Water monitoring for Alpine underground works: differences and similarities between France and Italy

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ABSTRACT: The works for the construction of the 57 km Transalpine Base Tunnel of the Turin-Lyon railway link are subject to extensive monitoring of ground and surface water. The purpose of the monitoring is to acquire the necessary knowledge of the natural context to guide the design choices towards less impactful solutions, to enable the facilities for the management of tunnel and platform water to be correctly sized and to anticipate the implementation of the measures to avoid or reduce the disturbance of water environments. The monitoring carried out for the Base Tunnel complies with the regulatory framework imposed by the country in which the work takes place: France and Italy respectively. This article analyses the similarities and differences between the two systems of water monitoring of the same work in two neighbouring countries.

1 THE BASE TUNNEL OF THE NEW TURIN-LYON LINK

1.1 *The project*

The new rail link from Turin (Italy) to Lyon (France) will complete the European rail network. It will constitute the key element of the east-west axis of the Mediterranean corridor, and will be one of the three main rail routes south of the Alps planned by the European Community.

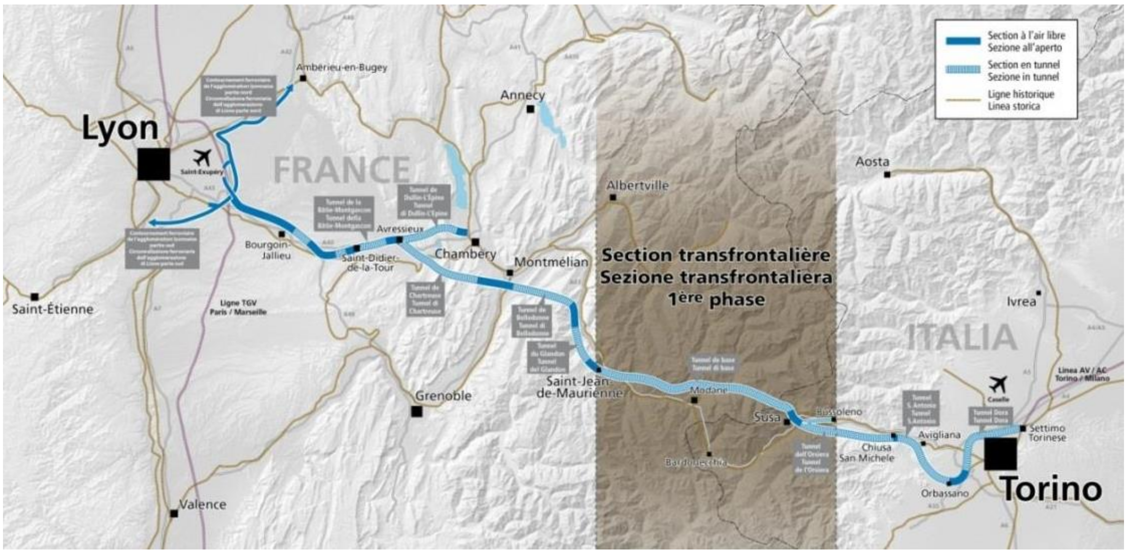

Figure 1. Location of the cross-border section of the new Lyon - Turin rail link.

This new rail link will have its profile at the base of the Alpine massif, at an altitude of around 600 m, and will have a maximum gradient of 12%, allowing the development of combined transport and authorizing the introduction of high-gauge and high-performance “rail-motorway” services. The project is designed for mixed traffic, it will allow freight trains as well as passenger trains to circulate.

The bi-national cross-border section between Italy and France includes a 57.5 km-long 8.70 m-diameter single-way twin-tube base tunnel, one of the longest in the world, which crosses the Alps roughly 45 km in France and 12.5 km in Italy (see figure 2) between Saint-Jean-de-Maurienne and Susa. The base tunnel incorporates many ancillary works: communications between tubs, sidings, exploratory adits and emergency access tubs, wells and ventilation tunnels, technical rooms for a total of 164 km of underground works. Design of the base tunnel includes four exploratory adits and geognostical tunnels.

Three French exploratory adits were completed between 2007 and 2010: Saint-Martin-La-Porte (2.4 km), La Praz (2.5 km) and Modane (4.0 km). The Italian exploratory tunnel of La Maddalena (7.1 km) was completed in February 2017 and the French exploratory tunnel of Saint-Martin-La Porte (9 km) has been under construction since 2014, more than 5 km of which have already been excavated.

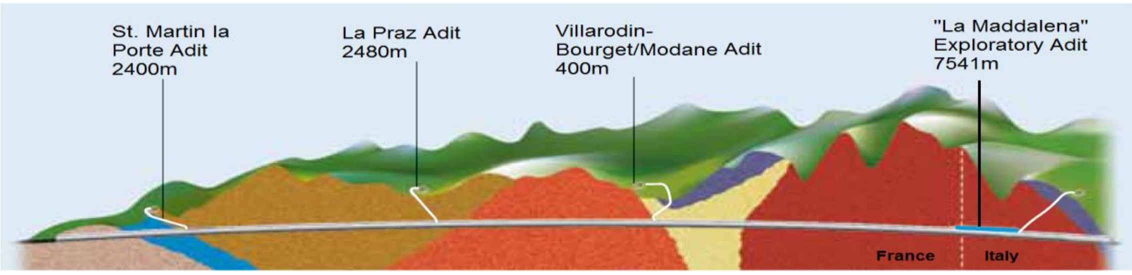

Figure 2. Simplified representation of the base tunnel and its ancillary works.

It is an ambitious infrastructure, including as regards the management of hydro-geological components related to boring the Alpine massif.

1.2 *The hydrogeological and hydrological context of the base tunnel*

Mastery of the hydro-geological situation traversed by underground structures makes it possible to understand the potential impact that base tunnel works can have. Broadly, two things have to be considered in particular: the modification of the hydro-geological system caused by the drainage carried out through the tunnel that could affect the surface water network on one hand, and the interception of underground water with physical and chemical characteristics different from those of the surface water network in which they will be emptied and whose quality they could change.

The base tunnel cuts, from west to east, across the Alpine massifs of Vanoise, Ambin (Mont Cenis) and the Graie Alps marginally.

Generally speaking, the hydro-geological description is divided into sections found in a somewhat homogeneous and consolidated rock, separated by shorter sections characterised by the presence of a tectonic contact, and thus potentially a fault, where permeability is lowest. All these sections have secondary porosity (pores, karst, micro and macro fissures) as opposed to the primary porosity made up of intergranular spaces and observed in sediments deposits. Most areas are characterized by a great depth and low permeability (close to 90% of the tunnel length is found at a depth of more than 300 m). The main impact risks with regard to considerable modifications of hydro-geological systems are thus found at the level of tectonic contacts with fault zones, which are sometimes found vertically to surface streams, as well as in some sections with special features. For example, fracturing strips and faults considered directly connected to the surface were found among the crystalline rocks (mica schist and gneiss) of the Ambin massif: the water intercepted during the excavation in this case should be a mixture of water from the surface more than groundwater. All these areas are in fact those over which uncertainty looms the most, and where real hydro-geological behaviour can be reliably understood only after a gallery has been dug.

In the other sections, the prevailing environment issue is the interception of highly-mineralised water: “fossil” water that can be found in the karst and fracturing systems not connected to the surface. Since hydrogeological data allow to forecast the general mineral characteristics of underground water intercepted by the works, the content in sulphates found in the geological context is the most representative indicator of water aggressiveness. In some sectors it exceeds regulatory standards for potable water. This is especially the case with strips of anhydrites.

The hydro-geological environment and the hydrological environment meet in springs and surface water feed and loss areas, and in the discharge of mine water in attack sites (adit platform, west and east portals of the tunnel). The latter are found in the two valleys of the internal Alps: the Maurienne valley and the Susa valley. These valleys are respectively bathed by rivers Arc and Dora Riparia, which are quite similar, with a length of between 120 and 130 km. They both take their rise at the foot of glaciers at an altitude of over 2500 m and have, in the relevant sections affected by works, a nival regime and high flow rates of several m3/s including during low-flow periods.

The tunnel's underground route is located westwards to the north of the Arc river over thirty kilometres, following the valley’s curve, to the right of the river’s right bank tributaries, which constitute the torrential watercourses flowing down in ravines, subject, in the central part of the valley, to torrential melts that from time to time (and regularly) fill the Arc with huge quantities of fines. All attack sites on the French side are directly connected to the Arc, located in a valley floor marked by the presence of metallurgical industries, hydroelectric structures, and high anthropization of shores.

All these elements account for the general quality characteristics of the Arc: the physical and chemical quality, in which the influence of the area’s special hydro-geological context is felt for example through its high sulphate content, generally ranges from good to very good, despite the existence of potential one-off alterations in heavy metal concentrations. The biological quality is generally mediocre, in terms of habitability for macroinvertebrates as well as for fish stock while aquatic and wetland habitats suffer from the artificialisation of banks over numerous sections.

In the east, after going past the valley of the Arc and the Ambin massif, the tunnel’s underground route is set over ten kilometres on the left shore of the Dora Riparia, shifting to the right of the Clarea Valley and the Cenischia Valley. The attack site on the Italian side is located perpendicularly and upstream of the confluence between the Clarea torrent and the Dora Riparia. Due to the low regime of the former’s flow rate, water from tunnel boring operations are discharged into the Dora Riparia, which has dug at this location a steep-sided valley with no human impact.

The Dora Riparia runs along the entire Susa Valley until it reaches the plain surrounding Turin. It is an important tributary of the Po river. The Dora has a very articulated and wide drainage basin with both left and right tributaries such as Clarea, Cenischia and other minor streams. The Dora Riparia basin is also characterized by the presence of numerous withdrawals for hydroelectric purposes close to the head of the basin and the tributaries (in particular Clarea and Cenischia for the Chiomonte and Susa plants) as well as downstream of Susa.

Therefore the main river channels are affected by numerous works in the riverbed, while at the head of the valleys there are some reservoirs with considerable impact on the hydrological regime.

2 MONITORING OF WATER DURING EXCAVATION PHASES

2.1 *The potential impacts of the work on the water environment and mitigation measures*

The same type of potential environmental impacts on water and aquatic environments related to the base tunnel building activities are found on both the French and Italian flanks of the infrastructure. This refers on one hand to all impacts that can be caused by open-air construction site activities and that mainly concern the Arc, the Dora Riparia and their associated groundwater: discharge on the surface environment of effluents from platform activities, run-off water from the construction site platforms and from provisional and final stocks of material, accidental infiltration of polluted water from construction site areas, other contaminations of groundwater.

On the other hand, there are potential impacts caused by the underground structure itself (”hole in the mountain”) and that mainly concern springs and tributary streams of the Arc and the Dora Riparia located to the right of underground structures: changes in the spring flow rates and in the hydrometric systems of streams. The discharge of mine water in the surface water environment, made of naturally-drained underground water potentially altered during the construction phase by industrial activities in galleries, takes place where these two impact categories intersect.

In any case, these impacts can produce indirect effects, causing the change in the hydro-biological quality of aquatic environments.

These incidences were assessed in order to improve the project in the logic of avoiding impacts and to identify and measure the necessary mitigation measures.

Focusing on the construction phase, based on the activities related to the construction of the work, the families of mitigation measures are listed in the table below.

Table 1. The mitigation measures in the construction phase

Nature of the impact	Mitigation measure family at construction site
Quantitative (disturbance/change of flow)	- Reduction of water flow rates in the tunnel (waterproofing, injections) - Reasoned management of the water pumped during excavation activities (limitation of the water withdrawn/drained with respect to the amount of water that can be renewed by precipitation, recycling of treated industrial water)
Qualitative (physical-chemical and bacteriological characteristics)	- Collection and treatment of construction site water before discharge into natural water bodies (filters and tanks for dealing essentially with suspended materials and correction of all parameters not compliant with the discharge) - Collection and treatment of the drainage water of the massif to regulate any physical-chemical differences (temperature and mineralization) with respect to the receiving water body - Waterproofing of work areas, product storage, parking areas and machine maintenance areas and other containment measures in case of accidental events.

The study of potential impacts of the work and of the mitigation and compensatory measures was carried out in the context of the Environmental Impact Assessments made on both the French and Italian sides according to the respective national regulations. There are no technical differences of approach in the conduct of Impact Assessments on the two sides of the project; the only difference lies in the fact that the Italian side of the project has been the subject of a “single environmental authorization” procedure, while in France the different environmental authorizations have been obtained in a disjointed way.

However, on the basis of the Environmental Impact Assessments, the project has been approved by both States, obtaining environmental compatibility on the Italian side (CIPE Resolutions 19/2015 and 30 and 39/2018) and the authorization concerning the “Law on water” on the French side (Prefectural Decree of 12/02/2007).

2.2 *The objectives of water monitoring*

By law, both on the Italian side and on the French side, the correctness of the assessments carried out during the Impact Assessment phase and the compliance with the protection requirements of the water environment must be confirmed by monitoring various parameters during both the construction and operation phases of the project.

In particular, during the excavation phase, the monitoring objectives are as follows:

- To verify the relevance and effectiveness of mitigation measures designed according to the expected impacts;

- To anticipate potential critical situations on sensitive water points to immediately activate the mitigation and compensatory measures necessary in close contact with local administrations and the population;
- To promptly identify any critical factors attributable to site activities to implement the intervention procedures envisaged in order to resolve anomalies in the shortest possible time;
- To provide the control authorities with the elements of verification of the execution of the works in compliance with environmental requirements.

These purposes are conceptually identical on both sides of the border and there are no differences in approach between the two countries in these terms.

2.3 *The contents of the water monitoring plans during the works*

The contents of the monitoring to be carried out to reach the objectives described in the previous paragraph, in terms of parameters to be measured, frequency of measurements, number of measurement points, measurement methodologies, etc., are established according to the expected impacts and submitted to the approval of the competent control authorities of the two countries.

In particular, the base tunnel water monitoring protocols have been approved:

- in Italy, as part of the “Environmental monitoring plan” of the project and therefore through the aforementioned CIPE Resolutions 19/2015 and 30 and 39/2018;
- in France, as part of the “initial state and monitoring protocols related to the water law”, through the Prefectural Decree of 4/03/2011.

These protocols are compared by subject in the tables of the following paragraphs.

2.3.1 *Physical and chemical quality of surface water*

Table 2. Comparison for physical and chemical quality of surface water

<table>
<tr><th rowspan="2">Secondary subject areas</th><th colspan="3">France</th><th colspan="3">Italy</th></tr>
<tr><th>Measurements carried out</th><th>Minimum frequencies</th><th>Spatial extent</th><th>Measurements carried out</th><th>Minimum frequencies</th><th>Spatial extent</th></tr>
<tr><td>Platform water</td><td>In situ measurements and laboratory measurements on water samples collected</td><td>Daily or continuous for 3 in situ parameters, monthly for others</td><td>A measuring point for each platform</td><td rowspan="2">In situ measurements and laboratory measurements on water samples collected</td><td rowspan="2">Every fifteen days for all parameters</td><td rowspan="2">A measuring point for each discharge (except in exceptional cases, there is only one discharge for mine and platform water)</td></tr>
<tr><td>Mine water</td><td>In situ measurements and laboratory measurements on water samples collected</td><td>Weekly for 8 parameters, monthly for others</td><td>A measuring point for each discharge</td></tr>
<tr><td>Receiving environment</td><td>In situ measurements and measurements on water samples collected, measurements on sediments</td><td>Weekly for 8 parameters, monthly for others on raw water, biannual for sediments</td><td>Upstream and downstream measurements with regards to discharges (2 points for each discharge)</td><td>In situ measurements and laboratory measurements on water samples collected</td><td>Quarterly, monthly for in situ parameters to the right of the attack site</td><td>Upstream and downstream measurements with regards to discharges (2 points for each discharge)</td></tr>
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Other watercourses (to the right of the tunnel's underground route)	No measurement, excluding an exceptional situation			In situ measurements and eventual laboratory measurements and for bacteriology on water samples collected	quarterly	2 measuring points for each relevant watercourse

This comparison highlights the fact that:

- In general, regarding platform and mine water, clearly more parameters are analysed in Italy: chlorine and aromatic components are not analysed in France, and the list of general, metal and hydrocarbon parameters is less complete. For example, manganese, whose eventual effects on health have not been proven, is not in the list of parameters analysed in France for this reason.
- In Italy, except in special cases, water management is the same for mine water and platform water.
- Measurements on sediment samples at the bottom of the bed are not carried out in Italy.
- The physical and chemical quality of watercourses to the right of the tunnel's underground route (which thus do not receive any effluent from the construction site) can be analysed on the French side by monitoring diatoms (see the paragraph on the lower hydro-biological quality).

2.3.2 *Bacteriological and toxicological quality of surface water*

Table 3. Comparison for bacteriological and toxicological quality of surface water

France			Italy		
Measurements carried out	Minimum frequencies	Spatial extent	Measurements carried out	Minimum frequencies	Spatial extent
No measurement, excluding an exceptional situation			Laboratory measurements on water samples collected	Quarterly for bacteriology, bi-annual for toxicology	Upstream and downstream measurements in the receiving environment with regards to discharges (2 points for each discharge)

On the French side, the site facilities are systematically connected to municipal waste water systems. Therefore, the very low impact risk of the construction site for this subject area can be the reason for lack of monitoring.

2.3.3 *Quantity of surface water and hydrometry*

Table 4. Comparison for quantity of surface water and hydrometry

	France			Italy		
Subject areas	Measurements carried out	Minimum frequencies	Spatial extent	Measurements carried out	Minimum frequencies	Spatial extent
Platform water	Flow rate of the discharge where necessary	Weekly	A measuring point for each platform	Flow rate of the discharge	Daily or continuous	A measuring point for each discharge

Mine water	Flow rate of the discharge	Daily or continuous	A measuring point for each discharge			(except in special cases, there is only one discharge for mine and platform water)
Receiving environment	No measurement, except in exceptional situations			Speed and flow rate under the current metre	quarterly	Upstream and downstream measurements with regards to discharges (2 points for each discharge)
Other watercourses (to the right of the tunnel's underground route)	Flow rate for each gauging station monitoring operation and mark-out operations	Weekly to monthly for the gauging station, and quarterly to none for mark-out operations, depending on the nearness of underground works	Approximately one gauging station reading and four mark-out operations for each watercourse	Speed and flow rate under the current metre	quarterly	2 measuring points for each relevant watercourse

- Given that the receiving environment in France is almost exclusively the Arc, which is a river with a considerable flow rate, monitoring the speed and flow rate under the current metre would not be significant when compared to the construction site's potential impact.
- As far as the other watercourses are concerned, different approaches exist to measure the flow rate, but the objective sought is the same.

2.3.4 *Quality of underground water*

Table 5. Comparison for quality of underground water

Subject areas	France			Italy		
	Measurements carried out	Minimum frequencies	Spatial extent	Measurements carried out	Minimum frequencies	Spatial extent
Physical and chemical quality of groundwater	Laboratory measurements on water samples collected in piezometers	quarterly	Piezometers located to the right, upstream and downstream of the open	In situ and laboratory measurements on water samples collected in piezometers	Monthly for in situ measurements, quarterly for laboratory analyses	Piezometers located to the right, upstream and downstream of

			air construction sites			the open air construction sites
Physical and chemical quality of springs (to the right of the tunnel's underground route)	In situ measurements of temperature and conductivity	Weekly to monthly depending on nearness of underground works	Network of springs and catchments	In situ and laboratory measurements on water samples collected	Monthly for potable water and in situ measurements of non-potable water, quarterly for laboratory analyses of non-potable water	Network of springs and catchments
Bacteriological quality of springs (to the right of the tunnel's underground route)	No measurement, excluding an exceptional situation			Laboratory measurements on water samples collected	Monthly	Network of potable water catchments among the network of springs and catchments

- In general, regarding the physical and chemical quality of groundwater, it is clear that more parameters are analysed in Italy: chlorine and aromatic components are not analysed in France, and the list of general, metal and hydrocarbon parameters is less complete.
- Regarding the physical and chemical quality of springs, in France only basic parameters are measured *in situ*, making it possible to detect a change in hydro-geological functioning, considering that underground works do not represent pollution risks for these springs beforehand.
- Regarding the bacteriological quality of springs, in Italy over 100 parameters are analysed, and additional analyses are carried out for potable water.

2.3.5 *Quantity of underground water*

Table 6. Comparison for quantity of underground water

France			Italy		
Measurements carried out	Minimum frequencies	Spatial extent	Measurements carried out	Minimum frequencies	Spatial extent
Measurements of the flow rate of springs, the piezometric levels of groundwater and the piezometric level of deep drilling	Weekly to monthly depending on nearness of underground works	Network of springs, catchments, network of piezometers, network of deep drilling	Measurements of flow rate of springs and piezometric level of groundwater	Monthly	Network of springs and catchments, network of piezometers

In France, the frequency is systematically weekly when underground works take place at less than 1 to 2 km from springs. In Italy, the frequency is monthly in standard situations, but more frequent measurements may nevertheless be carried out if an anomaly is noticed.

2.3.6 *Sediment transport*

Table 7. Comparison for sediment transport

France			Italy		
Measurements carried out	Minimum frequencies	Spatial extent	Measurements carried out	Minimum frequencies	Spatial extent
Measurement of transversal profiles and longitudinal reconstitution of profiles	Biennial	Mainly on the Arc (approximately 60 profiles, area of about 17 km)	No measurement, excluding an exceptional situation		

Although in France numerous hydraulic safeguards to the right of construction site platforms and the intense alluvial activity of the Arc explain this monitoring, the situation and stakes, which are quite different in the Dora valley, seem to suggest that this monitoring is not relevant in Italy.

2.3.7 *Hydrobiological quality*

Table 8. Comparison for hydrobiological quality

Subject areas	France			Italy		
	Measurements carried out	Minimum frequencies	Spatial extent	Measurements carried out	Minimum frequencies	Spatial extent
Macro invertebrates	Analysis of macroinvertebrates using the IBGN (Standardized Global Biological Index) method	Quarterly to annual	Other watercourses to the right of the tunnel's underground route	Analysis of macroinvertebrates using the IBE (Extended Biotic Index) or Macrobenthos multi-habitat method	quarterly	On the receiving environment of discharges and watercourses to the right of the tunnel's underground route
Diatoms	Analysis of diatoms using the IBD (Biological Diatom Index) method	Quarterly to annual	On the receiving environment of discharges and watercourses to the right of the tunnel's underground route (20 points)	No measurement, excluding an exceptional situation		
Aquatic and wetland habitats	Monitoring of watercourses using the method based on physi-	Annual	On the receiving environment and water-	Monitoring of watercourses using the river functionality in-	Annual	On the receiving environment and water-

	cal, morphological and ecological criteria		courses found to the right of the tunnel's underground route	dex		courses near open-air construction site areas
Fish stock inventories	Electrofishing for inventory purposes	Annual	On watercourses to the right of the underground route (12 points), exceptionally on the Arc	No measurement, excluding an exceptional situation		

- Regarding macroinvertebrates, in France the characteristics of the Arc, marked by very low habitability, make the results obtained from the monitoring operation carried out on this watercourse unusable, explaining the lack of monitoring of the receiving environment.
- Diatoms: this indicator is correlated to the physical and chemical quality of water. Although it is not monitored in Italy, the physical and chemical quality is on its part directly studied (see the paragraph on the physical and chemical quality of surface water above).
- The methodologies used for aquatic and wetland habitats are based on similar criteria although they seem to be slightly more specific on the Italian side. The area concerned by this monitoring operation is clearly weaker in Italy; the risks of impact on this subject area do not seem to justify wider monitoring on the French side.
- Fish stock inventories: this monitoring may suffer considerable bias caused by artificial fish populations, limiting its relevance.

3 CONCLUSIONS

The monitoring has the same objectives in both countries, it is based on the same principles and is organized in a very similar way.

The impact of specific regulations and standards in each country does not seem to be the reason for the differences between monitoring operations conducted in France and in Italy for the base tunnel construction work.

In fact, the several discrepancies noticed between the two monitoring protocols seem to hinge on the different methodologies in the countries (in particular regarding hydrobiological quality), the approach for the choice of parameters (complete, or more focused on those that seem to represent *a priori* the main risks), and even the distribution of tasks between the contracting authority and the company providing water monitoring services (regarding the frequency of monitoring operations for the physical and chemical quality of surface water, and the manner in which a link is established between the monitoring of discharges and the monitoring of the receiving environment).

Furthermore, the specificities of the hydrogeological and hydrological contexts encountered in France and in Italy are also the reason for the different considerations underlying some subject areas: for example, the transport of sediments on the Arc, which is not realized in Italy, or the monitoring of macroinvertebrates, which does not give convincing results on the Arc. The location of construction site areas hosting site facilities has also an effect on the method for managing waste water and the relevance or non-relevance of bacteriological monitoring operations.

Moreover, the spatial extent of monitoring operations and the number of measuring points are linked to the number of attack and construction sites, which are higher but more grouped in

France, as well as the tunnel area, which is less extensive in Italy. In any case, proportionality seems to be generally well respected.

Although there are slight heterogeneities regarding the frequencies of measurements, in France and in Italy these frequencies are adapted to the type and intensity of construction site activities.

Overall, the fact that the nature of potential impacts relating to TELT activities on water and the aquatic environment - and consequently monitoring objectives - are similar in France and Italy does not produce any significant and substantial heterogeneity in the monitoring operations carried out. Differences are found mainly in operational details.

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