1996* states how to take environmental and landscaping issues into account when developing road projects.

Lastly, there are specific regulations applying to:

- Protected species (*articles L411-1 et seq. and R411-1 et seq.*) under the Environmental code: this is based on a list of protected species in a given area established in national or regional orders. A decree laid down by the French Council of State sets out the conditions governing the limitative list of animal and plant species. This is established once the National Council for the Protection of Nature (CNPN) has issued its opinion by order of the minister responsible for the protection of nature. These orders shall specify the period of any permanent or temporary bans, made in order to allow the recovery both of natural populations and the area to which they apply.

- aquatic environments and wetlands under:
  > *Law No. 2006-1772 of 30 December 2006* relating to water and aquatic environments,
  > the definition of wetlands in *articles L211-1 and R211-108 of the Environmental code*,

> *law No. 2005-157 of 23 February 2005* relating to the Development of Rural Areas (DTR) (article L.211-1 to L.211-3 of the Environmental code),
> *Articles L212-1 and L212-5-2 of the Environmental code* relating to the legal scope of the SDAGE and the SAGE.

• Regulatory protection of natural spaces under:
> Protection orders covering biotopes,
> National parks,
> Regional national parks,
> Wetlands of special environmental interest,
> Strategic water management areas,
> National and regional nature reserves,
> Biological and forest reserves, and protected forests,
> National game and wildlife reserves,
> Classified and listed sites.

• the green corridor and the blue corridor (*articles L371-1 to L371-6 of the Environmental code*).

Lastly, "awareness raising" documents also come under the regulatory landscape with the ZNIEFF (Natural Zones of Animal and Plant Ecological Interest), sensitive natural areas, Red Lists of threatened species, Ramsar sites (convention on wetlands of international importance), biosphere reserves or areas located within National Botanical and Coastline Reserves.

10.7 USEFUL REFERENCES

[48] Prise en compte des milieux naturels dans les études d'impact (Guide méthodologique) / DIREN Midi-Pyrénées / 2002.

[49] États des lieux de la connaissance et des attentes des acteurs sur l'impact des infrastructures de transport terrestre sur les paysages et les écosystèmes, Biotope & BioGéo / MEDD / 2007.

[50] Les outils de protection des espaces naturels en France, (guide technique) / SETRA / 2004.

[51] Natura 2000, Principes d'évaluation des incidences des infrastructures de transports terrestres (note d'information) / SETRA / 2007.

[52] Natura 2000, Biodiversité et infrastructures de transports terrestres (note d'information) / SETRA / 2007.

11. LANDSCAPE AND HERITAGE

Since the introduction of the law of January 1993 on the protection and enhancement of landscapes, it is no longer just sites of outstanding interest that are to be protected. Now, all landscapes, both ordinary and outstanding, will have to be taken into account when defining land management and development policies.

Moreover, the European Landscape Convention, which entered into force in France on 3 July 2006, adds another dimension to the landscape and to the landscape quality objectives that have to be built up through dialogue together with input from local populations. This convention defines the landscape as "*belonging to the region, such as perceived by the residents, the nature of which is shaped by the action of natural and/or human factors and their diverse interrelationships*". As such, the landscape plays a role in defining the identity of a locality.

Heritage is what evolves from this identity. Architectural heritage was the first to be taken into consideration by the regulations, but this is only one aspect of heritage, to which must be added protected natural monuments (classified or listed sites) and archaeological remains. The Heritage Code defines the latter as "all movable or immovable property under public or private clientship that is of historical, artistic, archaeological, aesthetic, scientific or technological interest".

The concepts of landscape and heritage therefore clearly overlap. In this situation, a client can opt to build either a tunnel or a cut-and-cover section so as to preserve a landscape or items of heritage, or even to restore a landscape that has been degraded by a road infrastructure, particularly in urban environments.

11.1 SPECIFIC FEATURES OF TUNNELS RELATING TO LANDSCAPE AND HERITAGE

As with any other project, the building of a tunnel has an effect on the landscape due to worksite facilities, earthworks and the resulting rubble and debris. While, where tunnels are concerned, the worksite footprint is generally confined to the immediate vicinity of the tunnel portals, a cut-and-cover section usually covers a larger area.

From the perspective of the preservation of built heritage, such projects also require some degree of vigilance insofar as the technical used can affect ground stability (*see chapters 2, 3 and 4*).

As tunnels are by nature discreet objects, their impact is normally minimal during the operating phase. There are, however, more visible parts likely to alter the atmosphere of the landscape than it seems. In addition to the tunnel portals, and depending on the case, there may also be all or part of the following equipment:

- technical rooms, including ventilation plants,
- radio antennae, sometimes mounted on pylons,
- ventilation ducts or stacks,
- safety exits: the latter must provide direct communication with the outside whenever possible and under reasonable conditions,
- anchor blocks: cut-and-cover sections may specifically require additional height due to the integration of a sign or booster fan in the structure. This height may result in the ground being raised opposite the equipment outside the section.

The issues here differ significantly from those relating to a linear, open-air structure that plays an integral part in the structuring of the landscape. For tunnels, landscaping efforts mainly consist in integrating one-off visible components. This integration may prove tricky in urban areas, where constraints are stronger and space more limited than in the natural environment. In the natural environment, however, the materials used i.e. shotcrete applied to large surface areas in order to stabilise the ground around the portals, also contribute to the difficulty of performing this work.

Generally speaking, the positioning and architecture of tunnel portals plays an important role in this landscaped integration, and also in conditioning the users' view of the landscape (*see the CETU technical guide on the architecture of tunnel portals [53]*).

11.2 IMPACTS AND CHALLENGES RELATING TO LANDSCAPE AND HERITAGE

The relationship between tunnels and landscape needs to be looked at from two different angles:

- tunnels as a component of the landscape seen apart from the road, in terms of both the construction and operating phases,
- tunnels as seen by users who are going to discover a succession of landscapes, sometimes with landscape sequences that change dramatically between the tunnel's entry and exit.

11.2.1 Landscape

11.2.1.1 Construction phase

Impacts during the construction phase are a direct consequence of the works and only concern the first angle. These impacts relate to the presence of:

- large earthworks that are immediately visible to observers,
- diverse deposits including the storage of equipment,
- worksite facilities: worksite huts, transformers, works machinery, etc.

Photo 21 worksite at the Bois de Peu tunnel in Franche-Comté (source: CETU)

11.2.1.2 Operating phase

Specific tunnel components, unconnected to the original landscape, are incorporated into the new landscape. These components may not be in harmony with the immediate surroundings, resulting in a direct and permanent impact meaning that these components need to be incorporated into the landscape in an appropriate and meaningful way.
Indirectly, a tunnel can also have an important positive impact on a landscape. Driving a tunnel through can divert part of the traffic flow, making its invisible and freeing up space on the surface, thus making it possible to develop the landscape. This may involve:

- the preservation of an existing landscape as part of a new section of road,
- the rehabilitation of landscapes that have been degraded by road works, the aim being to return the landscape to the state it was in before the construction of the road,
- the creation of new landscapes: the entrenchment of a road crossing a town or neighbourhood opens up opportunities for redesigning the urban landscape.

Photo 22: The Croix Rousse tunnel in Lyon (source: CETU)

From the user's point of view, tunnels form a passageway between two landscapes, sometimes of very different natures. The way a tunnel affects a user's view of a landscape will depend partly on the architectural style of the tunnel portals, and partly on the discovery of the landscape at the tunnel exit.

Photo 23: former Grands Goulets road in the Vercors (source: CETU)

11.2.2 Heritage and archaelogy

There are several challenges linked to heritage in terms of:

- landscape – in the way monuments and their protection boundaries imprint on the environment,
- society – as a way of conserving memories and images, or even as the symbol of a country, region, town, etc.
- science – through the knowledge of a historical, technological, cultural nature, etc. gleaned from the study of monuments and archaeological sites,
- culture,
- economy, through the tourism generated.

11.2.2.1 Construction Phase

The conservation of heritage may be compromised by worksite disturbances such as vibrations or ground settlement (*see chapters 2 and 3*).

Archaeological heritage may also come under threat of destruction. Sensitivity to this issue varies and mainly depends on the following three factors:

- the area's archaeological potential,
- the type of structure involved,
- the structure's depth.

The sensitivity level will be higher for cut-and-cover section in an urban environment than for a tunnel being driven through a granite mountainside in a rural area. In the first case, the ground will be remodelled from the surface and along the whole length of the road. This ground may harbour some ancient remains. In the second case, only the portals would have any effect on ground that is generally of low archaeological interest.

Land development projects are covered by strong legislative guidelines on this aspect, which comes under the heading of preventive archaeology. The *Heritage Code* assigns the latter a public service mission. The aim is to "*ensure, on land and under water, within the appropriate times, the detection, preservation or safeguarding, via scientific study, of archaeological heritage objects that are affected or likely to be affected by public or private land development works. Another purpose of preventive archaeology is to interpret and circulate the findings of such studies*".

In view of the above, the building of infrastructures is actually more likely to further archaeological knowledge than to cause any inadvertent destruction of remains.

11.2.2.2 Operating phase

The impact here mainly consists in damage to the surroundings of monuments and sites, whether near or far, such as the covisibility of technical tunnel components (e.g. a stack or a ventilation plant) with a monument. However, these technical components can also be given an architectural design that would facilitate their integration.

A tunnel can also have a positive effect, by improving the environment in the vicinity of a building by diverting traffic away from it. This aspect needs to be incorporated into the overall landscape development design at the stage of drawing the line of the tunnel.

Lastly, it should not be forgotten that some tunnels are classified as heritage objects in their own right, relics from a particular technology or a bygone age.

11.3 STUDY APPROACH

The full study approach is summarised in *table 31*. It distinguishes between aspects relating specifically to the landscape and those relating specifically to heritage.

Note that it is essential to gather together a team of experts in the relevant fields. The best approach will be to look for people with varied and complementary backgrounds.

Care should be taken, in particular, to employ a landscaper and an architect with expertise in engineering structures. These skills must be secured sufficiently early on in the study phase.

Step	Actions to be carried out for the "landscape" topic	Actions to be carried out for the "heritage" topic
Opportunity study	• characterise landscaping units, • describe the transitions (e.g. rural to urban) and plan the possible developments, • highlight key areas of sensitivity.	• list the structures and objects covered by a protection procedure, • draw up a heritage overview for the study area, • identify the main known sites so as to avoid them.
Studies prior to the public investigation: comparison of options	• evaluate the insertion potential for each option in order to establish which options are the most favourable and unfavourable, and which are favourable under some conditions, • identify the foreseeable impacts (positive and negative), • plan possible courses of action, • define the main architectural principles.	• evaluate the sensitivity of each component to the various project options, • list and locate archaeological constraints, of the built heritage, of sites and of neighbouring protected areas, • evaluate the risks: deterioration or destruction, alteration of the immediate environment, passage through an area of high archaeological potential, etc., • assess enhancement opportunities, • work together with the competent department (DRAC - Regional Directorate of Cultural Affairs- and SDAP - Departemental Architecture and Heritage Service -) on the heritage-related challenges and the choice of alternatives.
Studies prior to the public investigation: study of the proposed option	Make a landscape development proposal and prepare the landscape sketches, specifying the: • desired results (enhancement or concealment), • technical and regulatory feasibility of the development components, • architectural treatment of tunnel portals, • principles of landscape enhancement, • sequencing of landscapes for users, • cost assessment.	Make a fine-scale assessment of the project impacts and the measures to be taken by: • furthering insight into the heritage relating to the field of study for the proposed option, • holding the mandatory consultation of the DRAC to secure an opinion on the file.
Design studies	Detail landscape and architectural proposals: • architecture of tunnel portals and overhead tunnel equipment, • lighting of tunnel portals, • detailed determination of grading and plantations, • creation of illustrative documents, for public use in particular (model, drawing, 3D computer modelling, etc.)	Carry out preventive archaeology procedures *(see 11.4.2)*

Table 31: overview of the study process and the taking account of landscape and heritage (source: CETE Lyon)

11.4 ASSESSMENT METHODS AND MEANS

A proper treatment of landscape and heritage means having to integrate all the components upstream of the studies and, therefore, to prepare an initial status in the greatest possible detail. This statement alone will not, though, be enough to identify all the hidden heritage elements that come within the preventive archaeology domain.

11.4.1 Assessing the initial status

11.4.1.1 Landscape

The initial status report has to draw attention to key landscape sensitivities. This is done by:

- defining landscape units according to geographic, historic, or cultural, etc. criteria as well as defining similar landscape areas,
- defining a visual typology based on the various physical, plant, architectural components, etc. and a compendium of specific areas, including those relating to heritage. This data requires a bibliographic search (data on farming, natural spaces, urbanism, etc.) in addition to fieldwork accompanied by a photo campaign. This work is also mapped in order to show landscape sensitivities by identifying areas to be avoided, sensitive areas and areas with no particular challenges, all of which are important elements required for the comparison of all the landscape schemes.

Finally, this work will receive further input from an analysis of the ways in which the tunnel will be seen from residential areas and from the road infrastructure and by an analysis of territorial land use.

This work will then be used to compare the options, in particular, so as to cross-check them with the technical components of each option that interferes with the landscape (location and architecture of tunnel portals, ventilation plants, technical rooms, etc.) and to specify the measures planned to ensure a successful landscape integration.

11.4.1.2 Heritage

The preparation of an initial status report on heritage involves the listing of:

- classified or listed monuments and sites together with their protective perimeter, and the perimeters of Areas of Protection of Architectural, Urban and Landscape Heritage (ZPPAUP),
- known archaeological areas and areas of high archaeological potential.

This data can be collected through the study of IGN maps and the consultation of online databases such as the Architecture-Mérimée database managed by the Ministry of Culture. Relevant departments like the DRAC or SDAP should also be included.

This listing is then mapped by distinguishing the type and level of protection of the various heritage components.

Lastly, the level of sensitivity of the heritage must also be analysed with respect to its structural vulnerability to foreseeable worksite damage resulting from vibrations or ground settlement in particular (*see chapters 2 and 3*). This means having to seek a closer working partnership with the departments responsible for the management of the identified built heritage.

11.4.2 Preventive archaeology procedure

All land development projects that affect or are likely to affect archaeological heritage objects are assumed to be governed by archaeological requirements prior to their construction.

The regional prefect therefore has to be referred to on the basis of a declaration file that contains the following documents in particular:

- description of the works,
- location provided for,
- surface area used as a basis for calculating the preventive archaeology fee,
- impact on the subsurface.

For projects that are subject to an impact study, the prefect has a period of two months in which to formulate their recommendations. If the project is likely to affect archaeological heritage objects, the Regional Prefect may prescribe the execution of archaeological diagnostic and, in cases where the archaeological heritage objects found on the site are already known, take specific measures such as the obligation to protect all or part of the site or alter the content of the project.

Should a diagnostic be required, several different situations may arise:

- the diagnostic is negative and the prefect authorises the developer to carry out the works;
- the diagnostic is positive but the archaeological remains are in a poor condition or are not of sufficient scientific interest, resulting in the prefect authorising the developer to carry out the works;
- the diagnostic is positive and the prefect decides to conduct an archaeological dig to modify the development project;
- the diagnostic is positive and leads to the discovery of exceptional archaeological remains that must be preserved in situ: the prefect requests the developer to integrate these remains into its development project.

11.5 IMPACT LIMITATION MEASURES

11.5.1 Landscape

Even if it is possible to limit the surface area of the worksite through the choice of excavation method, by and large, it is still difficult to mitigate the impact of the works the surrounding environment during project execution. However, it is possible to limit the duration of the works by rehabilitating the grounds on completion of the works, and by rapid replanting whenever this is included in the integration measures.

As this involves the operating phase, a series of measures allows for reducing or even eliminating the visual impact of a tunnel's technical components:

- burial of the facilities (technical rooms, ventilation plants, etc.),
- dissimulation behind plant barriers,
- construction of "dummy buildings" designed to shelter the facilities,
- integration of local landscaping: imitation of rocks, imitation of the architectural environment, etc.

In addition to these measures designed to counter any negative impacts, there are support measures that make it possible to optimise the positive impacts (see [53]):

- the monumentalization of tunnel portals when they mark the entry to a town or an abrupt switch from one landscape to another,
- the creation of new landscape environments (gardens or parks on the covered part of a cut-and-cover section e.g. etc.),
- urban redevelopment measures when the project will result in the freeing up of space on the surface.

Photo 24: ventilation plant for the Montolivet cut-and-cover section on the L2 east of Marseille (source: CETU)

Photo 25: Puymorens tunnel in the Pyrenees (source: CETU)

11.5.2 Heritage and archaeology

During the construction phase, heritage structures are particularly sensitive to any disturbances such as vibrations or ground settlement. The measures that can be taken to limit these disturbances are detailed in the relevant chapters.

It is nevertheless important to remember the importance should not be overlooked both of the choice of excavation methods and building development surveys via on-site measures during execution of the works.

For the operating phase, it may be decided either to exploit the heritage/infrastructure covisibility or, conversely, to limit the impacts.

In the first case, the necessary supporting measures involve enhancing heritage, which is to be dealt with alongside landscape integration measures. The second case involves reducing the visual impact by installing appropriate visual safeguards, here again to be dealt with alongside landscape integration measures.

With regard to archaeology, all preventive archaeology measures (*see chapter 11.4.2*) are designed to guarantee the safeguarding of heritage. Aside from these legal obligations, the developer can also decide to produce supporting exhibitions around any archaeological discoveries.

11.6 REGULATORY PROVISIONS

In the absence of specific laws on tunnels, all the relevant infrastructures are governed by general legislation.
Landscape regulations are generally based on *French law No. 93-24 of 8 January 1993* relating to landscape protection and enhancement. The latter has since been transposed into the various landscape codes, in particular:

- *Environmental Code,*
- *Urban Planning Code,*
- *Rural Code.*

The landscape has also been addressed in two important circulars:

- *Circular No. 96-21 of 11 March 1996* relating to the taking account of environmental and landscape-related issues in road construction projects,
- *Circular of 31 March 2005* relating to the "1% landscape and development" policy covering the French road network: this introduces the principle that 1% of the amount of the financial envelope allocated to a given infrastructure may be used for landscape enhancement and economic and touristic development (*see [54] and [55]*).

Lastly, note *decree No. 2006-1643 of 20 December 2006* relating to the publication of the European Landscape Convention signed in Florence on 20 October 2000.

The regulations relating to heritage and archaeology are concentrated within the Heritage Code, which contains legislation on:

- preventive archaeology (*Book V, Title II*),
- historic monuments, sites and protected areas (*Book VI, respectively Titles II, III and IV*).

11.7 USEFUL REFERENCES

[53] Architecture des têtes de tunnels (Guide technique) / CETU / 1991.

[54] Mise en œuvre de la politique du 1 % Paysage et Développement - Application de la circulaire du 31 mars 2005 (Fiche et note d'information) / SETRA / 2008.

[55] Politique 1 % Paysage et Développement, les itinéraires de découverte (Guide méthodologique) / SETRA / 2003.

[56] Le bloc-diagramme paysager : un outil d'analyse spatiale pour l'aménagement du territoire (Fiche et note d'information n°66) / SETRA / 2001.

[57] Insertion d'une infrastructure routière - Concilier terrassements et enjeux paysagers (Fiche et note d'information n°84) / SETRA / 2008.

[58] Paysage et infrastructures de transport (Guide méthodologique) / SETRA / 2008.

[59] Plantations, environnement, paysage - Recueil d'expériences (document technique) / CEERD / 2002.

[60] La végétalisation, un outil d'aménagement (Guide technique) / SETRA, Ministère de l'Environnement / 1994.

[61] Gestion des dépôts de matériaux excédentaires en zone agricole (Fiche et note d'information n°68) / SETRA / 2002.

12. LIVING ENVIRONMENT AND HUMAN ACTIVITIES

This chapter discusses the impacts that have not been dealt with so far in this document; readers should bear in mind the fact that each topic already addressed (noise, air, etc.) does, however, impact on the living environment and human activities in its own particular way.

12.1 SPECIFIC FEATURES OF TUNNELS RELATING TO THE LIVING ENVIRONMENT AND HUMAN ACTIVITIES

Tunnels are generally expected to improve the living environment or, at the very least, to ensure that the relevant road will deteriorate less the living environment than it would in the open air.

In rural areas, tunnels minimise the impacts on farming activities.

In urban areas, tunnels or sections of covered road may provide a solution to living environments that have become degraded due to heavy traffic flows. As such, tunnels provide a way both of limiting environmental disturbances engendered by surface road traffic and of using the freed up areas for other purposes.

Generally speaking, tunnels play an important part in urban development and organisation as well as in the socio-economic outcomes. A full analysis of the subject is not limited solely to the environmental aspects, but also refers back to wider issues such as sustainable development. While this is not, strictly speaking, the focus of this document which addresses environmental issues, it should be noted that this topic is currently under consideration. Thus, in 2006, in the explanatory statement for a symposium presenting the part to be played by below ground areas in sustainable town planning initiatives, the Association Française of the Tunnels et de l'Espace Underground stated:

"*Today's major climate, energy and ecological challenges will lead to a major reappraisal of how we organise and structure cities as part of our quest to create a viable model for a sustainable city. No solution may be ignored in the metamorphosis of our urban lifestyle expected over the course of just one or two generations. This provides us with an ideal occasion to make the most of a little used and poorly understood resource: the subsoil and, more generally speaking, subsurface areas. While it has a role to play is making cities sustainable, the idea then is to think about the urbanistic terms and conditions that will assist urban designers, land planning experts and city leaders in taking account of this space effectively*."

12.2 IMPACTS AND CHALLENGES RELATING TO THE LIVING ENVIRONMENT AND HUMAN ACTIVITIES

12.2.1 Construction phase

The most immediately visible impact is the degradation of the living environment in the relevant communes, both to the areas in the immediate vicinity of the worksite, and also along roads that are affected indirectly due to the redirection of traffic.

The construction phase also raises the issue of the temporary occupation of land and the modification of access points for pedestrians and road users: some roads are cut off; others are temporarily assigned new functions or new traffic directions. These changes to the traffic plan have a direct impact on the living environment, and also on the economy, particularly in urban environments where they result in:

- difficulties in householders accessing their properties and parking spaces,
- disruption to economic activities in areas where access is made more difficult, or where this generates safety issues (for example for pedestrian traffic).

Another aspect concerns the operation of networks, where interruptions or displacements are to be expected resulting, for instance, in the cutting off of gas or electricity supplies to users.

Lastly, some impacts common to all road construction projects may be amplified due to the specific nature of the work involved in boring a tunnel, such as:

- the use of land to store equipment,
- problems relating to irrigation: excessive drainage or, conversely, hydromorphy.

Taking all these impacts together, the problem will differ significantly depending on whether this involves a cut-and-cover section (high-level impact), or a driven tunnel (low-level impact).

12.2.2 Operating phase

During the operating phase, buried structures generally have no impact on surface areas except in the following instances:

- specific impacts mentioned in the preceding chapters,
- positive impacts linked to the space that has been freed up, with the main challenge being the improvement of the living environment:
  - > limitation of surface traffic,
  - > eradication of barrier effects between neighbourhoods,
  - > promotion of soft modes of transport,
  - > better safety for pedestrians and cyclists,
  - > social links encouraged by the creation of new public and/or group (public gardens, etc.) spaces.

Conversely, those parts of the tunnel in contact with the outside environment, whether tunnel portals or ventilation plants, may have an impact on the living environment. In the case of a cut-and-cover section, fire resistance requirements may also limit surface structures directly above the tunnel.

Furthermore, tunnels may also be the source of indirect adverse impacts that are more difficult to evaluate. These concern degradation of the living environment in the vicinity of roads that may suffer a strong increase in traffic flow, particularly within urban areas where tunnels may draw a significant amount of traffic towards the city. Lastly, in rural areas, the risk of the drainage of water tables may result in the drying out of farmland, planted or pastured, thereby disrupting the local economic activity. The possibility of land redevelopment, even where not specific to the tunnel, may also have an indirect affect leading to disturbances in human activities and the living environment.

12.3 STUDY APPROACH

The full study approach is summarised in table 32. It sets out the specific actions that need to be carried out in rural areas where forestry and farming often represent a major share of the activities there.

Step	Actions to be carried out for the topic "living environment and human activities"	Specific actions to be carried out in rural areas
Opportunity studies	• characterise the main urban development centres and the main communication networks • highlight the challenges	• characterise agricultural occupation: surface area, crop types, identification of boundaries for Appellation d'Origine Contrôlée (AOC) and organic farm holdings • characterise forest occupation: surface area, type of forest (species and purpose), owners (community, private, etc.) and protected areas
Studies prior to the public investigation: comparison of options	• evaluate the level of sensitivity of the challenges according to the characteristics of the various project options • compare the options against potential impacts such as: > elimination of buildings > breaks in the communications network > destructuring of the urban fabric > potential for optimising the freed up spaces	• complete and refine the information collected during the previous phase • compare project options based on an assessment of their impacts on forestry and agriculture: > use of space > risks of destructuring farms or functional units > whether there is a need for land redevelopment. It is vital to involve the Chambers of Agriculture in this phase.
Studies prior to the public investigation: study of the proposed option	• make a fine-scale assessment of the project impacts and the measures to be taken, • make a detailed study of land development proposals.	• make a fine-scale assessment of the project impacts and the measures to be taken, • kick-off land redevelopment procedures (development of farms and forests) where necessary.
Design studies	make a detailed study of the impacts of the construction phase: • identify possible routes for evacuating building materials and bringing machinery in and out, • locate areas for storage and car parks, • identify the temporary roads that need to be set up, • study a new traffic plan.	• make a detailed study of the reconnection of networks (access and irrigation), • carry out any necessary changes to land and/or farms.

Table 32: overview of the study process and the taking account of the living environment and activities (source: CETE Lyon)

12.4 ASSESSMENT METHODS AND MEANS

As with the studies on other topics, integrating the living environment and human activities into a project mainly involves the preparation of an initial status that is as comprehensive as possible.

The initial status has to highlight the key challenges. This is achieved chiefly by studying urban planning documents and should provide the following information on the study area:

- the principles and various development objectives,
- the land's intended general purpose: current and planned urban areas, current and future sites for Mixed Urban Development Zones (ZAC), natural and agricultural zones, purpose of currently undeveloped land, etc.
- roads, according to their type, use and traffic,
- public easements.

In rural areas, the highlighting of challenges has to be supplemented by further information on:

- crops types: grains, orchards, vineyards, etc.
- the boundaries of protected AOC areas,
- organic farming areas,
- location of the main drains and collective networks for farming,
- type, classification and types of clientship of wooded areas for forestry.

This means having to establish contacts with the organisations involved in these areas (DRAF, DOAF and Chambers of Agriculture).

This work is being mapped in order to rank the challenges, which is essential when making comparisons of the various development choices. When compared against the technical characteristics of the various options, this data should make it possible to classify project options according to their potential both for limiting and preventing constraints and for generating opportunities for development and requalification.

The initial status is refined at the time of the detailed assessment of the impacts of the proposed option, which requires a sound knowledge of the operation of the neighbourhoods that will be affected by the works concerning, in particular:

- neighbourhood paths and habits,
- the origin of the clientele of shopping areas,
- areas that need to be defined in particular during the construction phase (schools, public buildings, etc.).

In rural areas, there will be a need for more detailed information on land holdings:

- farm structure (size and possible division of plots),
- access roads,
- development outlook,
- trend of local rural development (activities in decline, new activities, etc.)
- management mode for wooded areas, etc.

12.5 IMPACT LIMITATION MEASURES

There are several measures designed to limit the impacts on the living environment during the construction phase:

- restrictions on the progress of the works such as specified timetables for any work likely to inconvenience local residents,
- search for worksite routes that would cause the least disruption to local residents, or even the creation of specific roads,
- setting up of temporary services for local residents,
- rapid reconstruction of land and grounds at the end of the construction project, in addition to communication lines and networks.

Impacts on economic activities can be reduced by ensuring appropriate phasing of the works.

The issue of urban redevelopment during the operating phase has already been raised at several points in this document. In rural areas, agricultural land development initiatives harbour similar objectives and provide for setting up mitigation measures. Additional compensation may also be paid out. With regard to the forestry sector, standard limitation and compensation measures may be planned:

- reparcelling of forest areas,
- acquisition of land outside forests,
- reforestation,
- inter-communal exchange of forest plots, possibly supplemented by compensation payments,
- re-establishment of service roads.

12.6 REGULATORY PROVISIONS

The legislation on these topics is codified in:

- the French *Urban Planning Code* and the following articles in particular:
  - > *L 123-16 and R 123-23* compatibility of local urban development plans),
  - > *L122-15 and R122-11* (compatibility of SCOT (Territorial Cohesion Plan)),
- le French *Rural Code* and the following articles in particular
  - > *L.112-2 and L.112-3,*
  - > *L.123-24 to L.123-26,*
  - > *L.352-1 and R.123-30,*
  - > *L511-3 and R511-66* relating to the consultation of the Chamber of Agriculture,
  - > *L642-11* relating to the consultation of the Institut national source and of the quality (French Institute for Origins and Quality).

This legislation indicates how to take account of impacts on farming relating to execution of the project (severance of agricultural plots and accesses, reduction in farmland area, changes to farm organisation, etc.).

It also indicates the measures to be planned, particularly in terms of the land use policy for the commune or the part of the communal territory affected by the works. The land use policy has to be decided by the CAF (Land Development Committee).

Lastly, the regulations governing forests and forestry are classified in the *French Forestry Code* - in particular, *articles R221-37 and R221-38* relating to the consultation of the French Regional Centre for Privately Owned Forests.

12.7 USEFUL REFERENCES

[62] Les études d'environnement dans les projets routiers - Projets routiers interurbains (Guide méthodologique, 308 p.) / SETRA / 1997.

[63] Les études d'environnement dans les projets routiers - Projets routiers urbains (Guide méthodologique, 191 p.) / CERTU / 1998.

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